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Research article

An evaluative tool for rapid assessment of derelict vessel effects on coastal resources

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A B S T R A C T

Derelict vessels impact coastal and estuarine habitats, fisheries resources, are aesthetically unappealing, and may be a hazard to navigation and recreation. The Government Accountability Office estimated in 2013 over 5600 derelict vessels existed throughout the coastal United States. Considering the large number of derelict vessels present in coastal areas, effective tools are needed to assess the environmental damage exerted by derelict vessels and aid in management strategies for their removal. After carefully reviewing regulations, we developed a 100-point scoring rubric (DVET) to evaluate damage by derelict vessels to natural resources with minimal field effort. The DVET's ability to rapidly assess a derelict vessel's impact on surrounding natural resources was confirmed with additional rigorous sampling and suggest environmental enhancement following vessel removal. The DVET shows promise for informing derelict vessel removal strategies, although more work is needed to quantify environmental benefits of derelict vessel removal and establish guidelines for removal prioritization.

1. Introduction

Anthropogenic litter is found throughout the ocean, even in remote areas far from human contact and obvious sources of pollution (Barnes et al., 2009; Derraik, 2002). Marine debris constitutes a serious problem with economic, environmental, human health and aesthetic ramifications, thus posing a complex international challenge. Among the most seriously affected are coastal communities because of increased expenses for beach cleaning, public health and waste disposal, as well as a loss of income from tourism (Smith et al., 1997; EPA, 2012). Shipping costs can be increased, due to fouled propellers and damaged engines, and anglers may suffer reduced or lost catch and damaged nets or lines (EPA, 2012). Marine debris can also harm wildlife, lead to loss of biodiversity and alter ecosystem function (Derraik, 2002; Islam and Tanaka, 2004; EPA, 2012).

One type of marine debris is abandoned or derelict vessels (ADVs), which are aground, broken apart, sunken, show no sign of maintenance, use, or are otherwise dilapidated in their condition. An all too common practice in the Gulf of Mexico (GoM) region by boat owners is to anchor vessels in river systems prior to hurricane landfalls- a misunderstood, unlawful act (Phillip Hinesley, pers.com.). These boats often lose their mooring and then drift into marshes and stream banks on both public and private property (Helton, 2003). Vessels may also be abandoned by their owners to save on disposal expenses and allow the owner to collect on insurance. ADVs remain along the rivers and tributaries that drain into coastal waters, impacting estuarine fisheries resources, are aesthetically unappealing, and may be a hazard to navigation and recreation (Helton, 2003; Smith et al., 2003). Bank erosion/stability, water quality (i.e. flow restriction), marsh growth, and submerged grasses can also be affected by ADVs (Smith et al., 2003).

However, some ADVs may be more harmful than others, some may do little damage, and it is possible that some may even have an overall positive effect on the environment (Jensen et al., 2012). For instance, the federal and state governments around the GoM frequently recycle old ships and sink them to create artificial reefs. Prior to scuttling careful attention is taken to remove anything that could pose a harm to the marine environment (e.g. oil/gas tanks, batteries, hydraulic fluids, paint, etc.). . Today hundreds of ships have been intentionally sunk in offshore GoM waters to create artificial reefs and promote wreck diving (Fikes, 2013). Likewise, ADVs in rivers and estuaries could act as valuable reef habitat if they have no harmful or toxic substances, do not smother any other

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valuable habitat, and do not pose any navigational hazard or aesthetic displeasure.

After Hurricanes Ivan in 2004 and Katrina in 2005, the Federal Emergency Management Agency (FEMA) set priorities for debris removal in coastal waterways of GoM including navigation channels and areas that posed a threat to public safety. A lot of debris was removed with these efforts but many ADVs remain in GoM waters. Currently, there are no clear laws in many states to deal with the removal of derelict vessels and responsibility often falls to affected private land- owners (GAO, 2017). Some federal, state or local funds may be available for vessel removal, but the process is expensive and funds are often limited (GAO, 2017). In 2013 an estimated 5600 derelict vessels existed throughout the coastal United States and between 2005 and 2015 the federal government spent $53.8 million to remove 1321 ADVs (GAO, 2017). Thus, there is a need to render the process cost-effective. Towards this end, the most damaging vessels should be prioritized for removal and selectively disposed of. Targeting the most damaging ADVs specifically, while leaving those with potentially less damaging or even beneficial effects, would allow for effective use of limited funds in remediating the problem and contributing to watershed improvement. Here we present a derelict vessel evaluation tool (DVET) that, based on few metrics, can be easily and quickly obtained, assesses ADV condition, and potential damage to the environment. The tool is easy to adopt, helps identify vessels that could potentially cause the most damage, and may facilitate decisions on removal prioritization for environmental managers and planners.

2. Methods

2.1. Study area

This study was conducted in the Dog River watershed located on the northwest side of Mobile Bay (Alabama, USA). Dog River is approximately eight miles long (not including its tributaries and bayous) and typically shows estuarine features (Bowden and Gilligan, 1971). The watershed drains approximately 233 km^2 and includes neighborhoods (37%), forests (36%), farmland (16%), and marinas, parks, schools, and businesses (10%, Scanlan and Wallace, 2000). Approximately 25 endangered, threatened, or of-concern species occur in the watershed, including two species of crawfish (*Cambarellus diminutus* and *Procamberus evermanni*), one fish (*Leptolucania omnatta*), and several species of amphibians, reptiles, birds, and mammals including the west indian manatee (*Trichechus manatus*) whose food sources are vulnerable to large debris deposition and environmental degradation (Scanlan and Wallace, 2000; IUCN, 2013).

2.2. Derelict vessel identification

In July of 2013, 54 sunk, derelict or abandoned vessels were located and identified in the Dog River watershed by local volunteers (Rob Nykvist, pers. com.). The ADVs and surrounding habitat were photographed, any identifying information (e.g. registration number, decals, boat name, etc.) recorded, and their position marked with GPS. In October and November of 2013, our team of researchers visited the area to confirm the location and identity of the ADVs. We confirmed 23 vessels out of the initial list were actually abandoned or derelict. In addition to those 23 we discovered six additional vessels for a total of 29 ADVs (Fig. 1). All these ADVs were surveyed using the evaluative tool presented below.

2.3. Evaluative tool

To help evaluate environmental damage and prioritize what derelict vessels should be removed first, we developed a decision support tool (i.e. the Derelict Vessel Evaluation Tool or DVET) based on a number of metrics that quantify potential vessel damage. Ultimately our goal is to help determine which vessels may potentially exert more damage and, thus, may pose a larger threat to the environment and locals. This information can help managers strategize effective removal plans given limited resources and funding. The DVET consists of ten metric categories including damage to habitat, vessel state of decay, navigation hazard, ease of removal, stability, eyesore, water quality, flora and fauna present, and remaining vessel materials (Table 1). These categories were

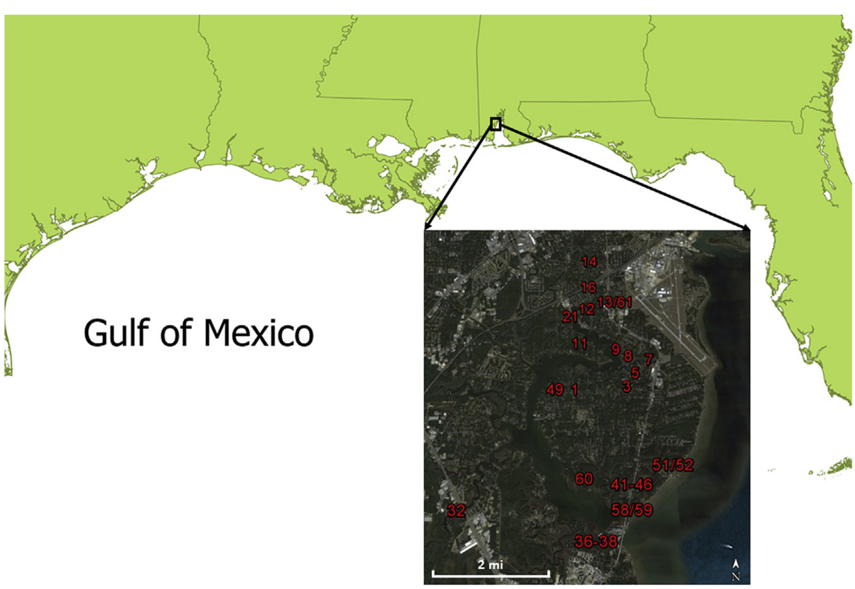

Fig. 1. Map of the Dog River watershed identifying the location of the 29 ADVs assessed for this study.

Table 1
Derelict Vessel Evaluation Tool (DVET) used to rank vessels for removal.

Marine Derelict Vessel Spreadsheet	date:
Vessel ID	
Registration	
Type	
comm/rec?	
Location	
water depth	
state or private lands	
~ **Area of Vessel** (length x width)	
estimated tonnage	
% submerged	
Materials present (1–10)	
Wood/metal/linen	
Rubber	
Paint	
Fiberglass	
Engine	
Gas/Oil	
Battery	
Fauna present (1–10)	
Blue Crabs	
Shrimp	
Fish (# of species)	
Oysters	
Endangered/Threatened	
Other (specify)	
Fisheries Habitat (1–10)	
Reef	
SAV	
Marsh	
Bare sediment	
Water Quality (1–10)	
Turbidity	
DO (mg/L)	
Salinity (ppt)	
Temp (°C)	
Drainage pattern	
Eyesore (1–10)	
Stability (1–10)	
Ease of removal (1–10)	
Navigation Hazard (1–10)	
State of Decay (1–10)	
Damage to Existing Habitat (1–10)	
(1 best, 10 worst)	
TOTAL SCORE	

selected in consultation with state and federal regulators and in compliance with existing ordinances concerning derelict vessels (Ansley et al., 2004; Helton, 2003; EPA, 2006; NASBLA, 2009). Each metric is ranked from 1 to 10, with 1 representing best and 10 worst habitat conditions. In an effort to maintain consistency across diverse users, qualitative, observable features were assigned to numerical scores.

The DVET companion guide (Table 2), like the DVET, is broken up into 10 categories and provides details to ensure consistent scoring. Category one examines vessel composition and potential contaminants, e.g. hazardous materials like batteries and oil will result in a higher score than materials that will biodegrade like wood. Category two examines presence of fauna in the immediate vicinity and determines whether commercially important or endangered species may be impacted by the vessel; additionally, these can be customized to fit specific locations. Category three identifies vessel grounding habitat and immediate impacts on habitat viability. An exceptional case exists within this category in the occurrences where a vessel grounding on bare sediments may be the only item providing structure. If assessment predicts that removal would decrease fisheries diversity, then the vessel receives a lower score. Category four examines water quality measurements at the vessel grounding site and consists of two parts: the EPA standards for water quality chart, which ranks various metrics from poor to good, and how to score the water quality based on those EPA standards. Category five refers to “eyesoreness”, which is a general observational assessment of the ADV in keeping with local aesthetics and appeals to the publics perceived impact of a derelict vessel on community satisfaction. In our DVET, a barely noticeable vessel scores lower than a vessel that is an obvious eyesore. The next 5 categories (stability, ease of removal, navigation hazard, state of decay, and damage to existing habitat) are regarding extent of impact a vessel is currently having on the area and difficulty of removal. For example, a vessel that is resting on a reef and blocking part of the channel not only presents a navigational danger but is also a potential future source of storm debris and further habitat damage.

2.4. *Derelict vessel evaluation and assessment of environmental improvement*

In March of 2014 prior to vessel removal, we carried out a first evaluation of all 29 ADVs using the DVET (Tables 1 and 2). This evaluation only considers metrics that can be easily evaluated from land or boat without any work that involves getting in the water, and included all metrics listed in the Tables. Fauna present was assessed based on organisms that were observed in the water from the boat, although this could be inaccurate when turbidity is high. Habitat was also observed from the boat and all habitats present were marked. Water Quality was assessed based on 5 metrics used by the EPA, turbidity (measured with a Secchi disk), dissolved oxygen (DO), salinity, and temperature (measured with a YSI Pro2030), and observed drainage pattern. The six categories Eyesore, Stability, Ease of Removal, Navigation Hazard, State of Decay, and Damage to Existing Habitat were observational and evaluated consistently using the DVET companion guide (Table 2).

Next, the 29 ADV's were broken into five groups of six vessels each (4 vessels in the final group) based on their ranking (i.e. the six worst ranking vessels and highest scores on the DVET into one group, the second six worst ranking vessels into the next group, and so forth with the best ranking vessels in the final group). We randomly selected two vessels out of each group, for a total of ten vessels, and these ten vessels were in turn re-ranked from worst (10) to best (1). Out of these ten vessels, five were removed, two were removed and the surrounding habitat restored (by planting SAVs to 50% cover), and three were left in place (the other 19 ADV's were also removed as per funding agency mandate). For these ten selected vessels we conducted in-depth pre- and post-removal sampling also using the DVET and in-water sampling methods. In depth pre-removal sampling took place in March 2014 shortly after the evaluation of all 29 ADVs and post-removal sampling was done six months (October 2014) and one year (April 2015) after vessel removal.

The comparison of the rapid, DVET-only with more rigorous pre-removal assessments allowed us to test the accuracy of the quick evaluation obtained with the rubric, i.e. how the quick evaluation based on features that can be readily observed from the boat compared with a more in-depth evaluation that involved intensive in water sampling methods. Our initial intent with the comparison between in-depth pre- and post-removal assessments was to quantify environmental improvement that results from derelict vessel removal, as well as whether that improvement was larger for vessels with a higher score. Unfortunately, due to requirements

Table 2
DVET companion guide for use to ensure accurate and consistent vessel evaluations.

Materials Present				**Eyesoreness**	
1–2	wood/metal/linen			1–2	not readily visible
3–4	rubber/peeling paint			3–4	barely visible
5–6	fiberglass			5–6	noticable
7–8	engine			7–8	obvious but whole area junky
9–10	battery, gas or oil			9–10	obvious, only junk in otherwise nice area
Fauna Present				**Stability**	
1–2	Blue crabs, fish, oysters and shrimp OR endangered species			1–2	mostly buried, not moving
3–4	Any 3 blue crabs, fish, oysters and shrimp			3–4	sunken but not buried
5–6	Any 2 blue crabs, fish, oysters and shrimp			5–6	free floating but tied to something
7–8	Any 1 blue crabs, fish, oysters and shrimp			7–8	resting on bank
9–10	No obvious species of commercial importance			9–10	free floating
Fisheries Habitat				**Ease of removal**	
1–2	bare sediment, vessel providing habitat (seen yourself)			1–2	sunken, buried and other obstacles
3–4	bare sediment, may be providing habitat (reported by anglers)			3–4	sunken, buried
5–6	bare sediments (no fauna)			5–6	sunken
7–8	other habitat (ex. logs)			7–8	Resting on bank
9–10	Marsh/SAVs/reef			9–10	Floating
Water Quality				**Navigation Hazard**	
1–2	everything within good values			1–2	blocking <10% of channel
3–4	everything within good/acceptable values			3–4	blocking <25% of channel
5–6	1 or more values poor			5–6	blocking <50% of channel
7–8	2 or more values poor			7–8	blocking <75% of channel
9–10	3 or more values poor			9–10	blocking >75% of channel
EPA standards for water quality				**State of Decay**	
Dissolved Oxygen				1–2	no noticable decay
poor	<2 ppm/< 5 mg/L			3–4	decay <25%
acceptable	2–5 ppm/5–6 mg/L			5–6	decay <50%
good	>5 ppm/> 7 mg/L			7–8	decay <75%
Water Clarity		**Temperature**		9–10	Decay >75%
poor	<0.33 m	poor	>85 °F		
acceptable	0.33–1 m	acceptable	82–85 °F	**Damage to Existing Habitat**	
good	>1 m	good	<82 °F	**1–2**	Floating, No damage visible
Salinity		**Drainage pattern**		**3–4**	resting on bare bottom (scarring, trench)
poor	<5 ppt	poor	stagnant	**5–6**	resting in marsh, reef, SAVs (no visible damage)
acceptable	5–10 ppt	acceptable	low flow	**7–8**	resting in marsh, reef, SAVs & signs of damage (scarring, trench) < 50%
good	10–28 ppt	good	high flow		
				9–10	resting in marsh, reef, SAVs & signs of damage (scarring, trench) > 50%

imposed by the agency that funded this work, we could not leave in place vessels with high scores. Thus, our "control" vessels left in place had relatively low scores in relation to removed vessels. Regrettably but inevitably, this negates a sound analysis of environmental improvement gained with derelict vessel removal since control (i.e. left in place) and removed vessels do not cover similar ranges in their scores. At any rate, our work can still offer some suggestions regarding potential environmental benefits of derelict vessel removal.

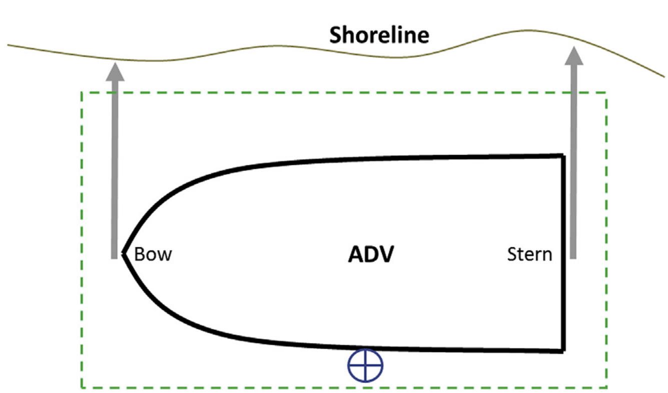

Fig. 2. Diagram showing area sampled "in-depth." The blue circle denotes where water quality was sampled, the dashed, green line denotes the area where macrophyte cover was evaluated, and the gray arrows denote where seining occurred.

For the in-depth sampling, we re-assessed categories 1–4 (Materials Present, Fauna Present, Habitat, with the addition of percent cover, and Water Quality), with a more rigorous inspection via direct sampling efforts. The scores for the other six categories remained unchanged. We also sampled more replicates or areas around the vessel footprint (Fig. 2) whereas the initial quick

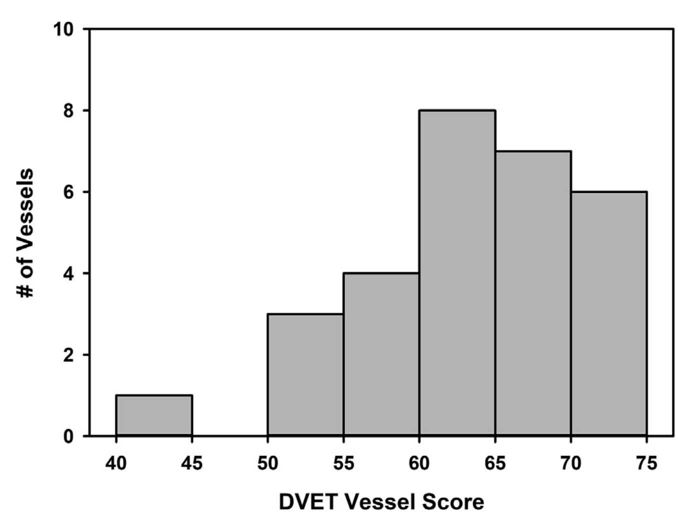

Fig. 3. Histogram depicting the range of DVET scores for the 29 derelict or abandoned vessels identified in Dog River, AL.

assessment resulted from a single observation at the center of the vessel. Water quality measurements were taken in the middle of the vessel for all sampling dates and included dissolved oxygen (DO), salinity, temperature, and flow, measured with a YSI Pro2030. Macrophyte cover at each vessel site was evaluated as percent cover using visual estimation from bow to stern and the immediate surroundings (Daubenmire, 1959; Tatu et al., 2007). Fauna Present was assessed by sampling nekton abundance using seine nets. Seining occurred at high tide (±2 h) and was repeated twice at each location, once from the vessel bow to the shoreline and once from the stern to the shoreline. Collected organisms were identified to the lowest practical taxonomic level (typically species) to determine abundance and richness.

2.5. Statistical analysis

Upon re-scoring the ten vessels with the in-depth sampling, these scores were compared with the scores obtained with the quick evaluation using a Wilcoxon rank test using IBM SPSS Statistics v22. A 0.05 significance level was used.

3. Results & discussion

Of the 54+ initially reported derelict vessels only 29 of them were determined to actually be derelict and/or abandoned. The DVET was used to assess these 29 vessels assigning each one a score from 1 to 100 and then ranking them by potential damage and removal priority (i.e. the higher the score the higher the potential damage and removal priority). The actual values resulting from the DVET ranged from 43 to 73 with a mean score of 62.5 and a median score of 61 (Fig. 3). The vessels surveyed were found afloat (14%), run aground (48%), or partially submerged (38%) on various subtidal substrates, primarily SAV (10%) or bare sediments (48%, the remaining 32% of vessels were in the marsh).

The purpose of the DVET is to allow a team to quickly and easily assess a large number of derelict vessels to help towards the

Table 3
Ranking and score of each of the 10 derelict vessels selected for in depth habitat sampling using only the DVET and then using the DVET with detailed habitat sampling. The highlighted selection shows where two of the vessels switched rank order.

Rank	DVET only	DVET + habitat sampling
1	Vessel 32 (score = 73)	Vessel 32 (score = 73)
2	Vessel 37 (score = 70)	Vessel 37 (score = 67)
3	Vessel 5 (score = 67)	Vessel 5 (score = 67)
4	Vessel 45 (score = 66)	Vessel 45 (score = 65)
5	Vessel 43 (score = 61)	Vessel 13 (score = 59)
6	Vessel 13 (score = 59)	Vessel 43 (score = 58)
7	Vessel 1 (score = 57)	Vessel 1 (score = 57)
8	Vessel 3 (score = 52)	Vessel 3 (score = 52)
9	Vessel 49 (score = 51)	Vessel 49 (score = 51)
10	Vessel 21 (score = 43)	Vessel 21 (score = 43)

determination of potential damage and removal priority. Here, we were able to relocate and examine 60+ vessels and evaluate the 29 used for this study in under 8 h with 2 investigators. Our subsample of 10 vessels provided a test of reliability for the quick DVET assessment. The re-ranking obtained with the in-depth assessment only resulted in one difference in relation to the quick ranking (Table 3 and Fig. 4), in that the vessels in spot 5 and 6 switched order. There was not a significant difference in overall removal rankings between the two methods suggesting the DVET does an adequate job evaluating vessels and eliminating the need for any more detailed sampling (Table 3 & Fig. 4, Wilcoxon signed-rank test $Z = -1.633$, $p = 0.102$). The in-depth sampling of just 10 vessels took ~7 h, split over 2 high tide cycles, and 4 people (a boat driver, 2 field techs, and a data recorder).

Over the course of one-year post vessel removal 80% of the derelict vessel sites experienced an increase in percent SAV cover (Fig. 5a). Two out of the three vessels left in place, and four out of the five removed, showed an increase in SAV cover. For the vessels left in place, the increase in SAV was ca. 20% and 100% for the two vessels with the lowest score (43 and 52), and 0% for the vessel with the highest score (59). Regarding removed vessels, the increase in SAV for lower scoring vessels (50–60) ranged from 20 to 50%, whereas for higher scoring vessels (65–70) it ranged from 0 to 100%. The two restored sites showed large increases despite high scores. Macrophyte composition consisted of 3 species, *Ruppia maritima* which was most prevalent near the mouth of Dog River and *Vallisneria americana* which was most prevalent throughout the rest of the river with patches of up to 25% *Potamogeton pusillus*.

The most common nekton species caught in the seines included juvenile blue gill, croaker, anchovy, goby, silversides, grass shrimp, and juvenile blue crab. All ten vessel sites monitored showed an increase in the number of nekton taxa (Fig. 5b). For the vessels left in place, the increase in taxa richness was 2 and 4 for the two vessels with the lowest score (43 and 52), and 1 for the vessel with the highest score (59). Regarding removed vessels, the increase in taxa richness for lower scoring vessels (50–60) was 2 whereas for higher scoring vessels (65–70) it ranged from 1 to 7. The two restored sites showed a modest increase of 1.

Unfortunately, due to funding agency mandates, we could only leave three ADV's in place ("control" vessels) with relatively low scores. Hence there is little overlap between removed and untampered ADV's in terms of their scores. This precludes sound

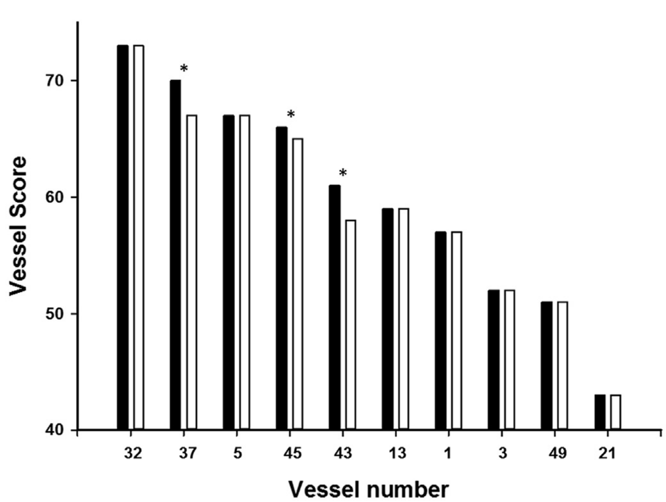

Fig. 4. Vessel scores recorded for each derelict vessel. Black bars show the score using only the DVET and white bars show the score when combining the DVET with detailed habitat surveys. The asterisk denotes which vessels had a change in vessel score.

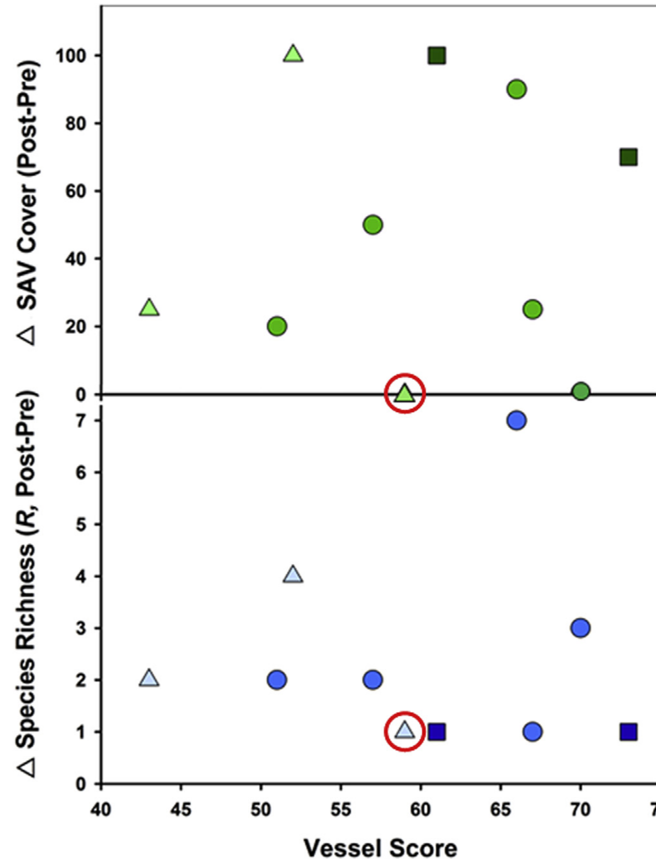

Fig. 5. Change in percent submerged aquatic vegetation (SAV, green) cover and nekton species richness (R, blue) 1 year post-removal minus pre-removal for each of the 10 "in-depth" sampled vessel sites. Triangles are sites where the vessel was left (red circle, nothing was done to it) or repurposed (vessels were used as a bulkhead and part of a floating dock), circles are sites where the vessel was removed, squares are sites where the vessel was removed and the SAV restored. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

analysis of environmental benefits resulting from derelict vessel removal by comparing pre- and post-assessments (i.e. change in the metric one year after removal in relation to pre-removal levels for vessels removed or left in place). At any rate, our results still allow us to suggest that ADV removal may indeed generate environmental benefits (i.e. increased SAV cover and nekton richness). Indeed, in all but one instance (no SAV increase for removed vessel with score 70) we found higher SAV cover or nekton richness for removed vessels one year after removal in relation to pre-removal conditions. In addition, the only "control" vessel left in place that overlapped significantly in score with the scores of the removed vessel ("control vessel" with score of 59) had generally lower SAV or nekton increases than the removed vessels. Although certainly only in a preliminary fashion, such observations suggest that removing derelict vessels may generate significant environmental improvement.

Due to the funding agency mandates regarding "control" vessels left in place, we cannot provide a robust test of whether removing vessels with higher scores generates larger environmental benefits, and thus such vessels should be targeted and prioritized for removal. In addition, removed vessels with high scores showed contrasting benefits, ranging from little to large change in SAV cover and nekton richness. However, it was observed that the vessels left in place with the lower scores show significant environmental improvement, as opposed to the vessel left in place with the highest score. Suggesting that low scores obtained with the

DVET may identify vessels with low priority for removal, since they may not be causing damage in the environment and may provide enhancement of ecosystem services via preferred nekton habitat. Better understanding the prioritization potential of the DVET requires more effort and assessment as mangers begin to use this tool.

In conclusion, we propose a tool (DVET) that can assess potential damage exerted by derelict vessels in an easy and quick fashion. The tool is based on metrics that can be readily obtained with a boat visit to the sites of the derelict vessels. The metrics can be recorded by several people simultaneously and, upon appropriate training and inter-personnel calibration, they should be comparable and consistent among surveyors. We demonstrate the accuracy of this tool with in-depth sampling, and suggest environmental improvement following derelict vessel removal. The DVET appears to be a promising tool for informing management strategies towards the removal of derelict vessels. For instance, the tool has been used in Bayou La Batre, Alabama to prioritize the removal of shrimp boats during 2016 that sunk during hurricane Katrina, in Florida to prioritize ADV removal after a large flooding event in 2014, and by NOAA in the U.S. Virgin Islands to assist in prioritizing removal of ADVs left over from past hurricanes and tropical storms. This demonstrates that the DVET is able to be used in a wide range of habitats and situations although future work is needed to accurately quantify the environmental benefits of vessel removal, as well as removal prioritization, as informed by the DVET.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jenvman.2017.11.046.

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