Fishing for common ground: Investigations of the impact of trawling on ancient shipwreck sites uncovers a potential for management synergy

ABSTRACT

Maximizing social and economic benefits from fisheries and protecting culturally significant archaeological sites are management goals often viewed to be at odds with eachother. However, a potential for management synergy arises if fisheries related benefits can be associated with the protection of shipwreck sites. This study reviews fish abundance and community assemblage on several ancient shipwreck sites in the Aegean Sea. In this region, the presence or absence of fishing has been correlated to shipwreck condition. The results indicate that, on average, wrecks in worse condition (heavily fished) had 55% lower species richness, 57% lower abundance, and 41% lower diversity than wrecks in pristine condition, though only the patterns for abundance and species richness were statistically significant. No statistically significant change in fish community composition between fished and unfished wrecks was observed, though community composition between shallow water and deep water wrecks was statistically different. This research highlights the potential benefit of marine protected areas around areas of high density of shipwrecks that can both protect these sites and increase local fisheries by preserving these artificial reefs.

KEYWORDS: *artificial reefs; fisheries management; marine protected areas; shipwrecks*

1. INTRODUCTION

Marine usage conflicts are common with issues of marine policy where multiple parties seek to exploit the same areas. As populations in coastal areas grow, and demands on marine resources struggle to keep pace, the frequency and severity of these conflicts between user groups only continue to increase. This conflict is especially acute between the fishing industry and the conservation community. Bottom trawl fishing operations have long been challenged by benthic ecologists and fisheries biologists for their destructive effects on the seabed and non-selective capture of species (e.g., Alceo et al., 2013; Roberts, 2002; Kaiser et al., 2000). Increasingly, however, the use of marine protected areas (MPAs) has been proposed as a potential management synergy where the exclusion of fishing within a protected area generates increased landings in adjacent fishing grounds by means of "spillover" (e.g. Forcada et al., 2009; Harmelin et al., 2008; Molloy et al., 2009). Here we investigate preliminary field data that suggest the possibility of using MPAs to protect shipwreck sites in order to enhance the fisheries value of the MPA, based on the improved ability of protected cultural heritage sites to function as artificial reefs, potentially supporting higher abundance and/or diversity of fish than unprotected sites.

The use of MPAs and artificial reefs for fisheries benefits dates back several hundred years (McGurrin et al., 1989; Christie, 2004; Kalikoski et al., 2007), however, their widespread use as a modern management tool dates back only a few decades. Fisheries benefits from MPAs center around the concept of spillover, wherein the fish population within the protected area grows rapidly. This can lead to fisheries benefits when adults migrate out of the reserve and into fishable waters to alleviate density dependence, or when the high density of spawners within the protected area create additional larval recruits which may advect or swim into fishable waters (Russ and Alcala, 1996; Planes et al., 2009). The fisheries benefit of artificial reefs on the other hand, is somewhat less clear. While artificial substrate has been clearly documented to attract fish (e.g., Wilson et al., 2001; Moberg and Rönnbäck, 2003), whether these structures can supplement regional fisheries production is the subject of some scientific debate, and is likely dependent on regional and species specific factors such as population size, availability of suitable habitat, and fishing intensity (Osenberg et al., 2002; Powers et al., 2003).

Suitable artificial reef habitats often include the architecture of a shipwreck. Whether an accidental or intentional sinking (e.g., Walker et al., 2007), the structure and cargo of a shipwreck provide a range of habitats highly suitable for colonization. Particularly in amphora pile or ballast stone wrecks where the cargo provides a range of mesoscale and microscale habitats, these artificial reefs can closely resemble the habitat assemblages found on natural reefs (Baine, 2001; Charbonnel et al., 2002; Sherman et al., 2002).

There is a strong interest within the marine archaeology community to protect known shipwreck sites, especially those in coastal deep waters that are below the reach of divers and the impact of storms, but within reach of fishing activities. In addition, the UNESCO Convention on the Protection of the Underwater Cultural Heritage calls for in situ preservation of underwater cultural heritage sites as the first option for site management (UNESCO, 2001). However, when it comes to justifying their protection in these areas at the expense of other extractive uses, it becomes a difficult proposition to suggest restricting or eliminating these known productive uses to protect resources that are hidden from the public eye. However, there is an increasing body of literature publicizing the amount of damage that trawling can do to shipwrecks (e.g. Brennan et al., 2012, 2013; Foley, 2008; Kingsley, 2010, 2012; Pringle, 2013), not only damaging and scattering artifacts, but also destroying the integrity and context of the sites. Some areas are so heavily trawled that locating shipwreck sites there may no longer be possible (Brennan et al., 2012). This opens up the legitimate possibility that continued unrestricted trawling in nearshore regions will reduce remaining undiscovered shipwrecks to indistinguishable rubble very rapidly. This is particularly true for ancient wrecks, as all that usually remains from shipwrecks more than a few centuries old is non-biodegradable cargo such as ceramics and ballast stones.

This call for shipwreck site preservation at first seems in direct opposition to increased pressure on the fishing industry to meet increasing demand for seafood, and to remain profitable despite rising fuel costs, depleted stocks, and falling quotas. However, in coastal marine areas, there may be a possibility for a synergistic and mutually beneficial relationship if both interest groups can be aided by the same management action. There are copious data on the ability of marine reserves to augment fisheries through adult fish spillover (e.g. Forcada et al., 2009; Harmelin et al., 2008; Molloy et al., 2009). There is also precedent for protecting shipwreck sites with MPAs, although they differ in their effectiveness. For example, Thunder Bay National Marine Sanctuary was established to specifically protect maritime heritage sites, whereas Stellwagen Bank National Marine Sanctuary in Massachusetts Bay does not prohibit trawling operations, leaving “protected” shipwreck sites entangled in and damaged by fishing nets (U.S. Department of Commerce, 2006, 2010). However, little effort has been put into determining the potential for additional nested fisheries benefits associated with protecting artificial reefs, which are also cultural heritage sites. This research demonstrates a potential for synergy to call for the protection of areas with high densities of shipwreck sites, based on data from the Aegean coast of Turkey and ancient shipwrecks located there. Additionally, this work emphasizes the importance of continued ocean exploration to determine other areas where this approach can be beneficial.

In order to demonstrate the potential for management synergy, the following argument must be established. Some of the steps are relatively well accepted in the literature, but others have been more difficult to support with data:

1. Fishing damages shipwreck sites (e.g. Brennan et al., 2012, 2013; Foley, 2008; Kingsley, 2010, 2012).
2. The exclusion of fishing protects these sites, making them better refugia.
3. Artificial reefs (including shipwrecks) aggregate commercially important fish in higher than ambient quantities (Wilson et al., 2001; Turpin and Bortone, 2002; Tallman and Forrester, 2007).
4. Protection of important fisheries habitats using MPAs increases overall fisheries production and ecosystem services in the region (Ami et al., 2005; Kalikoski et al., 2007).

Most of the steps in this argument have been well studied in the literature, and been shown to be true in most cases. However, data showing that the exclusion of fishing protects shipwreck sites and improves their ability to enhance the fishery remains limited. To address this gap, this study examines a series of 49 ancient shipwrecks located in the Aegean Sea off the coast of Turkey by Exploration Vessel (E/V) *Nautilus* from 2009-2012 in waters ranging from 50-600 m. These wrecks also lie in areas of heavy bottom trawl activity, as shown by Brennan and colleagues (2012), though some areas within this region have never been fished due to submarine cables or topography which prevents the use of bottom trawling equipment. When these wrecks are viewed as topographic features of the modern submarine landscape, the conditions of the sites illustrate the environmental effects of trawled and undamaged sites on fish populations. Analysis of 18 of these sites shows that shipwrecks in areas historically excluded from fishing are in better condition and support larger and more diverse fish communities than wrecks which have been damaged by trawling.

In addition, these results indicate that fishing pressure does not change the species assemblage, but wreck sites in better condition and not in the path of bottom trawls are positively correlated with both abundance and, to a lesser degree, species richness. While a relatively small sample size, this is the first time such an effort can be attempted statistically because this is one of the largest concentrations of ancient shipwrecks found in deep water. The results of this analysis suggest that protection of an area with a high density of archaeological sites, such as off Knidos, Turkey, can help to increase the south Aegean fishery through spillover into fishable areas. No protected areas have been established in these waters off Turkey to date, although some studies have indicated the southeastern Aegean by Rhodes, Datça, Bodrum, and Kos to be an ecologically important area and important for conservation (Katsanevakis et al., 2015; Micheli et al., 2013). This research illustrates a potential for management synergy between benthic ecology, marine archaeology, and the fishing industry in an already overburdened fishery that, upon the establishment of MPAs, would simultaneously protect maritime heritage sites in these waters.

2. STUDY AREA

E/V *Nautilus* conducted exploration operations along the Black, Aegean, and Mediterranean coasts of Turkey from 2009-2012. During these expeditions, a large number of shipwrecks were found in deep water ranging from 50-600 m and ranging in time from Archaic Greek to the 1950s (Brennan et al., 2012, 2013; Brennan, 2013). One wreck was found in the northern Aegean off the Gallipoli peninsula during a survey of the World War I battlefield (Brennan et al., 2011). Ancient wrecks were also located during surveys off the Bodrum peninsula near the modern town of Yalıkavak, and in the northeastern Mediterranean south of Marmaris, Turkey. However, the largest concentration of shipwrecks was found south of the ancient site of Knidos at the end of the Datça peninsula in the southeast Aegean Sea. Twenty six ancient wrecks were located here and provide the best case for a theoretical protected area. These approaches to Knidos were hazardous to mariners looking to round the point in ancient times, and today the flat area of seabed south of this peninsula is heavily trawled (Brennan et al., 2012). Bottom trawling is prohibited in certain areas, including within 2.5 km of the Turkish coast and within 100 m of any submarine cable (KKGM, 2006). However, the majority of the wrecks found in this area are just outside the 2.5 km zone and exhibit evidence of trawl damage.

3. METHODS

Shipwrecks were located with a side-scan sonar towfish from E/V *Nautilus* and then identified with the ROVs *Hercules* and *Argus*. Once identified and filmed with HD cameras, each wreck was mapped in high resolution with stereo cameras, multibeam bathymetry, and structured light lasers from *Hercules,* from which photomosaics of each site were produced (Roman et al., 2013). These mosaics were used to conduct counts of the surface artifacts on each wreck site and whether the artifacts were broken or unbroken. This determined a damage percentage which we use as a measure of trawl damage to each site. This damage assessment was limited to 18 of the 49 wrecks found off Turkey because only amphora cargo wrecks could be evaluated in this way, and we chose to limit our study to wrecks with sufficient ceramic artifacts (>10) to quantify in this way, and a minimum of 50 total pieces of substrate (artifacts + ballast stones), a size below which we felt that the structure provided by the artificial reef was not substantially different from the ambient bottom conditions.

[Table 1 Here]

The 18 wrecks in this study span a broad range of sizes, depths, and complexity levels (bottom), so for each wreck, the depth, total area of the wreck, vertical relief, # of observed artifacts (most wrecks used were amphora piles, except Marmaris C which is mostly ballast stones, but had enough amphora to determine % broken), and % of observed artifacts which were broken were recorded from photomosaics assembled of each wreck (Table 1). To analyze fish community screen captures (Figure 1) were taken from the HD video recorded during dives with the ROV *Hercules*, and the fish were identified to the lowest possible taxonomic level, and quantified using REEF abundance categories; Single, Few (2-10), Many (11-100), and Abundant (>100). Because the ROV surveys were not designed to count fish, it was often only possible to identify fish to the family level, and quantification beyond this relative abundance index was not possible, since it can be difficult to avoid double counting fish that move around the wreck site. In cases where the first analyst was not able to positively identify the species, a second analyst independently reviewed the image and both analysts assigned a level of certainty to their confidence with the identification at each taxonomic level (certain, reasonably certain,

uncertain). In cases where neither analyst was certain of the identification, the highest taxonomic level where both analysts agreed and were certain or reasonably certain of their identification was used.
[Figure 1 here]

Species richness (total # of species observed) was calculated for each wreck, two other semi-quantitative methods of assessing fish populations on the wreck, “abundance” and “diversity”, were devised for this analysis. The abundance index is calculated by assigning a relative abundance index to each observed species of 1, 2, 3, or 4 for single, few, many, and abundant (defined above) respectively, and summing those indices for all observed species on the wreck. The Simpsons reciprocal diversity index was then calculated with these relative abundance scores. The index (D) is calculated as the proportion (*p*) of the total abundance made up of species *I* squared then summed across all species observed (*S*), and ranges from 1; indicative of a community entirely dominated by a single species, to S; a community exactly evenly divided among S species:

Eqn. 1

These semi quantitative metrics of fish population (species richness, abundance, and diversity) can be compared between wrecks with differing levels of trawl damage to determine whether there are statistical differences in the fish populations between wrecks damaged to different degrees. It is important to note that, because these calculations are based on a relative abundance index rather than actual quantitative abundance data, these metrics should be viewed as semi-quantitative, rather than as true estimates of abundance and/or diversity, and therefore are useful only for internal comparison, and should not be compared to metrics from outside this study.

In order to assess whether wreck condition impacts richness, abundance, and diversity, a damage classification was assigned to each wreck of low (<10% of artifacts damaged, n=8), moderate (10-25% damaged, n=7), or high (>25% damaged, n=5). Percentage of artifact damage has been shown in this area to be correlated with areas where trawling is impossible, either due to legal restrictions (closed areas in the vicinity of the coastline) or terrain (rocky, steep slopes, ridges, etc.) (Brennan et al., 2012). For example, in the Knidos region, legal restrictions prohibit trawling within 4 km of shore, and a sharp increase in % damaged in wrecks was observed outside this protected area (Figure 2; Brennan et al., 2012). Also noted was whether trawl scars were present in the immediate area, and the presence or absence of fishing gear on the sites, and this was found to line up reasonably well with the above quantitative metric.

[Figure 2 here]

To get an idea of what external factors govern changes in the fish community, dendograms and MDS plots were developed with PRIMER to compare the similarity of the fish community at different sites, and determine whether any covariate parameters significantly impact the fish community. Shipwreck depth, wreck surface area, relief from bottom, and % broken artifacts were tested in this way, and ANOSIM (also in PRIMER) was used to determine the significance of any observed patterns. Because all of the wrecks surveyed are ancient, wreck age was not considered as a variable, since all of the wrecks surveyed were on the bottom long before mechanized fishing began. Depth groups were assigned as shallow (<100m, n=3) and deep (>100m, n=15) to the wrecks based on the presence or absence of surface light, as it was anticipated that the possibility that fish communities in the photic zone might vary from those in aphotic or disphotic waters. Species richness abundance and diversity indices were then compared across observed levels of fishing effort using regression and ANOVA to determine if wrecks in better condition supported larger or more diverse fish communities.

4. RESULTS

In total, on the wrecks surveyed, 23 unique fish species were identified, with 9 additional species likely to be unique (both analysts agreed and assigned certainty of "somewhat certain"), but conclusive confirmation was not possible due to limitations in imagery. This provides a total of approximately 32 observed fish species. Many of these species are commercially harvested and were found on several wrecks, often in large numbers. The most frequently observed species included Swallowtail seaperch (*Anthias anthias*), Picarel (*Spicara smaris*), European conger (*Conger conger*) several species of bream (including Common pandora (*Pagellus erythrinus*), Two-barred seabream (*Diplodus vulgaris*), and Saddled seabream (*Oblada melanura*), and several species of rockfish, (likely including *Helicolenus dactylopterus* and *Scorpaena spp.*). Common pandora was the most abundant fish overall, present on 6 wrecks, with an abundance score of 3 or greater on 3 wrecks, and a rockfish (probably *Helicolenus dactylopterus)* was the most frequently observed species, found on 12 of 18 wrecks surveyed. A few species were also observed, which we chose not to include in the analysis, because they are highly reclusive (e.g. Mediterranean moray (*Murena helena*), or not typically site associated (e.g. Cownose ray (*Rhinoptera marginata*), and thus, their observation on a wreck was more likely driven by chance than indicative of the local population.

Species richness ranged from 1-9 with a mean of 3.5, and the abundance index ranged from 1-18 with a mean of 6.6. Diversity measured on our modified diversity index, ranged from 1-2.8 with a mean of 1.5 (Table 1). The highest richness, abundance, and diversity were found on two wrecks, Yalıkavak II (8,19,2.8) and Gallipoli A (9,18,2.4), both of which showed no detectable evidence of fishing (trawl scars, broken amphora). A third wreck with moderate evidence of fishing damage, Knidos A (6,8,2.4) also showed high richness and diversity.

[figure 3 here]

Dendogram analysis (Figure 3) of the fish community using Bray Curtis similarity does not show clear patterns within the fish community, though wrecks tended to be more similar to other wrecks in the same geographic area and depth band. The dendogram identifies a statistically significant break between Yalıkavak I, II, and Knidos L and the remainder of the observed wrecks, and also generally observes more similarity of inshore wrecks (e.g. Knidos L & H, Marmaris B) to each other, than to the offshore wrecks, though some of these patterns are not statistically significant. MDS (Figure 4) provides a somewhat clearer picture of the impact of the covariates on fish community composition, clustering three wrecks apart from all others. The three wrecks in question (Gallipoli A and Yalıkavak I and II) are all less than 100 meters in depth. ANOSIM confirms a significant difference in fish community between wrecks shallower than 100 meters and those deeper than 300 meters (Global R= 0.45, p=0.008). However, none of the other parameters we tested (% breakage, bottom relief, wreck area, or presence/absence of fishing) significantly impacted the fish community, in terms of community assemblage.

[Figure 4 here]

On average, wrecks classified as poor condition (high % broken) had lower species richness (2.2 vs. 4.9), abundance (4.0 vs. 9.4), and diversity (1.06 vs. 1.72) than those classified as good or moderate condition (low to medium % broken). Regression analysis (Figure 5) shows a strong relationship between improving condition (decreasing % broken) and abundance (p=0.01, F=7.2, df=17) and a weaker but still significant relationship with species richness (p=0.04, F=3.3, df=17). No relationship (p=0.28, F=1.2, df=17) with the diversity index was observed. ANOVA confirms the above pattern for abundance, with a statistically significant difference in abundance between wrecks classified with high and low fish pressure (p=0.05, F=3.41, df=17), and no statistically significant difference (p>0.22) observed between high and moderate, or low and moderate fishing pressure. However, ANOVA results were inconclusive for differences in richness between high and low fishing pressure (p=0.08, F=2.41 df=17), and similarly to abundance, show no difference between low and moderate or moderate and high pressure (p>0.36). ANOVA observes no relationship between diversity and fishing pressure (p>0.56 in all cases).

[Figure 5 here]

5. DISCUSSION

The data presented here lend support to the hypothesis that shipwrecks that are in better condition provide additional habitat augmentation benefits (in terms of increased abundance and/or species richness of fish population) over those that are degraded by trawling. This analysis shows an increase in abundance, and to a lesser extent, species richness and diversity, on wrecks that show little or no evidence of trawl damage. In combination with previous research in this area (Brennan et al., 2012) suggesting that wrecks in areas that cannot be fished tend to be in much better condition than wrecks that are in areas open to fishing, the results therefore illustrate the possibility that improving protection for these wrecks would be beneficial for the fishery. Carefully placed restrictions on fishing in areas around known wrecks or with high concentrations of wrecks will not only preserve these historical sites from trawl damage, but will also create additional fisheries benefit over an MPA in an area which does not have high density of shipwrecks.

An interesting aspect of the results is that the community analysis (MDS and dendograms - Figure 3, Figure 4) show no impact on the species present at a given wreck associated with the presence or absence of fishing. To a certain degree, this allows us to remove as a potential covariate the impact of fishing on the species assemblage at the wreck sites, which lends further support to the hypothesis that the observed differences between wreck sites are indeed attributable to wreck condition. Community analysis did, however, show a significant impact of depth on fish community composition, with shallow wrecks substantially different than either moderate or deep ones. This finding is hardly surprising, as the wrecks classified as shallow were all euphotic (with surface light penetrating to the wreck) while the moderate and deep wrecks were mostly or entirely aphotic, and so a different fish community would be expected. This does highlight, however, that from an ecosystem-based management perspective, reserves of this type that cover a wider depth range might be expected to protect more species than those of uniform depth, and particularly, reserves which include shallow (but not too shallow or the wrecks are likely to experience storm damage) regions would be expected to protect a broader range and higher abundance of species.

The regression and ANOVA analyses (Figure 5) show clear and convincing evidence of increased abundance associated with improved wreck condition, both as a regression, and when the wrecks are grouped by fishing pressure. The results for species richness, however, are less conclusive. While regression analysis demonstrates statistically significant positive slope, ANOVA of wrecks grouped by fishing pressure is inconclusive (p=0.08). This may be because the pattern is largely driven by a few unfished wrecks which demonstrated very high species richness, which demonstrates the need (discussed further below) for further research. The diversity metric selected was relatively insensitive to changes in wreck condition, despite the fact that the wrecks in pristine condition generally appear to the eye (e.g. Figure 1) to be more diverse than those in poor condition. This may in part be because the diversity index used (Simpson's Reciprocal) is really a measure of community evenness, and so a hypothetical wreck with only 3 fish observed, one each of 3 species would score very high on this index (3.0). However, because this analysis is limited to semi-quantitative measures of abundance, so too is it limited its diversity metrics, so the lack of a detectable pattern should not be interpreted as a conclusive negative result.

This study does have several liabilities that need to be acknowledged. The sample size was small, with only a few wrecks in each treatment type (low, moderate or high fishing pressure). These parameters were unable to control for autocorrelation between factors which may influence both wreck condition and fish population (e.g. depth, initial wreck size, etc…). For this reason, this type of study can only show correlation between wreck condition and fish abundance and diversity and cannot be used to conclusively establish a causal linkage. Establishing causality would likely require some sort of experimental manipulation (e.g. intentionally inflicting trawl damage and measuring fish populations before and after), and would likely be difficult to permit and conduct. However, the dataset used represents the largest density of ancient shipwrecks in deep water located to date, so additional sample size would not be easy to obtain, and the observed patterns are noteworthy even at the present sample size.

Furthermore, since the imagery used for this study was primarily collected during the documentation of the wrecks rather than a fisheries survey, it was difficult to get accurate counts of fish, and frequently difficult even to estimate and identify the observed fish. Further directed study, either through fisheries specific ROV surveys on these wrecks or increasing sample size would likely improve our ability to resolve these patterns. It would be particularly helpful to collect more data on trawled and untrawled shallow wrecks, as the patterns observed on these wrecks tend to drive the relationships observed in this study and it would be interesting to see if these patterns hold across a larger sample size.

The results stress that, while fishing in the immediate vicinity of areas with known or unknown shipwrecks may result in temporarily higher catch per unit effort (CPUE) these gains are not sustainable, since damage inflicted on these ancient wrecks appears to be directly correlated to fishing effort (Brennan et al., 2012) and also appears to reduce the habitat quality of the wreck from a fisheries perspective. By extension, sustained trawling on these sites has, and will continue to eliminate not only the societal value provided by protecting these cultural heritage sites, but also the economic and ecological value provided by the artificial reefs. Our analysis of this large collection of deepwater shipwreck sites and the species observed on them suggests a mutually beneficial potential for the establishment of marine protected areas. Many areas of the Mediterranean are already being looked at for areas of important ecological regions for conservation, including the area of this study in the southeast Aegean (Katsanevakis et al., 2015; Micheli et al., 2013). The establishment of MPAs that restrict bottom trawling to protect both fisheries and cultural sites has the potential to both prevent further irreplaceable damage to shipwreck sites and increase the local Aegean and Mediterranean fisheries.

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Table

Table 1

Wreck Name	Depth (m)	Area (m2)	Relief (m)	# Visible Ceramics	% broken Artifacts	Fishing Pressure	Depth Group	Species Richness	Abundance Index	Diversity Index
Galipoli A	62			>1000	≈1	L	shallow	9	18	2.77
Knidos A	460	145	0.73	708	25	M	deep	6	8	2.40
Knidos B	595	76	0.43	298	11	M	deep	3	5	1.24
Knidos C	435	163	1.14	557	40	H	deep	3	5	1.24
Knidos F	370	136	0.52	506	5	L	deep	3	6	1.12
Knidos G	372	110	0.11	153	7	L	deep	3	5	1.24
Knidos H	372	160	1.7	459	9	L	deep	3	6	1.12
Knidos J	410			112	25	M	deep	2	3	0.91
Knidos K	386			426	25	M	deep	3	6	1.12
Knidos L	419			128	10	M	deep	3	5	1.24
Knidos M	348			90	13	M	deep	3	9	0.91
Knidos N	400			123	23	M	deep	3	6	1.12
Knidos O	430			73	48	H	deep	3	5	1.24
Knidos S	343			94	65	H	deep	4	5	1.81
Marmaris B	520			755	63	H	deep	1	1	1.00
Marmaris C	291			10*	0	L	deep	4	10	1.30
Yalıkavak II	50	157	1.4	365	<1	L	shallow	8	19	2.38
Yalıkavak I	82			544	24	M	shallow	5	8	1.92

* 10 Amphora observed plus large ballast stones that comprise the majority of the vertical relief

Figures

Figure 1

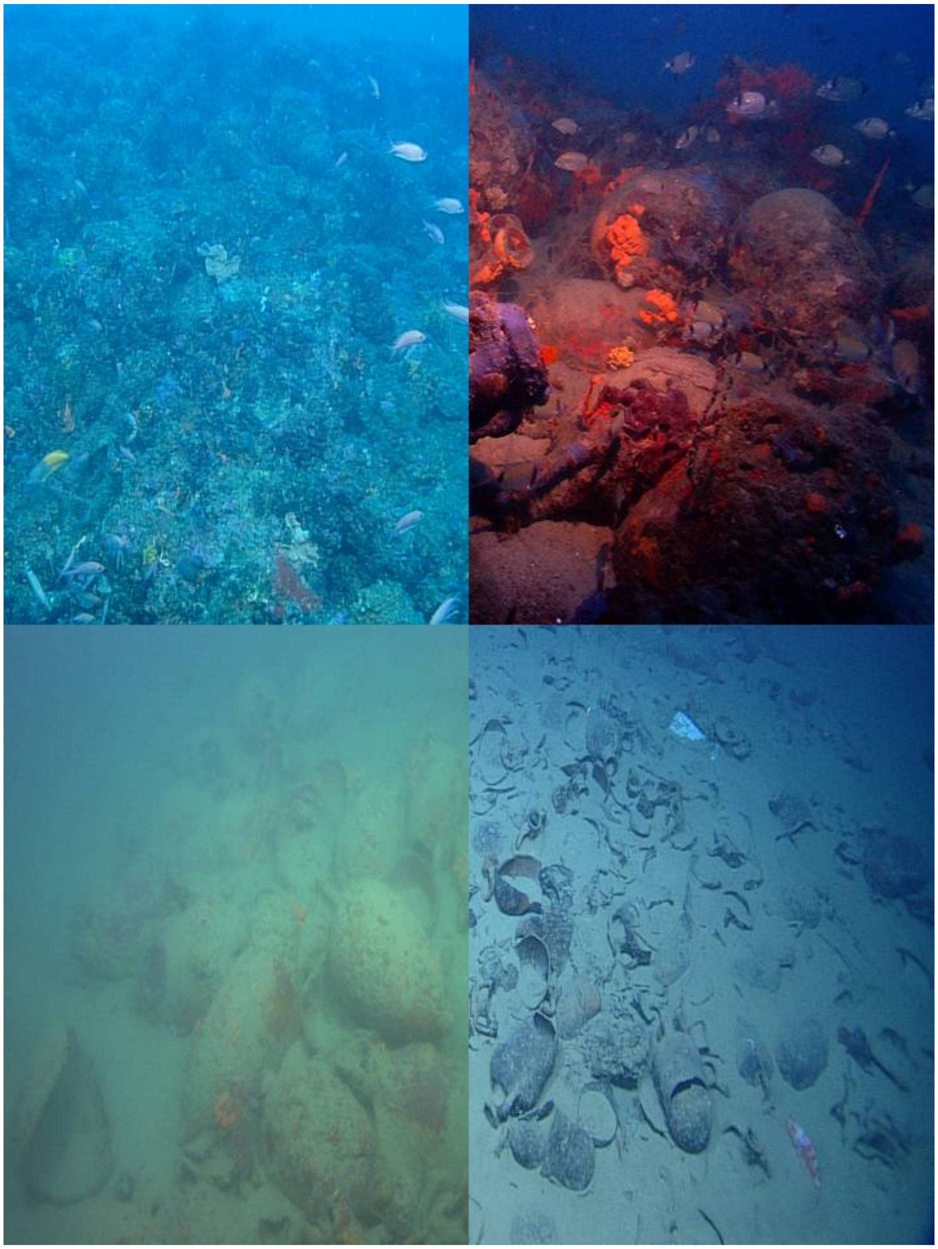


Figure 2

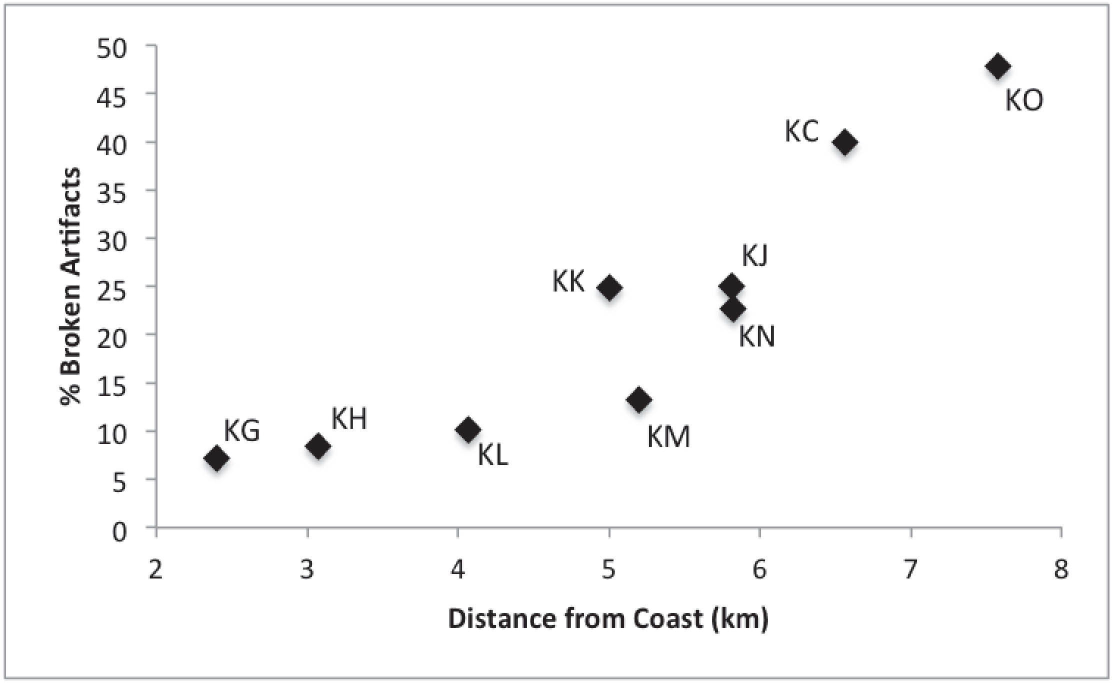

% Broken Artifacts
50
45
40
35
30
25
20
15
10
5
0
2
3
4
5
6
7
8
Distance from Coast (km)
KO
KC
KJ
KK
KN
KM
KG
KH
KL

Figure 3

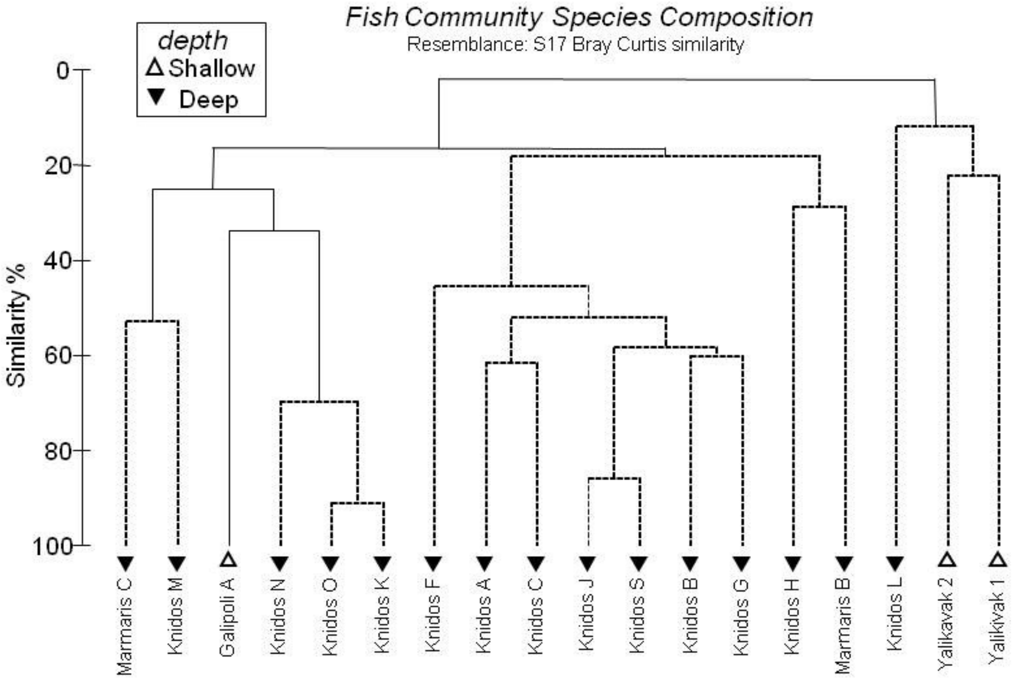

Fish Community Species Composition
Resemblance: S17 Bray Curtis similarity
depth
△ Shallow
▼ Deep
Similarity %
0
20
40
60
80
100
Marmaris C
Knidos M
Galipoli A
Knidos N
Knidos O
Knidos K
Knidos F
Knidos A
Knidos C
Knidos J
Knidos S
Knidos B
Knidos G
Knidos H
Marmaris B
Knidos L
Yalikavak 2
Yalikivak 1

Figure 4

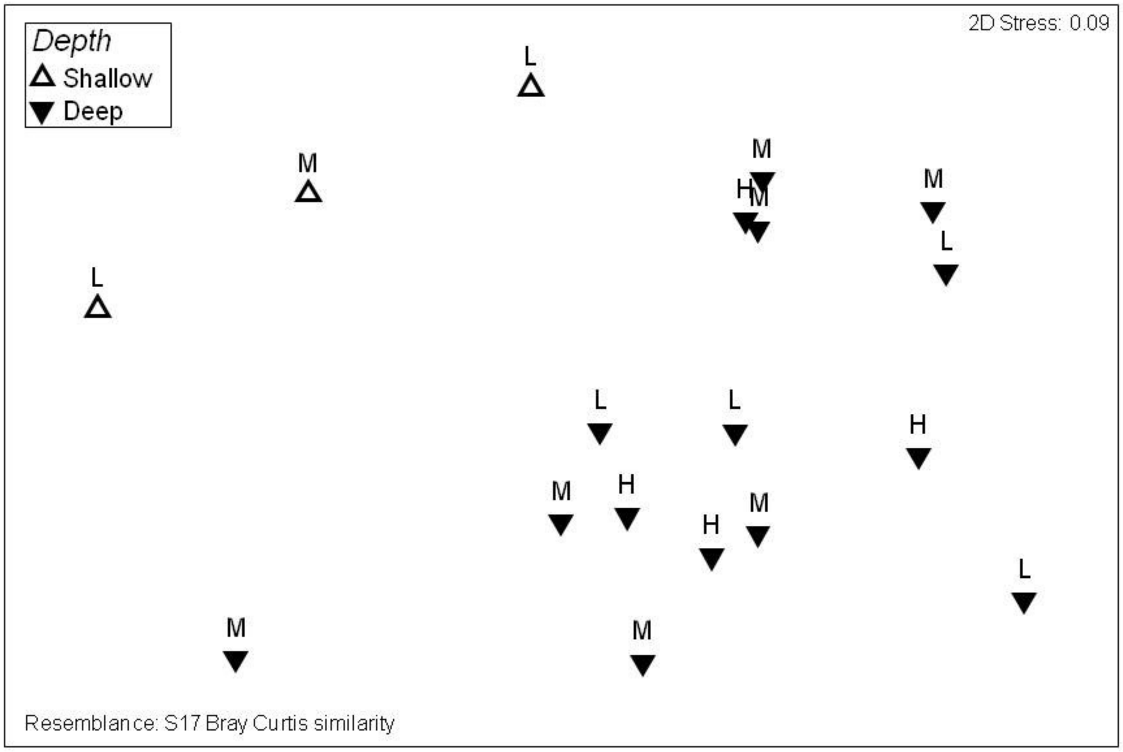
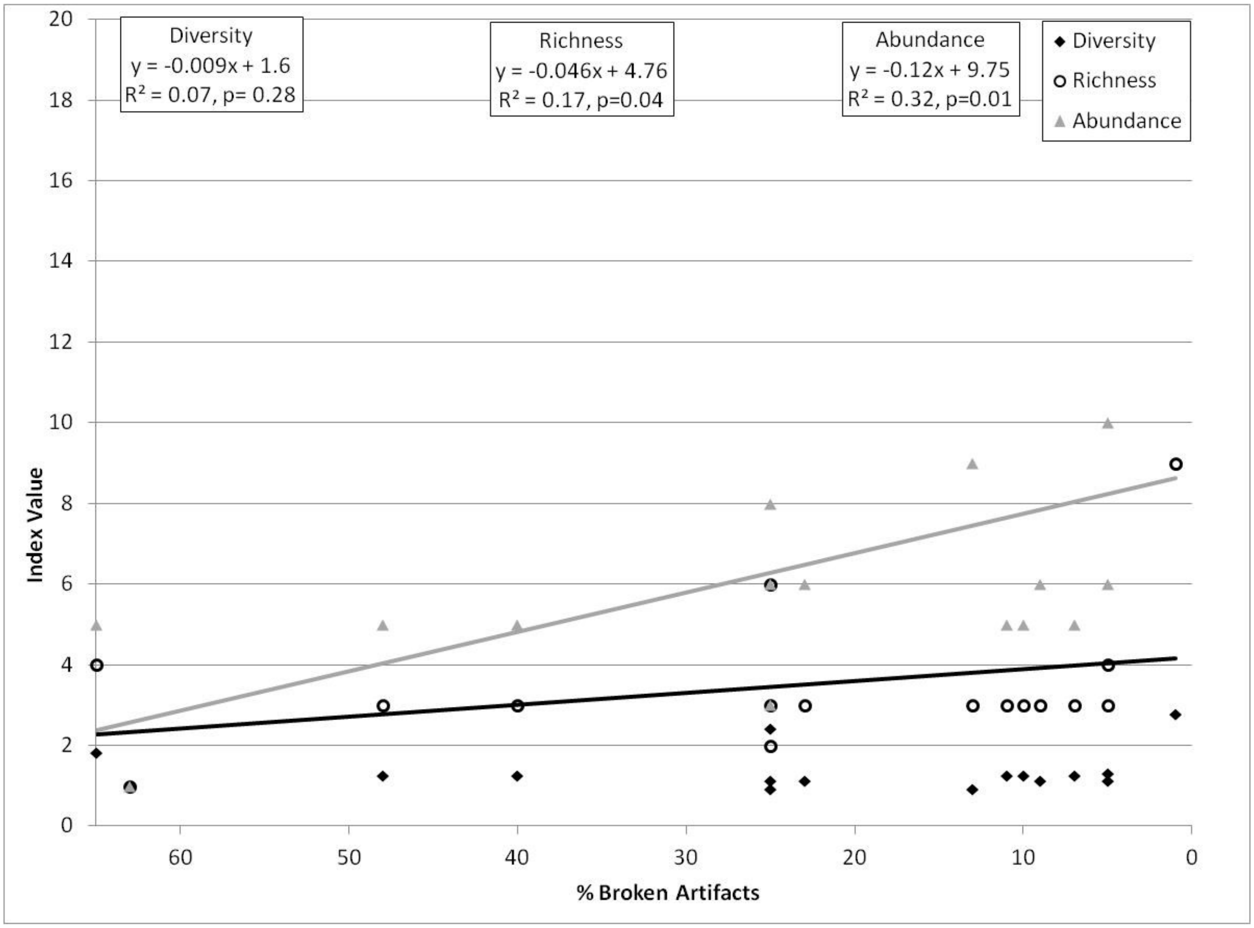

Depth
△ Shallow
▼ Deep
2D Stress: 0.09
L
M
L
M
H
M
M
L
L
L
H
M
H
H
M
L
M
M
Resemblance: S17 Bray Curtis similarity

Figure 5



Diversity
y = -0.009x + 1.6
R² = 0.07, p= 0.28
Richness
y = -0.046x + 4.76
R² = 0.17, p=0.04
Abundance
y = -0.12x + 9.75
R² = 0.32, p=0.01
◆ Diversity
○ Richness
▲ Abundance
Index Value
20
18
16
14
12
10
8
6
4
2
0
60
50
40
30
20
10
0
% Broken Artifacts

Fishing for common ground: Investigations of the impact of trawling on ancient shipwreck sites uncovers a potential for management synergy
J. Krumholz and M.L. Brennan
Figure Captions

Table 1: Properties of each of the 18 Wrecks surveyed. For purposes of statistical analysis wrecks with <10% broken artifacts were classified as "Low", 10-25% "Moderate" and >25% "High" fishing pressure. Wrecks in less than 100M of water were classified as "shallow", and deeper than 100M as “deep” as this breakpoint encompasses wrecks in the photic vs. aphotic zone.

Figure 1: Screen captures from wrecks across the range of conditions observed in the study.l The two wrecks on top are a pristine shallow (Galipoli A, top left) and deep (Yalikavak II, right) wreck, and on the bottom two heavily trawled wrecks, one shallow (Yalikivak I, left) and one deep (Marmaris B, right). Note that these images were intentionally chosen to depict the range of damage and fish abundance observed and are not representative of “average” wrecks in the dataset.

Figure 2: Percentage of artifacts damaged on each wreck vs. distance from shore for 9 wrecks in the Knidos region. In this area a legislative ban on fishing within 4 kilometers of the coast protects the inshore sites, while offshore sites exhibit increased damage from trawling (Figure from Brennan et al., 2012).

Figure 3: Dendogram analysis of wrecks based on fish community composition. The height of the divergence between the branch indicates the level of similarity between the clusters in question, with branches higher up the Y axis (closer to zero similarity) less similar than those closer to the abscissa. Solid lines indicate statistically significant differences while dotted lines indicate differences below the assigned ($\alpha=0.05$) level of significance.

Figure 4: MDS (Multi-Dimensional Scaling) plot of fish community on the observed wreck sites. Marker type indicates depth group assigned to the datapoint, while level of fishing intensity is represented by the label (H= high, M=moderate, L=low). ANOSIM reveals a statistically significant grouping by depth, with shallow wrecks hosting a different community from deep wrecks ($p<0.01$). No statistically significant difference was observed for any of the other tested covariates, including any of the levels of fishing intensity ($P>0.7$ for all permutations).

Figure 5: Relationships between Richness, Abundance, and Diversity Indices and the percentage of artifacts on each site which were broken. Solid lines indicate statistically significant (at $\alpha<0.05$) relationships. All three indices show positive relationships with improving wreck condition (lower % broken), though only abundance and species richness were statistically significant.

Fishing for common ground: Investigations of the impact of trawling on ancient shipwreck sites uncovers a potential for management synergy

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