2024-02

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10.1111/maec.12782
Marine Ecology
Wiley

Received: 4 June 2023 | Revised: 14 September 2023 | Accepted: 12 October 2023

DOI: 10.1111/maec.12782

RESEARCH ARTICLE

marine ecology WILEY

Shipwrecks act as de facto Marine Protected Areas in areas of heavy fishing pressure

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Funding information
Blue Marine Foundation

Abstract

Ubiquitous, industrial use of bottom-towed fishing gear since the 1800s has altered marine communities and ecosystem services. Outside of legal protection, only areas inaccessible to trawlers are offered any protection. Shipwrecks present hazards to fishing gear and are rarely subject to trawling pressure. As many have been in situ for >100 years, they offer a baseline of ecological potential when trawling pressure is reduced or removed. Five shipwrecks were surveyed off the Berwickshire coast, some within the Static Gear Reserve and others outside. Video transects were collected of shipwrecks, the surrounding 50 m radius and control locations >150 m from the wreck site. Species identified were assigned a category based on their vulnerability to trawling. The effect of distance from a shipwreck on ecological communities within sites Open and Closed to trawling was investigated. The ecological importance of shipwrecks increased relative to trawling pressure. In Open sites, abundance was 340% greater on Wreck locations than Control. Conversely, within Closed sites, abundance was 149% greater in Control locations than Wreck. In Open sites, shipwreck communities are more similar to those in Closed sites, than to the habitat surrounding the shipwreck. Vulnerable species, mostly large, sessile filter feeders, are almost entirely absent from Open sites, but account for ~28% of the total abundance on shipwrecks in Closed sites. This study offers a quantifiable method to evaluate the ecological contribution of shipwrecks in disturbed areas and suggests their role may warrant further research, and consideration in conservation policy, such as inclusion in 30 × 30 objectives. Our findings also demonstrate the possible ecological gains of expanding or including static gear reserves across Marine Protected Areas.

KEYWORDS
horse mussels, marine protected area, OECM, SAC, Scotland, shipwreck, trawling

1 | INTRODUCTION

The use of bottom-towed fishing gear (from herein; trawling) has been ubiquitous throughout UK waters since the 14th Century, beginning in the Thames estuary and gradually expanding throughout the North Sea (De Groot, 1984). Concerns surrounding the impact of trawlers on benthic ecosystems and fish stocks have been presented since the method was introduced, (Jones, 2018a) with the first Parliamentary Act to ban trawling passed in 1350 (De Groot, 1984). Over time, however, attitudes changed. By the 1890s, trawling had developed from sail power to steam (Callaway et al., 2007) and was widespread in both nearshore and offshore waters, beginning an era of unimpeded trawling throughout the North Sea (Jones, 2018b). Today, it is estimated that benthic fishing has impacted up to 99% of some management areas within the Northeastern Atlantic (Eigaard et al., 2017), accounting for up to 99% of the global footprint of anthropogenic activity (Foden et al., 2011).

It was originally thought trawling would have limited impact on the seafloor (De Groot, 1984) but significant impacts on the benthos are now well documented. Ecological responses are not linear, but dependent on multiple factors, including gear type, previous exposure to trawling and benthic habitat (Hiddink et al., 2017; Sciberras et al., 2018). Trawling reduces benthic biomass and production (Hiddink et al., 2006, 2011), decreases functional redundancy and species abundance (Davies, Holmes, Bicknell, et al., 2021; Davies, Holmes, Rees, et al., 2021) and alters benthic community structure, causing a shift from communities dominated by sessile, emergent fauna to small-bodied infauna, consequentially reducing topographic complexity (Kaiser et al., 2000; Van Denderen et al., 2015). Although the effects are similar to hydrodynamic impacts such as shear stress (Sciberras et al., 2013; Van Denderen et al., 2015), recovery time from trawling is far longer (Sheehan et al., 2021). While trawling is not the most influential factor shaping benthic communities, it is thought that trawling as little as once every 4 years can reduce ecosystem resilience (Couce et al., 2020) and removal of vulnerable species can reduce ecosystem health and functionality (de Juan & Demestre, 2012; Tillin et al., 2006).

Estimating long-term large-scale changes requires knowledge of an undisturbed system as a reference (Callaway et al., 2007; Couce et al., 2020). With such a long, intensive history of trawling, a true baseline of undisturbed seafloor for comparison is unavailable. Even areas in which trawling is restricted will have been previously fished and ecologically altered (Couce et al., 2020). Moreover, in around 800,000 km^2 of UK waters, only a small percentage of Marine Protected Areas (MPAs) have full legal protection from bottom-towed fishing (Dunkley & Solandt, 2021). This is an international problem, with bottom-towed fishing occurring throughout European MPAs (Dureuil et al., 2018). In this situation, areas such as renewable energy installations (Sheehan et al., 2013) and military sites (Smith & Marx Jr, 2016) from which bottom-towed fishing is excluded by default, provide de-facto protection and ecological baselines of otherwise severelyimpacted ecosystems.

Shipwrecks are commonplace around UK waters, with many still undiscovered (Firth, 2018). These hard, upright structures in often flat, soft-sediment habitats attract an abundance of life, consequentially attracting anglers, mid-water trawlers and SCUBA divers (Firth, 2018; Siciliano et al., 2016; Wiyanto et al., 2020). Although some low-lying wrecks are subject to trawling pressure (Hickman, pers. comms.), generally their presence is hazardous to trawlers, meaning encounters are rare (Firth, 2018). As with other anthropogenic structures in the marine environment, pollutants are a potential consequence of shipwrecks (Renzi et al., 2017). Materials such as copper act as antifoulants >100 years after sinking (Meyer-Kaiser, Mires, Kovacs, et al., 2022) and in fragile ecosystems such as coral reefs, shipwrecks can trigger an ecological phase shift (Work et al., 2008). However, in other environments, the biodiversity benefits appear to outweigh any negative impacts (Renzi et al., 2017). Due to the limited fishing pressure in comparison to adjacent habitats, shipwrecks are likely to offer de facto protection for marine fauna and provide an ecological baseline.

Many questions remain unanswered regarding the structural components impacting shipwreck communities. While depth (Meyer-Kaiser, Mires, & Haskell, 2022; Walker et al., 2007), vertical surface profile (Mondal & Raghunathan, 2017; Walker et al., 2007) and elevation from seafloor (Meyer-Kaiser, Mires, Kovacs, et al., 2022) affect community composition, the well-known 'species-area' relationship is not always observed, with larger and older shipwrecks supporting similar species richness to smaller or more recently-lost shipwrecks (Meyer-Kaiser, Mires, & Haskell, 2022). This is perhaps partly explained by a study of succession on the HMS Scylla in Cornwall, sunk deliberately as an artificial reef, which found the existence of a 'steel-wreck community', a community composition unique from those on naturally-occurring substratum within similar environments (Hiscock et al., 2010).

Shipwrecks offer refugia to commercially-valuable (Lengkeek et al., 2013; Schrieken et al., 2013) and rare species (Renzi et al., 2017), and seem particularly important for sessile filter-feeding species (Hiscock, 1981; Meyer-Kaiser, Mires, & Haskell, 2022; Meyer-Kaiser, Mires, Kovacs, et al., 2022; Mondal & Raghunathan, 2017), the most vulnerable to trawling (de Juan & Demestre, 2012). Shipwrecks with steel components support large sessile communities (Mondal & Raghunathan, 2017, Meyer-Kaiser, Mires, & Haskell, 2022; Meyer-Kaiser, Mires, Kovacs, et al., 2022), with hard surface and elevation from the benthos offering access to stronger currents and increased feeding opportunities (Meyer-Kaiser, Mires, & Haskell, 2022). Microbiome richness is increased on shipwrecks (Hamdan et al., 2021) and a 'halo' of microbial taxa around shipwrecks supports the idea that they influence the surrounding environment, acting as island-like stepping-stones within remote environments (Hamdan et al., 2021). Studies on a protected wreck, the SMS Karlsruhe in Scotland confirmed the existence of *Modiolus modiolus* (horse mussel) beds, protected by the wreck (Sanderson et al., 2014). *M. modiolus* beds are designated as a Priority Marine Feature (PMF) in Scotland, identifying them as characteristic of and important to Scottish marine biodiversity (SNH, 2022). If the presence of shipwrecks provides refugia for sensitive, rare or declining habitats and species such as *M. modiolus*, they can provide opportunities for the designation of protected areas. Ecologically speaking, though they present some risks in sensitive environments, and cannot be considered a sound substitute for natural habitat, shipwrecks can offer ecological benefits in otherwise degraded habitats.

Gathering meaningful data on shipwreck ecology presents many challenges. The hazardous conditions and complex topography can make accessing the shipwrecks dangerous and expensive, and the use of remote collection methods can result in unusable data due to high turbidity or failed technology. Various methods have been used, including remotely operated vehicles (ROVs; Meyer-Kaiser, Mires, & Haskell, 2022) sediment sampling (Hamdan et al., 2021) and photogrammetry (Olinger et al., 2019), yet studies on shipwreck ecology are still limited. There were two main aims of this study:

1. To collect high-quality data to assess the ecological importance of shipwrecks within areas subject to varying levels of benthic fishing pressure.
2. To locate and identify any potential *M. modiolus* beds which may occur within the locality of the shipwrecks.
3. This study addresses the following hypotheses: (1) species richness and abundance will be higher around shipwrecks than the surrounding environment (2) shipwrecks provide important refugia for marine biota in areas subject to high fishing pressure (3) shipwrecks support higher levels of rare and important species and PMF's than surrounding areas (4) shipwrecks support a functionally-different community to the surrounding environment.

2 | METHODS

2.1 | Survey site

The Berwickshire and North Northumberland coast Special Area of Conservation (SAC) is a 652 km^2 marine protected area spanning the Southeast coast of Scotland and the Northeast coast of England. The SAC was designated in 2005 under the Habitats Directive, due to diverse and varied Annex I habitats including mudflats, reefs and sea caves. Although much of the Scottish portion of the SAC is open to bottomtowed fishing gear and dredging, a Static Gear Reserve (SGR) is in place prohibiting the use of mobile or active fishing gear within 26 km^2 of the SAC, designated under the Inshore Fishing (Prohibition of Fishing and Fishing Methods) (Scotland) Order 2004. Prior to the legal enshrinement of these designations, a 10.3 km^2 area of these waters had been designated since 1984 as a Voluntary Marine Reserve (VMR), the only one of its kind in Scotland. The VMR lies entirely within the SAC, although only parts of it fall within the boundaries of the SGR (Figure 1). The VMR aims for sustainable use of the area through codes of conduct and voluntary agreements with recreational groups, but there are no legislative restrictions on bottom-towed fishing gear and regular fishing is known to occur in the area that lies outside of the SGR.

2.2 | Shipwrecks

Shipwrecks were selected based on their location relative to trawling pressure. To increase the sample size, shipwreck sites were combined and analysed in two ways. First, all shipwrecks were combined to look at the overall effect of distance from the shipwreck on ecological assemblages. Second, shipwrecks were assigned to two groups, 'Open' to trawling (Dove, Messina and Pettico) and 'Closed' to trawling (Glanmire and East Neuk). Here, some replicates were randomly removed to ensure an equal sample size. Full details of shipwrecks can be seen in Table 1.

2.3 | Survey team

Underwater video surveys were organised by Project Baseline. Local operator Marine Quest provided the boat and in-depth knowledge of survey sites.

2.4 | Data collection

Video surveys were conducted in August 2021 and June 2022. Three locations were sampled for each site: directly on the shipwreck ('Wreck'), within a 50 m radius of the shipwreck ('Near') and control locations >150 m from the shipwreck ('Control') (Figure 2).

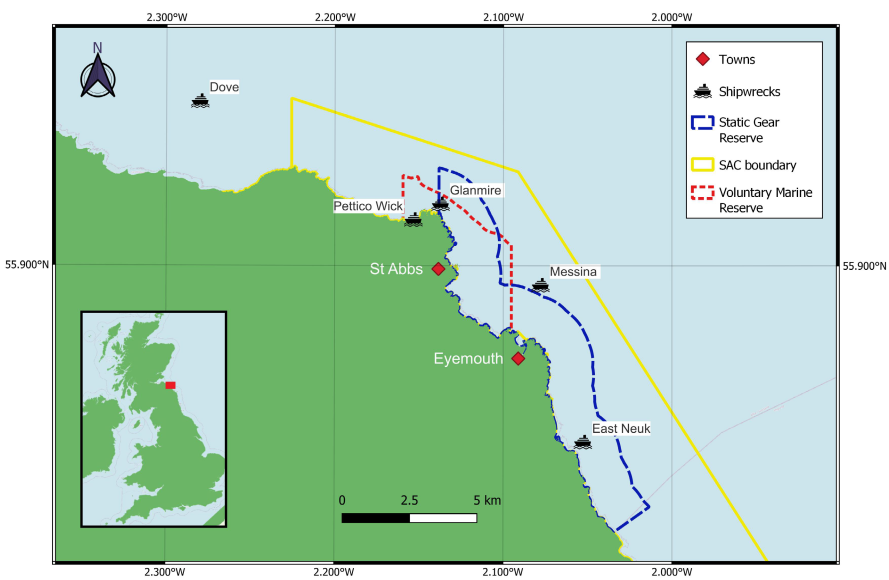

FIGURE 1 The Scottish section of the Berwickshire and Northumberland SAC, with locations of management designations and shipwrecks surveyed.

TABLE 1 Information on shipwrecks taken from wrecksite.eu and diver observation. Little is known about the Dove, provided is local knowledge and diver observation.

Wreck	Pettico	Messina	Glanmire	Dove	East Neuk
Ship type	Cargo	Cargo	Cargo	*Unknown*	Cargo
Date sunk	1917	1899	1912	*Unknown*	1923
Age	105	123	110	>100	99
Material	Steel	Wood	Iron	Wood	Wood
Depth (mtr)	17	47	33.5	43	20.7
Position	Upright	Upright	Upright	Upright	Low lying
Structure	Some intact	Some intact	Largely intact	Largely intact	Sections intact
Designation	VMR	SAC	VMR, SGR	None	SGR
Dimensions (m)	79.6×11×5.2	48×8×-	73.8×10.1×4.6	~40×8×-	28×6.1×3.2
Trawling	Open	Open	Closed	Open	Closed

Note: Data taken from wrecksite.eu.

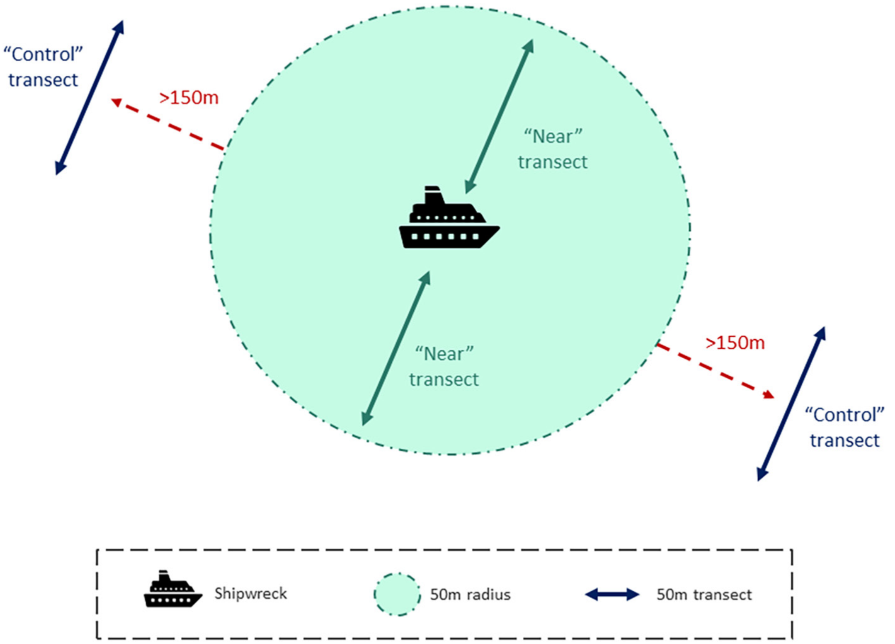

FIGURE 2 The experimental design shows the 3 locations sampled per wreck, 'Control', 'Near' and 'Wreck'.

Control locations were chosen to be a similar depth that comprised mixed sediments and hard substrata. The distance for Control locations was chosen to account for a 200 m zone of influence found in a previous study of microbial life around shipwrecks (Hamdan et al., 2021). A minimum of 4 replicates per location were collected. Near and Control transects were taken on opposite sides of the shipwreck to control for environmental variables such as current speed and wave exposure. Fifty metres transect lines were laid for Near and Control data collection and a metre rule laid down at the beginning of each transect for field of view (FOV) estimation (Figure 3a). The camera was angled directly at the seabed to ensure ~1 m^2 FOV was maintained. Due to the complex topography and challenging diving conditions on the wrecks, transect lines were not laid. Instead, to maintain consistency across all transects, a video was recorded using analogous camera orientation (horizontal), swimming speed (~20 cm/s) and distance to shipwreck (~1 m) to estimate 50 m^2 coverage in 4 min of footage (Figure 3b,c). All fauna was quantified using a combination of footage was used to quantify conspicuous and infrequent fauna and frame grabs were taken to quantify highly-abundant species, that is, *Alcyonium digitatum* (dead man's fingers). Metadata recorded included depth at the deepest part of the wreck, the highest elevation of the seabed, direction of transect and the benthic habitat type. Habitat complexity was also recorded as a score of 0–5, with 0 being the simplest (flat mud or sand) and 5 being highly complex with a variety of interstitial spaces and surfaces for attachment or refugia.

2.5 | Video analysis

All species in the video were identified and enumerated. Organisms were identified to species level where possible, or where this was not possible, grouped by similar taxonomy or functional group. Abundance was expressed as densities per square meter

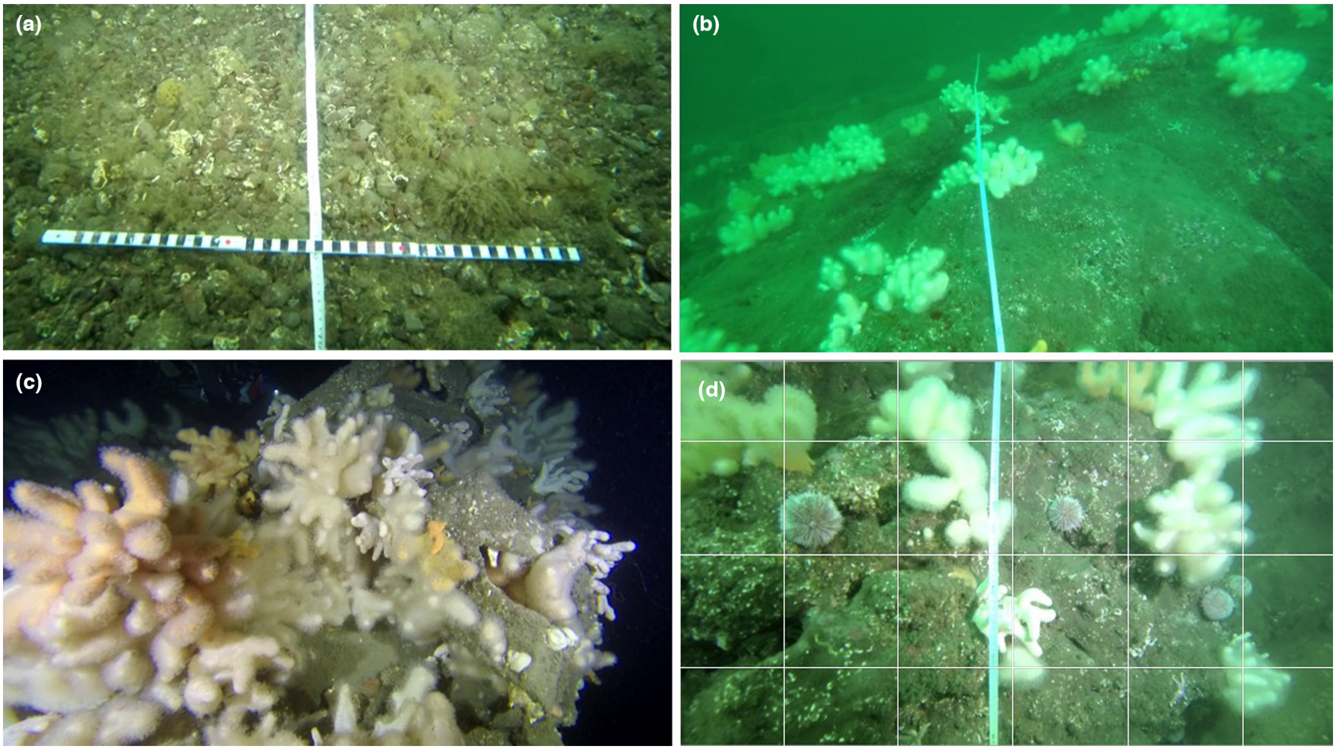

FIGURE 3 Samples of the footage analysed for the project. (a) a sample image of an acceptable transect, with a 1 m rule for FOV estimation. (b) A section of footage considered to be an anomalous angle and omitted from analyses. (c) An acceptable section of footage from 'Wreck' transects, clearly showing the wreck at a suitable distance and swimming speed. (d) The digital quadrat overlayed on frame grabs for % cover analysis of abundant species.

TABLE 2 The scoring methodology for the Trawl Disturbance Index (from herein 'Vulnerability categories') outlined in de Juan and Demestre (2012).

Score	Position	Feeding	Motility	Size	Other attributes
0	Deep burrowing	Scavengers	Highly mobile (swimming)	Small (<5 cm)	Hard shell/vermiform
1	Surface burrowing	Deposit feeders/predators	Mobile (crawling)		Strong/flexible
2	Surface		Sedentary	Medium (5-10 cm)	No protection
3	Emergent	Filter feeders	Sessile (attached)	Large (>10 cm)	Fragile shell/structure

(individuals m^{-2}). Large shoals of small fish seen around wrecks were grouped as 'Shoaling fishes' and enumerated as the maximum number seen on screen at one time (MaxN). A full list of species found is available in the Supporting Information (S1).

2.6 | Image analysis

Frame grabs were used to enumerate highly-abundant organisms. Grabs were extracted every 5 seconds using VLC Media Player. Images were deleted if they were too blurry, did not clearly show the seabed or were at an anomalous angle to the seabed (Figure 3b). Ten images were randomly selected from each video. Frames were used to quantify organisms which had been identified as highly abundant: *A. digitatum*, bryozoans and hydroids. A digital quadrat was overlaid with 15 equidistant points (Figure 3d). Abundance was calculated by dividing the number of points in contact with fauna by the total number of points and expressed as percentage cover per transect. Low-lying, unidentifiable abundant fauna such as hydroids were classified as turf (see Attrill et al., 2010; Rees et al., 2021).

2.7 | Vulnerability categories

To investigate changes to ecological functionality, all benthic species were assigned a category based on their vulnerability to trawling, using the methodology outlined in de Juan et al. (2009) and updated in de Juan and Demestre (2012) (see Table 2). Species were scored from 0 to 3 on traits including benthic position, feeding method, size and motility. Accumulated scores generated a final score from 0 to 15 and species assigned a category from 1 to 5. Lower scores indicate high resilience to trawling, while higher scores indicate vulnerability, thus Group 5 species are the most vulnerable to trawling pressure. As this method was designed for benthic species, pelagic species were grouped as 'Pelagic'. A full list of species and scores assigned is found in the Supporting Information (S2).

2.8 | Statistical analysis

All data were fourth root transformed unless otherwise specified and analysis was carried out using the VEGAN package in RStudio (RStudio Team, 2022). A Bray Curtis dissimilarity matrix was applied and permutational analysis of variance (PERMANOVA) used to compare between locations in all combined shipwrecks and determine the overall effect of distance from the shipwreck on ecological composition. Pairwise comparisons were run to identify where the differences could be found. Simper analysis was run to identify species contributing the highest difference and ANOVA used to compare the total abundance of the contributing species. ANOVAs were run on Shannon-Weiner diversity index, Pielou's evenness index, species richness and total abundance as well as to test the effect of environmental variables; habitat type, complexity, depth and elevation.

PERMANOVA was used to compare locations grouped as 'Open' and 'Closed' to trawling (Location + Trawling Pressure). A non-metric multidimensional scaling (nMDS) plot was used for visualisation. Due to the high number of comparisons, pairwise tests were not feasible. Instead, ANOVAs were used to compare abundance, Pielou's Evenness, Shannon-Weiner diversity and total abundance to identify the relative importance of the locations relative to trawling pressure.

Finally, vulnerability categories were compared across Location + Trawling pressure. As there were a high number of comparisons, a PERMANOVA was applied, but pairwise comparisons were not feasible.

3 | RESULTS

3.1 | Species found

A total of 49 unique species or taxa from 7 phyla were identified among all sites. The most abundant were *Munida rugosa* (rugose squat lobster—469 indiv.), *Echinus esculentus* (edible urchin—335 indiv.), *Asterias rubens* (common starfish—495 indiv.), shoaling fish (183 indiv.) and *Alcyonium digitatum* (dead man's fingers—enumerated as % cover). While no PMFs were found, 34 *Modiolus modiolus* individuals were identified and profuse shell cultch was observed in three transects (Glanmire Near, Pettico Near and Glanmire Control).

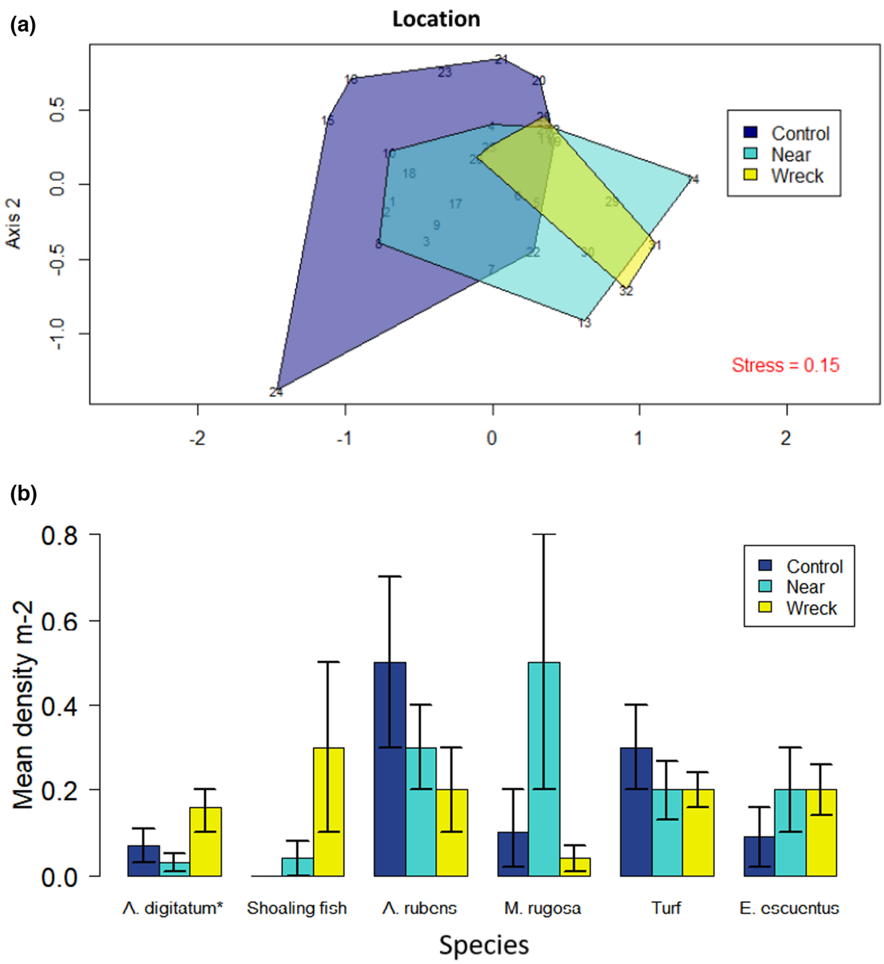

FIGURE 4 (a) Non-metric multidimensional scaling plot showing community differences between Location (Control, Near, Wreck) and (b) the highest contributing species to community comparison identified by SIMPER analysis. Asterix indicates significance in group, revealed by ANOVA.

3.2 | Community comparisons

There were significant community differences found between combined locations (Control, Near, Wreck) (PERMANOVA, $F = 2.0128$ $p = .016$) with pairwise comparisons revealing significant differences between 'Wreck: Control' and 'Wreck: Near' (PERMANOVA, $p < .05$) but no significance between 'Control: Near' (Figure 4). Simper analysis showed the most significant contributors as *A. digitatum*, Shoaling fish, *A. rubens*, *M. rugosa*, Turf and *E. escuentus*. ANOVA revealed *A. digitatum* % cover was 128% greater in Wreck locations than Control (0.16 and 0.07% cover m^{-2}, respectively), and 433% greater in Wreck locations than Near (0.16 and 0.03% cover m^{-2} respectively; Figure 4). Shoaling fishes were absent from Control locations but 650% greater in Wreck locations than Near (0.3 and 0.04 indiv. m^{-2} respectively). Scavenging species *A. rubens* and *M. rugosa* were least abundant in the Wreck locations. *A. rubens* density was 150% greater in Control than Wreck locations (0.5 and 0.2 indiv. m^{-2} respectively). *M. rugosa* density was >1000% greater in Near locations than Wreck (0.1 and 0.04 indiv. m^{-2} respectively). A full list of mean abundances and standard error can be found in the Supporting Information (S3).

Further comparisons on Location + Trawling Pressure revealed significantly different communities (PERMANOVA, $F = 2.5453$, $p < .001$; Figure 5a) with Open Wreck overlapping with all Closed locations. Pairwise comparisons revealed no significance between groups, likely due to increased family-wise error rate from a high number of comparisons. An ANOVA revealed significant differences between the overall mean density of locations (ANOVA, df = 5,19, $F = 4.8$, $p < .05$). Pairwise comparisons revealed strong evidence for differences between Open Control-Closed Control ($p < .005$), with individuals m^{-2} 431% greater in Closed Controls (0.55 and 2.92 respectively). Evidence of difference was also found between Open Near-Closed Near ($p < .05$), with density 53% greater in Closed Near locations (1.58 and 2.42 respectively). While no significance was found, mean density was 59.8% greater in Closed Wreck than Open Wreck locations (1.87 and 1.17 respectively; Figure 5b). Overall, in Open locations, density was 240% greater in Wreck locations than Control and 340% greater in Near than Control. In Closed sites, density of Control locations was 149% greater than Wreck and 85% greater than Near.

3.3 | Vulnerability categories

Vulnerability Categories were analysed with differences found between locations (PERMANOVA $F = 3.2083$, $p < .001$). Pairwise comparisons were not run due to high comparison rate, but the mean

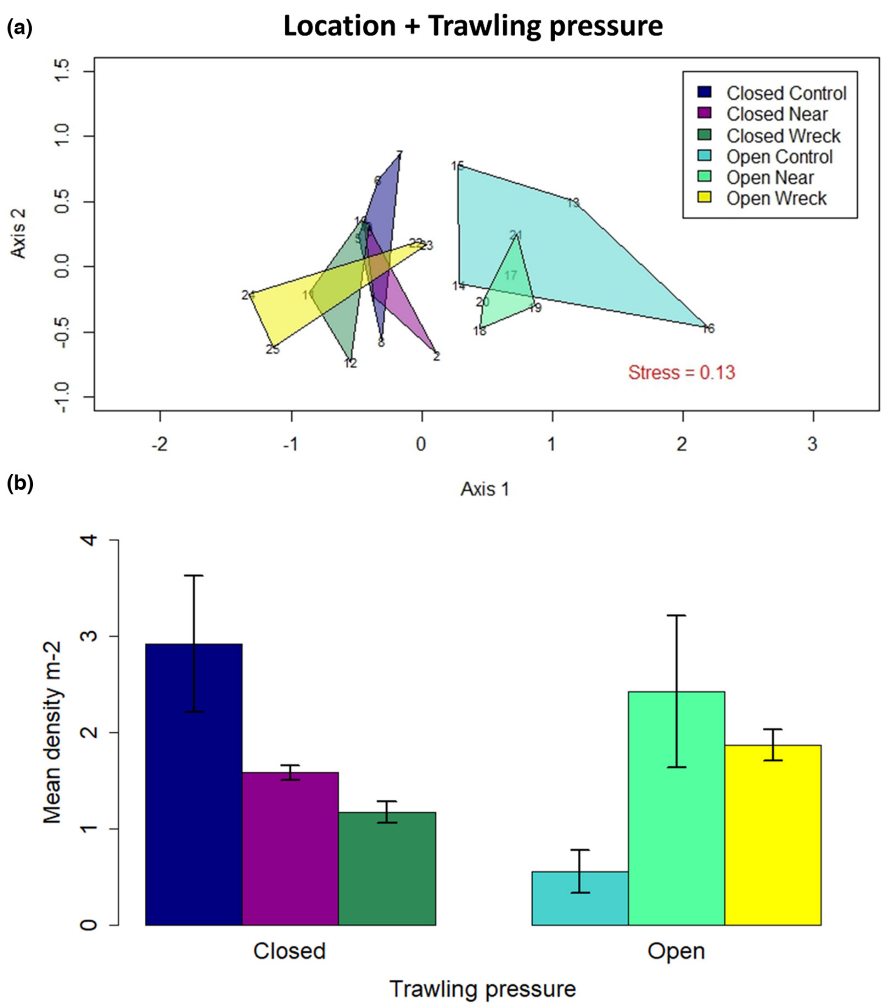

FIGURE 5 (a) Nonmetric multidimensional scaling plot showing community differences between Location + Trawling pressure and (b) Comparison of total mean density between locations.

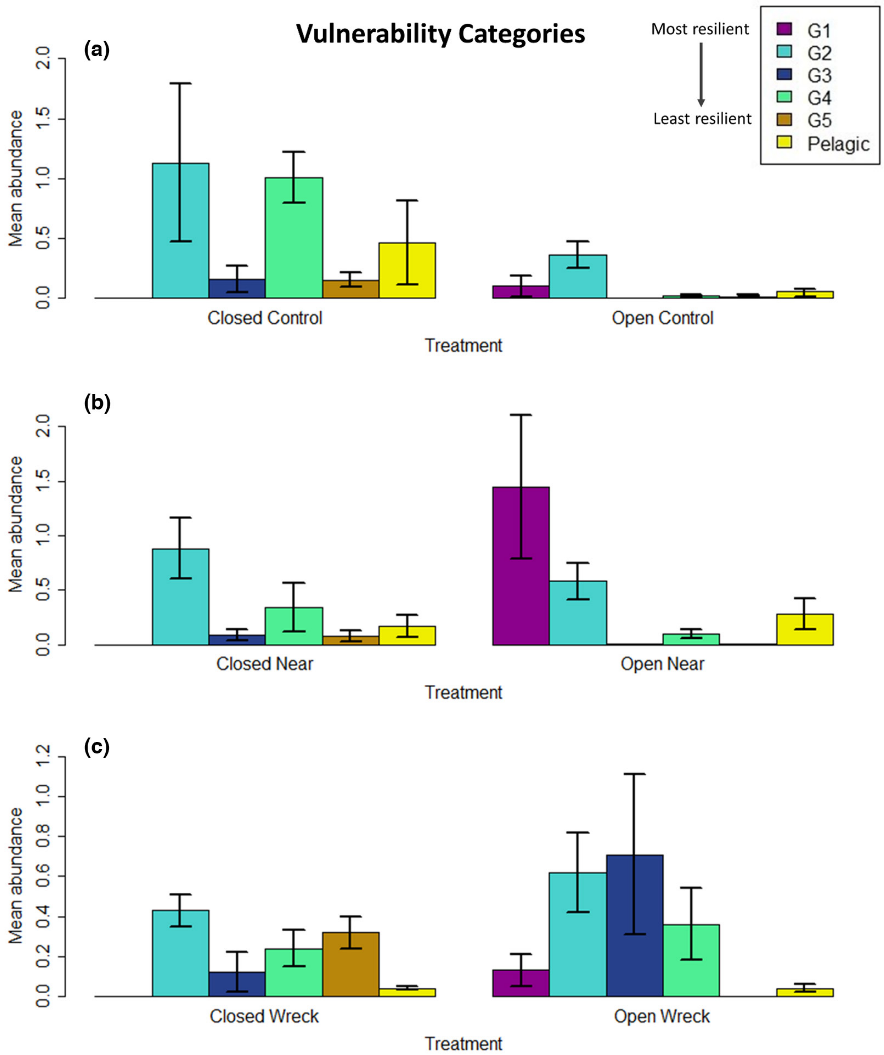

FIGURE 6 The mean density of Vulnerability categories across (a) Control (b) Near and (c) Wreck locations Open and Closed to trawling. Sensitivity to trawling increases from G1 to G5. Groupings encompass only benthic species, so pelagic were grouped separately.

densities are presented in Figure 6. G1, the most resilient group to trawling were absent from all Closed locations, but at their most abundant in Open Near (1.45 indiv. m^{-2}) whereas G5, the most sensitive to trawling were largely absent from all Open locations, but at their most abundant in Closed Wreck locations (0.32 indiv. m^{-2}). G4 were most abundant in Closed Control (1.01 indiv. m^{-2}) and Open Wreck (0.36 indiv. m^{-2}). Pelagic species were most abundant in the Closed Control locations (0.46 indiv m^{-2}) but at the lowest in both Open and Closed Wreck locations (0.04 indiv. m^{-2}). Overall, the greatest abundance within Closed sites was found in Control locations (2.91 indiv. m^{-2}). The greatest abundance in Open sites was found in Near locations (1.86 indiv. m^{-2}).

3.4 | Community metrics and environmental variables

When all transects were grouped and analysed by environmental variables (habitat type complexity, depth or elevation), no evidence was found for the significance of any environmental variables on species diversity, evenness or richness.

4 | DISCUSSION

This study has demonstrated the increased ecological importance of shipwrecks as refugia for marine life in heavily fished environments. While the hypothesis of increased species richness was rejected, and no significance was found for other community metrics (diversity, evenness), abundance increased on and around shipwrecks located within trawled environments. Within sites Open to trawling, the mean density of marine life was 240% greater in Wreck locations than Controls (1.87 and 0.55 indiv. m^{-2} respectively) and 340% greater in Near locations than Controls (2.42 and 0.55 indiv. m^{-2} respectively). Conversely, in sites Closed to trawling, abundance in Control locations was 149% greater than Wrecks (2.92 and 1.17 indiv. m^{-2}) and 85% greater than Near locations (1.58 indiv. m^{-2}). The ecological importance of shipwrecks increased relative to the fishing pressure of the area in which they were situated.

Community comparisons of Location + Trawling Pressure demonstrated a clear overlap of all Closed sites with Open Wreck locations. This overlap indicates communities found on shipwrecks situated in trawled environments are more similar to protected environments than surrounding areas subject to trawling pressure. This is further demonstrated by the indicator groups found within each environment. While Near locations had the greatest density of all Open sites, ~60% of this was made up of G1 species (1.45 indiv. m^{-2}), those most resilient to trawling. Open Wreck locations, however, hosted lower numbers of G1 groups (0.13 indiv. m^{-2}, ~7%) and greater levels of G2, 3 and 4 (33%, 38% and 19% respectively). Overall, Open locations hosted the lowest numbers of G5 groups, and Closed had the lowest number of G1 groups, demonstrating the impacts of trawling on the wider environment.

Only two species made up the G5 group: *Alcyonium digitatum* (dead man's fingers) and *Flustra foliacea* (hornwrack bryozoan). The video transects show *A. digitatum* was highly abundant in areas of hard substratum and a prominent feature across much of the Glanmire wreck. As soft-bodied, long-lived, filter-feeding species, they require hard surfaces for attachment and prefer elevation from the seafloor in areas of strong current (Budd, 2008). In increased sedimentation, *A. digitatum* retracts their polyps, entering a dormant phase (Budd, 2008). Their dependence on hard substrata and sensitivity to sedimentation make them vulnerable to trawling, and their long life spans mean they would likely take a long time to be replaced if removed by trawling. Similarly, *F. foliacea* is an active suspension feeder requiring a hard substratum for attachment (Tyler-Walters & Ballerstedt, 2007) and was only observed on the Glanmire Wreck. These species provide increased topographic complexity, refugia for othe rspecies and important ecosystem services, including water filtration. Overall, Closed Wreck locations were the most important for this group (0.32 indiv. m^{-2}), and the group was almost entirely absent from all Open sites, with the greatest abundance being in Open Control (0.01 indiv. m^{-2}). This finding suggests that in areas of heavy trawling pressure, the most sensitive groups are all but entirely removed from the ecosystem, changing the ecosystem functionality and services.

Shoaling fishes were absent from Control locations, but highly abundant around Wrecks (0.3 MaxN). However, when grouped with other pelagic species and analysed as a vulnerability category, Wrecks were the least important locations. Here, 'Shoaling fishes' encompasses any fish shoal which was not possible to identify to species level due to size, video clarity and speed of movement. While it is not possible to say for sure, observations of size and behaviour suggest that 'Shoaling fishes' were likely juveniles. Indeed, some individual juvenile fish species observed within the study were identified to species level; *Melanogrammus aeglefinus* (haddock), observed on both Near locations from the Messina shipwreck (Open) and *Anarhichas lupus* (Atlantic wolffish), observed on a Near location on the Dove shipwreck (Open) and a Control location on the East Neuk shipwreck (Closed). Both species are anecdotally known to be rare sightings. Adult *Anarhichas lupus*, impacted by habitat loss and commercial fishery bycatch (Bluemel et al., 2022), now draw many recreational divers to the area. *Melanogrammus aeglefinus* is a commercially valuable species which has undergone a long-term decline (Barreto & Bailey, 2016), and for which high relief substratum are known to be important nursery areas (Link & Demarest, 2003). This small number of observations, although by no means evidence of a nursery habitat, suggests that shipwrecks may provide protection for juvenile fishes, including those of commercial and recreational importance.

Within this study, no Priority Marine Features were found. Individuals of *Modiolus modiolus* and large quantities of cultch were found in 3 transects, Glanmire Near (Closed), Pettico Near (Open) and Glanmire Control (Closed). Although a widely distributed species, *M. modiolus* beds have been depleted by decades of fishing (Rees, 2009). As a result, they are now a rare occurrence and are listed as an OSPAR priority habitat and a Scottish PMF. An extensive bed around the protected wreck '*SMS Karsruhe*' suggests the presence of the shipwreck may provide protection for beds to thrive (Sanderson et al., 2014). Anecdotal evidence of *M. modiolus* on wrecks within the survey area of this study suggested similar beds may be found. The sighting of individuals, although not abundant enough to classify as a bed or PMF, are positive indications for the potential establishment or presence of beds within the area. As benthic settlers, *M. modiolus* are normally found partially buried in the substratum on gently sloping surfaces, and rarely on steep inclines (Dinesen & Morton, 2014). Therefore, occurrence on the wrecks themselves would be less likely than the benthic area surrounding the wreck. As with other bivalves, recruitment is believed to be reliant on established beds some distance away (Dinesen & Morton, 2014) and settlement encouraged by adult presence, as larvae settle in the exhalant water of large adults, and attachment aided by the interstitial spaces in adult beds (Dinesen & Morton, 2014). As prey of scavengers such as starfish, lone individuals are susceptible to predation in areas with abundant scavengers, as in the Near locations of this study (Dinesen & Morton, 2014). Finally, these are long-lived species, thought to live for >40 years (Anwar et al., 1990) and may not reach sexual maturity until ~8 years (Dinesen & Morton, 2014), thus in an area closed for only ~18 years, may not have had time to establish many adults of spawning age. The presence of individuals within these sites is evidence at least for habitat suitability and adequate protection. Further exploration of the area could potentially reveal a more extensive bed, and with time and continued protection, shipwrecks could prove important refuges for re-establishment.

Diver collection undoubtedly ensures high-quality datasets. Video clarity and quality are greatly increased when collected by a skilled SCUBA diver compared to towed video. This method is particularly useful in surveys such as this one, in which the area of interest is hard to access, difficult to navigate and presents hazards for towed equipment. However, the expense, time and skill required to conduct this study will, by default, limit the amount of data collected. In 2 weeks of data collection, dives were limited by weather, diver availability, safe diving limits and technical failures. The depth of some dives limited dive time, and subsequent dives that day. When diver-collected data are used, the benefits to quality are high, but the sample size is comparatively small to towed videos. For this study, the sample size was limited to ~4 replicates per location. While this was enough for analysis, a larger dataset would have allowed exploration of more areas of the wreck, and higher replication for statistical certainty. A continued study could further investigate environmental variables or structural factors influencing assemblages, for example, depth or surface profile. This study, while providing important insights into the ecological benefits of shipwrecks, could undoubtedly benefit from higher replication and more data.

To the authors' knowledge, this is the first study to demonstrate the increased ecological importance of shipwrecks and the surrounding 50 m radius in areas of heavy fishing pressure. While diversity, richness and evenness were unchanged, abundance within 50 m of a shipwreck was up to 340% greater than in trawled Control locations. In areas closed to trawling, shipwrecks provided an important habitat for sessile filter-feeding species, a group largely absent from trawled sites but accounting for ~28% of the total abundance on wrecks within protected areas. Trawled benthic habitats were characterised by a community of low abundance of all but scavenging species, whereas shipwrecks in Open areas supported communities similar to Closed areas. In areas of protection, shipwrecks provide vital habitat for vulnerable, slow-growing species and when located within heavily trawled areas, they function as de facto MPAs in otherwise degraded habitats.

5 | CONCLUSION

These findings provide evidence of an important ecological role being played by shipwrecks in disturbed areas. The provision of an elevated, complex habitat appears to provide a refuge from fishing disturbance within the surrounding area. Anecdotal evidence suggests that local fishers avoid the shipwrecks, most likely to avoid the risk of gear entanglement. Although ghost fishing gear was observed on the shipwrecks, and may in part explain a lack of sensitive, sessile species in some areas, it does not appear to have a significant negative impact on more resilient species or outweigh the ecological benefits of the shipwreck structure. The increased abundance in Closed Control locations demonstrates the ecological potential for recovery in areas close to trawling. We suggest this study offers a method for quantifying the ecological role of shipwrecks, particularly within disturbed areas, and provides evidence to warrant their consideration for further research, and potential inclusion within conservation policy. Providing insights into ecosystem interactions of historic artificial structures can also help predict long-term ecological effects of modern and planned artificial structures within the marine environment. This body of research can contribute directly to regional and high-level strategic policies aimed at implementing Ecosystem-Based Management approaches, by contributing to high-level descriptors such as Biodiversity and Seafloor Integrity required by the EU Marine Strategy Framework Directive (MSFD 2008/56/EC) and the UK Government's 25 Year Environment Plan (Defra (Department for Environment, Food and Rural Affairs), 2018). Additionally, it offers evidence for the consideration of artificial structures as areas to be protected. The potential ecological benefits of further protection around such structures could be realised through inclusion in the '30 × 30' conservation initiative, adopted during the 15th meeting of the Conference of Parties (COP 15), which calls for 30% of global seas to be in protected areas or OECMs (Other Effective area-based Conservation Measures) by 2030.

AUTHOR CONTRIBUTIONS

Emma V. Sheehan, Adam Rees and Joe Richards conceived the ideas and designed the methodology; Jenny Hickman processed and analysed the data provided by Project Baseline and led the writing of the manuscript. All authors contributed to the writing of the manuscript.

ACKNOWLEDGEMENTS

We acknowledge the dive team from Project Baseline UK for providing us with their data for this project and Marine Quest skippers for their expert knowledge of the local marine environment and cultural practices. We also thank Blue Marine Foundation for providing the funding for this project.

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data collected for this project have been made available through the 'PEARL' repository https://doi.org/10.24382/n8zv-hy23.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Hickman, J., Richards, J., Rees, A., & Sheehan, E. V. (2024). Shipwrecks act as de facto Marine Protected Areas in areas of heavy fishing pressure. *Marine Ecology*, *45*, e12782. https://doi.org/10.1111/maec.12782