Chapter 5
Wreck Sites as Systems Disrupted by Trawling

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Abstract This chapter examines the effects of bottom trawling on shipwreck sites, conceptualising them as process-response systems that achieve a quasi-equilibrium state over time. Disruptions to this state by bottom-contact fishing gear are analysed through examples from recent geophysical surveys in the Irish, Baltic, and North Seas. The study highlights the capabilities and limitations of modern geophysical methods in detecting changes at underwater archaeological sites caused by bottom trawling. Specifically, it addresses the challenges of identifying evidence of disturbance on dynamic seabeds and suggests that detailed analysis of wreck distribution might provide indirect proxies of structural damage due to trawling activities. Furthermore, it emphasises the potential of these disturbances to mobilise hazardous materials, such as unexploded ordnance and fuel from modern shipwrecks, posing an added environmental risk. Acknowledging existing knowledge gaps in the understanding of trawling impacts on underwater cultural heritage and the marine environment, the authors call for more case study research .

5.1 Introduction

Shipwreck sites can be considered as systems reaching a quasi-equilibrium state after the initial wrecking event (Astley, 2016; Majcher et al., 2021; Quinn, 2006; Quinn & Boland, 2010). This balanced state is fluid and is both susceptible to and dependent on external and internal influences. Any disturbances might lead to a new equilibrium state or maintain the existing one, contingent on the site's overall resilience to external forces (Quinn & Boland, 2010).

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C. Jarvis (ed.), *Threats to Our Ocean Heritage: Bottom Trawling*,
SpringerBriefs in Underwater Archaeology, https://doi.org/10.1007/978-3-031-57953-0_5

The internal factors can be understood as those variables which are determined before and during the ship's deposition on the seabed: its form, design, materials, function, operating conditions and the nature of the sinking (Gibbs, 2006; Gregory et al., 2012; Muckelroy, 1976). After the dynamic sinking event, the wreck begins interacting with its surrounding environment, settling onto the seabed. This is when the local ocean environment and human impacts—namely, the external factors such as bottom trawling—come into play.

The influence of the local environment depends on local and regional oceanographic and geological factors. If the archaeological material is exposed on highly energetic seabeds—affected by waves, strong currents, storms and induced sediment mobility—it will most likely undergo continuous alteration (Astley, 2016; Majcher et al., 2021; Quinn & Boland, 2010; Stieglitz & Waterson, 2013) (Fig. 5.1a). Such conditions can lead to site burial/exposure events, accelerated structural collapse from hydrodynamic forcing, and changes in the distribution of forces acting on the vessel due to sediment transport, such as mobile bedforms and seabed scour (Quinn, 2006). Conversely, the preservation of sites located in less dynamic ocean environments, with limited influence from hydrodynamic forcing, is primarily affected by processes like chemical corrosion and biological encrustation, and their associated parameters like oxygen concentration, temperature and salinity (Gregory, 2020) (Fig. 5.1b). No conditions exist in which a site deposited underwater is preserved indefinitely (Fig. 5.1c). Natural forces always induce positive entropy and a disequilibrium trend over time, even when their magnitudes are minimal.

The majority of natural processes, with the exception of heavy storms, exert a relatively weak long-term impact, especially when compared to often abrupt human impacts. Activities such as commercial fishing, illegal salvage, dredging, and seabed engineering are potentially capable of causing impulses of intense disruption to the archaeological record of an individual wreck site (Brennan et al., 2016; Quinn & Boland, 2010). Such disturbances are often challenging to identify and predict, and once detected, it is difficult to establish whether the causative force was natural or anthropogenic (Brennan, 2016), or a combination of both. Additionally, in cases where the disturbance is anthropogenic, pinpointing the exact type of human activity that caused the visible disruption can be difficult.

As outlined in other chapters of this book, commercial fishing—particularly bottom trawling—can exert a devastating impact on Underwater Cultural Heritage (UCH). There needs to be additional case studies to understand the magnitude and scale of these impacts. Such studies will pave the way for novel strategies to address the issue, encompassing both monitoring and prevention measures. This chapter delves into the potential consequences of bottom trawling on shipwreck sites, viewing them as systems at various stages of equilibrium corresponding to their surrounding environment. The discussion draws on examples from recent geophysical surveys carried out in the Irish, Baltic and North Seas. It examines the potential of contemporary geophysical techniques in tracking changes at underwater sites induced by bottom trawling. Through this discourse, the authors identify knowledge gaps related to the impact of bottom-contact fishing on UCH, as well as the challenges associated with addressing them.

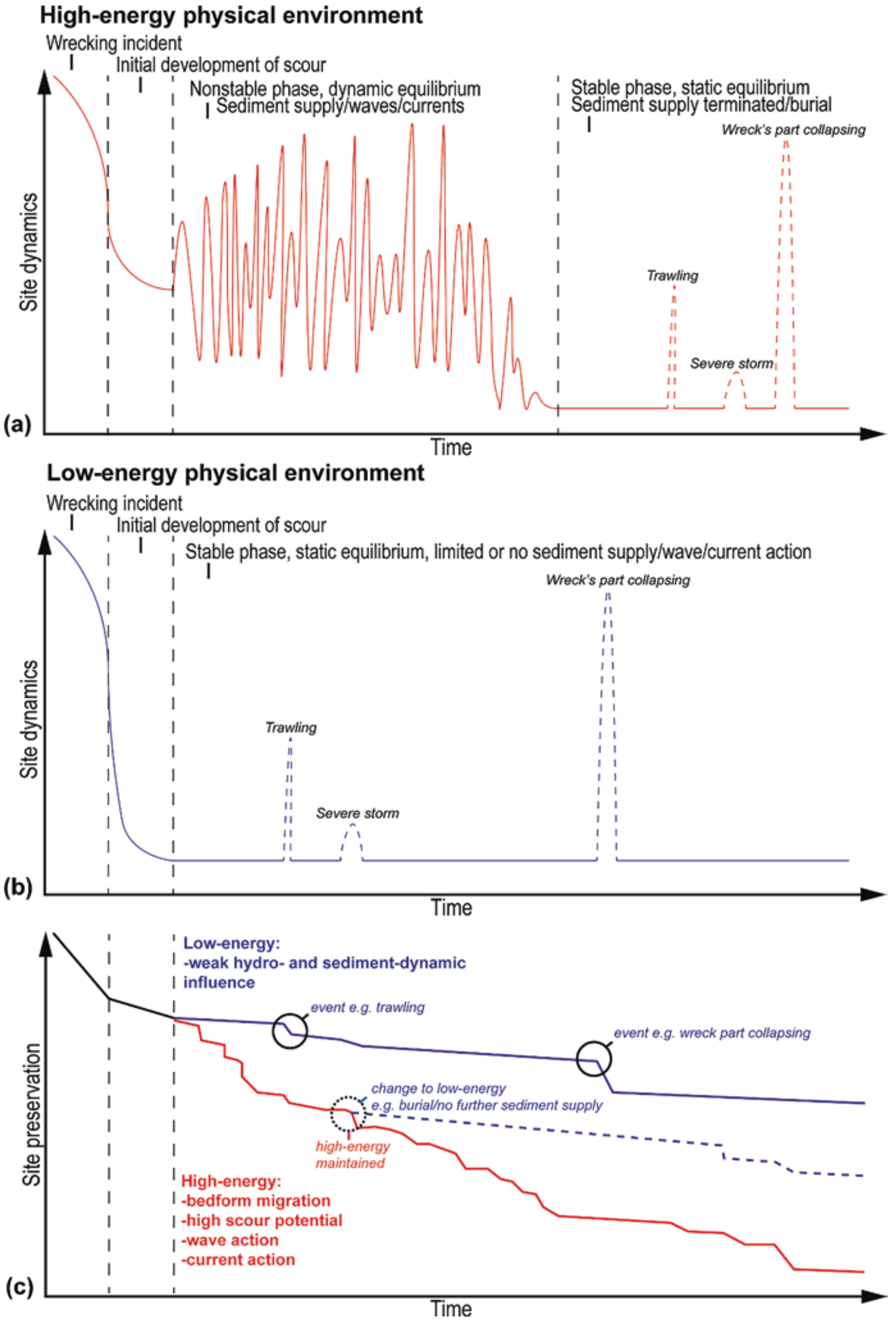

Fig. 5.1 Conceptual diagram for wreck site dynamics for (**a**) high-energy and (**b**) low energy environments, along with (**c**) corresponding estimates for site preservation in the two categories. Rapid changes in site dynamics due to either continuous sediment supply or singular events, result in accelerated degradation and lower site preservation. In contrast, periods of stability favour preservation. However, preservation is always steadily declining due to corrosion and biological action. (Adapted from Majcher et al., 2021)

5.2 Bottom Trawling as an Anthropogenic Trigger Disrupting Wreck Sites

When a wreck system experiences disruption due to external forcing, the site either absorbs the disruption, maintaining its current state, or undergoes change, reaching a new equilibrium state (Quinn & Boland, 2010). The outcome depends on the resilience of the site, which is determined both by its pre-depositional parameters (i.e., materials used to construct the hull, nature of the wrecking incident etc.) and post-depositional processes it undergoes. The composition of the seabed plays a significant role, either enabling or preventing further disruption. While the impact of bottom contact fishing has not been explored experimentally or through case studies within the 'open system' framework, potential scenarios can be inferred from known examples of natural and other anthropogenic forces disrupting sites.

The first relevant example, published by Quinn and Boland (2010), pertains to a site situated in a highly dynamic riverine environment. The *Drogheda Boat* site, near the River Boyne's outlet to the Irish Sea was discovered during dredging operations in 2006, and subsequently monitored for impacts associated with dredging. Even though much of the seabed surrounding the wreck mound had been excavated, the site itself remained undisturbed by the dredging operators. Successive geophysical surveys showed that the wreck mound was eroding rapidly, revealing artefactual material. This observation necessitated the redeposition of some sediment that had previously been dredged from around the site.

Quinn and Boland (2010) outlined how rapid erosion of the wreck mound was triggered by changes in hydrodynamic patterns associated with the dredging. They further framed this example within the 'open system' narrative, theorising that because of the external trigger (i.e., the capital dredging operation), the site exceeded its resilience threshold, transitioning to a new system state characterised by elevated erosion potential and consequent material loss. Bottom trawling possesses a similar capacity to push sites beyond their resilience thresholds, promoting erosion and/or site reorganisation.

Trawling is potentially capable of mechanically displacing or causing collapse of individual wreck site elements, leading to reorganisation of the site. The extent of this depends on the site's resilience and capacity to absorb such impacts. For instance, if the site is predisposed to erosion due to its sedimentary setting, like the *Drogheda Boat* site (Quinn & Boland, 2010), this will negatively affect the site's resilience. Specifically, displaced elements, particularly larger objects, would act as new obstacles to water flow. This alters the hydrodynamic regime at the site, effectively making these objects nuclei for further seabed scour (Quinn, 2006). Such dynamics might lead to the exposure or burial of other sections of the wreck, even if they were not originally in contact with the trawling gear. This is analogous to the dredging activity observed at the *Drogheda Boat* site. While the primary focus of dredging was directed away from the site, it inadvertently caused progressive exposure. As such, when trawling impacts a site, it is safe to assume that the resultant disturbance could extend beyond the initial point of interaction.

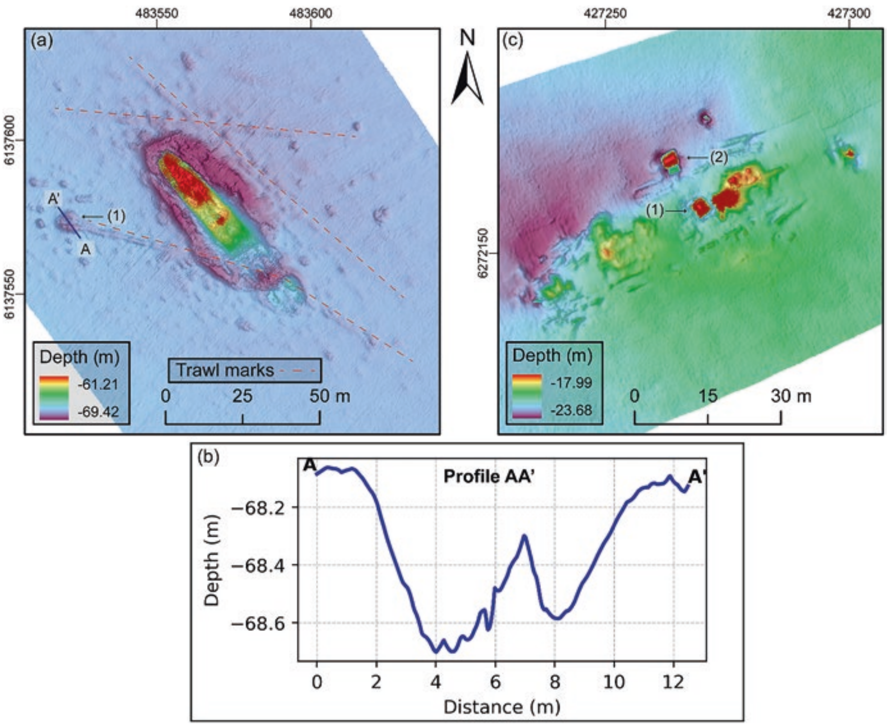

Fig. 5.2 Multibeam echosounder data-derived, hillshaded digital elevation models of (**a**) a steamship wreck, possibly *SS Edgar* in the Baltic Sea with (**b**) a bathymetric profile denoted as AA'. (**c**) hillshaded digital elevation model of an unknown wreck in the Danish North Sea. Numbers shown in on the figures correspond to structural elements discussed in the text. (Data courtesy of JD-Contractor A/S)

Convincing evidence of direct trawl damage to the wreck of a steamship (likely SS *Edgar*, lost in 1894) in the Baltic Sea is shown in Fig. 5.2a. The site is intersected by multiple interpreted trawl marks, and numerous displaced sonar contacts are scattered around the wreck. One particularly prominent example, marked as (1) in Fig. 5.2a, displays a structural element that measures roughly 4 × 1.5 × 0.3 m in terms of length, width, and height, respectively. The object is located 32 m from the wreck's hull and lies at the end of a linear trawl mark which intersects the stern section of the vessel. It is probable that this object was dislodged from the wreck and represents one of its original structural components. A scour pit measuring 10 m across and 0.5 m deep is developed around the object (Fig. 5.2b). Although, in this instance, the scour pit does not directly threaten the integrity of the hull, it shows how the site's system adapted to the redistributed wreck components on the seabed.

Another example of a site most likely impacted by trawling (Fig. 5.2b) is represented by a significantly deteriorated, unidentified wreck in the North Sea at a depth of 20 m. While a large portion of the wreck's hull has decayed, several heavily-engineered structural elements remain on the seabed, likely remnants of the ship's steam engine and machinery. Two boilers are imaged, one rests within the deteriorated hull ((1) in Fig. 5.2b) and the other is located externally, offset to the north of the vessel ((2) in Fig. 5.2b).

Multiple explanations for the second boiler's position outside of the main wreck structure are conceivable. One possibility is a salvage operation that resulted in the boiler's relocation. Another scenario is that the boiler slid out during the wrecking event. A third possibility is displacement due to trawling. While the first scenario remains plausible, the second appears less likely. This is because the ship's hull maintains a coherent shape, suggesting it did not break up or undergo a violent wrecking event to displace the boiler from its original position. Even though no prominent trawl marks are evident in the multibeam data, the third possibility is credible, depending on the specifications of the trawl gear (Brennan, 2016). Open-source Vessel Monitoring System (VMS) data from EMODnet (2023) demonstrate that beam trawls, bottom otter trawls, and bottom seines are operational in the area. Given that a significant portion of the ship's structure has decayed, the boilers, now largely exposed in the water column, pose clear obstructions to fishing gear.

As evidenced in many surveys (e.g., Fig. 5.2b) boilers are among the most resilient structural elements on shipwreck sites. This may be attributed to the fact that they were built to withstand high operating pressures and temperatures, with thick and strong iron or steel structures. Additionally, due to their location within a vessel, boilers are also sheltered from the physical forces affecting the wreck's hull externally, hence being protected by its structure until it gradually deteriorates or collapses. These factors possibly contribute to their long-term durability in the marine environment compared to the other parts of the ship.

Nevertheless, the displacement of the boiler recorded in the multibeam data (Fig. 5.2b) could have implications for its further preservation. Just as the structural element pulled out of the shipwreck in Fig. 5.2a, the displacement and exposure of the boiler to bottom currents led to the formation of a small scour pit around it. The boiler that remained within the hull is not affected by seabed scour, possibly because it is shielded by the hull remains. Therefore, the displaced boiler is more exposed to the physical environment, after losing the protective function of the wreck's structure. While both boilers appear to be in good condition presently, this example underscores the destructive potential that trawling or other human activities capable of causing displacement might have, especially when juxtaposed with natural forces. The future preservation potential of the boiler removed from the wreck's hull may be compromised due to that displacement event.

Given the examples mentioned here, it can be inferred that the detrimental impacts of bottom-contact fishing are not confined to ancient sites (Brennan et al., 2016). They also extend to larger, relatively more coherent modern wrecks, like the steamship shown in Fig 5.2a. In essence, a trawling event acts as a 'scrambling device' (Muckelroy, 1976)**,** initially triggering reorganisation of a wreck site. This site may then undergo further changes, depending on its capacity to absorb the disruption. Potential outcomes might involve seabed erosion leading to heightened exposure of relocated structural components to external forces, and result in the acceleration of corrosion process.

5.3 Challenges in Detecting Trawling Damage at Wreck Sites Using Geophysical Methods

When viewing an underwater wreck site through the lens of an open system—one that begins with a set of pre-depositional conditions and can adapt or change in response to various influences, both natural and anthropogenic—it becomes imperative to identify the primary drivers of these changes. Recent attempts at quantifying the rates of geomorphic change (e.g. scour, bedform migration) and associated hydrodynamic triggers were discussed by Majcher et al. (2021) using this 'open system' concept, inspired by earlier investigations (Astley, 2016; Quinn, 2006; Quinn & Boland, 2010). Geomorphic change can be effectively recorded using high-resolution geophysical data in a time-lapse sense. Furthermore, if the data collected over a shipwreck are of sufficient spatial resolution, an initial assessment of the wreck's structural changes can be conducted. However, as discussed in this chapter, determining whether the observed changes were caused by natural or anthropogenic forces presents a complex challenge.

Recent advancements in geophysical techniques have afforded researchers unprecedented insights into the dynamics of underwater shipwreck sites. For example a recent study captured centimetric-scale alterations in the seabed surrounding several metal-hulled shipwrecks in the Irish Sea (Majcher et al., 2021). The investigation determined that some of the sites, located on sandy seabeds with large active tidal bedforms, undergo constant change with high volumes of sediment transported through the sites. For example, between 2015 and 2019, the SS *WM Barkley* site experienced a remarkable elevation change of 4.9 m in one area, partly exposing the starboard side of the vessel (Fig. 5.3a). To investigate these rapid changes, Computational Fluid Dynamic (CFD) simulations were used to model tidal current flows which supported the understanding of the hydrodynamic patterns at the site and explained the pervasive bedform movement and seabed scour.

In addition to investigating geomorphic adjustment at these sites, an attempt was made to detect structural changes at these wrecks through point-cloud comparisons of high density multibeam data. Although the subjective nature of the manual point cloud cleaning process meant that detecting minor centimetric changes was challenging due to the noise associated with wreck data, the method was sensitive enough to identify substantial structural displacements. For example, between 2015 and 2019, the SS *WM Barkley* wreck suffered the detachment of a considerable part of its portside gunwale near the stern (Fig. 5.3a).

The environmental dynamics and the nature of the SS *WM Barkley* shipwreck's degradation present a compelling argument for the involvement of anthropogenic external forces, such as trawling, as catalysts for the observed changes. The wreck is tilted towards its starboard side, and if the gunwale had collapsed due to corrosion only, it would be expected to have moved gravitationally towards the deck. However, it moved in the opposite direction, towards the seabed. The possibility of an external force, like an anchor or trawl door pull, causing this movement becomes more likely given the direction of detachment.

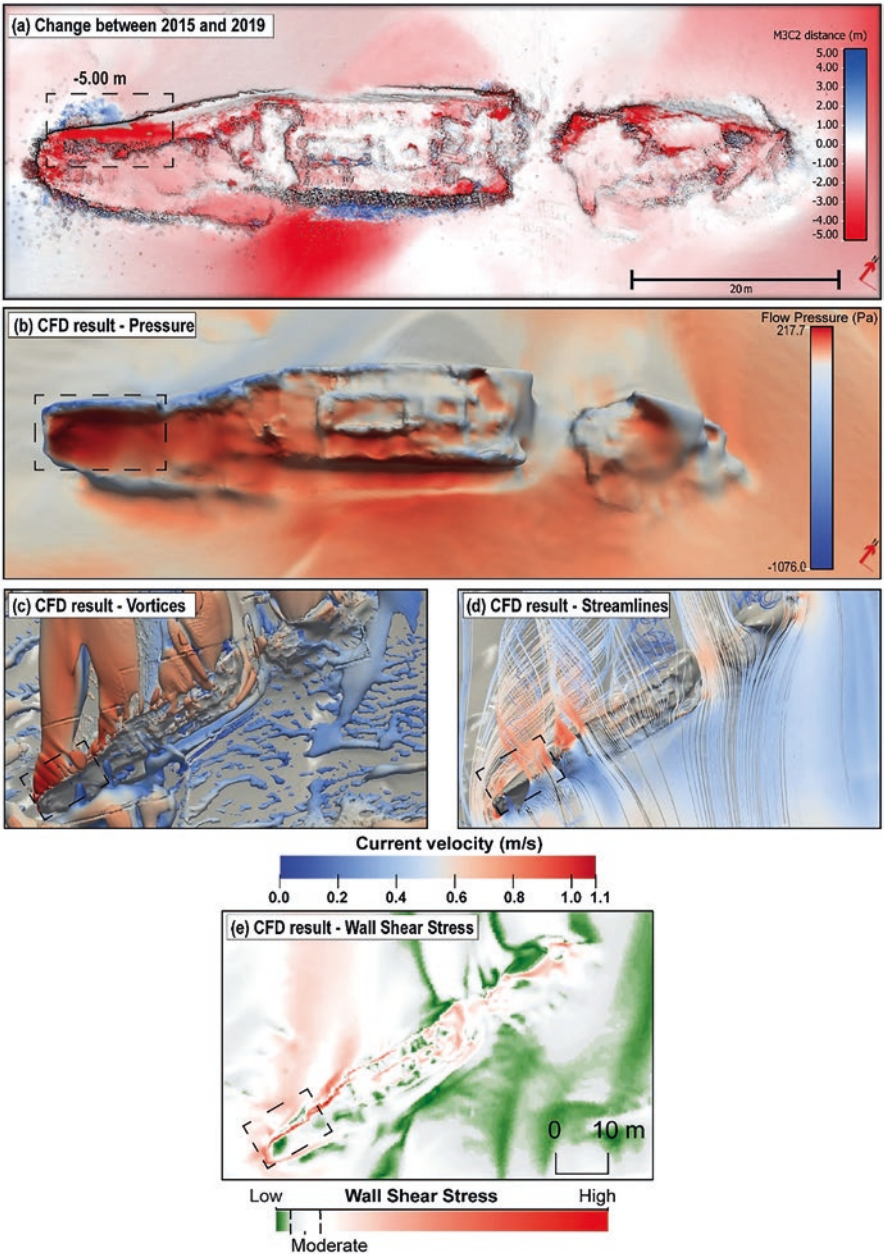

Fig. 5.3 (**a**) Differences between multibeam echosounder point clouds obtained for the SS *WM Barkley* site in 2015 and 2019. (**b**) CFD-simulated NNW-oriented tidal current flow pressure exerted on the modelled seabed at the same site, (**c**) vorticial patterns delineated by the simulations, (**d**) NNW-oriented current flow streamlines, and (**e**) wall shear stress. Dashed boxes show the stern and portside gunwale of the ship discussed in the text. A detailed data and methodology description is provided in the original publication of Majcher et al., 2022

The distant location of SS *WM Barkley* from significant ports (30 km from the port of Dublin) reduces the likelihood of anchor drags. Instead, it emphasises the potential impact of trawling activities in the area. As evidenced by the multibeam data, SS *WM Barkley* is located in a very dynamic environment, dominated by mobile sediment and strong bi-directional tidal currents. Pervasive sandwaves are capable of quickly masking any evidence of trawl scars. Although it has been shown that trawl marks can remain visible for 2–7 months in dynamic environments like inter-tidal basins (Brylinsky et al., 1994), significant geomorphic change and sandwave migration were detected even at a weekly time intervals at the SS *WM Barkley* site (Majcher et al., 2021), potentially eradicating any trawling evidence.

Therefore, to understand possible causes of the gunwale displacement, CFD-modelled variables (Fig. 5.3b–e) were compared against structural changes (Majcher et al., 2022). A few observations were made: (1) the stern section is generally subject to relatively high flow -exerted pressure under the NNW, flow, tidal current (Fig. 5.3b); (2) vortices are created over the gunwale (Fig. 5.3c) with streamline contraction and increase in the flow speed (Fig. 5.3d), and (Fig. 5.3) the collapsed gunwale was subject to high shear-stress exerted under the NNW flow conditions (Fig 5.3e). On the other hand, the modelled tidal current flowing in the opposite, ebb, SSE direction (tidal currents are bi-directional in the area) exerted lower shear stress on the same gunwale. Although these observations support the idea that the deterioration of the gunwale could be due to natural causes, specifically the NNW tidal current-induced push towards the wreck's portside, the influence of fishing cannot be ruled out. It remains probable that the tidal flows caused gradual wear which enabled a passing trawl door or net to eventually detach the gunwale.

A contrasting Irish Sea example, where bottom trawling is assumed to directly impact a site (similar to the Baltic site of SS *Edgar* discussed above), is the FV *St. Michan* (Majcher et al., 2021). *St. Michan,* a motor fishing trawler, was lost in 1918 at a depth of 70 m, close to the Western Irish Sea Mudbelt, an area heavily trawled for Dublin Bay prawn (*Nephrops Norvegicus*) (Coughlan et al., 2015). The site was surveyed with high-resolution multibeam echosounder data in 2015 and 2019, and recent trawl marks directly intersecting the wreck were detected in the 2019 data (Fig. 5.4). Although no substantial damage was observed to the wreck's structure in the multibeam data, it cannot be ruled out, as the vessel is relatively small (30 m long) and lying exposed in a scour pit.

The examples provided here show that the degree of ambiguity in determining the influence of bottom trawling on UCH using non-invasive geophysical methods depends on many things, including local seabed conditions and the timing of surveys relative to trawling activities. It is nearly impossible to directly detect evidence of trawling on dynamic seabeds, due to high rates of sediment transport masking trawl scars. Detailed examination of wreck distribution on the seabed, aimed at finding displaced structural elements and assessment of sediment- and hydro-dynamic conditions may provide some clues about whether structural damage may be attributed to anthropogenic activities such as bottom trawling. Additionally, analysis of fishing activity data, for example based on AIS or VMS tracking (EMODNet, 2023)

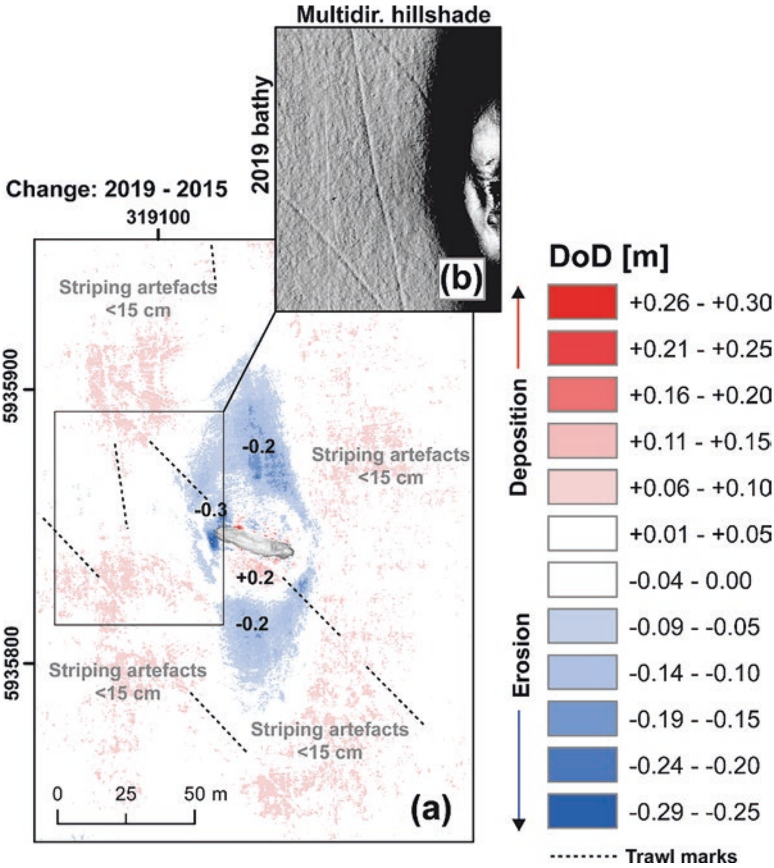

Fig. 5.4 (**a**) Digital Elevation Model of Differences (DoD) for the FV *St. Michan* site, showing bathymetric changes between years 2015 and 2019, and (**b**) inset map showing a hillshaded elevation model created using the data collected in 2019. New trawl marks were recorded in the 2019 data. (Adapted from Majcher et al., 2021)

can provide information about trawling intensity in the area. Following this, more detailed examination of wrecks could be carried out by visual inspection with a remotely operated vehicle or by diving and photogrammetric techniques to detect primary damage or other proxies of trawling e.g. presence of ghost nets (Pedersen et al., 2022). Conversely, in more static seabed environments, with minimal sediment transport, trawling can easily be evidenced and monitored using high resolution bathymetry, backscatter or side-scan sonar data (Brennan et al., 2016; Gournia et al., 2019; Majcher et al., 2021).

5.4 Conclusion and Further Research

The preservation of historic wrecks on the seabed is controlled by a complex set of changing environmental and anthropogenic variables. Considering underwater sites as process-response systems at some equilibrium state with their environment, enables an in-depth analysis of a degree of influence of individual factors and their potential to cause disruption affecting long-term preservation. Bottom-contact fishing can be considered one element of the system. Such an abrupt, high-impact trigger can lead to significant disruption of a site, permanently displacing structural elements, which in turn may lead to wholescale changes at the site in terms of dominant processes, such as a new scour regime.

However, determining the exact combination of factors responsible for particular damage recorded at a site is challenging. High-resolution geophysical methods do provide some proxies of trawling under the right seabed conditions; if the seabed is relatively static with no significant sediment transport, trawl marks will be recorded. Conversely, identification of trawl scars at highly dynamic sites with mobile sediments is often impossible. In the latter case, visual inspection may provide information about the presence of anthropogenic interference, such as ghost nets. Additional information can be sourced from open-source portals providing fishing intensity data or delineating common fishing areas. Case studies conducted in the Danish Baltic Sea (Pedersen et al., 2022) and the British North Sea (Revill & Dunlin, 2003), found the presence of ghost nets on 11 out of 18 investigated wrecks located in known fishing areas. This shows high likelihood (>50%) of direct interaction between fishing gear and a shipwreck if it is indeed located within a fishing zone.

In order to reduce the gap in knowledge pertaining to the influence of anthropogenic factors like fishing on shipwrecks, extending the sample of case studies is necessary. A quantitative statistical assessment could shed light on the scale of the problem. A new study conducted in terms of the ENDURE project (www.endureerc.com), described in Chap. 6 and Gregory et al. (2024), presents a possible further research direction by integrating geophysical datasets (high-resolution multibeam echosounder scans) with various metocean, oceanographic and human activity information sourced online. Another novel approach considers a shipwreck site as a complex adaptive system, which can be studied using Agent Based Modelling (ABM) (Vega-Sánchez & Herrera, 2022). Various pre-depositional and post-depositional factors are included in the ABM conceptual model, which could refine our understanding and determine pathways of deterioration for individual wreck sites.

Understanding anthropogenically-induced preservation or deterioration of shipwreck sites is crucial not only for their heritage value, but also from a potentially polluting perspective. Many modern wrecks, especially those from World War II, contain fuels and other hazardous materials like unexploded ordnance which are potentially detrimental to the ocean environment. Assessing their stability on the seabed is vital for environmental health (Carter et al., 2021; Szafrańska et al., 2021).

As demonstrated in this chapter, bottom-contact fishing has the potential to displace large and heavy structural elements, such as steam boilers. Consequently, it can be inferred that trawling is also capable of moving unexploded ordnance and triggering the sudden release of pollutants to the ocean environment. This potential for pollution introduces another dimension to the importance of understanding and monitoring the impact of trawling on shipwreck sites.

Acknowledgements The authors thank Rasmus Normann Andersen of JD-contractor A/S for granting us permission to use the multibeam echosounder data presented in the paper for the two North and Baltic Sea wrecks. We also extend our gratitude to Ruth Plets (Flanders Marine Institute in Belgium), Chris McGonigle (Ulster University), Fabio Sacchetti (Marine Institute Ireland), Thomas Smyth (University of Huddersfield), Mark Coughlan (University College Dublin) and Kieran Westley (Ulster University), who took part in project planning, acquiring, processing and analysing the data acquired for the mentioned Irish Sea wrecks in terms of the Marine Institute's (Ireland) ship-time applications: APP-CV15021, CV16031 and CV19027.

This work was supported by the Danish Ministry of Culture under Grant FPK.2017-0037 and the European Union (ERC, ENDURE, 101053993). Views and opinions expressed are however those of the authors only and do not necessarily reflect those of the European Union or the European Research Council Executive Agency. Neither the European Union nor the granting authority can be held responsible for them. The authors report that there are no competing interests to declare.

References

Astley, A. (2016). *The taphonomy of historic shipwreck sites* [Doctoral thesis, University of Southampton]. https://eprints.soton.ac.uk/402317/

Brennan, M. (2016). Quantifying impacts of trawling to shipwrecks. In M. E. Keith (Ed.), *Site formation processes of submerged shipwrecks* (pp. 157–179). University Press of Florida.

Brennan, M. L., Davis, D., Ballard, R. D., Trembanis, A. C., Vaughn, J. I., Krumholz, J. S., Delgado, J. P., Roman, C. N., Smart, C., Bell, K. L. C., Duman, M., & DuVal, C. (2016). Quantification of bottom trawl fishing damage to ancient shipwreck sites. *Marine Geology, 371*, 82–88. https://doi.org/10.1016/j.margeo.2015.11.001

Brylinsky, M., Gibson, J., & Gordon, D. C., Jr. (1994). Impacts of flounder trawls on the intertidal habitat and community of the Minas Basin, Bay of Fundy. *Canadian Journal of Fisheries and Aquatic Sciences, 51*(3), 650–661. https://doi.org/10.1139/f94-066

Carter, M., Goodsir, F., Cundall, P., Devlin, M., Fuller, S., Jeffery, B., Hil, G., & Talouli, A. (2021). Ticking ecological time bombs: Risk characterisation and management of oil polluting World War II shipwrecks in the Pacific Ocean. *Marine Pollution Bulletin, 164*, 112087. https://doi.org/10.1016/j.marpolbul.2021.112087

Coughlan, M., Wheeler, A. J., Dorschel, B., Lordan, C., Boer, W., van Gaever, P., de Haas, H., & Mörz, T. (2015). Record of anthropogenic impact on the Western Irish Sea mud belt. *Anthropocene, 9*, 56–69. https://doi.org/10.1016/j.ancene.2015.06.001

EMODNet. (2023). *European marine observation and data network—GeoViewer [dataset].* https://emodnet.ec.europa.eu/geoviewer/

Gibbs, M. (2006). Cultural site formation processes in maritime archaeology: Disaster response, salvage and Muckelroy 30 years on. *International Journal of Nautical Archaeology, 35*(1), 4–19. https://doi.org/10.1111/j.1095-9270.2006.00088.x

Gournia, C., Fakiris, E., Geraga, M., Williams, D. P., & Papatheodorou, G. (2019). Automatic detection of trawl-marks in sidescan sonar images through spatial domain filtering, employing Haar-like features and morphological operations. *Geosciences, 9*(5), 214. https://doi.org/10.3390/geosciences9050214

Gregory, D. (2020). Characterizing the preservation potential of buried marine archaeological sites. *Heritage, 3*(3), 838–857. https://doi.org/10.3390/heritage3030046

Gregory, D., Jensen, P., & Strætkvern, K. (2012). Conservation and in situ preservation of wooden shipwrecks from marine environments. *Journal of Cultural Heritage, 13*(3), S139–S148. https://doi.org/10.1016/j.culher.2012.03.005

Gregory, D., Dam, M., Majcher, J., Matthiesen, H., Normann-Andersen, G., & Quinn, R. (2024). Using open-data portals, remote sensing and computational modelling to investigate historic wreck sites and their environments: 45 years on from Muckelroy. To be submitted to *International Journal of Nautical Archaeology*. https://doi.org/10.1080/10572414.2024.2320774

Majcher, J., Quinn, R., Plets, R., Coughlan, M., McGonigle, C., Sacchetti, F., & Westley, K. (2021). Spatial and temporal variability in geomorphic change at tidally influenced shipwreck sites: The use of time-lapse multibeam data for the assessment of site formation processes. *Geoarchaeology, 36*(3), 429–454. https://doi.org/10.1002/gea.21840

Majcher, J., Quinn, R., Smyth, T., Plets, R., McGonigle, C., Westley, K., Sacchetti, F., & Coughlan, M. (2022). Using difference modelling and computational fluid dynamics to investigate the evolution of complex, tidally influenced shipwreck sites. *Ocean Engineering, 246*, 110625. https://doi.org/10.1016/j.oceaneng.2022.110625

Muckelroy, K. (1976). The integration of historical and archaeological data concerning an historic wreck site: The 'Kennemerland'. *World Archaeology, 7*(3), 280–290. https://doi.org/10.1080/00438243.1976.9979641

Pedersen, E. M., Andersen, N. G., Egekvist, J., Nielsen, A., Olsen, J., Thompson, F., & Larsen, F. (2022). Ghost nets in Danish waters. *DTU Aqua*, 394–2021, 83. https://www.aqua.dtu.dk//media/institutter/aqua/publikationer/rapporter-352-400/394-2021_ghost-nets-in-danish-waters.pdf

Quinn, R. (2006). The role of scour in shipwreck site formation processes and the preservation of wreck-associated scour signatures in the sedimentary record—Evidence from seabed and sub-surface data. *Journal of Archaeological Science, 33*(10), 1419–1432. https://doi.org/10.1016/j.jas.2006.01.011

Quinn, R., & Boland, D. (2010). The role of time-lapse bathymetric surveys in assessing morphological change at shipwreck sites. *Journal of Archaeological Science, 37*(11), 2938–2946. https://doi.org/10.1016/j.jas.2010.07.005

Revill, A. S., & Dunlin, G. (2003). The fishing capacity of gillnets lost on wrecks and on open ground in UK coastal waters. *Fisheries Research, 64*(2–3), 107–113. https://doi.org/10.1016/S0165-7836(03)00209-1

Stieglitz, T. C., & Waterson, P. (2013). Impact of Cyclone Yasi on the wreck of the SS Yongala documented by comparative multibeam bathymetry analysis. *Queensland Archaeological Research, 16*, 33. https://doi.org/10.25120/qar.16.2013.222

Szafrańska, M., Gil, M., & Nowak, J. (2021). Toward monitoring and estimating the size of the HFO-contaminated seabed around a shipwreck using MBES backscatter data. *Marine Pollution Bulletin, 171*, 112747. https://doi.org/10.1016/j.marpolbul.2021.112747

Vega-Sánchez, R., & Herrera, J. M. (2022). Agent-based modelling for the study of shipwreck site formation processes: A theoretical framework and conceptual model. *F1000Research, 11*, 1525. https://doi.org/10.12688/f1000research.125089.1

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