

Evaluation of Polycyclic Aromatic Hydrocarbon Pollution from the HMS Royal Oak Shipwreck and Effects on Sediment Microbial Community Structure

On the 14th October 1939, six weeks after the start of World War II, the British battleship HMS Royal Oak was torpedoed by a submarine and sank to the bottom of Scapa Flow (Orkney Islands, Scotland UK). Given many shipwrecks contain oil products (which include polycyclic aromatic hydrocarbons (PAHs), many of which are toxic, carcinogenic, and persist in the environment) there is a lack of studies investigating the release of oil from shipwrecks. HMS Royal Oak sank with approximately 3,000 tonnes of fuel oil on board and was observed to leak oil in the 1960s and 1990s; currently, it is estimated to hold 697 tonnes of fuel oil. Whilst any visible oil leakage from HMS Royal Oak in Scapa Flow has subsided, it is unknown whether there is a legacy of hydrocarbon contamination in the sediments. This study evaluated any potential effect of oil released from the shipwreck HMS Royal Oak on the surrounding seabed. Sediments were analysed, over a 17.5 cm depth profile, along four 50 – 950 m transects (N, E, S, W) away from the shipwreck. Analysis of PAHs, via gas chromatography-mass spectrometry, revealed low concentrations ($205.91 \pm 50.15 \mu\text{g kg}^{-1}$ of dry sediment), which did not significantly differ with either distance from the shipwreck nor sediment depth. PAH concentrations were well below the Effects-Range Low for the OSPAR (Oslo/Paris convention for the Protection of the Marine Environment of the North-East Atlantic) maritime area. Multiple models were tested for their ability to source type environmental PAHs. The average Pyrogenic Index, in sediments around HMS Royal Oak, was $1.06 (\pm 0.34)$, indicating PAHs were pyrogenic rather than petrogenic. A second line of investigation involved the analysis of sediment microbiomes, via DNA sequencing, which revealed no significant differences in bacterial community structure with distance from the shipwreck. Sediments contained extremely low levels of obligate hydrocarbonoclastic bacteria (OHCB; $0.21\% \pm 0.54\%$); bacteria capable of attenuating hydrocarbons (PAHs) from the environment. Both lines of evidence suggest, at the time of sampling, sampled sediments are not currently being impacted by petrogenic hydrocarbons and show no long-term impact by previous oil-spills from HMS Royal Oak.