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Remote sensing and modelling of marine habitats

Challenges and results of the Heligoland survey campaigns

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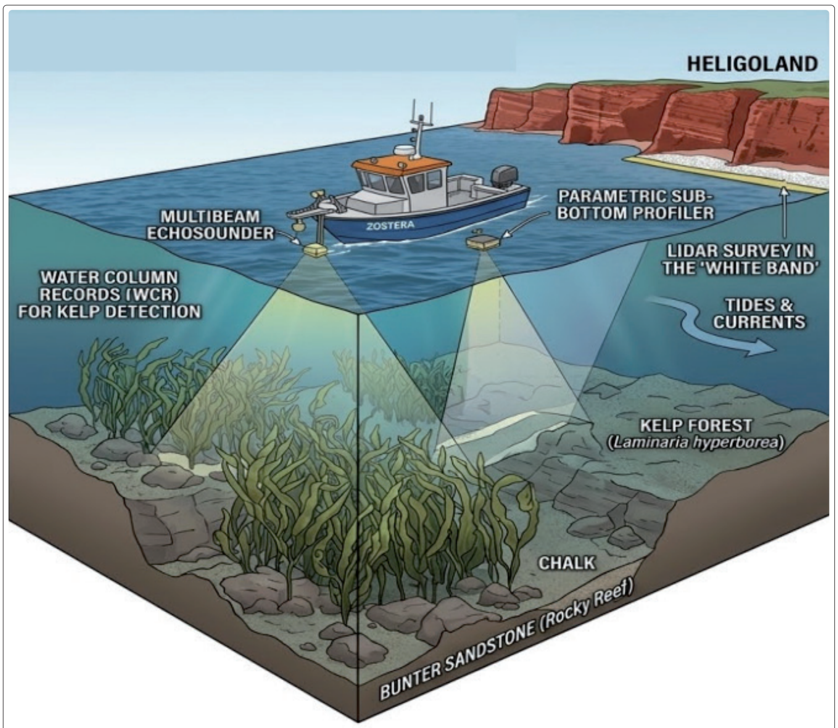
The survey of the Heligoland shallow-water zone represents a significant frontier in modern hydrography and marine geo-ecology. From a geological perspective, Heligoland is unique within the German Bight, as Mesozoic rock layers – most notably the red Bunter Sandstone – were pushed to the surface by salt tectonic processes. This anomaly creates an underwater landscape of rocky reefs that fosters the most biodiverse region in German waters, providing essential habitats for kelp forests and lobsters. However, mapping this area is exceptionally demanding due to strong tidal currents, shoals and the notorious ›White Ribbon‹ – the ultra-shallow transition zone between 1 and 6 metres depth. This zone is largely inaccessible to traditional research vessels and remains hidden from optical remote sensing, such as airborne LiDAR, because of high turbidity and dense vegetation cover. To bridge this gap, the Marine Geophysics and Hydroacoustic working group at CAU Kiel utilises the research boat *FB Zostera*, a specialised 7-metre platform equipped for high-resolution acoustic records.



A core focus of these campaigns is the rigorous inspection of water column records to investigate submerged aquatic vegetation (SAV). Heligoland is home to over 250 algae species, dominated by dense forests of the kelp *Laminaria hyperborea*. These »underwater forests« pose a significant challenge for hydrographers because the bottom-finding algorithms of multibeam echo sounders (MBES) often trigger false detections on the canopy of the kelp rather than the true seafloor. By inspecting the raw data, researchers can identify these »miss-detections« and manually clean the records. To refine this process, the team employs a parametric sub-bottom profiler (Innomar smart) synchronised with the MBES. This system emits a high-frequency primary signal (100 kHz) and a low-frequency difference frequency (10 kHz) that effectively penetrates the dense kelp canopy. In the resulting echograms, the hard seafloor – such as the Bunter Sandstone – appears as a sharp, continuous reflector, while the vegetation appears as a diffuse layer above it. By analysing the time-of-flight difference between these two signal components, the canopy height of the vegetation can be precisely determined across the entire survey area.

The high-resolution bathymetric data, with a grid resolution of 0.5 metres, allows for a new dimension of geological and ecological analysis. Fine-scale tectonic faults, bedding planes and erosion patterns in the shell limestone and other rock formations can be quantitatively measured, which is fundamental for 3D geological reconstruction. Furthermore, these data products serve as critical predictors for habitat modelling. Derived parameters such as slope, aspect and the terrain ruggedness index (TRI) – which quantifies topographic heterogeneity – are used in machine learning algorithms to predict where specific benthic species will settle. For instance, the TRI is an excellent indicator of exposed rock and micro-niches essential for juvenile lobsters.

Complementing the bathymetry is the analysis of snippet-backscatter data, which provides side-scan-like mosaics at a resolution of 0.1 metres. After radiometric and geometric corrections – including accounting for the true angle of incidence on the detailed digital terrain model – the compensated backscatter strength allows for the clear acoustic differentiation between various geological formations like chalk, sandstone, shell limestone and clastic sediments. Interestingly, massive bedrock often shows lower backscatter intensity compared to surrounding clastic sediments because the latter has a higher micro-roughness relative to the 400-kHz acoustic wavelength.

The ultimate goal of this work is a seamless model of the entire Heligoland rocky reef. This is achieved by fusing CAU's ultra-shallow data with MBES measurements from the Federal Maritime and Hydrographic Agency (BSH) and LiDAR data from the State Agency for Coastal Protection (LKN.SH). The resulting map not only ensures nautical safety in previously unmapped areas but also provides a ›ground-truthing‹ foundation for assessing the total biomass and CO_2 storage potential of the kelp forests within projects like LABLUC. Ongoing efforts include a detailed full-waveform analysis of the acoustic data to derive species-specific acoustic signatures, potentially allowing for the purely acoustic differentiation of various macroalgae types. This multidisciplinary approach proves that high-resolution hydroacoustic technology on small, flexible platforms is the key to closing the mapping gap in complex coastal environments. //