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Research Article
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Tracking Sea Level Changes and Their Effect on The Seabed Geomorphology and Sediment Depositional System in Menai Strait by Using SBES and MBES Data

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Abstract
The Menai Strait, a tidal channel in northern Wales, represents a unique and dynamic marine environment where strong tidal currents drive significant changes in seabed geomorphology and sediment distribution. This study aims to investigate these changes using a combination of Single Beam Echo Sounder (SBES) data collected over seven years (2007–2014) and Multibeam Echo Sounder (MBES) data acquired over two years (2011–2012). The SBES data provide a long-term perspective on water depth variations, while the MBES data offer high-resolution insights into sedimentation rates and geomorphological processes. Advanced geospatial analysis tools, including ArcGIS, were utilized to process and interpret the bathymetric data. Hillshade and slope analyses of MBES datasets revealed distinct patterns of sediment deposition and erosion, driven by tidal dynamics. The study identified significant sediment accumulation in the central channel and pronounced erosion along the Strait's edges, which correlates with varying tidal velocities and substrate types. Sand wave features observed in the MBES data highlighted dynamic sediment transport mechanisms, with changes in wave morphology indicating active seabed reworking processes. The findings underscore the effectiveness of integrating SBES and MBES data for monitoring seabed geomorphological changes in complex tidal environments. The study also highlights the necessity of tidal corrections and spatial analysis tools to enhance the accuracy and reliability of bathymetric surveys. By providing a detailed understanding of sedimentary processes in the Menai Strait, this research contributes valuable insights into the broader study of coastal and marine geomorphology. These results not only inform future studies on the impact of climate change and anthropogenic activities but also aid in developing sustainable management strategies for similar tidal environments worldwide.

Keywords: Menai Strait, Seabed Geomorphology, Tidal Phenomena, SBES Data, MBES Data.

INTRODUCTION

The Menai Strait, located in northern Wales, UK, is a narrow and shallow channel that stretches approximately 25 kilometers from northeast to southwest. This strait, separating the Isle of Anglesey from mainland Wales, ranges in width between 500 and 1,100 meters, with depths generally less than 18 meters (Figure 1). The Menai Strait is believed to have formed due to the melting of the Welsh Ice Sheet during the transition from the Late Pleistocene to the Early Holocene. At its maximum, the Welsh Ice Sheet, estimated to have reached a thickness of approximately 600 feet above present sea level, covered most of Wales (Embleton, 1964; Hughes, 2022). The strait is highly influenced by tidal forces, with both spring and neap tides generating strong bidirectional currents. These tidal movements transport an estimated 30 million cubic meters of water through the strait, with velocities averaging 15 cm/s (Harvey, 1968; Krivtsov et al., 2011; Hoare & Peattie, 1979). Seismic profiles from the northeastern Menai Strait reveal three distinct depositional cycles corresponding to glacial, post-glacial, and modern sedimentary environments (Ali, 1992). Modern technologies, such as Multibeam Echosounder Systems (MBES) and Single Beam Echo Sounders (SBES), have become integral tools in studying the geological and geophysical characteristics of marine environments (Pratomo & Saputro, 2021; Bannari & Kadhem, 2017).

MBES devices are highly efficient and provide high-resolution mapping of seafloor features. Their ability to capture detailed acoustic reflections allows for precise characterization of the seafloor's morphology and water-seafloor interfaces (Hellequin, 2003; Raihan, 2015). To ensure accurate operation, MBES systems require ancillary equipment such as heading sensors, motion compensators, and sound velocity profilers to account for ray refraction and real-time transducer velocity corrections. Accurate calibration of MBES, alongside regular system standardization, is essential to minimize errors related to sensor offsets, sound velocity anomalies, time delays, and vessel motion (Jena et al., 2012).

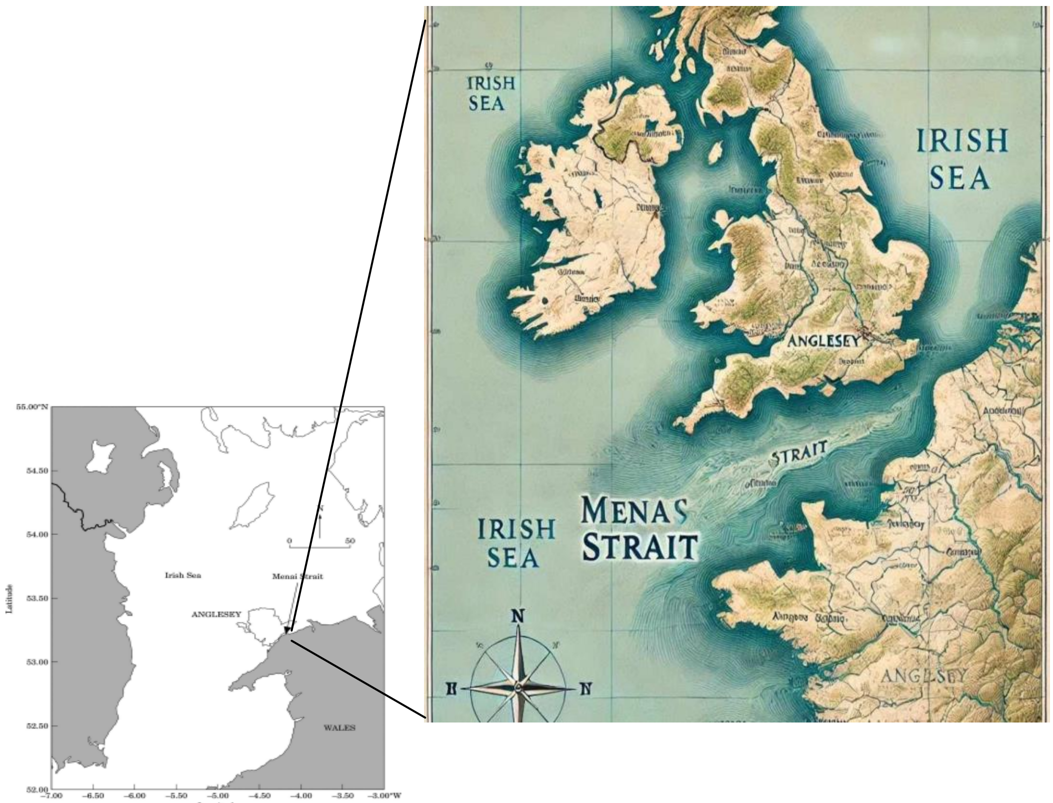

Figure: (1). Shows the location of Menai strait in the Irish sea (after: Kratzer, S, et al. 2003).

In comparison, SBES systems are typically used for shallow water surveys, with depth ranges between 5 and 10 meters and operating frequencies of 200–400 kHz (Kloser & Penrose, 2000; Trzcinska et al., 2021). However, SBES can only cover approximately 5% of the seafloor during surveys (Clarke, 1999). Furthermore, the system is prone to errors caused by vessel motion, survey speed, and sea surface conditions, limiting its standalone effectiveness. Consequently, SBES is often combined with MBES for more comprehensive data acquisition and seabed classification (Parsons et al., 2004). Calibration of SBES systems, such as bar checks for sound velocity corrections, ensures accurate depth measurements below the sea surface (Jena et al., 2012). By integrating advanced acoustic systems like MBES and SBES, researchers can obtain precise and comprehensive data on the Menai Strait's geological history and hydrodynamic processes, contributing significantly to marine and geophysical studies.

MATERIALS AND METHODS

The data for this research was collected aboard the research vessel Prince Madog using various advanced technologies and methodologies to ensure accurate and reliable results. Data acquisition spanned seven consecutive years using a Single Beam Echo Sounder (SBES) and two years of continuous Multibeam Echo Sounder (MBES) surveys. Geographic Information Systems (GIS) were integrated into the survey process to georeference the data and correlate the survey paths with the collected measurements, ensuring precise spatial representation of the study area. The research procedures are:

Data Collection

The SBES and MBES systems were utilized to capture bathymetric data at different resolutions and frequencies. The SBES was primarily used for shallow water measurements, while the MBES provided high-resolution mapping of the seafloor. Data collection was synchronized with GIS tools to ensure spatial consistency across survey datasets. These systems captured key bathymetric parameters, such as depth values and seabed morphology, allowing for the detailed study of the Menai Strait's geological and hydrodynamic features.

Data Processing

To ensure the accuracy of the results, raw data underwent several stages of processing and correction. First, the data Cleaning and Noise Removal in which raw SBES data was carefully reexamined to eliminate noisy or erroneous readings. The SBES depth values were imported into Microsoft Excel, where they were sorted and visualized using conditional formatting. Depth readings greater than 23 meters, which were beyond the scope of the study, were excluded (Figure 2).

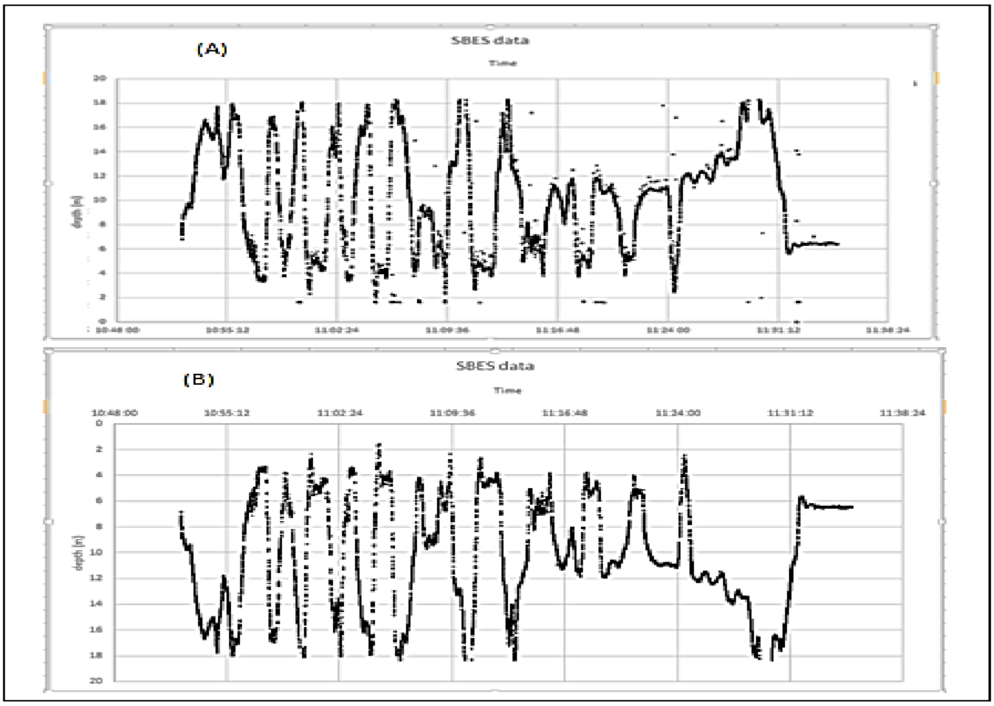

Figure: (2). (A) shows the noisy data of Single Beam Echo Sound (SBES) that was collected on 28.10.2014 between 10:52:14 and 11:35:04, while (B) shows the same SBES data after sorting from the noisy data.

Second, the error Detection and Correction in which errors caused by fluctuations in water levels above the transducer were identified. These errors were corrected by applying a linear equation to standardize the data (Figure 3).

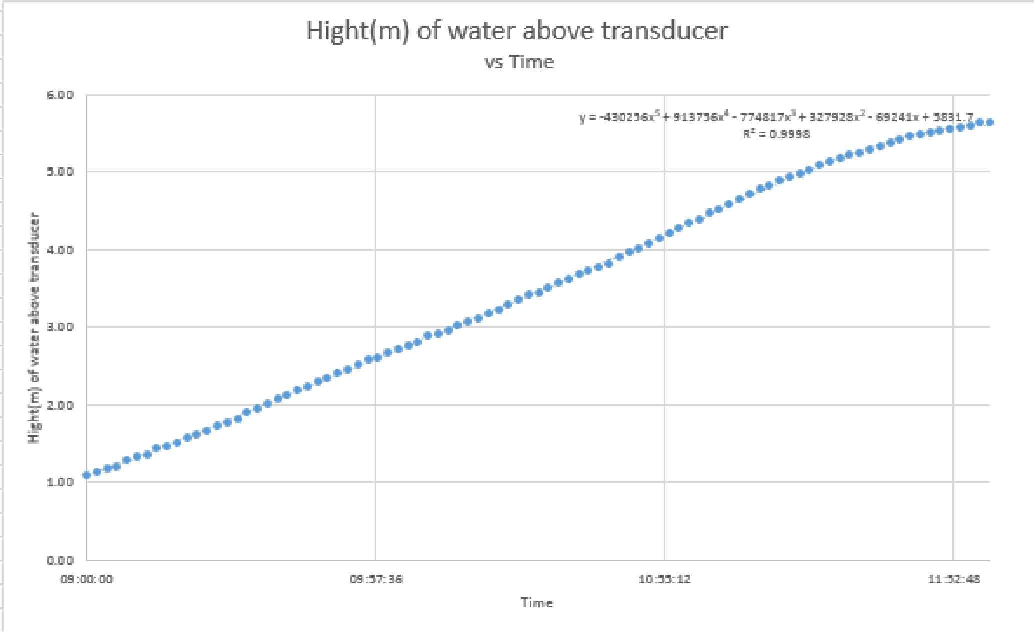

Figure: (3). Shows the height of water above the transducer on axis y against time on axis x with the linear equation and R in order to correct the data.

The tidal corrections were applied to all data to account for changes in water levels due to tidal fluctuations. This included detailed analysis of tidal data from specific time intervals (e.g., 10:52:14 to 11:35:04) as shown in (Figures 4 and 5).

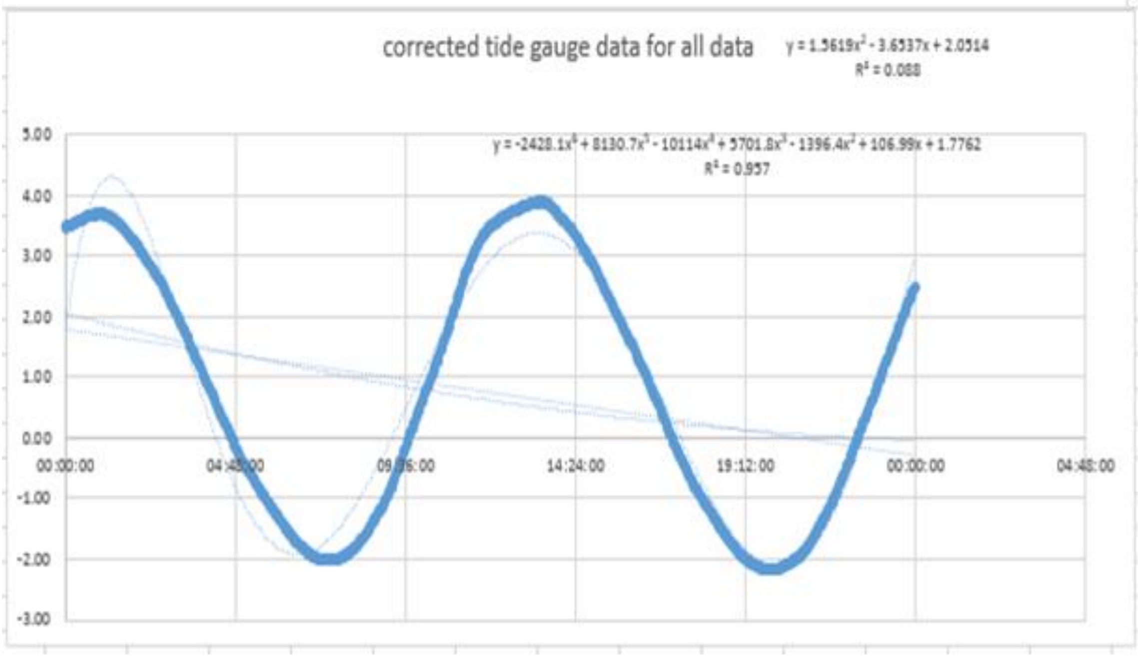

Figure: (4). Shows the corrected tide data for all data with the linear equation and R, where the values are between 4 and -2.5

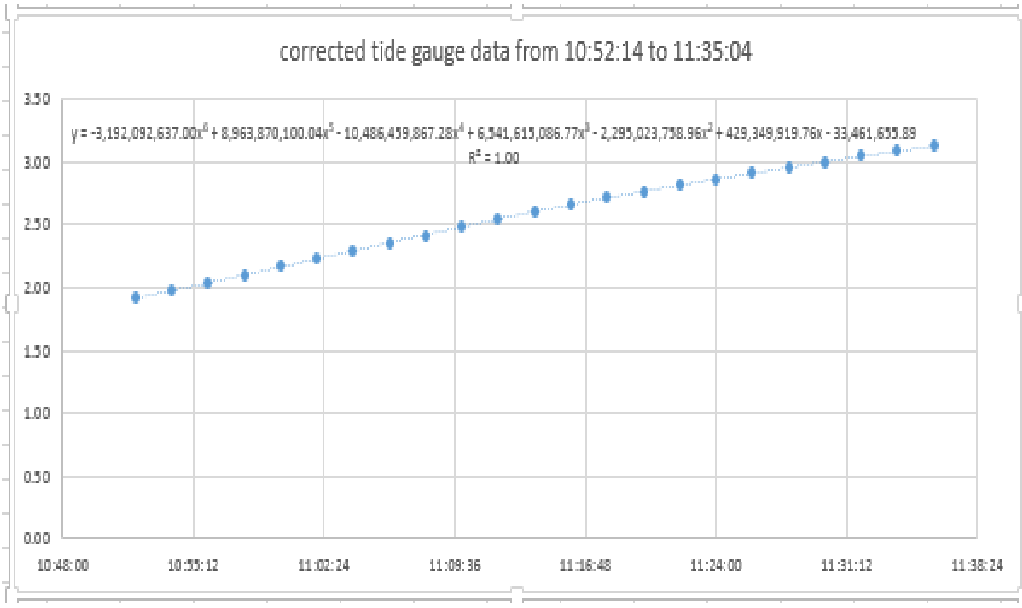

Figure: (5). Shows the corrected tide data for the data from 10:52:14 to 11:35:04 with the linear equation and R.

Third, the integration of GPS Data GPS data was incorporated into the dataset to improve spatial accuracy. This step ensured the alignment of the bathymetric data with precise geographic coordinates (Figure 6). Finally, the tidal corrections in which bathymetry data was adjusted to the Ordnance Datum Newlyn (ODN), accounting for the vertical difference between the echo sounder and the seabed. Two sources of tidal information were used for calibration: A tide gauge deployed within the straits, and Real-Time Kinematic (RTK) GPS data collected from the Prince Madog vessel. The RTK system was mounted on a 2.7-meter pole directly above the SBES transducer, ensuring precise tidal corrections.

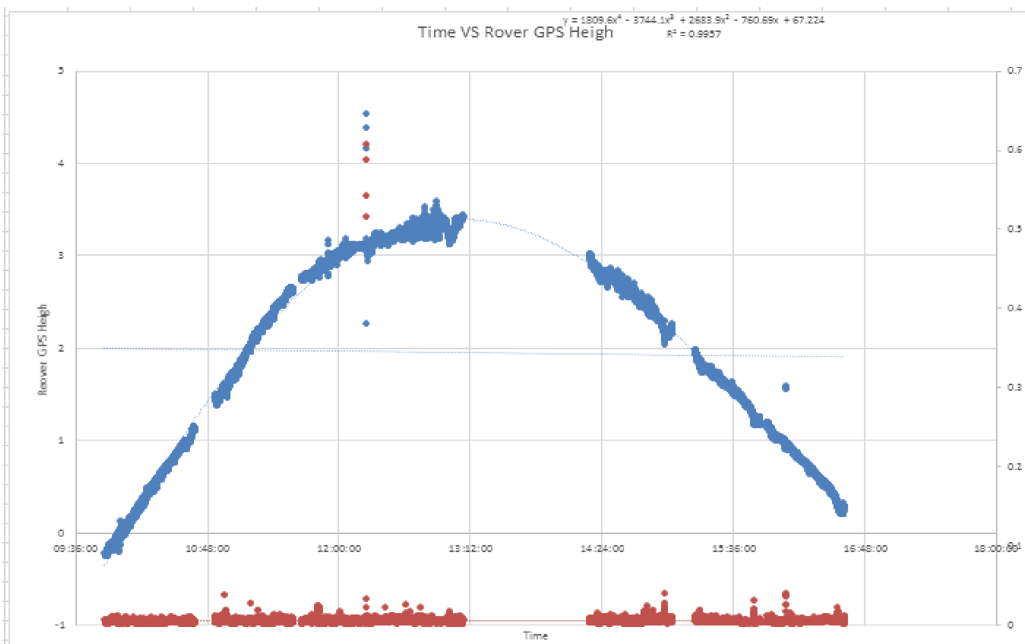

Figure: (6). Shows the rover GPS height on axis y against time on axis x with the linear equation and R to correct the data.

Final Data Refinement

After processing and correcting the SBES and MBES data, the resulting bathymetric data was refined and validated. This included verification of depth values, removal of residual errors, and the integration of tidal and spatial corrections. The corrected dataset provides a reliable foundation for studying the geological and hydrodynamic processes of the Menai Strait. This rigorous methodology ensures high-quality data collection and processing, enabling accurate bathymetric analysis and supporting the research objectives effectively.

RESULTS

The bathymetric data analysis revealed notable variations in the geomorphological and sedimentary features of the Menai Strait over the study period. The SBES dataset, spanning 2007 to 2014, showed long-term trends in water depth changes across the channel, with significant variations identified in areas exposed to higher tidal velocities. These changes were attributed to erosion and deposition processes influenced by the tidal dynamics of the Strait.

The MBES dataset provided high-resolution insights into the spatial variability of seabed features between 2011 and 2012. Hillshade analysis highlighted dynamic sedimentary structures, including sand waves and ripples, predominantly located in the central channel. These features exhibited changes in morphology, such as variations in wavelength and amplitude, indicative of active sediment transport processes. Slope analysis further emphasized the distinct patterns of erosion and deposition. The steepest slopes were associated with areas of erosion, while flatter regions corresponded to zones of sediment accumulation. Spatial analysis confirmed that sediment deposition was concentrated in the central channel, while erosion dominated along the Strait's edges. These patterns aligned with the expected influence of tidal currents, where high-velocity currents caused scouring along the edges and reduced flow velocities in the center facilitated sediment settling.

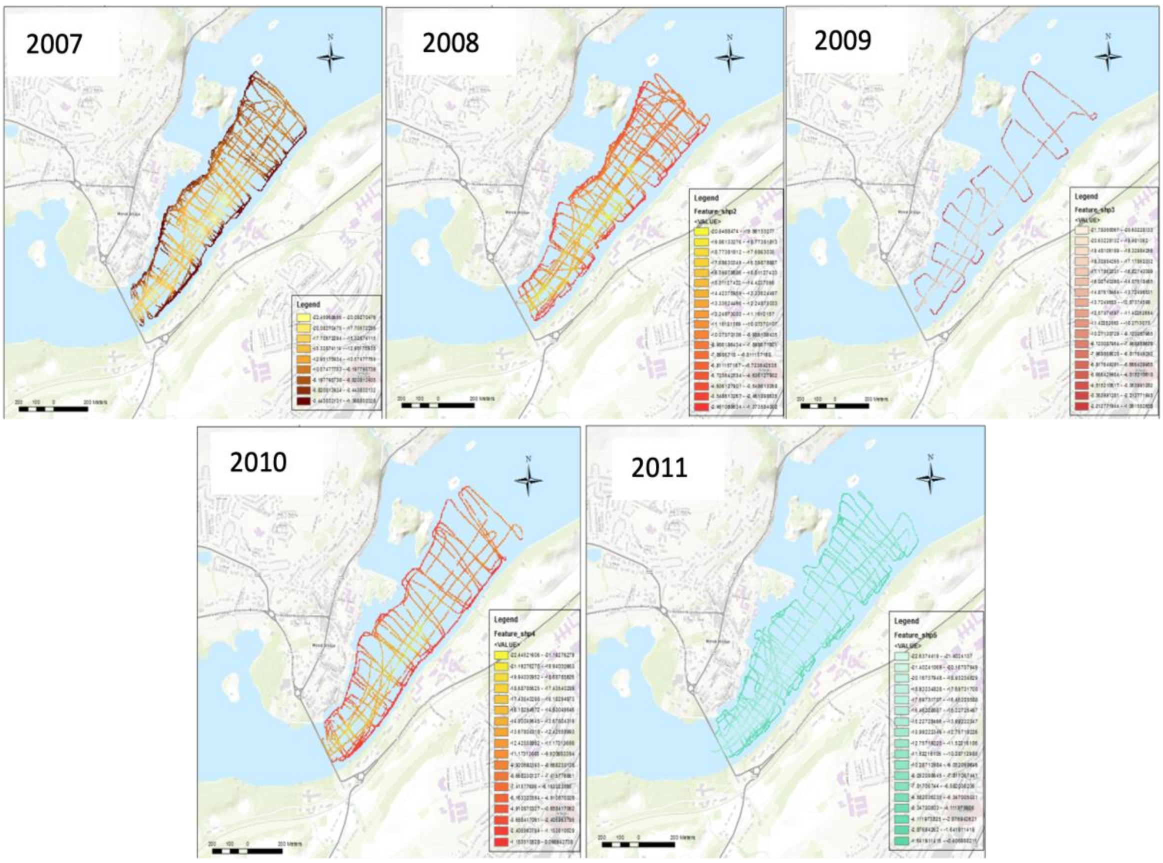

Figure: (7). Presents Small Baseline Subset (SBES) data spanning the years 2007 to 2011, illustrating variations in water depth levels across the study period. The data reveal a progressive reduction in water depth at the periphery of the strait, accompanied by a concurrent increase in water depth within the central region of the strait. These trends indicate a spatially heterogeneous pattern of water level changes over time.

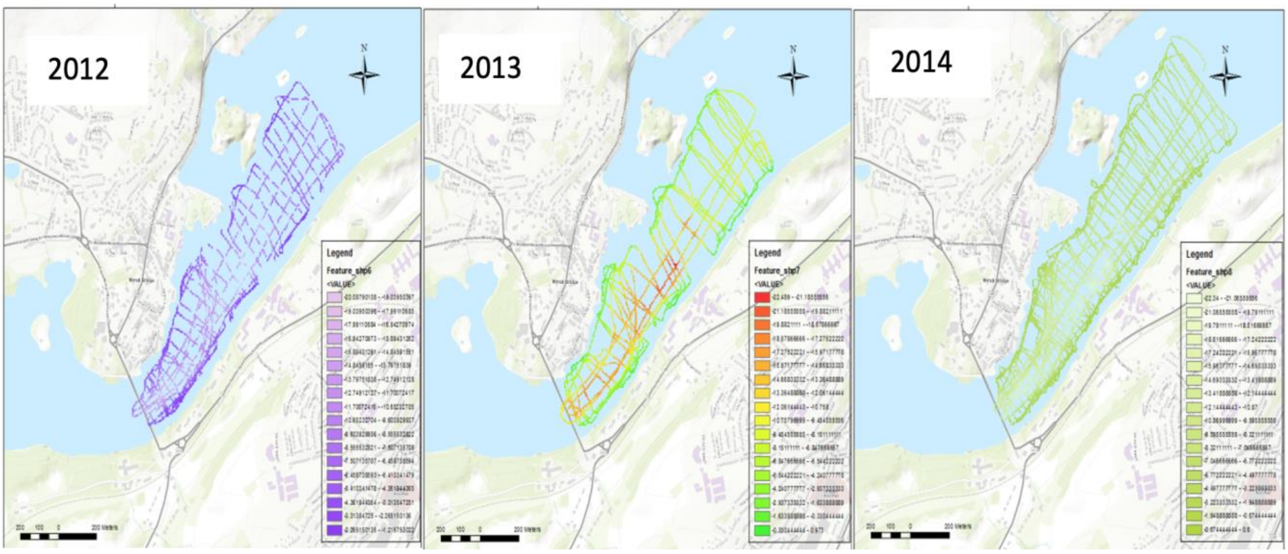

Figure: (8). Presents Single Beam Echo Sounder (SBES) data collected between 2012 and 2014, highlighting changes in water depth across the strait. The survey indicates an increase in water depth along the peripheral areas of the strait, while the central region exhibits a notable decrease in water depth during the study period.

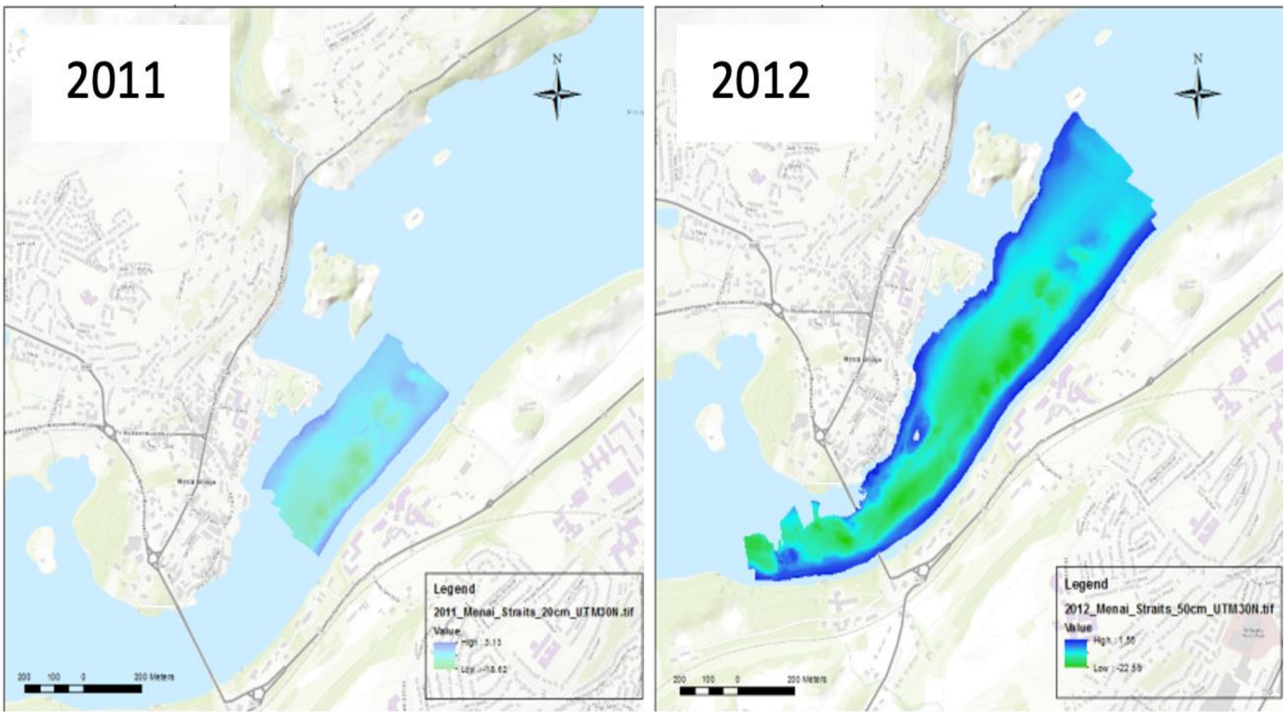

Figure: (9). Presents Multibeam Echo Sounder (MBES) data of the Mani Straits, comparing sediment deposition in 2011 and 2012 at two resolutions: 20 cm and 50 cm, respectively. In 2011, light green indicates minimal sediment deposition (-18.62 cm) in the central region, while blue represents higher deposition (3.13 cm) at the channel edges. In 2012, green signifies lower deposition (-22.59 cm) in the central region, while dark blue indicates higher deposition (1.55 cm) at the edges. Between 2011 and 2012, sediment deposition in the central region increased by approximately 4 cm, whereas deposition at the edges decreased by about 2 cm. The data demonstrate an overall increase in the sedimentation rate within the central channel and a reduction at the edges, indicating a spatial shift in sediment dynamics across the study period.

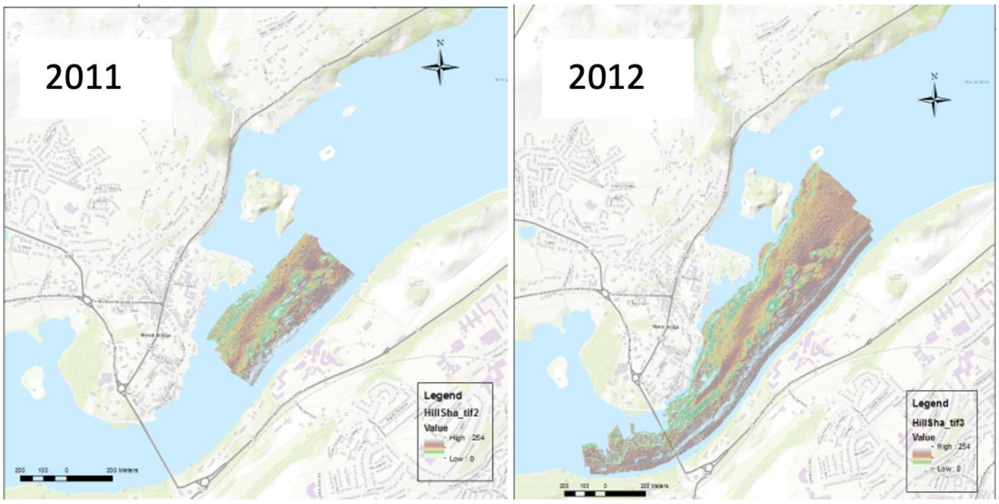

Figure: (10). Shows the hillshads of MBES in 2011, sediment deposition in the Menai Strait exhibited a low value of -18.62 cm in the central region and a high value of 3.13 cm along the channel edges. By 2012, sediment deposition further decreased to -22.59 cm in the central region, while the maximum deposition at the channel edges dropped to 1.55 cm. Comparative analysis indicates that sediment deposition decreased by approximately 2 cm along the edges of the channel and increased by 4 cm in the central region between 2011 and 2012. These trends suggest a shift in sedimentation patterns, with a notable increase in deposition rates in the central region and a decrease at the channel edges, as revealed by MBES (Multibeam Echo Sounder) data.

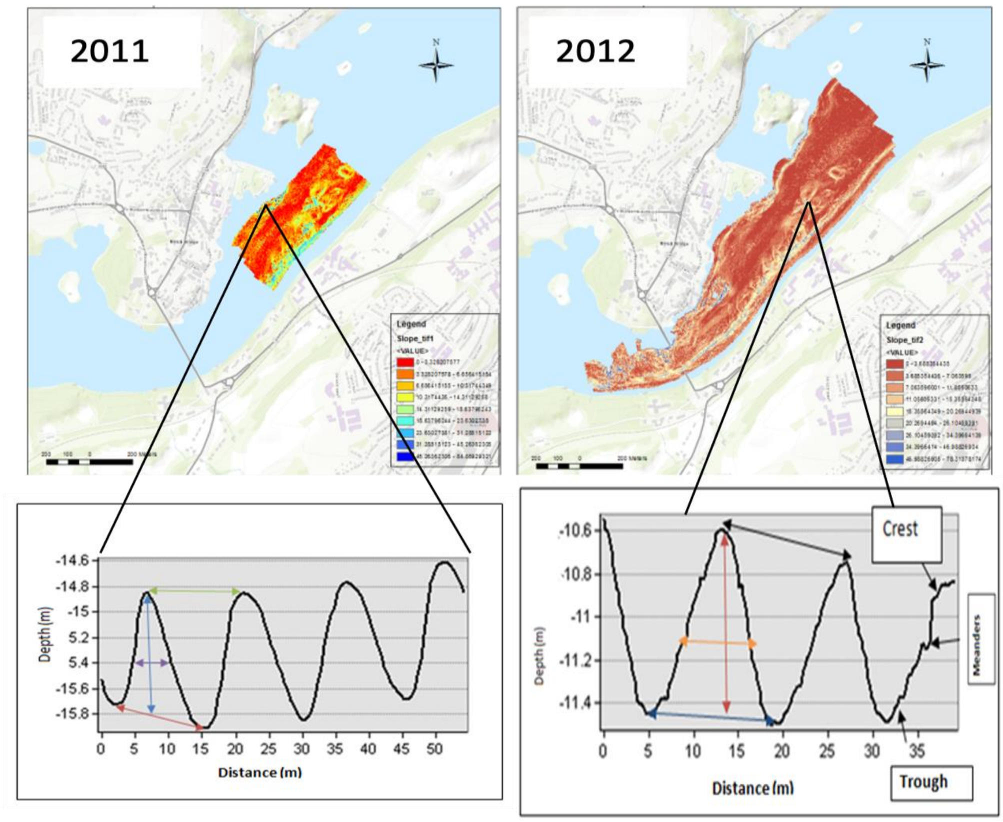

Figure: (11). Illustrates the slope derived from MBES (Multibeam Echo Sounder) data for 2011 and 2012. The slope values are particularly significant in identifying areas prone to erosion, as steeper gradients often correlate with increased sediment transport and scouring activity. The data also reveal a notable accumulation of sediments in the central zone of the Menai Strait, indicating high deposition rates in this region. Additionally, the analysis highlights the morphological characteristics of the sand waves covering the seabed in 2011 and 2012. The wavelength, height, length, and width of these sand waves were measured, providing valuable insights into sediment transport dynamics and seabed morphology. The observed differences between 2011 and 2012 reflect changes in hydrodynamic conditions and sedimentation processes within the Strait, underscoring the importance of slope and sand wave analysis in understanding sediment distribution and movement.

DISCUSSION

The bathymetric and sedimentary analysis of the Menai Strait provides critical insights into the geomorphological evolution and sediment transport processes driven by tidal dynamics. By combining data from Small Baseline Subset (SBES) and Multibeam Echo Sounder (MBES), the study highlights the spatial and temporal variability of erosion and deposition patterns, as well as their relationship with hydrodynamic forces in the strait.

Sediment Deposition and Erosion Patterns

The analysis of SBES data spanning 2007 to 2014 revealed long-term trends in water depth changes, which are closely linked to tidal velocities. Regions exposed to higher tidal currents, particularly along the edges of the strait, exhibited significant erosion, as evidenced by decreasing water depths. In contrast, reduced tidal velocities in the central channel facilitated sediment deposition, leading to an increase in water depth. This spatial heterogeneity underscores the role of hydrodynamics in shaping the seabed morphology, with scouring dominating high-energy zones and sedimentation occurring in low-energy zones (Dyer, 1997; McCave, 1971). The MBES data provided a more detailed snapshot of sediment dynamics between 2011 and 2012. Hillshade and slope analyses highlighted that sediment deposition was concentrated in the central channel, where deposition rates increased by approximately 4 cm, while erosion was predominant along the edges, resulting in a decrease of 2 cm in sediment levels. These findings align with the classic "sediment sorting" mechanism in estuarine systems, where fine sediments settle in low-energy zones, and coarser materials are transported to higher-energy areas (Allen and Posamentier, 1993; Woodroffe, 2002).

Influence of Hydrodynamic Conditions

The variations in sediment deposition and erosion are strongly influenced by tidal currents. The steep slopes identified in the MBES slope analysis correspond to regions of high-energy tidal flows, which enhance sediment transport and erosion. Conversely, flatter slopes in the central channel correspond to areas of reduced flow velocity, allowing for sediment accumulation. This spatial distribution is consistent with tidal dynamics observed in similar semi-enclosed systems, where convergence and divergence of flow play a key role in sediment redistribution (Van Rijn, 1993; Paphitis, 2001). The hydrodynamic control of sediment transport is further supported by the study of tidal asymmetry and flow patterns in estuarine systems. The Menai Strait exhibits characteristics of a semi-enclosed tidal environment, where residual currents promote sediment sorting and redistribution between erosion-prone and depositional areas (Brown & Blondel, 2009).

Morphological Changes in Sand Waves

The MBES analysis further highlighted changes in the morphology of sand waves between 2011 and 2012. These features, characterized by their wavelength, height, length, and width, are indicative of active sediment transport processes driven by tidal currents. The observed variations in sand wave morphology reflect temporal changes in hydrodynamic conditions, likely influenced by seasonal variations in tidal energy, sediment supply, and anthropogenic activities (Kenyon et al., 1981; Mitchell, 2005). The reduction in deposition along the channel edges and increased sedimentation in the central channel suggest a dynamic redistribution of sediments, possibly linked to changes in flow patterns or external disturbances, such as dredging or changes in sediment supply (Van der Wal and Pye, 2004). Sand wave dynamics are crucial indicators of seabed mobility and sediment transport pathways in the Menai Strait.

Implications for Sediment Dynamics

The observed patterns have significant implications for understanding sediment dynamics and seabed evolution in the Menai Strait. The central channel acts as a sediment sink, while the edges are more prone to scouring and sediment removal. This behavior has critical implications for habitat distribution, navigation safety, and coastal management strategies (Woodroffe, 2002; Van Rijn, 1993). Effective sediment management in tidal systems like the Menai Strait requires a detailed understanding of these processes to mitigate erosion, maintain navigational depth, and preserve habitats.

LIMITATIONS AND FUTURE RESEARCH

While the MBES and SBES datasets provide valuable insights, some limitations must be acknowledged: The analysis is constrained to a specific timeframe (2007–2014), and longer-term studies are required to capture broader trends. The resolution of the MBES data (20 cm and 50 cm) may not capture finer-scale sedimentary features. The study does not account for external factors, such as sediment supply from upstream sources or anthropogenic influences, which could significantly impact sediment dynamics. Future research should focus on integrating hydrodynamic models with sediment transport data to better understand the interactions between tidal currents and sediment dynamics. Additionally, high-resolution time-series data and multi-method approaches, such as acoustic Doppler current profiling (ADCP), could enhance our understanding of the processes driving sediment redistribution.

CONCLUSION

The analysis of bathymetric data has revealed significant changes in the seabed of the Menai Strait, including variations in water depth and sediment deposition over time. Data collected using Single Beam Echo Sounder (SBES) equipment from 2007 to 2014 provided insights into long-term changes in water depth, highlighting areas influenced by tidal dynamics. In addition, high-resolution data obtained using Multibeam Echo Sounder (MBES) for the years 2011 and 2012 demonstrated detailed spatial variations in sediment deposition and seabed morphology, showcasing MBES's superiority in capturing high-resolution bathymetric features compared to SBES. Geospatial analysis conducted using ArcGIS software confirmed that MBES, combined with tidal gauge measurements, is a highly accurate method for monitoring dynamic seabed changes over time. This approach outperforms traditional methods, such as Global Positioning System (GPS) and SBES, in terms of coverage and resolution. While SBES and GPS are effective for measuring tidal height and water depth, real-time kinematic GPS (RTK-GPS) enhances the horizontal positional accuracy, making it a valuable tool for complementary measurements. The study underscores the critical role of MBES and tidal gauges in capturing sediment deposition processes and changes in seabed morphology, providing a robust framework for understanding the dynamics of tidal environments. These findings highlight the importance of integrating advanced bathymetric techniques for accurate monitoring and management of coastal and marine systems.

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Author contributions: A: Writing – original draft, supervision, software, methodology, investigation, conceptualization B: Writing – review & editing, resources, methodology, investigation. C: Writing – review & editing, software, methodology, investigation.

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REFERENCES

Ali, A., (1992). Sedimentological, geophysical and oceanographic studies of postglacial and contemporary sedimentary processes of the NE Menai Strait and Conwy Bay (Wales, UK). Bangor University (United Kingdom).

Allen, G. P., & Posamentier, H. W. (1993). Tidal influences on sedimentary sequences in foreland basins: Evidence from the Albian Lower Potomac Group, Virginia and Maryland, U.S.A. AAPG Bulletin, 77(3), 545-566.

Bannari, A. & Kadhem, G., (2017). MBES-CARIS data validation for bathymetric mapping of shallow water in the Kingdom of Bahrain on the Arabian Gulf. Remote Sensing, 9(4), p.385.

Brown, C. J., & Blondel, P. (2009). Developments in the application of multibeam sonar backscatter for seafloor habitat mapping. Applied Acoustics, 70(10), 1242-1247.

Clarke, J.H., (1999). Provisional swath sonar survey specifications. University of New Brunswick, Fredericton, NB, Canada, TH Technical Report, 2.

Dyer, K. R. (1997). Estuaries: A physical introduction (2nd ed.). Chichester: Wiley.

Embleton, C., (1964). The deglaciation of Arfon and southern Anglesey, and the origin of the Menai Straits. Proceedings of the Geologists' Association, 75(4), pp.407-429.

Hellequin, L., Boucher, J.M. & Lurton, X., (2003). Processing of high-frequency multibeam echo sounder data for seafloor characterization. IEEE Journal of Oceanic Engineering, 28(1), pp.78-89.

Hoare, R. & Peattie, M.E., (1979). The sublittoral ecology of the Menai Strait: I. Temporal and spatial variation in the fauna and flora along a transect. Estuarine and Coastal Marine Science, 9(6), pp.663-675.

Hughes, P.D., Glasser, N.F. & Fink, D., (2022). 10Be and 26Al exposure history of the highest mountains in Wales: Evidence from Yr Wyddfa (Snowdon) and Y Glyderau for a nunatak landscape at the global Last Glacial Maximum. Quaternary Science Reviews, 286, p.107523.

Kenyon, N. H., Stride, A. H., & Johnson, M. A. (1981). Sand wave studies: Their relevance to sediment transport and offshore industries. Marine Geology, 42(1-4), 1-2.

Kloser, R. J., & Penrose, J. D. (2000). *Optimal seabed habitat mapping using multibeam acoustics with associated physical and visual sampling devices–at sea trials.* Paper presented at the Australian Acoustical Society Conference Proceedings.

Kratzer, S., Buchan, S. & Bowers, D.G., (2003). Testing long-term trends in turbidity in the Menai Strait, North Wales. Estuarine, Coastal and Shelf Science, 56(2), pp.221-226.

Krivtsov, V., Gascoigne, J. & Skov, M.W., (2011). Dynamics of suspended particulate matter in the Menai Strait (UK) and its implications for ecosystem functioning and management. In The Marine Environment: Ecology, Management and Conservation, pp.179-197.

McCave, I. N. (1971). Sand waves in the North Sea off the coast of Holland. Marine Geology, 10(3), 199-225.

Mitchell, N. C. (2005). Interpreting long-term seabed change through regional surveys: The UK example. Geological Society, London, Special Publications, 244(1), 81-91.

Paphitis, D. (2001). Sediment movement under unidirectional flows: An assessment of threshold shear stresses for initiation of motion. Marine Geology, 177(1), 17-30.

Parsons, A., Barton, K., Brown, C., Berry, A., Curtis, J., Emblow, C., Hartnett, M., Nash, S. & Rooney, S., (2004). Feasibility study on the establishment of a large scale inshore resource mapping project.

Pratomo, D.G. & Saputro, I., (2021). Comparative analysis of singlebeam and multibeam echo-sounder bathymetric data. In IOP Conference Series: Materials Science and Engineering (Vol. 1052, No. 1, p.012015). IOP Publishing.

Raihan, A.T., (2015). An overview of the bathymetric and undersea features of Sunda Trench using multibeam survey datasets from German RV Sonne. Doctoral dissertation, University of Chittagong.

Trzcinska, K., Tegowski, J., Pocwiardowski, P., Janowski, L., Zdroik, J., Kruss, A., Rucinska, M., Lubniewski, Z. & Schneider von Deimling, J., (2021). Measurement of seafloor acoustic backscatter angular dependence at 150 kHz using a multibeam echosounder. Remote Sensing, 13(23), p.4771.

Van der Wal, D., & Pye, K. (2004). Patterns, rates, and possible causes of saltmarsh erosion in the Greater Thames area (UK). Geomorphology, 61(3-4), 373-391.

Van Rijn, L. C. (1993). Principles of sediment transport in rivers, estuaries, and coastal seas. Aqua Publications.

Woodroffe, C. D. (2002). Coasts: Form, process, and evolution. Cambridge University Press.