INTRODUCTION

Monitoring concepts for an evaluation of marine environmental states in the German Bight

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Preamble

Coastal and shallow shelf seas are high-energy environments and feature intense interactions of physical, biological and biogeochemical processes. In a large bandwidth of spatial and temporal scales, marine processes interact with meteorological, terrestrial and open sea drivers and form highly dynamic conditions for marine ecosystems (e.g. Kösters and Winter 2014). Detailed information on the state of marine environmental systems is required to satisfy societal and science-driven interest in fundamental system understanding, the need for knowledge on contemporary system stability, and the prediction of future developments of the coastal realm. Besides an intrinsic motivation of science and society, also political requirements call for an investigation of environmental conditions and process interactions in the marine environment. The European Marine Strategy Framework Directive (MSFD) demands regular reporting on the environmental state and the achievement of a Good Environmental Status (GES) of the EU's marine waters by 2020. In 2010 the European Commission issued criteria and methodological standards for reports on the environmental state. Eleven descriptors were constituted and associated criteria and indicators were defined to interpret the GES (EU 2010), leading to a number of research initiatives in this context. Following the need for enhanced scientific knowledge on the marine environment in order to discuss and further develop criteria and indicators of

environmental states, and to provide an evaluation of suitable observation techniques, the German research project WIMO (Scientific monitoring concepts for the German Bight) was carried out from 2010 to 2015 (Winter et al. 2014, 2016). The collaborative project involving twelve German research institutions and authorities investigated the applicability of MSFD descriptors, developed observation techniques and contributed to an enhanced understanding of habitats and ecosystems. The focus was set on issues of biodiversity (descriptor 1), eutrophication (descriptor 5) and seafloor integrity (descriptor 6) in the highly dynamic environment of the German Wadden Sea, southern North Sea.

The state and development of marine systems can only be assessed based on observation data and well-suited approaches for spatiotemporal inter- and extrapolation of those data. Observations include all direct and local investigations from short-term scientific field campaigns, as typically carried out within the framework of research projects, to long-term monitoring, which typically is realized by responsible authorities and agencies. Methods for spatiotemporal inter- and extrapolation of observations and scenario analyses encompass modelling approaches of different complexity: from conceptual system descriptors to empirical formulations to complex numerical modelling systems. Data analysis and numerical modelling ideally are combined in an iterative and adaptive approach: besides the use of models for the inter- and extrapolation of data and scenario experiments, also field campaigns and monitoring locations can be optimized by dedicated model experiments. Models in turn are evaluated and enhanced based on relevant field data.

This special issue on outcomes of the WIMO project comprises ten articles that mainly focus on different aspects of the MSFD descriptors 5 (eutrophication) and 6 (seafloor integrity). Hydrodynamics, sedimentological and biogeochemical characteristics of the seafloor determine the state of benthic

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ecosystems but are difficult to observe because of spatial scales, accessibility and visibility.

Contributions

Observations of the seabed in shallow waters can be carried out by visual inspection (divers or cameras), direct sampling (ship-based grab or core samples) or remote sensing (ship-based or airborne). Whereas optical methods are suitable for the (temporarily) dry intertidal zones—like the mudflats of the Wadden Sea—they are of limited applicability in the turbid waters of the sublittoral zone. Here mainly hydro-acoustic methods are used for the mapping of seafloor habitats. Numerical models can serve to interpolate between known stages, and to extrapolate findings in scenario analyses.

Inter-comparison of methods

In the recent past, research institutions and relevant authorities have developed and applied various remote sensing methodology which can be applied for the characterization of seabed characteristics in the eulittoral zones. Inter-comparative studies on multi-method approaches, however, are rare. In this context, habitat mapping by different remote sensing methods was performed for a selected area in the Wadden Sea. Adolph et al. (2016a) analysed data from airborne lidar, satellite-based radar (TerraSAR-X) and satellite-based electro-optical sensors (RapidEye) which imaged a backbarrier tidal flat. Results show how the performance of the different sensors relates to different surface characteristics and how they can be applied to characterize distinct sedimentological and morphological features. To derive information on seafloor properties in sublittoral zones in which satellite and airborne remote sensing is not applicable, direct sampling of bed sediments and benthic fauna and flora at distinct positions must be extended by interpolation.

To determine the spatial distribution of sediment properties and benthic macrofauna communities, ship-borne hydro-acoustic methods can be applied. Holler et al. (2016) inter-compared four devices and acoustic seafloor classification software near the island of Helgoland in the German Bight. Areas of different acoustic backscatter intensity were identified by automatic seafloor classification methods. Partly these classifications were shown to be independent of sediment texture. Instead, benthic organisms influence the acoustic signals. For example, a correlation between the abundance of benthic organisms and backscatter intensity in a part of the domain suggests that the feeding arms of brittle stars increased the sediment surface roughness.

Assessment of temporal variability

Marine systems are continuously changing environments and any observation of seafloor properties may just reflect a transient state. The identification of the natural temporal variability and possible trends or abrupt changes is necessary. This can be achieved by frequent repeated measurements or dedicated modelling of system drivers and states. Blossier et al. (2016) reveal the spatial and temporal variability of the shoreline for a beach on the island of Sylt, German Wadden Sea, based on quasi-continuous video camera monitoring data from 2011 to 2014 and a semi-empirical model. The measured variability was related to the frequency of common geodetic beach surveys, which may only reveal a small portion of the beach variability. Video cameras were identified as a favourable technique providing the high spatiotemporal resolution required to monitor subkilometre-scale morphodynamic processes also involving beach nourishments.

For beaches and intertidal areas, also satellite remote sensing by synthetic aperture radar (SAR) holds a high potential for habitat dynamics analyses. Adolph et al. (2016b) show how bedform structures on tidal flats can be detected. Further investigations of these structures reveal the local distribution of benthic macrofauna communities. Bedform formation and sedimentology has implications for benthic faunal diversity in back-barrier settings of the Wadden Sea.

For the subaqueous shelf environment, the temporal variability of habitats can be shown by repeated ship-based hydro-acoustic surveying. At a monitoring site west of the island of Helgoland, Hass et al. (2016) measured several times with a hydro-acoustic ground discrimination system. The complex seafloor characteristics varied from out-cropping bedrock to sandy and muddy sectors with mostly gradual transitions. Direct seafloor samples and video data were used for ground-truthing of the hydro-acoustic signals.

The role of models

Numerical models are common tools in environmental research and monitoring. In the framework of the WIMO project on scientific monitoring concepts, exemplary modelling approaches were developed and applied for the interpolation and interpretation of field data, scenario analyses, the evaluation of monitoring stations, and enhanced system understanding (Winter et al. 2016).

As synoptic and continuous field measurements of seafloor habitats are not feasible for large domains, the spatiotemporal interpolation of sedimentological and morphological data can be achieved by numerical modelling approaches. Herrling and Winter (2016) applied a process-based numerical model with multiple sediment fractions to interpolate morphological and sedimentological states. Morphodynamic simulations driven

by real-time boundary conditions of tides, wind and waves were carried out for a representative period of 2 years. The spatiotemporal variability of the nearshore sedimentology and morphology is shown by dedicated descriptors. The effect of storm events and timescales of the sedimentological adaptation after storms to typical fair-weather conditions are shown at the highly dynamic ebb-tidal delta. The method may serve to identify areas of high sedimentological and morphological activity to evaluate habitat characteristics in the framework of coastal monitoring strategies.

Applications of morphodynamic numerical models which fully couple process modules for the simulation of waves, flows, sediment transport and bed evolution may be limited to some years of model time, depending on the size of the model domain, grid resolution and available computational power. Longer-term studies, however, may be necessary in order to evaluate system variations at larger timescales. Callies et al. (2016) studied the variability of residual currents in the German Bight, based on multi-decadal model simulations. Principal component analyses (PCA) were performed to find representative states. A concise description of residual current variability can be represented in terms of only 2–3 degrees of freedom, partly linked to wind directions. Using a Lagrangian tracer modelling system, the origin and fate of water masses and pollutants in the complex flows of coastal and shelf seas can be reconstructed. Schwichtenberg et al. (2016a) used this modelling approach in ensemble simulations of a probabilistic assessment of oil spills. The effects of chemical dispersants on oil spill drift paths in the German Bight were evaluated and shown in probability maps. A similar modelling approach was used to understand regional differences in Wadden Sea eutrophication. Schwichtenberg et al. (2016b) calculated and interpreted the residence time of water masses in different tidal basins of the Dutch, German and Danish Wadden Sea, and explained observed regional variations in eutrophication levels.

Models also help to understand fundamental process interactions. A coupled hydrodynamic and biogeochemical model was used by Hofmeister et al. (2016) to simulate the dynamics of nutrient gradients and to derive budgets of organic matter flux for a schematic coastal transect. Simulations show how the accumulation of organic matter near the coast is very sensitive to variations in the sinking velocity of suspended matter and precipitation.

Concluding remarks

Scientific interest in system understanding, precautionary principles and legislative requirements call for a frequent evaluation of the marine environmental state. The project WIMO (Winter et al. 2014, 2016) has focused on the evaluation of descriptors and the development and inter-comparison of

methods for the observation and modelling of habitats. This special issue features articles on observations by satellite and airborne sensors for the intertidal areas of the Wadden Sea and hydro-acoustic methodology for habitat mapping in subtidal areas. Numerical models of different complexity extend observations by inter- and extrapolation and scenario analyses. All methods were evaluated in terms of their applicability in long-term monitoring programs.

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Compliance with ethical standards

Conflict of interest The author declares that there is no conflict of interest with third parties.

References

- Adolph W, Jung R, Schmidt A, Ehlers M, Heipke C, Bartholomä A, Farke H (2016a) Integration of TerraSAR-X, RapidEye and airborne lidar for remote sensing of intertidal bedforms on the upper flats of Norderney (German Wadden Sea). *Geo-Mar Lett*. doi:[10.1007/s00367-016-0485-z](https://doi.org/10.1007/s00367-016-0485-z)
- Adolph W, Schückel U, Son CS, Jung R, Bartholomä A, Ehlers M, Kröncke I, Lehner S, Farke H (2016b) Monitoring spatiotemporal trends in intertidal bedforms of the German Wadden Sea in 2009–2015 with TerraSAR-X, including links with sediments and benthic macrofauna. *Geo-Mar Lett*. doi:[10.1007/s00367-016-0478-y](https://doi.org/10.1007/s00367-016-0478-y)
- Blossier B, Bryan KR, Daly CJ, Winter C (2016) Spatial and temporal scales of shoreline morphodynamics derived from video camera observations for the island of Sylt, German Wadden Sea. *Geo-Mar Lett*. doi:[10.1007/s00367-016-0461-7](https://doi.org/10.1007/s00367-016-0461-7)
- Callies U, Gaslikova L, Kapitza H, Scharfe M (2016) German bight residual current variability on a daily basis: principal components of multi-decadal barotropic simulations. *Geo-Mar Lett*. doi:[10.1007/s00367-016-0466-2](https://doi.org/10.1007/s00367-016-0466-2)
- EU (2010) Commission Decision of 1 September 2010 on criteria and methodological standards on good environmental status of marine waters (notified under document C(2010) 5956). *Off J Eur Union* 53:14, **L232**
- Hass HC, Mielck F, Fiorentino D, Papenmeier S, Holler P, Bartholomä A (2016) Seafloor monitoring west of Helgoland (German Bight, North Sea) using the acoustic ground discrimination system RoxAnn. *Geo-Mar Lett*. doi:[10.1007/s00367-016-0483-1](https://doi.org/10.1007/s00367-016-0483-1)
- Herrling G, Winter C (2016) Spatiotemporal variability of sedimentology and morphology in the East Frisian barrier island system. *Geo-Mar Lett*. doi:[10.1007/s00367-016-0462-6](https://doi.org/10.1007/s00367-016-0462-6)
- Hofmeister R, Flöser G, Schartau M (2016) Estuary-type circulation as a factor sustaining horizontal nutrient gradients in freshwater-influenced coastal systems. *Geo-Mar Lett*. doi:[10.1007/s00367-016-0469-z](https://doi.org/10.1007/s00367-016-0469-z)
- Holler P, Markert E, Bartholomä A, Capperucci R, Hass HC, Kröncke I, Mielck F, Reimers HC (2016) Tools to evaluate seafloor integrity:

- comparison of multi-device acoustic seafloor classifications for benthic macrofauna-driven patterns in the German Bight, southern North Sea. *Geo-Mar Lett*. doi:[10.1007/s00367-016-0488-9](https://doi.org/10.1007/s00367-016-0488-9)
- Kösters F, Winter C (2014) Exploring German bight coastal morphodynamics based on modelled bed shear stress. *Geo-Mar Lett* 34:21–36. doi:[10.1007/s00367-013-0346-y](https://doi.org/10.1007/s00367-013-0346-y)
- Schwichtenberg F, Callies U, Groll N, Maßmann S (2016a) Effects of chemical dispersants on oil spill drift paths in the German Bight—probabilistic assessment based on numerical ensemble simulations. *Geo-Mar Lett*. doi:[10.1007/s00367-016-0454-6](https://doi.org/10.1007/s00367-016-0454-6)
- Schwichtenberg F, Callies U, van Beusekom JEE (2016b) Residence times in shallow waters help explain regional differences in Wadden Sea eutrophication. *Geo-Mar Lett*. doi:[10.1007/s00367-016-0482-2](https://doi.org/10.1007/s00367-016-0482-2)
- Winter C, Herrling G, Bartholomä A, Capperucci R, Callies U, Heipke C, Schmidt A, Hillebrand H, Reimers C, Bremer P, Weiler R (2014) Scientific concepts for monitoring the ecological state of German coastal seas (in German). *Wasser Abfallwirtsch* 07–08:21–26. doi:[10.1365/s35152-014-0685-7](https://doi.org/10.1365/s35152-014-0685-7)
- Winter C, Backer V, Adolph W, Bartholomä A, Becker M, Behr D, Callies U, Capperucci R, Ehlers M, Farke H, Geimecke C, Grayek S, Hass C, Heipke C, Herrling G, Hillebrand H, Hodapp D, Holler P, Jung R, Krasemann H, Kröncke I, Kwohl E, März J, Meyerdierks D, Mielck F, Millat G, Reimers HC, Reuter R, Schmidt A, Staneva J, Stanev E, van Beusekom J, Wirtz K (2016) *Wiss Monit Dtsch Bucht*. doi:[10.2314/GBV:86382577X](https://doi.org/10.2314/GBV:86382577X), **in German**