Abstract book

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BALTIC SEA SCIENCE CONGRESS

– understanding transitions in the Baltic Sea

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Oral presentations

Keynotes

Katherine Richardson

Professor at University of Copenhagen

Climate Change: The elephant in the room when it comes to human pressures influencing ocean life

Fishing and eutrophication usually steal center stage when we consider anthropogenic influences on the ocean biosphere. In fact, the most profound anthropogenic changes in the ocean are caused by the release of waste greenhouse gases into the atmosphere. Enormous ocean habitat changes are caused through the acidification of surface waters as a consequence of the changing CO2 in the atmosphere. In addition, well over 90% of the excess heat energy stored near the Earth's surface associated with recently recorded global warming is stored in the ocean. Many studies on the effect of climate change on the ocean biosphere have focused on the effects of temperature change on individual organisms. In fact, what is likely far more interesting is how temperature changes along with associated changes in oceanographic features, such as currents and water column stratification characteristics, influence the structure and function of marine ecosystems. These changes not only directly impact economically important ecosystem services such as fishing but can also have knock-on effects that impact provisioning services such as the global carbon cycle, thus creating positive feedbacks in the global climate system. This talk focuses on the potential consequences of climate change induced changes in ocean ecosystem function on the ecosystem services we have come to take for granted.

Ann Swanson

Executive Director of the Chesapeake Bay Commission

Lessons Learned in Chesapeake Bay Using the Past to Inform the Future

Critical and creative leadership is needed now more than ever. As political landscapes remain tumultuous, human populations continue to demand more of our natural resources every year. Nowhere is this more apparent than in the Chesapeake Bay watershed, the largest and most productive estuary in the United States and home to six percent of the country's population. What can be learned from success achieved in the Chesapeake Bay region as we close the gap in achieving our water quality and fisheries management goals. How can we navigate the best response to impending changes and resource demands triggered by climate change, coastal inundation, population growth, intensification of agriculture, invasive species and so much more? Are these expected changes irreversible and how do we apply the best lessons learned to address anticipated future regime shifts? This talk reflects on five decades of science and policymaking to work in collaboration, as the Chesapeake Bay joins the Baltic Sea and all Coastal Sea restoration programs around the world to address the environmental challenges of the future.

Matthew Bracken
Professor at University of California, Irvine

Functional consequences of realistic biodiversity changes in marine ecosystems

Growing evidence highlights the importance of biodiversity in mediating how communities and ecosystems function. However, the applicability of biodiversity research to real-world biodiversity changes has been hampered by a lack of realism in experiments to date. This is a particular concern, as current global-scale, non-random, and largely human-caused declines in biodiversity are a primary motivation behind research into the functional consequences of biodiversity change. In my presentation, I will present several case studies from coastal marine systems highlighting how incorporating realism into experiments can enhance our understanding of how biodiversity affects communities and ecosystems. These will include (1) an analysis highlighting how the effects of species loss on intertidal primary productivity change along a 500-km latitudinal gradient; (2) an experiment demonstrating the cornerstone role that rare basal species can play in disproportionately mediating the structure of the community they support; and (3) experiments illustrating the unexpected consequences of the loss of consumers for the functioning of marine ecosystems.

Carlos M. Duarte
Professor at the King Abdullah University of Science and Technology (KAUST), in Saudi Arabia, and Professor at the Arctic Research Center, Aarhus University, Denmark.

At the crossroads with no time to lose: Seeking positive synergies in the intersection between UN SDGs 14 (Life Below Water) and SDG (Climate Action)

Deterioration of marine ecosystems under multiple pressures, including local pressures, such as eutrophication, and global pressures, such as climate change, as epitomized by the Baltic Sea, requires major efforts to meet global and regional biodiversity goals, such as vision for a healthy ocean embedded in SDG 14, Life Below Water. Likewise, the window of opportunity to meet climate goals, as delineated by the Paris Agreement is narrow and is rapidly closing, requiring prompt and effective action, as demanded under SDG 13, Climate Action. Clearly, SDG14 cannot be reached without meeting the objectives of SDG13. However, progress toward rebuilding marine life and achieving SDG14 is emerging as a powerful component toward achieving climate goals. This includes a growing focus on Nature Based Solutions, which include a diversifying slate of options involving the conservation and restoration of marine ecosystems. The Baltic Sea has often pioneered the actions to reverse the deterioration of marine ecosystem and also has a pioneering role to play in the deployment of Blue Nature Based Solutions to advance toward achievement of marine biodiversity and climate goals.

Markus Meier
Professor at the University of Rostock and Head of Department at Leibniz Institute for Baltic Sea Research Warnemünde, Germany

Current knowledge about past and future climate changes in the Baltic Sea region

The Baltic Earth program, an independent network of scientists, is focusing on Earth system science within the Baltic Sea region, organizing regular conferences, workshops and summer schools. One of the ongoing activities of Baltic Earth is the implementation of assessment reports of the current state of the science in different research fields in the Baltic Earth context. Currently, a series of review papers, called BEAR (Baltic Earth Assessment Reports), is underway, summarizing the state of knowledge in various research fields identified by the Baltic Earth science plan. This work also discusses uncertainties and knowledge gaps. The reviews focus, inter alia, on climate change and impacts in the Baltic Sea region. Two of such assessments have been performed before, in 2008 and 2015. In this presentation, I will summarize first results of this latest, third assessment of our current knowledge about past and future climate changes in the Baltic Sea region and its consequences for the marine and terrestrial ecosystems.

Bo Barker Jørgensen
Professor at Aarhus University

The methane cycle of the Baltic seabed – an old theme with new surprises

Methane is a terminal degradation product of deeply buried organic matter. It is produced in great quantities in the subsurface seabed but is broken down again by microbial oxidation with sulfate so that very little escapes from the sediment. We combined seismo-acoustic surveys and geochemical analyses of sediment cores to quantify methane fluxes in the southern Baltic Sea and to map the distribution and regulation of methane production. Highly sensitive radiotracer experiments to determine the rates of methanogenesis and sulfate reduction showed that the degradation of organic matter is controlled by sediment age according to a power law, irrespective of the terminal process. Surprisingly, we discovered that the predominant archaea producing methane are also oxidizing the methane, partly in the same sediment. This generates a cryptic methane cycle where up to 40% of the entire methane production remains undetected by chemical analyses and diffusion-reaction modeling. The dual function of methanogenic archaea appears to be due to a syntrophy with different bacteria, whereby the direction of archaeal methane metabolism depends on whether they team up with bacteria that either donate electrons to or accept electrons from the archaea.

Andris Andrusaitis
Executive Director of BONUS EEIG

Decades of the Baltic Sea science contribution to societal needs

In this keynote I will explore the evolvement of the Baltic Sea science through the prism of its linkages to societal needs. From urge to understand the complex hydrology of the unique brackish see and limits of its biological productivity in early 20th century, to necessity to assess true levels and effects of contamination, status of biological diversity in the 70-ties and 80-ties, to holistic assessments of the state of marine ecosystem underpinning the Baltic Sea Action Plan, projections of the potential effects of climate change. This development in turn has led to ever increasing demand for cooperation and coordination – from individual scientists and small university-based groups to specialized institutes and eventually to larger cross-border collaborative programmes. Moreover, the search for solutions of today's 'grand challenges' has led us to necessity of combining the effort of natural and societal science. Now stepping into the third decade of XXI century, do we have a shared vision on the role of the Baltic Sea science and responsibilities of its man- and women(!) power, are we capable to convey the scientific message so that it is embraced by ordinary citizens and policy levels? This presentation was inspired by Dr. Kaisa Kononen – former Executive Director of BONUS, and will be rooted to a great extent in the BONUS experiences and lessons learned.

Tuesday, Theme 2, from 14:00 – 16:00

Large-scale effects of benthic fauna on carbon and nutrient dynamics

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Even though the effects of benthic fauna on biogeochemistry have been long recognized, few studies have addressed the combined effects of animal bioturbation and metabolism on ecosystem-level carbon and nutrient dynamics. We integrated a model of benthic macrofauna (BMM) into a physical-biogeochemical ecosystem model (BALTSEM) to study the long-term and large-scale effects of benthic fauna on nutrient and carbon cycling in the Baltic Sea. We include both the direct effects of faunal growth and metabolism and the indirect effects of their bioturbating activities on biogeochemical fluxes of- and transformations between organic and inorganic forms of carbon (C), nitrogen (N), phosphorus (P) and oxygen (O). Results of simulations in the Baltic Proper and Gulf of Riga indicate that benthic fauna make up a small portion of sediment organic stocks, but contribute considerably to benthic-pelagic fluxes of inorganic C, N and P through their metabolism. Further, bioturbation decreases benthic denitrification and increases P retention in sediments, the latter having far-reaching consequences throughout the ecosystem. Reduced benthic-pelagic P fluxes lead to a reduction of primary production and N fixation, lower organic matter sedimentation fluxes and thereby generally lower benthic stocks and fluxes of C, N and P. This chain of indirect effects overrides the direct effects of faunal respiration and excretion on biogeochemical cycling. Thus, benthic fauna seems to alleviate the 'vicious circle' of eutrophication by withholding part of P from biotic cycling. Due to large uncertainties related to parameterization of benthic processes, we consider this modelling exercise a step towards disentangling the complex large-scale effects of benthic fauna on biogeochemical cycling, but recognize that the magnitude and generality of effects shown here need further verification in future studies.

Blue mussels along a salinity gradient: prediction for the future in space and time

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The Baltic Sea is an ideal ecosystem to study the consequences of multiple and interacting pressures expected on future coastal areas. Climate related factors such as accelerating warming of coastal waters, declining salinity conditions are predicted to have important, but hitherto, poorly quantified consequences for organisms' physiology and trophic interactions. Projected decreases in salinity are expected to limit northern distribution of species with marine origin, however, the large-scale salinity gradient in the Baltic is confounded by a similar temperature gradient. The Gulf of Finland (GoF) captures the same salinity gradient as in the entire Baltic (ca. 3-7 permille) within a relatively short spatial scale (ca. 300 km) where temperature remains relatively constant. Hence, this sub-basin provides a unique opportunity to test salinity effects on individuals, populations and communities such as the key-species *Mytilus edulis/trossulus* (blue mussel). Mussels dominates the benthic biomass in the Baltic Sea, maintain biodiversity and promotes benthic-pelagic coupling and nutrient cycling by its filter feeding activity. Recently, decline in *Mytilus* population have been described in different areas of the Baltic Sea, including the GoF along the salinity gradient. The reasons for these declines are unknown but changes in sea surface temperature, salinity, or food quality are proposed as likely causative agents. By investigating mussels response along the spatial gradient in salinity our aim is to infer temporal effects of salinity changes on a key-species of the Baltic Sea ecosystem. We sampled blue mussels in 14 stations along the ca. 200km salinity gradient of the GoF and measure isotopic ratios of carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) along with body condition to understand the effects of salinity changes on *Mytilus* physiology, diet and trophic niche. We compare spatial data to time series data from the past two decades in both mussels and environmental drivers. We found a decrease over time in $\delta^{13}C$ and an increase in $\delta^{15}N$ along the salinity gradient and discuss these results in relation to altered salinity, temperature and physiological effects.

Benthic macrofauna mediates N-fixation in Baltic Sea sediments

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Benthic macroinvertebrates are renowned ecosystem engineers of estuarine sediment. Their metabolism as well as their ability to alter the geochemical structure of the sediment profoundly influence key processes of the N cycle, *i.e.*, organic matter ammonification, nitrification and dissimilatory nitrate reduction. In addition, macroinvertebrates can host complex microbiomes whose metabolic repertoire may add to the impact that these animals exert to the environment. However, to date, the contribution of such microbiomes on the benthic N cycling has not been fully constrained neither qualitatively nor quantitatively. Here we report stable isotope data to show that nitrogen fixation, a process assumed irrelevant in nutrients-rich sediment, occurs in close association with macroinvertebrate species that dominate in Baltic Sea estuarine sediments (*i.e.*, *Dreissena polymorpha*, *Chironomus plumosus*, *Limnecola Balthica* and *Marenzelleria sp*). 16s r-RNA and functional gene analysis support the geochemical evidences indicating the presence of an active N-fixing community hosted by the macroinvertebrates.
Given the common distribution of these species and their potential to reach high density, macroinvertebrate-associated N2 fixation may account for a so far overlooked source of bioavailable N in Baltic Sea sediments. The nature of these host-microbes symbiotic relationship and the environmental factors that regulate them remain to be addressed.

Partitioning of benthic nitrogen cycling among three macrofauna holobionts in an oligotrophic coastal area (Öre estuary, Sweden)

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The effects of single macrofauna taxa on benthic nitrogen (N) cycling have been extensively studied, whereas the effects of whole macrofaunal communities on N cycling remains poorly explored. The simultaneous analysis of whole benthic community functioning and of the metabolic activity of single macrofauna taxa it is needed to understand the species role in the community, and to identify interspecific interactions. In this study, we used a methodologically integrated approach, which included whole benthic community as well as individual holobiont incubations, to disentangle and reconstruct benthic N cycling in the Öre Estuary (northern Baltic Sea). The oligotrophic estuary is characterized by a low-diverse macrofaunal community dominated by three taxa: the surface deposit feeder amphipod *Monoporeia affinis*, the surface deposit and suspension feeding clam *Limnecola balthica* and the deep burrowing deposit feeding polychaetes *Marenzelleria* spp. In this talk we will highlight hidden and interactive effects among the abiotic environment, microbes and macrofauna. The results showed that these taxa significantly contributed to the benthic metabolism via both direct (e.g. excretion) and indirect effects (e.g. bioturbation, stimulating microbial activity). Collectively, the macrofauna community promoted recycling and reuse of N at the benthic level, limiting net losses (e.g. denitrification) and effluxes to bottom water. The detection of multiple N transformations in dominant macrofauna holobionts suggested a community-associated versatile microbiome, which actively contributes to the biogeochemical processes. Overall, in this simplified benthic community, the marked decrease of a single functional group may eventually alter biogeochemical functions or services in surface sediments.

Variations in species-genetic diversity correlations in benthic macroinvertebrate communities in the Baltic Sea

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Biodiversity is traditionally accessed by species richness, but diversity can be measured on several levels in the same system, for example by determining the genetic diversity within the populations. Changes in the diversity of marine communities are affected, to various degrees, by extrinsic factors such as environment, area, connectivity, heterogeneity, and anthropogenic disturbances. However, communities are also affected by intrinsic factors such as population size, or the biology and interactions between the species in the community. Both intrinsic and extrinsic forces give rise to changes in species composition, but also cause changes in genetic diversity. The species- and genetic diversity in an ecosystem might therefore be correlated if driven by the same factors or linked interactions (Vellend and Geber, 2005, Vellend, 2005), resulting in a species-genetic diversity correlation (SGDC). By investigating the correlations between genetic diversity within populations and the community diversity, we might better understand the underlying essential evolutionary and ecological mechanisms affecting the biodiversity in a system.

Using a traditional species diversity approach together with ultra-conserved elements (UCEs) and high throughput sequencing, we evaluate the α-SGDCs of six focal marine benthic invertebrate species of different taxonomic, life history and ecological backgrounds in the Baltic Sea. The survey was carried out on both a large spatial scale in the Baltic Sea and adjacent North Sea along a salinity gradient, as well as on a seasonal temporal scale in a subset of the communities. By examining the SGDCs on both a spatial and temporal scale, together with several environmental factors, we attempt to evaluate which factors drive the SGDCs.

No general α-SGDC was shared for all focal species, on either spatial or temporal scale; in contrast, both negative and positive α-SGDCs were found for the individual focal species. No common pattern was shared even among species within the same taxonomic groups, and when comparing species with the same type of SGDC, we found that these similar relationships were determined by different driving factors. We expect that the local population dynamics of the individual species, together with invasion history and adaptation to the distinctive environment of the Baltic Sea, have had a major influence on the observed SGDCs. Our results highlight the distinctive ecological and evolutionary history of these macrofauna communities. Moreover, they provide unique insight into the large differences in patterns of genetic diversity in species adapted to the Baltic Sea environment, which is particularly important to consider when assessing and including genetic biodiversity in environmental and conservation management plans.

References:

Vellend M. Species Diversity and Genetic Diversity: Parallel Processes and Correlated Patterns. *Am Nat* 2005;**166**:199–215.

Vellend M, Geber MA. Connections between species diversity and genetic diversity. *Ecol Lett* 2005;**8**:767–81.

Food sources drive temporal variation in ecological stoichiometry of benthic consumers

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Stoichiometric balance between organisms and their habitat is critical for ecosystem functioning. Benthic fauna plays an important role in mediating biogeochemical cycles in coastal areas by storing carbon (C), nitrogen (N) and phosphorus (P) in their body tissues at theoretically homeostatic rates. To maintain homeostasis, the benthic consumers need to be in balance with their resource supply or alter their stoichiometric traits in response to environmental change. By monitoring two sites over a year, we quantified the size and temporal stability of benthic faunal carbon and nutrient pools in coastal soft sediment habitats. We combined stoichiometric traits with analyses of stable isotopes to explore consumer-resource relationship. Our results show that the benthic consumers form a substantial organic carbon and nutrient pool in coastal areas. We found that the benthic fauna is not strictly homeostatic, but instead expresses temporal variation in elemental content ratios. These aquatic consumers undergo ontogenetic changes in diet and morphology, which alter their stoichiometric characteristics. In addition, the faunal C:N:P ratios showed strong seasonal variation at both species and community level in response to changes in food availability and environmental conditions. The ability to adapt to varying stoichiometric conditions is essential in face of the current imbalances in resources caused by anthropogenic activities. Therefore, it is critical to identify the stoichiometric tolerance of different species, before environmental change causes a shift in the benthic community composition that will alter functions on an ecosystem level. Understanding the contribution of benthic consumers to the carbon and nutrient cycling is especially valuable in areas such as the Baltic Sea, where anthropogenic nutrient input has significantly altered the biogeochemical cycles in the coastal zone.

Allometric and stoichiometric traits predict nutrient excretion rates by benthic consumers

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Benthic consumers can have a profound impact on nutrient regeneration in coastal marine ecosystems. In face of global warming and environmental change, biodiversity, dominance hierarchies, and size structure of benthic communities are increasingly disrupted. The consequent changes in benthic biological traits are likely to have a profound effect on N and P cycling at the ecosystem level. In this paper, we studied the excretion of benthic consumers, and explored if their nutrient recycling rates can be quantified with basic biological traits by using allometric and stoichiometric relationships. We found that N and P excretion rates are species-specific and positively related to increases in allometric traits, i.e. to individual body mass and temperature; while small individuals had higher mass-specific excretion rates than larger ones. Moreover, stoichiometric traits and stable isotope signatures ($\delta^{13}C$ and $\delta^{15}N$) explained a minor, but significant, additional proportion of variability in excretion rates between species. Excretion rates of benthic consumers showed a strong seasonal pattern, and the highest nutrient recycling was noted during summer months. Importantly, biomass was not a significant predictor of seasonal differences in excretion rates at a community level, emphasizing that changes in temperature and food availability were affecting the metabolic processes of the benthic consumers. Our results highlight the benefits of using allometric and stoichiometric traits of benthic consumers when quantifying species-specific contribution to nutrient recycling in coastal marine environments, and when predicting how their function is altered in response to environmental change.

Amphipod isotope composition, condition and reproduction in contrasting sediments: a reciprocal transfer experiment

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Eutrophication is a process that results in excessive phytoplankton blooms, which sink to the sediment and enrich the organic matter (OM). This alters the available resources of benthic organisms and may have consequences for feeding ecology and reproduction strategies of marine populations. While effects of eutrophication on biodiversity are well documented, the more subtle effects from OM content on population dynamics and diet plasticity are less studied. We performed a reciprocal transfer experiment with the benthic bioindicator amphipod *Monoporeia affinis* from two stations in the Baltic Sea with differing OM content in sediment (high and low) creating four treatments. We investigated sediment OM content effects on the dietary niche and organism body condition utilizing bulk stable $\delta^{13}C$ and $\delta^{15}N$ isotopes of two different life stages of *M. affinis*, as well as effects on their fecundity and embryo viability. There was no initial significant differences between the stations in terms of $\delta^{13}C$, $\delta^{15}N$, C:N, fecundity or viable embryos. We found that moving females from high OM to low OM significantly depleted their ^{13}C values, amphipods in low OM sediment had significantly enriched ^{15}N regardless of female origin, and that those in low OM sediment had significantly higher C:N than those in high OM sediment. Conversely, no such effects were seen for juveniles between treatments in terms of $\delta^{13}C$ or $\delta^{15}N$ but their individual biomass was larger in high OM and low transferred treatments. Our results indicate that the low range of OM content tested here altered amphipod $\delta^{13}C$ values, $\delta^{15}N$ values and C:N ratios. Our findings help to understand the effects of OM content on amphipod populations used as bioindicators for anthropogenic impacts.

Tuesday, Theme 3, from 14:00 – 16:00

Distribution, sources, and fate of microplastics in the Baltic Sea

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Microplastics (MP) in the Baltic Sea are still poorly understood. Based on a polyphasic approach, combining environmental studies, microbial analyses, modelling, beach monitoring, and ocean management, we investigated the behavior and accumulation of MP in the Baltic Sea and its river catchments. Exemplarily, we focused on the catchment area of the Warnow river, the second largest German freshwater Baltic Sea inflow. It includes a wide variety of land uses and integrates a high population density with industrial and agricultural areas. Thus, this river catchment can be considered representative for many areas of the southern Baltic Sea. In an extensive field sampling campaign, 197 sandy beach samples were taken and analyzed with regard to large micro- and mesolitter (2-25 mm) content, covering all nine boarding states of the Baltic Sea. The campaign showed that Baltic beaches are significantly polluted with plastic litter, esp. with industrial pellets and cigarette butts. The evaluation of MP emission data from the entire Baltic area revealed that waste water treatment plants and especially sanitary sewer overflow events are major sources for MP in the Baltic Sea. A modeling approach estimated that the residence time of MP in the Baltic Sea is relatively short with an average of 14 days, and that a majority of the particles accumulate at the shorelines. Thus, garbage patches, analogous to the sub-equatorial gyres of the Atlantic Ocean, cannot be expected in the Baltic Sea.A detailed look into the catchment area of the Warnow river revealed that sewage sludge is the most important agricultural MP source in the Warnow catchment. The application of sewage sludge increased the soil load from 4 to 15 MP particles/g. Although MP concentrations in the river were highly variable, it was clear that urban emissions dominate the Warnow estuary; 49.4 % of MP inputs originate from the Warnow river and 43.1 % from stormwater runoff, followed by combined sewer overflows (6.1%). The estimated annual input of MP from the Warnow into the Baltic Sea was 152-291 billion particles (mainly 10-100 µm in size).Analyses of MP-related biofilms revealed that the microbial colonization is driven by environmental factors rather than the polymers themselves. The results indicate that MP are not degraded/assimilated by microorganisms in the Warnow or Baltic Sea, but simply continue to fragment. Overall, a reduction of MP in the Baltic Sea will be most effectively achieved by a mitigation of the emissions, e.g. technical solutions for stormwater runoffs and environmental education to avoid beach littering.

Distribution of meso - and large microplastic on sandy Baltic beaches

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Harmonized beach litter monitoring methods are important to allow comparability of results. But most methods used across Europe focus on macro-litter (>25 mm) on rural beaches only and urban pollution hot-spots are currently not taken into account. This leads to an incomplete pollution pattern and an underestimation of the present pollution.

To overcome these weaknesses different methods to examine meso-litter (5–25 mm) and large micro-litter (2–5 mm) were developed and tested at rural and urban Baltic Sea beaches. A tested sand rake method, investigating the whole backshore of the beach, turned out to be useful and reliable.

In more than 200 sand rake surveys, a total of 9,345 litter pieces were found, on 10,271 m², of which 69.9% were 2–25 mm in size. Plastic (4,921 pieces) was the dominant material (mean 52.7% ± 13.3) and the abundance of litter was 0.91 pieces/m² ± 1.50 (median 0.40 pieces/m²). Beaches show a high pollution level with large micro- and meso-litter and in terms of plastics, colorless pieces (barely visible for the naked eye) predominated. Even if beaches are regularly cleaned, most litter (<25 mm) remains in the sediment, which leads to a litter accumulation and further fragmentation over time.

In contrast to naked eye methods for macro-litter, the sand rake method is generally applicable on all sandy beaches, both urban and remote. The sand rake method is a cost-effective approach that allows for the involvement of volunteers, meets policy demands, and fits within monitoring requirements of the Marine Strategy Framework Directive. Our large micro- and meso-litter data can be used for a) calculating a pollution baseline; b) defining the Good Environmental Status, c) assessing the effectiveness of marine litter mitigation measures, and d) the provision of a full spatial pollution pattern.

Impact of the ship-borne pollution to the Baltic Sea

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The Baltic Sea is a severely eutrophicated sea-area where intense shipping is an additional pollution source and a potential contributor to changes in the ecosystem. Major sources of pollution from shipping to marine environments are the ship emission to the air and following deposition, leaching of antifouling paint residues and discharges of bilge, black, grey and ballast water and scrubber discharge water. The dispersion of copper, zinc, naphthalene, pyrene, and dibromochloromethane and the impact of the two most important shipborne nutrients, nitrogen and phosphorus, on the overall nutrient-phytoplankton-oxygen dynamics in the Baltic Sea in 2012 was determined by using the coupled physical and biogeochemical model system General Estuarine Transport Model–Ecological Regional Ocean Model (GETM-ERGOM) the Eulerian tracer transport model in a cascade with the Ship Traffic Emission Assessment Model (STEAM) and the Community Multiscale Air Quality (CMAQ) model.

Annual loads of the contaminants ranged from kilograms for pyrene to 100s of tons for copper. The dispersion of the contaminants is determined by the surface kinetic energy and vertical stratification at the location of the discharge. The elevated concentration of the contaminants at the surface persists for about two-days and the contaminants are dispersed over the spatial scale of 10-60 km. The shipping contribution is about 0.3% of the total phosphorus and 1.25–3.3% of the total nitrogen input to the Baltic Sea, but their impact to the different biogeochemical variables is up to 10%. Continuous input of ship-borne nitrogen is compensated by steady decrease of nitrogen fixation and increase of denitrification. Ship-borne phosphorus input results in a decrease of phosphate content in the water and increase of phosphorus binding to sediments. Oxygen content in the water decreases, but reaches a stationary state eventually.

^{137}Caesium contents in the northern Baltic Sea sediments

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Marine and coastal areas throughout the world are stressed by increasingly intensive human activities. Anthropogenic radionuclides are one of those substances, which can be seen widely in the marine ecosystems. Fallout from the April 1986 Chernobyl nuclear power plant accident has rendered the Baltic Sea as the most polluted marine body in the world with respect to ^{137}Caesium (^{137}Cs).

We have investigated sediment cores from 56 sites around the Gulf of Bothnia, the northern Baltic Sea. Radioactivity from ^{137}Cs in sediments has generally declined due to the radioactive decay of ^{137}Cs over the last decades. However, ^{137}Cs contents in subsurface sediments remain at high levels compared to pre-Chernobyl levels.

The highest ^{137}Cs activity contents in subsurface sediments occur in coastal areas, many of which are currently experiencing anthropogenic pressures.

Data on harmful substances in seabed sediments are useful for coastal management and marine spatial planning efforts while assessing risks associated with construction in marine areas. Seabed constructions like dredging in areas where sediments contain the high concentrations of radioactive or other harmful substances can cause re-mobilization and transport of these contaminants. Climate change is also likely to shift many of the parameters that affect sediment distribution and pollution in the Gulf of Bothnia.

This study is part of the SmartSea project funded by the Strategic Research Council of the Academy of Finland, the SEAmBOTH project funded by Interreg Nord, and the EMODnet Geology project funded by The European Climate, Environment and Infrastructure Executive Agency (CINEA). The study utilized research infrastructure facilities provided by FINMARI (Finnish Marine Research Infrastructure network).

Reproductive disorders in *Monoporeia affinis* as a biological contaminant effect indicator in the Baltic Sea

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The embryonic development of sediment-dwelling amphipod *Monoporeia affinis* is sensitive to contaminant exposure. Therefore, the frequency of embryo malformation in gravid females and the proportion of females carrying malformed embryos are currently used to detect the biological effects of chemical exposure in the Baltic Sea sediments. Together, these parameters are used as an indicator for environmental status assessment within the Marine Strategy Framework Directive. However, the applicability of the indicator has only been shown for the limited number of subbasins.

Here, a comparative study was conducted using the data from the Gulfs of Finland and Riga and the published assessment from the Bothnian Sea and the Western Gotland Basin to evaluate the indicator applicability in the Gulfs. The overall frequency of the aberrant embryos in the Gulf of Riga (4%) was low compared to the Gulf of Finland (11%), Bothnian Sea (10%), and Western Gotland Basin (8%). Moreover, a significantly high malformation frequency was observed in several areas with high anthropogenic impacts. The malformations were primarily associated with heavy metals and some PAHs as suggested by multivariate analysis. However, there were no significant univariate correlations between the malformation types and single pollutants, indicating mixture effects. Also, a significant geographic component was present: in the Gulf of Finland, stations located in the Neva Estuary were similar but significantly different from other stations in the Gulf.

Using the established threshold values of 0.06 and 0.30 for the embryo malformation frequency and the proportion of females carrying malformed embryos, respectively, we conducted a preliminary assessment of the Gulfs of Finland and Riga. In the Gulf of Finland, these values were were 0.11 and 0.49, respectively, with only 14% of the stations complying with the good environmental status (GES). In the Gulf of Riga, the GES was achieved for 63% of the stations, with the subbasin values being 0.04 and 0.19. These values are comparable to those reported by the first assessment (2011-2016), for the Bothnian Sea: 0.04 and 0.26, and the Western Gotland Basin: 0.04 and 0.24. The applicability of the indicator for the Gulfs of Finland and Riga and methodological implications for the indicator-based assessment will be discussed.

Effects of organic carbon origin on hydrophobic organic contaminant fate in the Baltic Sea

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Hydrophobic organic contaminants (HOCs) such as polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs) are ubiquitous in the Baltic Sea. They sorb to organic carbon (OC), and their environmental fate is therefore closely linked to OC fluxes and pools. In the water column, HOCs partition to mainly natural OC and undergo vertical export with sinking particles to deep-water layers and sediment. As a consequence, Baltic Sea sediment store significant amounts of HOCs, which may re-enter and contaminate the water column in the future. Here, we test the hypothesis that future changes in OC cycling can influence HOC flux from air to sediment and reduce the HOC sink in Baltic Sea sediments. The hypothesis relies on the assumption that the sorption capacity of the sediment OC is affected by the relative contribution of terrestrial versus marine OC of the area, with OC of marine origin having a higher sorption capacity. Two coastal sites in the Gulf of Finland were investigated, one closer to the open Baltic Sea, with a higher contribution of marine OC, and the other site closer to the river mouth in the estuary, with a higher contribution of terrestrial OC. Concentrations of PCBs and PAHs were analysed along high-resolution sediment porewater to bottom water interface profiles, in sediment, suspended matter collected in sediment traps, in the water column and in air. Stable carbon isotope signatures ($\delta^{13}C$) and lignin phenol concentrations measured in surface sediment supported the different OC mass balance at the two sites, with the marine site having a $\delta^{13}C$ signal of -22.68‰ and the terrestrial site -24.42‰. Total lignin phenol concentrations were almost a factor of two higher at the terrestrial site than at the marine site (6.97 and 3.66 mg/g OC, respectively). Stronger sorption of the larger PAHs (>four rings) and PCBs (penta-heptachlorinated) was observed at the site dominated by marine OC. The partition coefficients calculated between concentrations in sediment organic matter and sediment porewater (log K_{oc}) were 0.2-1.0 log units higher at the marine OC site compared with the terrestrial OC site. In accordance, reduced fluxes of the most hydrophobic PCBs from sediment to water were observed at the site characterized with marine OC. These findings support the hypothesis that increased input of terrestrial OC to the Baltic Sea as a consequence of climate change can have consequences for the availability and mobility of HOCs in the aquatic system, including the capacity of the sediments to store HOCs.

Tuesday, Theme 2, from 16:30 – 17:30

Zooplankton dominance shift in response to changing salinity – results from mesocosm experiment

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Current climate change predictions indicate declining salinity in the Baltic Sea with negative implications for plankton food webs. In this study, we investigated the response of plankton communities to different salinity change scenarios of the Baltic Sea. Projections for future salinity change derived from regional physical-biogeochemical models were used to set-up an outdoor mesocosm experiment offshore Tvärminne Zoological Station, Finland. Each mesocosm was inoculated with natural plankton using a mixture of both marine and freshwater communities, mimicking the natural influx of freshwater species from rivers into the Baltic Sea. As the water column either declined or increased in salinity, the biomass of phytoplankton increased. This had an indirect effect on higher trophic levels through altered prey availability. Zooplankton diversity and composition changed possibly due to different salinity tolerances among the species. Among zooplankton, small sized ciliates and rotifers dominated in low salinities and larger ciliates, cladocerans and copepods in high salinities. Collectively, our results indicate that freshening of the Baltic Sea will result in a restructuring of the plankton community through bottom-up effects of increased phytoplankton productivity controlling zooplankton populations through resource competition or niche complementarity. The zooplankton community will shift to a rotifer dominated community in low salinities due to the intolerance of other zooplankton groups to freshening.

Browning in the northern Baltic Sea alters the phytoplankton composition and reduces the zooplankton nutritional quality

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Increased inflow of colored terrestrial organic matter causes seawater browning in the coastal ecosystems of the northern Baltic Sea. However, the consequences of browning on the nutritional quality of food webs, especially in terms of fatty acids (FA) are unknown. We analyzed the community composition of phytoplankton and the FA composition of two common zooplankton taxa, i.e., *Eurytemora affinis* (Copepoda) and cladocerans, at three stations from north to south of the northern Baltic Sea in 2017. The middle coastal and the northern offshore stations had higher concentrations of dissolved organic carbon (DOC) and humic substances, indicating a higher level of browning. In contrast, the southern offshore station had lower DOC and humic substances. The ratio between the alga-specific omega-3 polyunsaturated FA and the terrestrially derived monounsaturated FA (MUFA) in seston was lowest in the coastal station. In both *Eurytemora affinis* and cladocerans, the ratio between the alga-specific docosahexaenoic acid (DHA) and the terrestrially derived MUFA increased from north to south. Similarly, total biomass of the DHA-rich phytoplankton taxa (i.e., chrysophytes, cryptophytes, dinoflagellates etc.) also increased from north to south. Overall, the DHA-rich phytoplankton became less dominant and the zooplankton DHA availability decreased at the browner site. Our findings imply that the colored terrestrial organic matter shapes the phytoplankton composition and PUFA availability of seston, which in turn affects the zooplankton nutritional quality in the northern Baltic sea.

Terrestrial dissolved organic matter inflow drives temporal dynamics of the bacterial community of a subarctic estuary (northern Baltic Sea)

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Climate change is projected to cause increased inflow of terrestrial dissolved organic matter to coastal areas in northerly regions. Estuarine bacterial community will thereby receive larger loads of organic matter and inorganic nutrients available for microbial metabolism. The composition of the bacterial community and its ecological functions may thus be affected. We studied the responses of bacterial community to inflow of terrestrial dissolved organic matter in a subarctic estuary in the northern Baltic Sea, using a 16S rRNA gene metabarcoding approach. Betaproteobacteria dominated during the spring river flush, constituting 60% of the bacterial community. Bacterial diversity increased as the runoff decreased during summer, when Verrucomicrobia, Betaproteobacteria, Bacteroidetes, Gammaproteobacteria and Planctomycetes dominated the community. Network analysis revealed that a larger number of associations between bacterial populations occurred during the summer than in spring. Betaproteobacteria and Bacteroidetes populations appeared to display similar correlations to environmental factors. In spring, freshly discharged organic matter favoured specialists, while in summer a mix of autochthonous and terrestrial organic matter promoted the development of generalists. Our study indicates that increased inflows of terrestrial organic matter-loaded freshwater to coastal areas would promote specialist bacteria, which in turn might enhance the transformation of terrestrial organic matter in estuarine environments. Environmental Microbiology (2021) doi:10.1111/1462-2920.15597

Novel environmental niche for mercury-methylating microorganisms

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Methylation of inorganic Hg leads to formation of much more toxic methylmercury (MeHg) that has a great ability to bioaccumulate in organisms and biomagnify in food webs. The biological processes that control Hg methylation and bioaccumulation in the aquatic food web are not well understood. Globally, hypoxia has been escalating in aquatic ecosystems since the middle of the 20th century, including the Baltic Sea. Such hypoxic waters potentially offer ecological niches suitable for Hg-methylators. Here, we tested the effects of hypoxia on Hg methylation potential in the amphipod gut microbiome that may provide suitable niches for Hg methylators in hypoxic environments. To investigate methylation potential of the amphipod gut microbiota, we used PCR-based techniques and sequencing. Baltic amphipods were tested positive for the presence and abundance of *hgcA* gene in the three main clades Deltaproteobacteria, Firmicutes and Archaea. We also conducted 16S rRNA gene analysis using high-throughput amplicon sequence analyses to identify taxa associated with Hg-methylation under hypoxic environments. Identification of new Hg methylators in animal microbiomes can help understanding sources and pathways of MeHg in food webs. To our knowledge, this is a first study addressing endogenous methylation in benthic invertebrates as a MeHg source in ecosystem. These findings will provide crucial insights on the origin and pathways of MeHg in aquatic food webs under global change scenarios.

Understanding adaptation of phytoplankton to sea surface temperature increase during the last 60 years in the Baltic Sea

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The Archipelago Sea, SW Finland, is one of the fastest warming areas globally. This poses a strong selection pressure on the local organisms. Sea surface temperatures during spring have increased by ca 2 °C since the 1960s in the N Baltic Sea, yet it is unknown how phytoplankton are able to adapt to such rapid environmental change. Here we used the Archipelago Sea as a model system for studying potential adaptation to temperature increase during the last 60 years in a chain forming marine diatom *Skeletonema marinoi*. This species often dominates the spring bloom in the Baltic Sea and is considered a key species because of its high relevance in the food web. It also forms resting stages that stay viable buried in the sediment at the sea floor for up to 120 years. In this study, we utilized annually laminated sediments formed in a seasonally anoxic coastal setting, providing a long-term high resolution archive of historical adaptation. Resting stages of *S. marinoi* were collected from several sediment cores retrieved with a gravity corer during spring 2020. The sediment cores were sliced into 2 cm subsamples and chronologically dated using a combination of varve counting and the ^{137}Cs method. The resting stages were resurrected from three different layers, corresponding approximately to the years 1960, 1986 and 2012. After resurrection, seven chains of the diatom from each sediment layer were isolated by micropipetting. The growth rate of each clonal isolate was investigated in temperatures ranging from +6 to +26 °C by daily measurements of *in vivo* chlorophyll *a*. In general, our results show that older isolates, that we hypothesized to be better adapted to lower temperatures, reached stationary phase sooner towards the lower temperature range when compared to isolates from the 2000s. The isolates from 1960 and 1986 also displayed significantly higher growth rates in the lowest tested temperature when compared to isolates from 2012. The mean growth rate was in general highest for isolates from 1986 suggesting that adaptation manifested as an increase in growth rate has not continued until 2012. The variation of growth rates in non-optimal temperature conditions was lowest within isolates from 2012, suggesting impoverished phenotypic diversity in modern diatom populations inhabiting the Archipelago Sea. Overall, we could demonstrate that historical strains display a different temperature reaction norm compared to modern strains of *S. marinoi*.

High resolution temporal dynamics of phytoplankton in the Baltic Sea

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Phytoplankton has a key role in the biogeochemical cycles. Due to their fast life cycle, fast methods are needed to understand mechanisms behind many processes, such as growth and loss within populations, which will ultimately shape seasonal and interannual changes. Among the methods available that can fast evaluate phytoplankton community composition, the pulse-shape recording flow cytometry (PFCM) has been highlighted as a promising tool to observe changes in phytoplankton at high temporal resolution. Here we aim to show the application of this technique to improve determination of carbon pathways in the Baltic Sea, by showing data collected at Utö Atmospheric and Marine Research Station (59º 46'50N, 21º 22'23E) from February to September 2021. Due to the combination of two lasers, scattering and fluorescence sensors, PFCM can identify multiple populations of phytoplankton based on the individual particle optical profiles. Besides that, this technique is also able to detect and quantify picophytoplankton, which remains an overlooked community component in the region. Hourly observations on phytoplankton community were supported by ancillary data from other sensors at the station, by discrete nutrient sampling and experimental data to survey functional diversity. Phytoplankton abundance and biomass is low and mostly dominated by small flagellates from end of January to mid March. From mid March, larger phytoplankton starts to appear, and inorganic nutrients starts to decrease shortly after. Steady phytoplankton growth is observed until ca. 20 April, when a shift is detected, and phytoplankton start to decrease until first week of May. May and June are mostly characterised by dominance of small flagellates and low inorganic nutrients concentrations. In late June, an increase in cyanobacteria is observed, peaking in the first week of July. In mid-July and increase in the abundance of particles with low fluorescence is observed, likely indicating the decaying cyanobacteria and increase in heterotrophic organisms. This is supported by phagotrophy essays conducted at the station, which show that the number of heterotrophic and mixotrophic organisms increase towards summer, indicating the shift in the main carbon pathways through the food web and the importance of microbial loop in summer. From mid July to mid August, an increase in picophytoplankton is observed followed by an abrupt decrease in phytoplankton around 18 August. This shift coincides with a shift in the CO2 concentrations, indicating that the system has become net heterotrophic. Although preliminary, this dataset shows the potential of PFCM for assessing changes in phytoplankton community and to identify the key moments for the Baltic Sea biogeochemistry when allied to other data. This data set highlights the importance of autonomous multi platforms that are able to perform observations at high frequencies in the Baltic Sea, such as Utö Atmospheric and Marine Research station.

Promise and pitfalls of compound specific isotope analyses in Baltic Sea monitoring and assessment

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Compound-specific stable isotope analyses are becoming increasingly popular in food-web studies but also have the potential to be useful in environmental monitoring and an important tool for status assessments. I will present some experience of using nitrogen isotope analyses in amino acids (δ^{15}N-AA) in a wide range of organisms including algae, invertebrates, fish and birds and applied to different research questions. Analyses of δ^{15}N-AA can reveal both ultimate sources of nitrogen in organisms (from the so-called source AAs which are unchanged in δ^{15}N during trophic transfer) and the trophic position of a consumer. Trophic position (TP) estimates using the compound specific approach in higher trophic level organisms such as fish means there is no need for an external spatially and temporally matching isotope baseline (needed when calculating TP using the traditional bulk nitrogen isotope method). Regardless of method used, contaminant concentrations in fish are required to be normalized against the trophic position according to EU Marine Strategy Framework Directive and nitrogen isotope analysis is the recommended approach. The results from the various projects suggest that the compound specific approach give different TP estimates compared to the bulk isotope method and that it is important to include ecological and environmental knowledge when interpreting isotope data and derived metrics (e.g. TP). Importantly, adjusting TP data for physiological status of consumers is important for ecologically realistic estimates.

How much heat is too much? Effects of marine heatwaves on benthic ecosystem functioning depend on the intensity of the heatwave

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Marine heatwaves are increasing in intensity and frequency due to climate change. Temperature fundamentally affects all processes on Earth from chemical to biological. We tested the effect of short-term heatwaves in the moderate (13°C) and strong (18°C) categories on the bioturbation of benthic macrofauna and the associated solute fluxes and excretion rates in cores containing the natural animal community from an aphotic, muddy site. Oxygen consumption was significantly lower under strong heatwave conditions compared to *in situ* (7.5°C) and moderate heatwave, indicating lower macro- and micro-organismal activity. Also nitrate+nitrite and silicate fluxes were the lowest under the strong heatwave. For ammonium and phosphate there was a similar, but non-significant, trend. Bioturbation was not affected by the treatment but rather by the macrofauna present in the cores. The macrobenthic N and P excretion rates were positively related to biomass per core, and the highest excretion rates were measured under strong heatwave compared to moderate heatwave and *in situ* temperature. The estimated excretion rates were higher than measured effluxes of ammonium and phosphate. Sediment organic matter content, chl *a* and phaeophytin measured at the end of the experiment revealed lowest organic matter content in the moderate heatwave treatment, and highest chl *a* and lowest phaeophytin concentration in the strong heatwave treatment. Although the increasing variance from *in situ* towards strong heatwave prevented the detection of significant differences, these results indicate an increase in the turnover of nutrients during moderate heatwaves but a decrease during strong heatwaves. A prolonged, moderate heatwave could thus potentially lead to a depletion of resources and subsequent starvation if primary production cannot meet the demands of the benthic consumption. Decreased degradation activities under strong heatwaves, on the other hand, can lead to a build-up of organic material and potentially hypoxia.

Leveraging a whole ecosystem manipulation of dissolved oxygen via engineered de-stratification to quantify the impact and cost of hypoxia on nitrogen cycling

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Eutrophication in temperate coastal ecosystems worldwide, including the Baltic, is commonly the consequence of nutrient inputs from adjacent drainage basins, with symptoms of system degradation including low dissolved oxygen. This hypoxia can impact biogeochemical cycling, with the potential of creating an ecosystem that more efficiently recycles nitrogen and phosphorus through benthic-pelagic coupling where denitrification is reduced and phosphorus sediment release is enhanced as a consequence of redox conditions. Rapid recycling of nutrients can lead to a positive feedback on water column phytoplankton, creating a eutrophic ecosystem condition that can be resistant to restoration, resulting in hysteresis and frustrating nutrient reduction efforts. It is of value in ecosystems like the Baltic, as well as the Chesapeake Bay where this study takes place, to understand the impact and cost of hypoxia on this nutrient cycling. However, quantifying these impacts can be difficult. This presentation leverages a whole ecosystem manipulation of dissolved oxygen via engineered de-stratification using largescale aerators in Rock Creek, a sub-estuary of the Patapsco in Maryland, USA. This system allows for aerator "on" conditions that are normoxic for comparison with aerator "off" conditions, where the system rapidly deteriorates to hypoxia and anoxia. This study creates an opportunity to evaluate how the trophic status of an estuary is impacted by hypoxia and anoxia, and to compute the cost of hypoxia as mediated through biogeochemical feedbacks that induce hysteresis of idealized restoration trajectories. This is presented in the form of mass balance budgets for nitrogen and phosphorus under normoxic and hypoxic conditions, combined with cost estimates for nutrient removal grounded in management and mitigation actions. We anticipate these results being of interest to both managers and those studying biogeochemical feedbacks.

Spatial analysis of water quality and income in Europe

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The purpose of this study is to empirically investigate the environmental Kuznets curve (EKC) relationship between water quality and income within the European Union, considering spatial interdependences across countries. To this end, we apply a spatial econometrics framework using panel data, at the national level, for twenty EU countries across seventeen years, 1998 to 2014. Furthermore, we account for the role of human and livestock population size, institutional quality and economic openness for water quality. Results show that a significant EKC relationship is seen with an inverted N-shaped relationship between income and water quality. Water quality is decreasing in income for low income levels, increasing in income when GDP per capita for medium income levels, and deteriorating for high income levels. Eight out of twenty countries have income levels associated with a declining water quality. Spatial spillovers between countries are significant. Higher livestock density levels are associated with lower levels of water quality, while institutional quality and openness to trade are positively associated with water quality.

Wednesday, Theme 2, from 14:00 – 16:00

Water Level Changes in Small Lakes in Sweden Using High-Coherence Pixel Interferometry

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Lakes cover nine percent of Sweden; however, the water level is only monitored in 36 lakes due to economic and logistic constraints. Space technologies can fill this gap; however, we need to overcome the limitations of space-borne methods regarding scale and resolution. We exploit Interferometric Synthetic Aperture Radar (InSAR) to monitor water level changes in small lakes. While previous InSAR studies determining water level retrieve spatially relative water level changes between two locations, the novelty of this study measures absolute water level change in 30 small lakes not covered by altimetric sensors but monitored by the Swedish Meteorological and Hydrological Institute. We take advantage of the 6-day revisit time of the Sentinel-1 satellites and generate 40 short temporal-baseline interferograms for each lake from March to December 2019. We accumulated the phase change of all the pixels inside the lakes' surface area that exhibit a steady, coherent behavior in all interferograms. We find correlation coefficients between our water-level method estimates and in-situ observations ranging from 0.31 to 0.93. Based on geomorphological and vegetation similarity among lakes, we extended the methodology to 20 ungauged lakes and selected the potential pixels that replicate water level changes. Moreover, the phase change of candidate pixels was compared with precipitation patterns in the lakes' basin area for validation purposes. This study shows that pixel-specific InSAR can monitor absolute water level change in small lakes not covered by other conventional water level gauges and satellite altimetry.

Sandy beach evolution in the low-energy microtidal Baltic Sea: attribution of changes to hydrometerological forcing

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We analyse the response of small sandy pocket beaches to various hydrometeorological drivers. The processes that generate the biggest changes on the coast of the Baltic Sea are highly variable along the coast. Processes such as extreme water levels, wave induced set-up and severe waves fields are highly localised. As large proportion of annual wave energy flux is packed into a very few days in the year, the wind direction and thereby the direction of the wave fields of the strongest storm in the year determines which coastal areas suffer the most. The focus on this study is on the evolution of two sandy beaches in Tallinn Bay that are about 3 km apart from each other and considered individual littoral cells. We quantify the response of the beaches to hydrometeorological conditions in 12 years, 2008–2020 based on high-resolution measurements using airborne and terrestrial laser scanning technology. As the coastline orientation of the two beaches is about 30° different, the beaches react differently. The fastest sediment removal from the subaerial beach occurs during time periods that contain elevated water level and strong waves. Accretion occurs during time intervals when water level is less elevated. Even though annual variations in the sand volume of subaerial beach are significant, both beaches seem to be stable. A comparison of the link of volume changes of the beaches with the monthly average intensity of hydrometeorological drivers suggests a specific mechanism that supports the beaches. Namely, sand that is removed from the higher beach and moved to the south and deposited in the shallow nearshore during elevated water levels and north-western storms is transported back to the north in very shallow water during periods of low water level and moderate south-western winds.

Seasonal impact of optically significant water constituents on radiative heat transfer in the Western Baltic Sea

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Heating rates induced by optically significant water constituents (OACs), e.g. phytoplankton and coloured dissolved organic matter (CDOM), contribute to the seasonal modulation of thermal energy fluxes across the ocean-atmosphere interface in coastal and regional shelf seas. We consider this relationship in the Western Baltic Sea, a region characterised by considerable inputs of nutrients, CDOM and freshwater, and complex bio-optical and hydrodynamic processes. Using a coupled bio-optical-ocean-atmosphere model (ROMS-BioOptic), we spectrally resolve the underwater light field in a dynamic ocean and model the inherent optical properties of different water constituents under varying environmental conditions. We estimate the relative contributions of these water constituents to the divergence of the heat flux and heating rates and find that phytoplankton dominates absorption in spring, while CDOM dominates absorption in summer and autumn. In the Pomeranian Bight and Arkona Basin, water constituents increase the temperature in surface waters by up to 0.1°C d^{-1} in spring and summer, predominantly as a result of increased absorption by phytoplankton and CDOM, respectively during these periods. Warmer surface waters are balanced by cooler subsurface waters. Surface heat fluxes (latent, sensible and net longwave) all increase in response to warmer sea surface temperatures. We find good agreement between our modelled water constituent absorption, and in situ and satellite observations. Accounting for the impact of water constituents on radiative heating in surface waters in regional seas has important consequences for the exchange of energy fluxes across the air-sea interface and the distribution of heat within the water column. More rigorous co-located heating rate calculations using an atmosphere-ocean radiative transfer model provide further evidence of the suitability of ROMS-BioOptic for this purpose.

Striped texture of submesoscale fields and seasonality of submesoscale coherent vortices in the northeastern Baltic Proper: a very high-resolution modelling study

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Very high resolution modelling in the central part of the Baltic Sea is applied with horizontal grid spacing of 250 m and 60 vertically adaptive layers. Simulation results indicate that the submesoscale inhomogeneities of hydrodynamic fields or stripes of the order of 10 – 20 km in length and 1 km in width, are typical for summer season both in the surface mixed layer but also in the interior layers, which are not directly influenced by the atmospheric surface. The presence of the stripes in the surface layer is also supported by the remote sensing imagery and their vertical extension is comparable with the mixed layer depth. The vertical extension of stripes in the interior layers is considerably larger and their vertical slopes exceed the isopycnal slope.

We have considered four competitive mechanisms of formation of mesoscale striped texture: strain-induced frontogenesis, the classic inviscid adiabatic fluid symmetric instability, the McIntyre instability and the stirring of large-scale ingomogeneities by the eddy field. The classic symmetric instability and the strain-induced frontogenesis are probably responsible for the formation of submesoscale striped texture in the surface layer, while in the interior the strain induced frontogenesis and hypothetically the McIntyre instability can be essential.

The seasonality analysis indicate that in summer the cyclonic and anticyclonic submesoscale coherent vortices (SCVs) with extrema of vertical component of vorticity at the surface are formed, while the anticyclonic SCVs in the shape of convex lenses in density field dominate in the intermediate cold layer below the seasonal thermocline and above the permanent halocline. The seasonal thermocline and cold intermediate layer are replaced by a relatively deep convectively-mixed layer during the winter season and where the cyclonic SVCs dominate. The core of winter-time cyclonic SVCs is characterized by a negative temperature anomaly throughout the mixed layer. The life-time of simulated SCV can be more than several months during which the simulated SCV can repeatedly merge with other SCVs of the same sign of vorticity. Merger makes the eddy stronger and contribute to its longevity.

Range expansions along multiple environmental gradients

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The Baltic Sea is an important system presenting with varying environmental conditions and ecosystem configurations and thus is considered by many a natural laboratory for all aspects of marine sciences. Because of its history of recent (post-glacial) colonization, the Baltic Sea is a very suitable region to study range expansions and local adaptation. Range expansions can be stopped by a failure of a population to adapt further along an environmental gradient. A factor that is often invoked to explain the failure to adapt further, and thus expand over a territory, is a mismatch in environmental conditions between the core and the front of the expansion. Classical models generally consider adaptation and expansion of a population over a single environmental gradient. Such models predict that expansion stops when dispersing along a spatially varying environment generates a fitness cost which is too high with respect to the efficacy of selection in the presence of genetic drift. In reality, more than one environmental gradient affect a population expanding over space. For example, in the Baltic Sea, salinity is considered an important gradient, but populations need to adapt to other gradients such as temperature or acidity. In our work, we extend this classical theoretical framework and study how range expansions are affected by the presence of multiple environmental gradients to which a population has to adapt to thrive and expand. We find that the composite effect of multiple environmental gradients on range expansions is analogous to the effect of a single effective environmental gradient that we can compute analytically. Importantly, our result shows that multiple locally shallow environmental gradients can combine to become a steeper effective gradient leading to a sharp range margin – even when the population could adapt easily to each gradient if taken by itself. Because of these findings, we conclude that the existence of shallow gradients that could generally be overlooked cannot be ignored. In the Baltic Sea, these shallow environmental gradients may also combine with steep gradients such as salinity, further reducing the ability to expand in space. The implications of our findings for the Baltic Sea are that it is necessary to carefully consider any possible change in the environment that might generate a new gradient, as even small changes can have important effects on the local collapse of a population.

The response of coastal benthic food webs to spatio-temporal variability in organic matter properties

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The quantity and quality of organic matter (OM) available for macrobenthos vary on temporal and spatial scale, especially in temperate coastal areas, where the seafloor is supplied by both seasonal pulses of primary production and terrestrial carbon transported by rivers. Human-induced environmental changes (climate change and eutrophication) alter OM transport to the seafloor, thus, it is of crucial importance to recognize the impacts of spatio-temporal OM variability on benthic food webs.

In this study, the seasonal variability of quantity and quality of OM and its effect on benthic food-web structure were studied at four locations along the southern coast of the Baltic Sea, characterized by similar species pools but different environmental settings and various scales of anthropogenic and riverine influence. Stable isotopic composition of carbon and nitrogen ($\delta^{13}C$ and $\delta^{15}N$) in combination with Bayesian Layman metrics and standard ellipses were used to analyse the variability in the isotopic niche of benthic communities and particular feeding groups. Additionally, nine different OM parameters were measured to assess the quantity and quality of food available for the benthos.

Our results show that temporal changes in the isotopic niche of benthic consumers follow the patterns of OM quantity and quality that reflect seasonal changes of pelagic primary production, riverine discharge of terrestrial OM, and the input of anthropogenically enriched sources. In the semi-enclosed Puck Bay, where intensive summer blooms are common, all feeding groups expressed lower $\delta^{15}N$ values in autumn, suggesting the incorporation of $\delta^{15}N$-depleted cyanobacteria. In the Vistula estuary, supplied by a higher proportion of OM from allochthonous sources (riverine discharge), omnivores occupied higher trophic levels, probably due to a higher abundance of meiobenthic prey. In contrast, at the open Polish coast, where the main food supply occurs during the diatom spring bloom, the isotopic niche of omnivorous species showed much higher seasonal variability, underlining the importance of food availability for food-web diversity.

Fast adaptation of benthic food-web structure to seasonal variations in OM properties and its modification by local conditions, may indicate high plasticity of species feeding behaviour. This suggests a high capacity of benthic communities to mitigate ongoing changes in the marine environment, at least within the range observed today. At the same time, the variable food-web structure in these similar communities suggests that community composition is an insufficient indicator of ecosystem functioning.

Trend correlations for coastal eutrophication and its main land, hydroclimatic and whole-sea drivers

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Coastal eutrophication is a major environmental issue worldwide. In the Baltic Sea, eutrophication affects coastal waters as well as the open sea. Various management frameworks have been implemented for its mitigation. However, eutrophication-relevant variables, such as Chlorophyll-a concentration, exhibit opposite (increasing as well as decreasing) temporal trends in various Baltic Sea marine basins and coastal waters. In this study, we investigate the observed linkages between coastal eutrophication and various anthropogenic, hydroclimatic and hydrospheric drivers and variables during the period 1990-2020. We focus our analysis on the relationships between land, coast and open sea parts of the Baltic Sea system. Change trends in various drivers have been correlated with change trends in eutrophication variables for the Swedish coastal waters, partitioned into coastal basins, and their related open sea basins.

We find that classifying the investigated coastal basins into more and less isolated, depending on their water exchange with the open sea, is necessary in order to capture the different coastal eutrophication dynamics. Eutrophication conditions in the less isolated coastal basins are primarily related to nitrogen concentrations, while they are more mixed, with stronger phosphorus influences, in the more isolated ones. Hydroclimatic and hydrospheric drivers, such as wind speed and water salinity, correlate best with recent changes in open sea eutrophication conditions. The driver signal is more mixed for the coastal basins, with influence of both land-based, anthropogenic nutrient loads and sea-ice cover duration, relating to winter and spring hydroclimatic conditions. Open sea Chlorophyll-a concentration stands out as the main driver of change in the coastal concentrations of Chlorophyll-a for the less isolated coastal basins. Thus, coastal waters act as a melting pot of various scale and driver influences, in response to changes in hydroclimatic and land-based drivers, and open sea conditions that propagate towards the coast. The latter in turn also depend on the open-sea hydroclimatic conditions, as well as on strong internal feedback loops, and long-term integration of pathway-dependent coastal responses to land-based nutrient loading. Thereby, our results challenge any unidirectional source-to-sea paradigm for management of the coastal zone and emphasize the need for both whole-sea and land-based measures for robust coastal eutrophication management.

Environmental DNA biomonitoring of hot-spots of biodiversity in Danish waters

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We investigated the use of eDNA metabarcoding for supplementing traditional diver-based monitoring of biodiversity of marine boulder reefs within the photic zone. We applied a sampling design, which made it possible to 1) assess the local imprint of boulder reefs on biodiversity across the North Sea to Baltic Sea transition zone and 2) assess if patterns in marine biodiversity relates to environmental gradients and 3) to evaluate the usefulness of eDNA monitoring as a supplement for traditional monitoring. At each reef (location) water was sampled near the bottom, over the reef and ca. 2 km upstream and down stream (placement) and sequenced with metabarcoding using COI, 18S and 12S primers. We compared the composition and abundance of benthic species associated with nine reefs, representing an environmental gradient of high saline (33 psu) North Sea waters to the less saline (16 psu) waters in the Western part of the Baltic Sea. Multivariate analysis showed a good agreement between eDNA and diver based descriptions of reef communities, with significant differences in species composition between reef locations and placement. Patterns in species distribution was significantly related to geographical distance, salinity, water temperature and water depth. While eDNA identified 414 species, diver based observations identified 183 with an overlap of 57 species. Several key stone species were not identified by the eDNA technique.

Human impacts and their interactions in the Baltic Sea region

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Coastal environments, in particular heavily populated semi-enclosed marginal seas and coasts like the Baltic Sea region, are strongly affected by human activities. A multitude of human impacts, including climate change, affects the different compartments of the environment, and these effects interact with each other.

As part of the Baltic Earth Assessment Reports (BEAR), we present an inventory and discussion of different human-induced factors and processes affecting the environment of the

Baltic Sea region, and their interrelations. Some are naturally occurring and modified by human activities (i.e. climate change, coastal processes, hypoxia, acidification, submarine groundwater discharges, marine ecosystems, non-indigenous species, land use and land cover), some are completely human-induced (i.e. agriculture, aquaculture, fisheries, river regulations, offshore wind farms, shipping, chemical contamination, dumped warfare agents, marine litter and microplastics, tourism, coastal management), and they are all interrelated to different degrees.

We present a general description and analysis of the state of knowledge on these interrelations. Our main insight is that climate change has an overarching, integrating impact on all of the other factors and can be interpreted as a background effect, which has different implications for the other factors. Impacts on the environment and the human sphere can be roughly allocated to anthropogenic drivers such as food production, energy production, transport, industry and economy.

We conclude that a sound management and regulation of human activities must be implemented in order to use and keep the environments and ecosystems of the Baltic Sea region sustainably in a good shape. This must balance the human needs, which exert tremendous pressures on the systems, as humans are the overwhelming driving force for almost all changes we see. The findings from this inventory of available information and analysis of the different factors and their interactions in the Baltic Sea region can largely be transferred to other comparable marginal and coastal seas in the world.

Baltic Earth Assessment Report on biogeochemistry of the Baltic Sea

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Location, specific topography and hydrographic setting together with climate change and strong anthropogenic pressure are the main factors shaping the biogeochemical functioning and thus also the ecological status of the Baltic Sea. The recent decades have brought significant changes in the Baltic Sea. First, the rising nutrient loads from land in the second half of the 20th century led to eutrophication and spreading of hypoxic and anoxic areas, for which permanent stratification of the water column and limited ventilation of deep water layers made favourable conditions. Since the 1980s the nutrient loads to the Baltic Sea have been continuously decreasing. This, however, has so far not resulted in significant improvements in oxygen availability in the deep regions, which has revealed a slow response time of the system to the reduction of the land-derived nutrient loads. Responsible for that is the low burial efficiency of phosphorus at anoxic conditions and its remobilization from sediments when conditions change from oxic to anoxic. This results in a stoichiometric excess of phosphorus available for organic matter production, which promotes the growth of N_2-fixing cyanobacteria and in turn supports eutrophication.

This assessment reviews the available and published knowledge on the biogeochemical functioning of the Baltic Sea. In its content, the paper covers the aspects related to changes in carbon, nitrogen and phosphorus (C, N and P) external loads, their transformations in the coastal zone, changes in organic matter production (eutrophication) and remineralization (oxygen availability), and the role of sediments in burial and turnover of C, N and P. In addition to that, this paper focuses also on changes in the marine CO_2 system, structure and functioning of the microbial community and the role of contaminants for biogeochemical processes. This comprehensive assessment allowed also for identifying knowledge gaps and future research needs in the field of marine biogeochemistry in the Baltic Sea.

Baltic Sea eutrophication status in a changing climate

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Predicting the potential future eutrophication status of the Baltic Sea need to factor in both (i) expected nutrient reductions from implementing relevant EU Directives and the 2013 update of the HELCOM Baltic Sea Action Plan and (ii) the potential consequences of a changing climate including changes in precipitation, runoff and seawater temperatures. We present the results of a Baltic Sea-wide modelling and assessment study covering the period 1900-2100. Including climate change scenarios in the modelling indicates that eutrophication status trajectories, using the HEAT tool, will not meet the objectives of the 2013 revision of the HELCOM Baltic Sea Action Plan in most sub-basins, with high spread between climate scenarios after 2070. This study documents that the future eutrophication status is not dictated by the inputs of nitrogen and phosphorus alone but the changes in climate have also a substantial imprint. Any ecosystem-based nutrient management strategy should therefore include climate change, one of the key drives of environmental change in the future, but how this can be done remains an open issue.

Time-scales of the Baltic Sea eutrophication state – implications for predicting recovery

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Large-scale eutrophication developed in the Baltic Sea during about 100 years. Nutrient loads peaked decades ago, but signs of recovery are lacking in most major sub-basins. The most accepted view is that recovery, in terms of, for example, reduced phosphorus concentrations, will eventually happen given that loads are at today's levels or lower. The apparent lack of response to the considerable investments made to curb nutrient inputs cause significant frustration in the society. Thus, there is a demand for quantifications of the effect of measures made and how the eutrophication state could develop in the upcoming years.

Driven with nutrient inputs reported by riparian countries within the HELCOM Pollution Load Compilation, physical-biogeochemical model BALTSEM rather accurately reproduces the oxygen and nutrient concentration dynamics up to present, which indicate that the coupled physical transports and biogeochemical transformations are captured in the model. A simulation experiment with constant high nutrient inputs in recent decades shows that eutrophication symptoms would have been much worse today had the nutrient input reductions not taken place (e.g., 50% higher winter DIN and DIP, primary production and summer phytoplankton biomass).

Model simulations with nutrient inputs representing recent years show significant improvements (e.g, 40% decrease in winter DIP concentration in about 50 years). However, there are significant modulation of the state due to variability. Sensitivity studies indicate that conditions at the end of the long-stagnation period in the late 1980s and early 1990s as well as the past 15 years have been exceptional. The possibility of predictions of the state in upcoming years are discussed on the basis of these experiments.

Nitrogen in the Baltic Sea: Long-term trends, a budget and decadal time lags in responses to declining inputs

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The Baltic Sea Nitrogen (N) cycle has changed since the beginning of the 20th century due to increased nutrient inputs from rivers and the atmosphere. In order to better understand the N-budget in the Baltic Sea and possible recovery we assembled a dataset from 255 stations over about 50 year (>390.000 observations) of water column total nitrogen (TN) concentrations to determine long-term changes. In addition, we constructed a simple TN budget based all available data sources. We show that in most regions the water column TN pool increased from the 1970s and up to the early 1990s. Hereafter it leveled off and in most regions it has then remained stable or started to decrease in the early 2000′s. Declines in TN concentrations were only evident in nearshore areas (<12 nautical miles from the shoreline), which are more directly impacted by river inputs than open areas. The entire Baltic Sea water column TN-pool has declined with 31-kiloton (kt) N y^{-1} in the period from 2011 until 2018. This corresponds well with our budget with inputs (1438 kt N) and outputs (1486 kt N) giving a deficient of 48 kt N y^{-1} or about 3 percent of the balance.

We compared the observed concentrations with regional threshold concentrations suggested by HELCOM for a Baltic Sea unaffected by eutrophication. This comparison showed that a reduction by 28 percent of the current TN pool is necessary to reach the ecological targets, which according to our calculations will require a reduction of about 50 percent in all manageable TN inputs. For the water column, the 28 percent reduction in the TN-pool will then be achieved within an 8-year period. However, as only about 5 percent of the active TN pool is present in the water column, with the majority (95 %) being in the top 0.2 m of the sediment, the likely time lag is approximately 20 times longer. Hence, when the entire N-pool is considered, the time lag before good ecological status is reached is estimated to be c 400, 200 and 100 years for TN-input reductions of 20, 30 and 50 %, respectively. Thus, our study shows that recovery of the Baltic Sea ecosystem is only possible if N-input reductions are considerably higher than the current ambition of only 9%. Moreover, even with several fold higher input reductions than the current ambition, the time lag for improvements is decades and most likely centuries.

Nutrient pools and development of hypoxia in the Baltic Sea over a period of 1993-2019.

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Eutrophication is a challenge in the Baltic Sea, with estimates of annual total input of about 830 kT of nitrogen and 31 kT of phosphorus in 2014. Oxygen deficiency, in the form of hypoxia and anoxia, is a direct consequence of the eutrophication of the Baltic Sea. Nutrient pools and hypoxic areas were estimated using the state-of-the-art coupled physical and biogeochemical numerical model reanalysis data from Copernicus Marine Environment Monitoring Service for the period of 1993-2017.

During the period of 1993-2017, the pelagic nitrate pool decreased from ~2400 to 1700 kT in the Baltic Sea. The reduction of the nitrate pool was uniform over the Baltic Sea, with the exception of the Gulf of Bothnia, where decrease in the intermediate layer was small or even turned into an increase in the deep layer. The pelagic phosphate pool increased from ~600 to 750 kT, with most of the increase taking place in the surface and intermediate layers. The pool in the deep layer remained on a more stable level, with only a slight increasing trend. The increase of the phosphate pool covers the Baltic Proper area. In the Gulf of Bothnia, a decrease of phosphate has occurred in the upper layers and a slight increase in the deep layer. Decreasing dissolved inorganic nitrogen pools and increasing phosphorus pools results in a decreasing nitrogen to phosphorus ratio. Statistical analysis showed that the variability of hypoxic area represents a trend-stationary process of the increase of hypoxic area from 20000 km^2 in 1993 to a level of about 60000 km^2 in 1999 and a stationary process around its respective mean level since the year 2000. From 2000 to 2017, the hypoxic area varied between 50 000 and 80 000 km^2. Different methods and data sources indicate that the uncertainties of the estimates account for about 10 000 km^2. Probability distribution maps of hypoxia provide detailed information about the persistency of hypoxia in different parts of the Baltic Sea. The probability of hypoxia exceeds 0.9 in the eastern and western Gotland basins and in the deep area of the Bornholm basin. Pelagic ammonium pools increased in the deep layer of the Baltic Proper due to decreasing oxygen concentrations there. The Gulf of Finland and the shallower areas that connect different deep basins of the Baltic Sea exhibit seasonal and episodic hypoxia. Our study supports previous knowledge that hypoxia development is controlled to a large degree by the depth of the permanent halocline.

Nearshore Dissolved and Particulate Organic Matter Dynamics in the Southwestern Baltic Sea: A Time Series Analysis (2010 – 2020)

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Nearshore systems are highly dynamic environments: Due to the high light and nutrient availability, they are hotspots of dissolved and particulate organic carbon (DOC, POC) and nitrogen (DON, PON) cycling. The organics in the seawater do not only act as nutrient sources, but also impact chemical and physical properties such as light availability, alkalinity or trace element solubility. From the coastal waters, where organic nutrients are usually present in excess, they can be exported to the Open Ocean and support heterotrophic activity in the more nutrient-depleted waters.

We here present results from a weekly sampled time series station in the southwestern Baltic Sea (Heiligendamm, Germany). Particulate and dissolved organic carbon and nitrogen were assessed in the surface water from 2010 to 2020. Additionally, all parameters including water temperature, salinity, chlorophyll *a* and inorganic nutrients publicly available through the oceanographic database of the Institute for Baltic Sea Research Warnemünde, ODIN 2 were used.

Mixing of high-salinity North Sea water with low-salinity, high-DOC Baltic Sea water, as well as in-situ primary production, were identified as the main drivers of organic carbon and nitrogen concentrations. POC, PON, chlorophyll *a* and biota biomass were tightly coupled to DON seasonal dynamics, corroborating the close relationship between phytoplankton production and degradation of organic nutrients. Preferential remineralization of nitrogen was observed in both, particulate and dissolved, phases. Significant increases of air and water temperature and salinity as well as decreases of inorganic nutrients over the assessed period indicated effects of climate change and improved water quality management in the eutrophic Baltic Sea. Bulk organic nutrient concentrations remained stable, but the salinity-corrected fraction of the DOC increased by ~0.5 µmol L^{-1} yr^{-1} over the 11-year period. Phytoplankton carbon as a potential source of DOC did not significantly change over time, while contributions of certain phytoplankton classes, including Bacillariophyceae and Cryptophyceae, increased, potentially impacting the quality of the released DOC. The high variability of the shallow system exacerbates the detection of long-term trends, but our results emphasize the value of these extended samplings. Only through these observations can we better understand coupled biogeochemical cycling of organic matter in the heavily anthropogenically impacted Baltic Sea and detect trends in this important carbon reservoir, relevant on global scales.

All water column data are available to the scientific community upon registration through the oceanographic database of the Institute for Baltic Sea Research Warnemünde, ODIN 2 (odin2.io-warnemuende.de).

Assessing acidification in the Baltic Sea, scientific basis and implications for monitoring

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Anthropogenic CO_2 emissions are expected to gradually drive the oceans towards a state where acidification becomes harmful for some organisms – unless the emissions are drastically reduced. Ocean acidification is caused by CO_2 uptake, but can be further altered by climate change effects. The Baltic Sea and other coastal seas are highly influenced by their catchment areas, which leads to more complex pH dynamics than in the open ocean. Both changes in hydrology and changes in the supply of carbon and nutrients can influence pH in addition to the impact of increasing atmospheric CO_2. High-productive waters typically experience larger seasonal pH variations than low-productive waters because of a more intensive carbon cycling. Marine organisms can to varying degrees adapt to ocean acidification, but unabated CO_2 emissions are expected to lead to both direct and indirect changes in species composition over time, potentially influencing ecosystem functioning.

Model simulations with the coupled physical-biogeochemical BALTSEM model, performed as part of the OMAI (Operational Marine Acidification Indicator) project, indicate that acidification in the Baltic Sea can be expected to generally follow the same trajectory as in the open oceans. In a worst-case emission scenario, pH could decline by almost 0.4 by year 2100. In contrast, acidification trends could in a best-case emission scenario be reversed before the end of this century. The development of eutrophication is likely to have a comparatively small effect on the annual mean pH of open Baltic Sea waters, but on the other hand a considerable impact on the seasonal variations and thus annual minimum and maximum values. The Baltic Sea spans large regional differences in terms of salinity as well as properties of the catchment areas, influencing carbon and nutrient supplies to different sub-basins and in extension pH and other parameters of the inorganic carbon system. Because of the complex situation in the Baltic Sea, it is strongly recommended to improve the temporal and spatial coverage of acidification monitoring. This is necessary to broaden the understanding of current acidification trends, but also to improve the capacity to predict future changes. The technology required for precise measurements is in place.

Wednesday, Theme 1, from 16:30 – 17:45

Emerging ecosystem services under climate change in the Lithuania coastal zone environment: the physical basis

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Transitional basins and lagoons will be some of the water bodies heavily impacted by climate change. These changes will affect also ecosystem services that both already exist, or will be emerging in the near future. Here a first attempt of quantifying these changes in ecosystem services will be done. All physical parameters that possibly can affect these services will be analyzed. There will be also implications on nutrients and other ecological parameters that will be considered at a later time.

Since we want to focus on socioeconomics, two future periods will be analyzed: short-term (2027-2035), mid-term (2045-2055), with a reference period of 1990-2005. The meteorological data used was acquired from CORDEX (Coordinated Regional Downscaling Experiment) scenarios for Europe from the Rossby Centre regional climate model (RCA4), which consisted of five sets of simulations (downscaling) driven by five global climate models.

Temperature, salinity, and water level data were bias corrected by using data from Copernicus Marine Environment Monitoring Service (CMEMS) Baltic Sea Physical Reanalysis product data, provided by EU Copernicus Marine Service. The period used for determining the bias correction parameters was 1993-2007.

For the entire Nemunas watershed, a hydrological model using SWAT was applied and its data has been used here. The Nemunas River basin SWAT model consists of 11 different smaller SWAT models each representing one of the main tributaries of the Nemunas River.

For the Curonian Lagoon a hydrodynamic model has been set up consisting in 1309 nodes and 2027 triangular elements, with a much higher resolution in the Klaipėda Strait area. The hydrodynamic properties were output every 6 hours and the modelling results were analysed by computing the average of all five models. Salinity intrusion has been computed, as well as changes in water exchanges inside the lagoon as well as between the lagoon and the sea, and water residence times.

Results show that fluxes between in the Klaipeda Strait will diminish especially with RCP8.5 (higher outgoing fluxes). This can be also seen when looking at the average days of salinity intrusion, which decrease from 80 days to 34 days under RCP8.5 in the mid term. Water temperature increases steadily, with highest increase during autumn, winter, and spring. Finally, water residence time generally decreases, due to stronger mixing between the northern and southern basin and higher outgoing fluxes through the strait.

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Intercomparison of chlorophyll-a measurements for data quality assurance of the Swedish monitoring program

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Chlorophyll-a (Chl-a) is used as a key parameter for the status classification of coastal water bodies as well as for the validation of satellite images. Both accurate *in situ* as well as satellite data are required for understanding coastal dynamics and for assessing long term ecological trends. Thus, it is very important that the measurements are consistent between groups.

A dilemma is that all groups use different methods for measuring Chl-a which can lead to systematic differences in the Chl-a concentration. Some use the fluorometric method, some the spectrophotometric method, and some groups use High Performance Liquid Chromatography (HPLC). Besides this, there are also large differences with regards to handling, storing and pigment extraction.

We used historical data from two summer cruises in 1998 on R/V Argos as well as data from SU's coastal monitoring program from 2011 for initial comparisons. Furthermore, we performed an additional intercomparison on R/V Svea during Oct 2020 (funded by the Swedish National Space Board and the Swedish Agency for Marine and Water Management (SwAM). Our Chl-a measurements from the Marine Remote Sensing Group (MRSG) at Stockholm University (SU) were statistically compared to those from SMHI and the Monitoring Group at SU. The results showed that there are substantial differences between groups, ranging from 24 -76%.

Thus, there is a clear need for the correction of the Chl-a data contained in the Swedish marine monitoring data base (i.e. SMHI's SHARK database) as these data are used for the periodical status assessments within HELCOM as well as for oceanographic research and modelling. As some of the groups measure primarily in the open sea, and some primarily in coastal areas, we may get a skewed picture of coastal vs. open sea production, which may lead to inadequate conclusions about the ecological status of open sea vs. coastal water bodies.

On 1-2 July 2021, we did another dedicated intercomparison within the Swedish monitoring program, including the MRSG, the monitoring groups at Stockholm, Gothenburg and Umeå Universities, as well as NIVA (Norway), IOW (Germany) and JRC (Italy). We performed a dedicated transect through Bråviken bay and sampled 7 stations along a gradient from the outer to the inner bay (3 surface samples per group and per station). The filters were frozen in liquid nitrogen and distributed to all groups in dry ice at the beginning of September.

In my presentation I will show the first results from this intercomparison and discuss what are the main factors that lead to large differences between groups and how we can correct for this, so that both current as well as historical monitoring data is consistent and helps us to understand real environmental trends in the Baltic Sea, e.g. as a response to climate change.

Intra- and interspecific traits variability of the Baltic Sea phytoplankton

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Climate driven salinity change in the Baltic Sea causes stress to phytoplankton species with possible implications for biodiversity and functioning of phytoplankton communities. This study uses trait-based approach to experimentally assess the effect of salinity change on growth of 12 species and the intraspecific response of different strains isolated from the Baltic Sea. We measured a set of phytoplankton traits (light saturated growth rate, maximum carrying capacity, nutrient uptake, cell morphology, and photosynthetic apparatus) under different salinity levels (0 – 35 psu). Cell size explained > 50 % of the variation, which confirms it's meaning as a master trait. Response to salinity stress varied significantly between species with *Phaeodactylum* and other diatoms showing exceptionally high morphological plasticity. Plasticity in nutrient uptake could be partially explained by intraspecific diversity. Overall, our results suggest that trait plasticity is species-specific, cannot be attributed to one class of phytoplankton, but it rather depends on intraspecific diversity. While some species are more plastic in morphology, other species can be more plastic in nutrients acquisition.

Medieval versus recent environmental conditions in the Baltic Proper, what was different a thousand years ago?

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A sediment core from the western Gotland Basin, northwestern Baltic Proper, covering the last 1200 years, was investigated for past changes in climate and the environment using diatoms as a proxy. The aim was to compare the environmental conditions reconstructed during Medieval times with settings occurring the last century under influence of environmental stressors like eutrophication and climate change. Our data shows that more marine conditions than today prevailed during Medieval times, reaching at least 8 in the surface waters compared to present-day about 6.5. The higher salinity made it possible for *Pseudosolenia calcar-avis*, an autumn blooming warm water diatom which forms massive algal mats in stratified waters, to thrive which effectively enhanced the vertical export of organic carbon to the sediment and contributed to form extensive areas of benthic hypoxia. Both higher salinity and higher temperatures (stronger thermal stratification) during the Medieval Climate Anomaly (MCA; 950-1250 C.E.) were probably favourable to the vast production of *P. calcar-avis* in the Baltic Proper. Accordingly, our data support that a warm and dry climate induced the extensive hypoxic areas in the open Baltic Sea during the MCA. A more efficient coastal filter and higher retention capacity in coastal wetlands could explain why intensified land-use during Medieval times did not result in higher nutrient discharge in the open Baltic Sea. Instead we suggest that massive flux of diatom "shade flora" promoted by warm and dry climate (higher salinity and thermal stratification) reinforced by cyanobacterial blooms and nitrogen fixation increased carbon sequestration to the sediments by diatoms due to extended length of the growing season, which made it possible to get high primary productivity and hypoxia during the MCA despite oligotrophic conditions. The diatom data indicates decreased salinity, weaker stratification and low primary production during the Little ice Age (LIA; 1400-1700 C.E.) which resulted in a low organic content, homogeneous sediments and well oxygenated bottoms. The first signs of human-induced eutrophication are recorded about 1940 visible as a shift in diatom composition, increased primary production as well as carbon content, and benthic hypoxia. Impact of climate change is visible in the diatom composition data starting about 1975 C.E. and becoming more pronounced 2000 C.E. The less marine conditions in the area during present-day most probably prevent re-appearance and an expansion of *P. calcar-avis* from the southern Baltic Sea. However, other large diatom taxa that thrive in stratified waters during autumn blooms (*Coscinodiscus granii* and *Actinocyclus octonarius* including varieties) have increased the last two decades, interpreted as being the result of the documented global warming.

Alive; Methusaleh of the diatom world

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We show for the first time the revival, viability and germination rate of resting spores of the diatom *Chaetoceros* deposited in sub-seafloor sediments from three ages (recent: 0-80 years; ancient: ~1250 (Medieval Climate Anomaly) and ~6600 (Holocene Thermal Maximum) calendar year before present). Our findings showed that *Chaetoceros* resting spores from ~6600 calendar year before present (cal. yr BP) are still viable and the physiological response pertaining to vegetative reproduction in recent and ancient resting spores vary. The time taken to germinate is three hours to 2-3 days in both recent and ancient spores but the germination rate (%) of the spores decreased with increasing age. The germination rate of the recent spores was ~50% while that of the ancient spores were ~40% and ~19% for the ~1250 and ~6600 cal. year BP old resting spores, respectively. Based on the morphology of the resting spores as well as the germinated vegetative cells we were able to identify the species as *Chaetoceros muelleri* var. *subsalsum* (Lemmerman) J.R. Johansen and Rushforth. Sanger sequences of nuclear and chloroplast markers identified the species as *Chaetoceros muelleri*.

Thursday, Theme 4, from 09:00 – 10:30

OmiBox: towards *in-situ* monitoring of microbial communities

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Until recently, the need for fully equipped laboratories for environmental studies based on omic technologies (i.e., DNA/RNA sequencing) has compelled researchers to preserve and transfer the samples for further analysis. The ability to process and analyse environmental samples immediately after collection would enhance our understanding of natural communities of different organisms by reducing potential degradation of molecules due to sample storage, as well as disturbance of the naturally occurring microbial communities, which can rapidly respond to freeze-thaw events. In this project, we are developing a cost-time-efficient method for a rapid assessment of natural microbial communities using Oxford Nanopore sequencing technologies. Integrated into a fully equipped, portable laboratory (OmiBox), this technology will enable multiomic experiments (i.e., metagenomics and metatranscriptomics simultaneously) entirely conducted in the field, from sample collection to sequencing data acquisition. The methodology developed in this project will contribute to make environmental genomic data more available, reliable and cheaper, which in turn will enhance our understanding of biological systems functioning in their natural environments.
For monitoring and risk assessment purposes, we will apply this methodology as a bioindication tool on Baltic Sea contaminated sediments, where microbial communities will be used as rapid and sensitive indicators of environmental disturbance induced by the occurrence of contaminants, particularly Hg. Relevant genes and microbial taxa will be identified and integrated into a modelling approach to link patterns of gene expression and community structure to loads of pollutants and bioaccumulation in the food web. The knowledge and technology developed during this project will be integrated to describe a cost-efficient, easy-to-use standardized method to provide a robust framework for national and international environmental monitoring initiatives.

Plankton biodiversity and species co-occurrence monitoring using environmental DNA – a multiple marker study

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Metabarcoding in combination with high-throughput sequencing (HTS) allows simultaneous detection of multiple taxa by targeting single or several taxonomically informative gene regions from environmental DNA samples. In this study, a multiple-marker HTS approach was applied to investigate the plankton diversity and seasonal succession in the Baltic Sea from winter to autumn as well as the applicability of the method for plankton monitoring. Four different markers targeting the 16S, 18S, and 28S ribosomal RNA genes were employed, including a marker for more efficient dinoflagellate detection. Typical seasonal changes were observed in phyto- and bacterioplankton communities. In phytoplankton, the appearance patterns of selected common, dominant, or harmful species followed the patterns also confirmed based on 20 years of phytoplankton monitoring data. In the case of zooplankton, both micro- and mesozooplankton species were detected. In total, 15 and 2 new zoo- and phytoplankton species were registered from the Baltic Sea. HTS approach was especially useful for detecting microzooplankton species as well as for investigating the co-occurrence and potential interactions of different taxa. The results of this study further exemplify the efficiency of metabarcoding for plankton monitoring and the advantage of employing multiple markers through the detection of species not identifiable based on a single marker survey and/or by traditional morphology-based methods.

Keywords: bacteria, Baltic Sea, metabarcoding, phytoplankton, rRNA genes, seasons, zooplankton

PHOSPHORUS BIO-RECOVERY STRATEGIES FROM THE BALTIC SEA

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Phosphorus is one of the vital building blocks for life and a valuable source for improving crop productivity in agriculture. Globally, phosphorus demand is being met from phosphate rock mines which is non-renewable and unevenly distributed all around the world. European Commission classified phosphate as a critical raw material in 2014, so; current strategies within European Union have been focusing on possible ways to recover and sustainable use of phosphorus. Besides, unsustainable use and poor recovery of phosphorus has led to intensive accumulation in the receiving water bodies. Baltic Sea is one of the examples that faces severe eutrophication due to nutrient inputs and their high residence time. Oxygen depletion in the sea bed and the loss of biodiversity are some of the consequences of the eutrophication in the Baltic Sea and the economic loss is also predicted as 3.8-4.4 billion €/year [1,2]. In case of phosphorus, input reduction strategies reduced further accumulation of phosphorus in the Baltic Sea; however, past accumulation still emerges as a eutrophication problem due to internal phosphorus release form the sediments.

So, future strategies for abating eutrophication in the Baltic Sea should focus on innovative approaches that are capable of removing phosphorus as well as recovering it for valorization. At this point, in-situ/ex-situ bio-based approaches that rely on exploitation of living organisms for phosphorus removal and recovery can be outstanding for addressing eutrophication problem in an eco-efficient manner. Microorganisms such as phosphate accumulating microorganisms that are able to release and accumulate phosphorus can be manipulated in ex-situ bioreactors for treatment and recovery. Phosphate solubilizing/leaching microorganisms such as *Pseudomonas* sp.*, Bacillus* sp., and acidophiles could be also investigated for phosphorus recovery from the sediment in ex-situ bioreactors. Algae is valuable in terms of its high phosphorus uptake capacity and biomass recovery as in multiple ways. Plants can be also exploited for their self-purification capacity in engineered wetlands. Kelp/mussel farming are also efficient for removing phosphorus from the sea and biomass harvesting for energy production or soil amendment is quite promising. Although, there are some limited applications in the real-scale, most of these approaches are still in the research phase and future research should focus on improvement and testing new technologies considering feasibility and sustainability issues for a healthier Baltic Sea.

[1]http://stateofthebalticsea.helcom.fi/pressures-and-their-status/eutrophication/
[2] http://stateofthebalticsea.helcom.fi/humans-and-the-ecosystem/use-of-baltic-marine-waters/

TESTING ANAEROBIC PHOSPHORUS RELEASE FROM BALTIC SEA SEDIMENT VIA BIOENGINEERING STRATEGY

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Large mass of Baltic Sea water is suffering from eutrophication due to extensive accumulation of nutrients through inputs from land and internal recycling from the sediment. Internal phosphorus release from the sediment under anoxic conditions is one of the major challenges of the Baltic Sea that triggers eutrophication problem although strict nutrient input reduction strategies have been applied so far. To figure out eutrophication problem in an effective and sustainable manner, in-situ/ex-situ engineering technologies should be developed for phosphorus removal to achieve a good ecological status in the Baltic Sea. Simultaneously, these strategies should also cover recovery technologies to promote circularity of phosphorus as being a `critical` raw material.

This study aimed to investigate phosphorus release from the Baltic Sea sediment through adding waste derived volatile fatty acids (VFA) as the carbon source to stimulate phosphorus release from the sediment under anaerobic conditions. Batch experiments were conducted in 50 mL reactors that included sediment and water mixture taken from two different sampling points, Baggensfjärden and Farstaviken in the Stockholm archipelago. The experiments were run under anaerobic conditions at room temperature at different VFA concentrations (1000-10000 mg COD/L) and different hydraulic retention times (3-21 days). Ammonium molybdate was also added to some reactors to inhibit activity of sulfate reducing bacteria (SRB) and to investigate the role of SRB on the phosphorus release.

Experimental results showed that the highest phosphorus release for Farstaviken sample was achieved as 6.14 mg/L PO_4-P/L with VFA loading of 1000 mg COD/L after 21 days. The highest phosphorus release for Baggensfjärden sediment was achieved with VFA loading of 10000 mg COD/L as 15.85 mg PO_4-P/L after 21 days. For both samples, the control reactors without VFA addition showed lower phosphorus release than VFA added reactors. Inhibition of SRB resulted in no phosphorus release from the sediment which could be attributed to the active role of SRB on phosphorus release mechanisms. In conclusion, VFA addition improved phosphorus release from the sediment and two samples showed different responses to different VFA concentrations. So, further research could cover increasing phosphorus release efficiency by changing operational parameters and mode as well as recovery of phosphorus from the water column.

Oil spill detection using fluorometric sensors: Laboratory validation and implementation to a FerryBox and a moored SmartBuoy

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The risk of oil spills is highest near areas of heavy maritime traffic and the relatively small Baltic Sea has one of the highest maritime activity in the world. Oil and oily discharges from ships, referred to as operational oil spills, represent a serious threat to marine ecosystems. Presently, methods like aerial surveillance and ship-based, and satellite monitoring are used for oil spill detection and monitoring but all these methods still have drawbacks and limitations. As a possible extension to the limitations of these remote sensing techniques, we tested and evaluated the operational capabilities of two real-time in-situ oil spill detection systems that were based on fluorometric sensors. Our laboratory tests showed that the sensors were capable of detecting the presence of oil, but natural constituents (CDOM, turbidity and algae-derived substances) considerably affected the detection capabilities. The sensors were then integrated into autonomous platforms covering areas with high traffic in the Baltic Sea. The first platform was a FerryBox flow through system installed on M/S Baltic Queen, which commutes between Tallinn and Stockholm. The second was a SmartBuoy moored in the Gulf of Finland. Operationally, both systems worked well and the gathered data supported the laboratory results regarding the effects of the natural substances. No oil spills were detected during the two-month testing periods, and we were therefore unable to conclusively confirm the field capabilities of these systems. Other concerns affecting the oil detection that arose during the testing of the sensors and platforms were the measuring depth and the sensors' calibration and specificity. To combat the problem of the natural interferences we suggest exploring suitable mathematical methods or more advanced sensors with built-in correction. When the detection capabilities of these systems have been confirmed, a comprehensive network of SmartBuoys and FerryBoxes covering the major fairways can greatly complement conventional oil spill detection methods.

Simulating oceanographic conditions at fairways for remote piloting

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In maritime traffic a lot of research and technological development is focusing on autonomous vehicles and steps towards remote piloting. Transition from conventional piloting to remote piloting reduces piloting costs (maintenance and fuel for pilot ships) and moreover reduces the risks that pilots take in embarking and disembarking the vessels at high sea states. In remote piloting it is important to provide similar situation awareness about the oceanographic conditions as the pilots would have on board the vessel.

Presently, fairways are unevenly equipped with measurement providing weather and oceanographic conditions. In the Finnish coast most fairways have weather station and tide gauge close to them, but information about wave and currents are typically unavailable. High resolution coastal models might be one possibility for providing wave and current nowcasts and forecasts for the coastal fairways. However, a good quality of the model results needs to be established to ensure that they provide the appropriate situation awareness.

A specific measurement campaign was planned for Rauma fairway in the southern part of the Bothnian Sea to collect wave and current data in three different areas: open sea, close to the pilot station at the entrance of the fairway, and in the fairway. The data was used to evaluate the performance of a WAVEWATCH III multigrid setup, including four grids from Baltic Sea scale (2 nmi) to the nearshore high resolution grid (0.1 nmi). We present the capability of the model setup in simulating the wave conditions in the Rauma fairway and evaluate its applicability to be used in operational forecasting and as oceanographic information in remote piloting together with other relevant weather information.

Thursday, Theme 2, from 09:00 – 10:30

C sequestration along the Baltic Sea coast – a poorly described, but significant part of the regional C budget

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Coastal systems with high biodiversity and productivity have been proposed as potential powerhouses of climate mitigation and part of the ocean-based solutions to combat climate change. Especially vegetated coastal ecosystems have a great capacity to stabilize carbon (C) over long time scales. However, studies in the Baltic Sea are sparse, and we currently lack a C budget for the coastal zone. Here we present a novel research approach and present first results aligning geophysical and atmospheric measurements of greenhouse gases (GHGs) with ecological studies on C turnover and biodiversity. First studies in the Finnish Archipelago have indicated high C sequestration potential and a net ecosystem metabolism of 0.2 tons ha^{-1} y^{-1} in key coastal habitat types. However, the degraded biodiversity and ecosystem health observed in many Baltic Sea coastal systems compromises this potential. With high C stocks and turnover rates, these habitats may also contribute significantly to methane (CH_4) emissions, thereby counteracting the C sequestration potential of Baltic Sea coastal areas. Indeed, in a recent study, we found that CH_4 emission from vegetated coastal ecosystem in the Stockholm Archipelago could offset the atmospheric carbon dioxide (CO_2) uptake by up to 40%. However, the rates of coastal CH_4 emissions are highly variable in space and time and need to be further constrained in future studies. Moreover, the eutrophication-driven deposition of organic carbon (OC) to coastal sediments commonly causes hypoxic or even anoxic bottom waters, leading to the formation of an OC legacy pool. Our model result indicate that this OC legacy pool could act as a significant CH_4 generator along the shorelines of the Baltic Sea even if anthropogenic perturbations become considerably diminished.

The CO_2 system dynamics in the vicinity of the Vistula River mouth (the southern Baltic Sea): a baseline investigation

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The CO_2 system dynamics in coastal areas strongly controlled by river outflow is largely understudied. In this study, the influence of a large, continental, carbonate-rich river on the carbonate system was seasonally examined in the vicinity of the Vistula River Mouth. Three parameters describing the CO2 system were investigated: the partial pressure of carbon dioxide (pCO_2), total alkalinity (TA), and pH, together with salinity, temperature, oxygen concentration, calcium cation (Ca^{2+}), particulate inorganic carbon (PIC), and inorganic carbon (IC) in sediments. TA varied from 1700 µmol kg^{-1} in the brackish water of the Gdańsk Bay to 3475 µmol kg^{-1} in the Vistula River plume, highlighting the difference between the two end-members. Highest pCO_2 was observed in October (855 µatm) and lowest in May (148 µatm). Oxygen concentration was negatively correlated to pCO_2 in all seasons, suggesting that both were inversely controlled by the net ecosystem production (NEP). The pH seasonal variation was significant with a range of 0.72 unit. The calcium carbonate saturation (Ω) varied from 0.8 to 8.5 for calcite and from 0.5 to 8.5 for aragonite, both displaying Ω<1 in February 2018.This study shows the importance of ecosystem metabolism and TA end-member variability (3138-3631 µmol kg^{-1}), for controlling pH in the vicinity of the Vistula River Mouth. In addition, we present data on PIC, supporting possible deposition of inorganic forms of carbon to the sediments near the Vistula River Mouth.

Spatial patterns and drivers of benthic nutrient and carbon fluxes in the Baltic Sea

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*lead presenter

In the Baltic Sea, a large fraction of the organic matter degradation and recycling of biogenic elements takes place in the sediment. This makes the sediment an important source of dissolved nutrients (N, P, Si) and dissolved inorganic carbon (DIC) to the water column. This internal source of nutrients is currently several-fold higher than nutrient supply from land.

We will present benthic nutrient and DIC fluxes from the three major basins of the Baltic Sea; the Baltic proper, the Gulf of Finland and the Gulf of Bothnia (Bothnian Sea and Bothnian Bay). The dataset was collected *in situ* using benthic chamber landers, spans the last 20 years and is comprised of ca 30 stations and hundreds of individual flux measurements from sediments underlying oxic and anoxic bottom waters.

We show how benthic nutrient and DIC fluxes vary within and between basins and how they relate to sedimentary inventories of nutrient elements and organic carbon. We conclude by describing how organic matter origin (i.e. terrestrial and marine), particle shuttling and bottom water oxygen concentration affect the fluxes. The information gained from this extensive data set will be important to consider when discussing strategies to manage the input of nutrients and organic matter to the Baltic Sea.

High spatiotemporal variability of methane distribution across coastal habitats of the Baltic Sea

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Shallow coastal waters dominate global ocean methane (CH_4) emissions, but supporting studies do not sufficiently reflect the heterogeneous and dynamic nature of coastal environments. In fact, most studies focus on blue carbon habitats in low- and mid-latitudes and either use time-averaged measurement techniques or discrete water sampling at frequencies of no more than 1 – 5 samples per day and location. Here, we present continuous measurements of CH_4 concentrations, $\delta^{13}C$-CH_4 isotope values, and CH_4 sea-air fluxes from widely distributed but typically overlooked northern temperate coastal habitats of the Baltic Sea. Based on measurements across four seasons, we found an exceptionally high spatiotemporal variability of surface water CH_4 concentrations (median 67, range 6 – 460 nM CH_4) and resulting sea-air fluxes (median 9, range 0.1 – 3852 µmol CH_4 m^{-2} day^{-1}) in adjacent mixed-vegetated, algae-dominated, and bare sediment habitats. We emphasize that high-resolution measurements are needed to resolve the scale and drivers of distinct diurnal, seasonal, and spatial CH_4 patterns and improve the certainty of justified mean CH_4 concentrations for flux computations by up to 70%. Applying such an approach across a wider range of intrinsically heterogeneous coastal environments will help refine the coastal CH_4 budget from regional to global scales.

Sulfurimonas spp. affects the geochemistry of the pelagic redoxcline of the Black Sea by catalyzing sulfide oxidation with particulate manganese oxide

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In the pelagic redoxcline of the central Black Sea, oxygen and sulfide are separated by several meters' water depth, potentially due to the intense cycling of manganese. Although the reduction of manganese (IV) oxide with sulfide was previously considered to be mainly chemical, the recent isolation of *Candidatus* Sulfurimonas marisnigri strain SoZ1 suggests an important role for biological sulfide oxidation. In this study, high relative abundances of *Sulfurimonas* spp. were found across the redoxcline in the central western gyre of the Black Sea (15% via CARD-FISH, 14% via 16S rDNA, 38% via 16S rRNA), coinciding with the high-level expression of the sulfide:quinone oxidoreductase gene (*sqr*, up to 93% of total *sqr* transcripts) and other sulfur oxidation genes. The cell-specific rate of manganese-coupled sulfide oxidation by *Ca.* S. marisnigri SoZ1 determined in laboratory experiments was combined with the in-situ abundance of *Sulfurimonas* spp. in a one-dimensional numerical model to calculate the vertical sulfide concentration profile. The model's results suggested that rapid sulfide-oxidation within a narrow depth horizon account for the observed sulfide concentration profiles. Abiotic sulfide oxidation was too slow to counterbalance the sulfide flux from euxinic waters. According to our findings, up to one-third of the total sulfide oxidation activity is driven by manganese reduction catalyzed by *Sulfurimonas* spp.

Diversity of inherent optical properties of suspended particulate matter in the southern Baltic Sea in relation to the concentration, composition and selected characteristics of the particle size distribution

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This presentation reports on the diversity of inherent optical properties (IOPs) of suspended particulate matter populations occurring in southern Baltic Sea waters, and their relationships with the basic biogeochemical and morphological quantities enabling particle populations to be generally characterized. Specifically, these IOPs were the spectral absorption coefficients by all particulate matter, phytoplankton pigments and detritus, the spectral scattering and backscattering coefficients by particles, and the backscattering ratio. In most cases IOPs were measured over a wide spectral range (from the near ultraviolet to the near infrared), and at the same time with high spectral resolution. The biogeochemical properties of suspended matter populations were characterized by measuring concentrations of suspended particulate matter (SPM), particulate organic matter (POM) and particulate inorganic matter (PIM), as well as concentrations of various phytoplankton pigments, including chlorophyll *a* (Chl*a*). We also took into account particle size distributions (PSDs) measured using a Coulter counter. We collected samples at different times of the year and in various parts of the southern Baltic Sea: from the mouth of the River Wisła (Vistula), from coastal waters, and from open sea areas.

The rich empirical material was used to document the diversity of particulate matter properties in the examined environment. We analyzed how the typical relationships between the IOPs of suspended matter and the concentrations of the main water constituents (SPM or Chl*a*) can be influenced by differences in the general composition and size distributions of the suspended matter. We statistically described the possible impact on these relationships of the variability of composition ratios, such as POM/SPM and Chl*a*/SPM, as well as the impact of the variability of the average particle diameter weighted by the particle's projected area (D_A) calculated from measured PSDs. We also demonstrated the significant variability of the specific IOPs (SIOPs) on attempting to determine them in the classical way for our southern Baltic data, and we give a possible interpretation of this variability. On the basis of these analyses, we derived new, multicomponent IOP parameterizations, which are functions of up to four variables: SPM, POM, Chl*a* and D_A. These new parameterizations enable the IOPs of suspended matter to be characterized and predicted with better accuracy than with the often used standard relationships.

We believe that the new knowledge acquired should enable us to interpret more accurately and with greater awareness the results of various optical (in situ and remote) measurements, which are used nowadays as one of the basic sources of regularly available information on the state and processes occurring in the complex marine environment such as the Baltic Sea.

Thursday, Theme 5, from 09:00 – 10:30

Europe-wide thematic assessments of environmental status: a comparison with EU member states' own MSFD assessments

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Recent thematic assessments of the state of Europe's seas by the European Environment Agency (EEA) have applied multimetric indicator-based assessment tools (MIBATs) on a Europe-wide scale. This study compares the methodologies and results of the EEA thematic assessments with those of the European Union (EU) Member States' own assessment of 'good environmental status' for their second reporting under the Marine Strategy Framework Directive (MSFD).

Focusing on assessment of biodiversity (MSFD descriptor 1), eutrophication (MSFD descriptor 5) and contaminants (MSFD descriptor 8), we are able to show a large degree of agreement between EEA and Member States' identification of 'problem areas' and 'non-problem areas'. We report further on the comparisons with different regional seas and the Baltic Sea in particular and we discuss how the lessons learned can increase the potential for reaching the goal of harmonized assessment methods across marine regions and policy contexts.

A method for quantifying and graphically representing marine ecosystem service supply using expert judgement and field data

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Ecosystem structures, functions and a sustainable supply of ecosystem services (ES) are critical for the survival of life on earth. Across the globe, the European union, and the Baltic Sea region an ecosystem approach (EA) is being adopted in decision making in the marine context as a way to promote the protection and conservation of biological diversity and equitable sharing of benefits in society. An ES perspective is increasingly recognised for it's potential to support the implementation of ecosystem-based management of marine space through integrated ES assessment, which enable trade-off analysis and illustrate the effects of decisions ecosystems and human wellbeing.

Here an ES supply quantification method, which follows the widely used ES cascade model is presented. It allows quantification of service supply based on social and ecological expert knowledge and a range of other data sources. Using this method, it is possible to estimate the relative importance of species and habitats in ecosystem functioning and service supply, and conduct scenario analysis to quantify the impacts of environmental change using observed or estimated change in habitat spatial distribution or species biomass.

To illustrate how the method works, results of assessments conducted for several case study sites using expert judgement and video observation of the spatial distribution of species are presented. The case study sites are situated in NATURA2000 sites protecting stony reef habitats on the Latvian coasts, which are under pressure from various human activities but most significantly impacted by the spread of an alien species – the round goby, and eutrophication.

The results of the assessment are visually represented in diagrams and maps and describe the importance of benthic habitats. They highlight how the ecological and social value of NATURA2000 sites may have changed over time, further could inform analysis of the consequences of environmental change in social and economic terms and improve decision-makers' understanding of the link between marine ecosystems, service and benefit supply.

Farmers' incentives to enroll in long-term versus shorter-term voluntary agri-environmental contracts around the Baltic Sea – combining experimental data with large scale hydroeconomic modelling

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The EU Common Agricultural Policy (CAP) is under revision, and the European Commission's suggestions for CAP-Post 2020 indicate that environment and climate objectives will have a larger focus than previously (European Commission 2019, ECA 2017). The Agri-Environmental and Climate Schemes (AECS) is one program under the CAP umbrella, which aims to protect the environment including the aquatic, to reduce greenhouse gas emissions (GHG) and to improve carbon sequestration in agricultural soils.

In this study, we use data from a survey of farmers in 5 countries around the Baltic Sea, conducted in September 2017, to investigate their preferences for adopting agri-environmental contracts that support practices to reduce nutrient leaching and GHG emissions. The measures considered are set-aside, catch crops and reduced fertilization; all with effects on nutrient abatement and GHG. The contracts vary with respect to attributes that are important for both effects: the contract length, the possibility of premature termination, area enrolled in the contracts and availability of professional advice, as well as the level of annual compensation for entering into contract and implementing the measures. Using the choice modelling approach, we quantitatively describe farmers' preferences in terms of their willingness-to-accept compensation for specific attributes of these contracts, if implemented. The results differ substantially between farm types (farmers' characteristics), and support the argument for differentiating contract obligations and payments to improve the uptake of Agri-Environmental and Climate Schemes.

The payment levels derived from the choice model are then subsequently integrated into a cost-minimisation model where the spatial location of the contracts is optimised in order to achieve climate and nutrient load policy objectives. This is achieved by further extending the BALTCOST model (Nainggolan et al 2019, Hasler et al 2014). This extended model therefore captures farmer heterogeneous preferences, which in turn generates more realistic cost estimates. The results reveal the nutrient abatement and climate change mitigation potential of these contracts, if negotiated with farmers. The results can be applied to improve the design of country-specific support schemes in accordance with the revision of the Common Agricultural Policy.

The Impact of the Danish Catch Crop Subsidy Scheme on Farms' Economic and Environmental Performance

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*lead presenter

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This study investigates the impact of the targeted Danish catch crop scheme on nitrogen use and agricultural production for both arable and dairy farms. The scheme came into effect in 2017, and its objective is to reduce nitrogen leaching to coastal waters. Adoption is voluntary, and a farmer can apply for a subsidy if she/he plants catch crops, or undertakes alternative measures with a similar effect, in a field mainly located within a coastal water catchments (ID15 areas). Our econometric analysis is based on 1,177 arable and 858 dairy farms for the years 2015 to 2019. We apply a difference-in-difference propensity score matching to quantify the difference in the outcome variables between treated and non-treated farms. For arable farms, the results suggest that program participation significantly reduces nitrogen use per hectare while, at the same time, it increases the revenues per hectare from arable farming. For dairy farms, we could not detect a significant effect of program participation on either nitrogen use per hectare or revenues per hectare from dairy farming.

Integrated ecological economic modelling for cross sectoral water policy evaluation

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Improving coastal and marine water quality has been on the political agenda in Europe, as well as in other parts of the world, for decades. Nitrogen (N) and Phosphorus (P) loads from agricultural non-point sources (NPS) has been a continuous environmental problem (OECD 2012; 2017)). At EU level the most recent targets to reduce N loads and pollution are set in the EC Farm to Fork Strategy as part of the Green Deal (EC, 2020), with an aim to reduce N loads related to the agricultural sector by 50% in 2030. Phosphorus (P) reductions are also required to achieve water quality targets in freshwater bodies. HELCOM, being responsible for the regional agreement for the Baltic Sea, declares that further reductions of nutrient loads will be on the agenda for the update of HELCOMs Baltic Sea Action Plan in 2021. HELCOM has also introduced a strategy to strengthen the recirculation of nutrient in the Baltic Sea in the Regional Nutrient Recycling Strategy. Prior to these initiatives EU has implemented strong framework directives for the management of nutrient inputs to the aquatic environment, including the Water Framework Directive (WFD) and the Marine Framework Strategy Directive (MSFD).

In recent years, spatially differentiated regulation has been on the political agenda in Europe. The spatially targeted regulation has the potential to take into account differences in productivity and hydrology in agricultural catchments, but combining the diverse sets of information on agronomy, hydrology and economics for policy purposes is challenging.

We have developed an integrated model system TargeteconN_P for Denmark, and have applied this integrated catchment model system for cost-effectiveness assessment in 108 coastal catchments in Denmark with nitrogen reduction targets, and 187 lake catchments with phosphorus reduction targets to achieve the WFD objectives. The multiple interacting processes and data layers on nitrogen and phosphorus loss pathways and sources are included in the model and the model is used to assess the synergies and trade-offs between nitrogen and phosphorus abatement. The detailed modelling at catchment level, including data at field level, is novel and is used as decision-making support tool to enable analysis of the implications of different abatement strategies for the implementation of the WFD and BSAP.

Agricultural nutrient management by the littoral countries: a comparative assessment of implementation gaps

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Following decades of international collaboration to restore the Baltic Sea, the BONUS TOOLS2SEA project (https://projects.au.dk/bonus_tools2sea/) has synthesized evidence and insights from the available studies relating to the national implementation of the Helsinki Convention's provisions on agricultural nutrients, a main source of marine pollution.

TOOLS2SEA provides an assessment of the domestic implementation of measures agreed to limit diffuse agricultural pollution and the patterns of policy instruments applied. Despite the Helsinki Convention being unusually specific in detailing what measures countries should introduce, TOOLS2SEA finds many shortcomings. These are most pronounced in the larger countries (Poland, Germany and Russia), while the smaller countries perform somewhat better. The patterns of policy instruments applied differ, influenced by domestic politics, despite the legally binding nature of the Convention's Annex III part 2 on agriculture.

The limited use of complementary policy instruments suggests that other priorities overrule full and effective implementation, with engagement mirroring the advantages that a restored Baltic Sea can bring to countries. Using the European Agricultural Fund for Rural Development to support farmers in managing nutrients, particularly advisory services and investments in modern manure management technologies, represents a significant but missed opportunity for reducing agricultural pollution in most countries.

National policy styles and path-dependencies are inflicting on the abilities of Baltic Sea countries to deliver on their commitments under the Helsinki Convention. We contend that governments that are strongly concentrated vertically, while fragmented horizontally, are lacking capacity, including with respect to informal institutions that can leverage implementation. As a stocktaking of institutional impediments to sustainable development, the analysis has relevance to other international agreements where Baltic Sea countries are involved as key players.

Climatology of the marine heatwaves in the Baltic Sea

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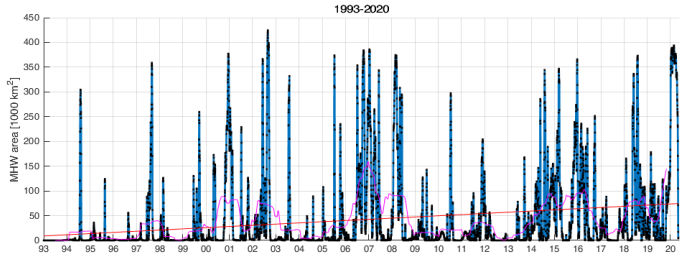
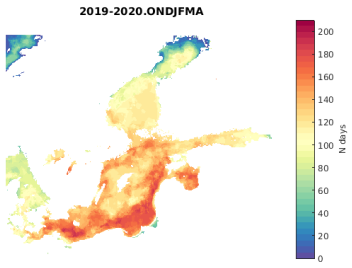
The marine heatwaves are extreme events of water temperatures above 90th percentile of daily climatological values and that might have shocking impact on marine ecosystem. Recently, the most pronounced marine heatwaves were recorded in summer 2018 and winter 2019/20. Usually, the marine heatwaves are described as the events at specific location. The aim of this study is to describe the climatology of the marine heatwaves in the whole Baltic Sea. Satellite remote sensing level 4 sea surface temperature data with daily resolution for the period 1982-2020 from the Copernicus Marine Environment Monitoring Service were used for the analysis.

The mean length and mean intensity of the marine heatwave events range 15 - 25 days and 2 - 3.2 °C, respectively. Long lasting marine heatwave events occur in the southern Baltic Proper, while the most intensive heatwaves in the Gulf of Riga and in the eastern Gulf of Finland. Mean annual frequency of the marine heatwaves is between 1.5 and 2.6 events per year without clear spatial pattern. Marine heatwaves can occur at any time of the year. We have calculated time series of the surface area of the Baltic Sea covered simultaneously by marine heatwave with daily resolution. There have been several marine heatwave events that have covered entire Baltic Sea, i.e. up to 390 000 km^2. The last such event was in winter 2019/20. In summer 2018, the maximum extent of the marine heatwave was 375 000 km^2.

Total length of the marine heatwave event in July-August 2018 was 40 days. Although, the marine heatwave was the longest in the coastal zone of the southern Baltic Sea, its mean intensity was low, i.e. 3 °C. The marine heatwave was slightly shorter (about 30 days) in the Bothnian Bay, but the mean intensity, i.e. 5.5 °C, was the highest there. Maximum length of the marine heatwave in winter 2019/20 was 195 days (from about mid-November 2019 to the end of April 2020). The marine heatwave was the most persistent in the southern – eastern part of the Baltic Proper with the mean intensity of about 2 °C. In the Gulf of Riga and western Gulf of Finland the mean intensity of the heatwave was 2.5-3.5 °C and the length of about 120-160 days.



MHW area in the Baltic Sea.



Duaration of MHW in winter 2019/2020

Swell hindcast statistics for the Baltic Sea

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Swell waves – waves that travel faster than the wind – affect processes both at the air and seabed interfaces. Swell waves are also the part of the waves field that, almost by definition, can be detached from the local wind conditions. The presence of swell thus potentially limits the reliability of studies where the impact of waves are derived using only the wind speed. While it is obvious that oceanic swell doesn't shape the Baltic Sea wave climate, it is equally obvious that neither is the Baltic Sea free from swell. Still, no prior study has reliably quantified the swell climate of the Baltic Sea. We now present such statistics using data from a wave hindcast. Our results show that long and high swell is rare. Nonetheless, swell in itself is common, with the sea state in large parts of the Baltic Sea being dominated by swell waves over 30% of the time. Areas where swell was most prevalent were found near the coast. Further, we showed that the de-coupling between swell and wind waves is different near the coast compared to the open sea. Our results are important for studies both at the air–sea and sediment–water interface.

Hidden from the satellite's eyes: centennial-scale trends and increasing sub-surface marine heatwaves in a coastal archipelago

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The increasing frequency, magnitude, and duration of marine heatwaves (MHW) is causing devastating changes to marine ecosystems globally. However, a key element in the determination of an extreme event is the climatological data used to define the reference period. In global MHW assessments, researchers often have to rely on satellite-derived sea surface temperature data. Nevertheless, these are inaccurate in coastal areas, are incapable of measuring sub-surface temperatures and have only been initiated in the 1980s. In this study, we evaluated 90 years of in situ surface and sub-surface (1 & 30 m depth, 10-day frequency) temperature data from a monitoring station in the Finnish coastal archipelago. We compared in situ data from the surface and sub-surface layers for multiple 30-year climatological periods, and also compared this to satellite-derived SST. We analyzed the occurrences of extreme temperature observations across 90 years and, in addition, utilized recently deployed automated sensors delivering daily, sub-surface temperature data to investigate marine heatwaves on the seafloor for the years from 2016 to 2020. The temperature distributions from 1931-1960 and 1961-1990 are significantly different to 1991-2020 for most days of the year in both layers. Satellite-derived and in situ-surface temperature distributions from 1982-2011 also differed significantly. Both cold and warm extreme temperatures occurred until the 1990s when cold extremes disappeared, and warm extremes started to dominate. Between 2016 and 2020 MHWs on the seafloor have occurred during all seasons of the year with record-breaking absolute temperatures in the summer and durations of up to 198 days. The increased frequency of unprecedentedly warm temperatures since the 1990s resulted in a shift of temperature distributions between consecutive 30-year climatological periods so that temperatures that have been considered as a warm extreme in the past have become "normal".

Present and future marine heat waves in the Baltic Sea

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The most recent IPCC AR6 on climate change highlights marine heat waves (MHW) as particular challenge for physical, biological, social and other geoscientific and environmental disciplines. Studies suggest that many regions of the world ocean could end in a permanent heat wave state at the end of the century based on present-day metrics. The Baltic Sea is among the most rapidly warming regions worldwide and therefore particularly vulnerable to MHWs. Consequently, it is excellently suited to study the impact of MHW on various climate and environmental services.

Here we assess the capability of state-of-the-art Baltic Sea models from the Baltic Sea Model Intercomparison Project (BMIP) to simulate marine heat waves. We further explore the frequency, duration, the spatial extend, and intensity of MHW during the last 6 decades (1961-2018). Finally, we employ a high resolution future climate ensemble to investigate future MHW dynamics up to 2100 and provide a first estimation on uncertainties.

Our results indicate pronounced decadal variations during the hindcast period which is robustly represented in all BMIP models. However, significant differences are found in the most extreme MHW classes on the year-to-year scale and in particular during the most recent decade. In parallel, we find stronger rising trends of yearly maximum temperatures than in annual and seasonal average water temperatures. Systematic model differences are likewise found in the duration and frequencies of MHW along with differences in the spatial pattern: Largest discrepancies occur in the Bothnian Sea and Bothnian Bay. Overall, we conclude that inter-model discrepancies are more pronounced in the extreme temperature regime compared to the average regime which translates in higher uncertainties regarding MHW.

Global climate change projections up to the year 2100 were downscaled using a hierarchical suite of existing high resolution regional atmosphere and ocean models for the Baltic Sea. We find significant increases in frequency, intensity, and spatial extension already in the mid-century around 2050 that clearly exceed the decadal variability of the historical period. At the end of the century most Baltic Sea basins end up in permanent moderate MHW state when present day metrics are applied. However, our preliminary results further indicate that at least the most extreme effects of climate change on MHW could be avoided by already moderate climate mitigation efforts and by limiting global warming to the 1.5° or 2°K targets of the United Nations Framework Convention on Climate Change (UNFCCC).

Extreme large heat content and low ice extent in the Baltic Sea during winter 2019/20

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Under global warming, exacerbated weather and ocean conditions are expected. The current study represents the response of the Baltic Sea to the extremely warm weather conditions in winter 2019/20, which could be explained by interaction of large-scale atmospheric circulations linked to a high positive NAO index and an unusual high positive AO index. During the winter of 2019/20 (December to February), upper ocean (0-50m) warming of the Baltic Sea reached an unusually high value of 295 MJ/m^2. This observed heat storage is the highest value on record since 1993 - 1.7 times higher than the record warming of 178 MJ/m^2 during the winter of 2000/2001. Maximum ice extent of the Baltic Sea was only 45 000 km^2 which is the lowest value on record since 1720.

On average, calculated over the period 1993-2014, the Baltic Sea energy loss to the atmosphere is approximately 64 W/m^2 during the winter season. Average energy loss to the atmosphere was smaller by 29 W/m^2 during the 2019/20 winter season due to significantly warmer atmosphere and lower sea ice volume. This anomaly would explain about 77% of the excess heat storage of the topmost 50 m of the Baltic Sea. Due to small sea ice volume, the latent heat in sea ice accounted for 5-10% of total heat loss.

Over the period 1993-2019, the heat content of the upper layer (0-50 m) of the Baltic Sea has increased at a rate of 0.20 W/m^2. The statistically significant correlation coefficient between the upper 50 m layer heat content anomaly and maximum sea ice extent anomaly in December-February was -0.7. The most recent 30-year period (1991 - 2020) with a limited sea ice extent is statistically significant compared to any other 30-year period since 1720.

Wave climate change in the Gulf of Bothnia

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Wave climate change in the Gulf of Bothnia in 2030–2059 was investigated in SmartSea project using regional wave climate projections. For the simulations we used wave model WAM. As the atmospheric forcing for the wave model we had three global climate scenarios (HADGEM2-ES, MPI-ESM, EC-EARTH) downscaled with RCA4-NEMO regional model. The ice concentration for the wave model was obtained from NEMO ocean model simulations made in SmartSea project using the same atmospheric forcing. We used both RCP4.5 and RCP8.5 greenhouse gas scenarios. The spatial resolution of the simulation data was 1.8 km, enabling detailed analyses of the wave properties near the coast. From the simulation data we calculated statistics and return levels of significant wave heights using extreme value analysis, and assessed the projected changes in the wave climate in the Gulf of Bothnia. The projected increase in the significant wave heights is mainly due to the decreasing ice cover, especially in the Bothnian Bay. In the Bothnian Sea, extreme wave heights increase near the coast. The highest projected 100-year wave heights are found in the northern Bothnian Sea.

Filling the puzzle, Baltic Sea surface salinity from space

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Remote sensing has for long time being standard method for mapping the surface processes in the sea. Surface temperature, sea ice, plankton blooms, sea level have been measured with success. Salinity has been the essential missing piece from remote sensing products in the Baltic Sea until now.

European Space agency funded a group of projects for developing better satellite-based products for the Baltic Sea, Baltic+ projects. Among these was Baltic+ Salinity Dynamics, which was led by ARGANS Ltd (UK) and participated by Barcelona Expert Centre (BEC/ICM-CSIC, Spain) and Finnish Meteorological Institute (FMI, Finland).

Salinity is a parameter that is very challenging to observe from space especially in the temperate small sea areas. Considerable efforts were needed in BEC to develop algorithms and methods to build products that can be considered useful in the Baltic Sea research. We now believe that such products are here though needs for further developments have been identified.

At present we have daily surface salinity maps for the Baltic Sea for 2011 – 2019. Comparison with in-situ data shows that the general levels and large-scale gradients of salinity is reasonably reproduced in the product. It seems that time variability of salinity in the products is larger than in in-situ data, but seasonal variations are similar. The products are published (http://bec.icm.csic.es/new-baltic-smos-sea-surface-salinity-products/).

Near-coastal marine habitat mapping using topo-bathymetric lidar

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Marine habitats in the near-coastal environment contains valuable ecosystems, such as stone reefs, sandbanks and submerged aquatic vegetation (SAV). However, these habitats are under pressure in many areas due to human impact and climate change. If we want to conserve the habitats, it is important to gain knowledge on their location, spatial distribution and temporal changes.

Mapping of these marine habitats is traditionally carried out using vessel borne geophysical surveying systems, such as multibeam echosounder (MBES), sidescan sonar and/or seismic acquisition systems, combined with ground truth verification. However, it is difficult or even impossible to map and investigate seabed habitats with the traditional surveying methods in the near-coastal zone in high spatial resolution due to challenging environmental conditions and vessel draft limitations. The lack of data in shallow water is reflected by a gap of information, often called the "white ribbon", along the coast, where there is little or no data at all. In recent years, airborne topo-bathymetric (green wavelength) lidar has emerged as a new possible method for collecting bathymetric information with high resolution and full-coverage in shallow water (e.g. Andersen et al., 2017). Thus, topo-bathymetric lidar may be a good choice for carrying out investigations of marine habitats in the near-coastal zone.

The main objective of this study was to investigate the potentials and limitations of mapping marine habitats, specifically stone reefs, sandbanks and SAV, in shallow coastal water using topo-bathymetric lidar. Airborne topo-bathymetric lidar data were collected by Airborne Hydro Mapping GmbH (AHM) in September 2015 in the Hyllekrog-Rødsand marine Natura 2000 habitat area, which is located in Rødsand lagoon in southern Denmark. The water depths in the lagoon are ranging between 0-8 m. The data processing included several steps, e.g. swath alignment, point cloud classification, refraction correcting and generation of a 0.5 m x 0.5 m digital elevation model from the processed point cloud.

The study demonstrated that it is possible to detect and classify stone reefs, sandbanks and SAV in very shallow coastal waters using airborne topo-bathymetric lidar. However, the study also demonstrated certain limitations using the lidar technology, primarily; 1) large spatial variations in maximum laser beam penetration depth, and 2) inability to distinguish between species of SAV.

Reference:
Andersen M.S., Gergely A., Al-Hamdani Z., Steinbacher F., Larsen L.R., Ernstsen V.B. (2017). Processing and performance of topobathymetric lidar data for geomorphometric and morphological classification in a high-energy tidal environment. *Hydrology and Earth System Sciences*, 21: 43-63, DOI: 10.5194/hess-21-43-2017.

Monitoring the water extent of Swedish wetlands using satellite images and Google Earth Engine

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Wetlands are essential for controlling the global climate, sustaining the global hydrological cycle, conserving ecological variety, and ensuring human wellbeing. As wetlands are one of the most endangered environments, they require constant monitoring. In Sweden, there are 68 sites recognized as wetlands with international importance with Baltic coastal wetlands accounting for roughly a fourth of them. The inundated area and the connectivity of the wetlands are affected by changing climate, for this reason, we need to better delineate water in these valuable environments. Advances in remote sensing technologies helped us to improve the monitoring of the wetlands; however, mapping the water under vegetation is still a challenge for delineating water extent. Here we employed different polarization of SAR sentinel-1 data in combination with optical sentinel-2 data. We used machine learning clustering algorithm provided in the cloud computing platform of Google Earth Engine, to detect the increased backscatter coming from flooded vegetation duo to the double-bounce of the radar signal. At this stage analysing the increase in the interferometric coherence was also helpful as a sign for inundated vegetation. Furthermore, we used Otsu's thresholding method to extract also open water in the wetlands. Our workflow improved water delineation in Swedish wetlands by detecting hidden water below the vegetation which was not recognized by the optical methods. This will help understanding wetlands' water availability changes and increase their resistance to the impacts of human activity and climate change.

Long-term remote analyzes of primary production of the Baltic Sea based on data from the SatBałtyk System

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To meet the requirements of present-day oceanography, especially in tracking changes in the marine environment the comprehensive, precise and high-quality data should be used. Since 2015, such data has been shared by the SatBałtyk System, an innovative tool for monitoring of the Baltic Sea environment. This system provides reliable information by effectively combining three types of data: satellite data used for day-to-day monitoring of the whole Baltic Sea area, model data using hydrodynamic and ecohydrodynamic models describing phenomena taking place in the marine environment, and point data obtained using traditional oceanographic measurement techniques. As a result, the SatBałtyk System presents on the website www.satbaltyk.pl current daily maps of the spatial distribution of values of several dozen curent characterristics of the Baltic Sea environment, including the coastal zone as well as the state and optical properties of the atmosphere. The available data set covers 8 selected areas: 1. Atmosphere, meteorology, 2. Hydrology, 3. Ocean optics, 4. Radiation budget, 5. Sea water components, 6. Phytoplankton, photosynthesis, 7. Coastal zone, 8. Hazards. Such complete information on the state of the marine environment supports advanced analyzes of complex physical, chemical and biological processes occurring in the Baltic ecosystem. There is no doubt that one of the most important processes in the sea is the photosynthetic conversion of solar energy into chemical energy stored in biomass. The consecutive stages of this transformation, starting from the inflow of radiation to the sea surface, through the transport of this radiation into the sea and its conversion in the processes of absorption and scattering, to primary production, can be traced using the resources of the SatBałtyk System. Analyzes can be performed for any period, starting from 2010, for the entire Baltic Sea area with a resolution of 1 x 1 km. This shows the spatial and seasonal variability of both light-related processes in the sea, and the environmental factors that influence these processes. Thanks to the data resources offered by the SatBałtyk System, for the first time we have the possibility of long-term detailed analysis on such a scale of processes controlled by solar radiation in the Baltic.

The SatBałtyk System was developed and launched by SatBałtyk Scientific Consortium as a result of the project “Satellite Monitoring of the Baltic Sea Environment (SatBałtyk)” realized in the frame of European Funds (Innovative Economy Programme).

The SatBałtyk Scientific Consortium associates four institutions: the Institute of Oceanology PAN in Sopot –the coordinator, the University of Gdańsk, the Pomeranian Academy in Słupsk and the University of Szczecin.

A method for assessment of the general circulation model quality using K-means clustering algorithm

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The model's ability to reproduce the state of the simulated object or particular feature or phenomenon is always a subject of discussion. Multidimensional model quality assessment is usually customized to the specific focus of the study and often to a limited number of locations. In this paper, we propose a method that provides information on the accuracy of the model in general, while all dimensional information for posterior analysis of the specific tasks is retained. The main goal of the method is to perform clustering of the multivariate model errors. The clustering is done using the K-means algorithm of unsupervised machine learning. In addition, the potential application of the K-means clustering of model errors for learning and predicting is shown. The method is tested on the 40-year simulation results of the general circulation model of the Baltic Sea. The model results are evaluated with the measurement data of temperature and salinity from more than one million casts by forming a two-dimensional error space and performing a clustering procedure in it. The optimal number of clusters that consist of four clusters was determined using the Elbow cluster selection criteria and based on the analysis of the different number of error clusters. In this particular model, the error cluster of good quality of the model with a bias of 0.4 °C (std=0.8 °C) for temperature and 0.6 g kg^{-1} (std=0.7 g kg^{-1}) for salinity made up 57% of all comparison data pairs. The prediction of centroids from a limited number of randomly selected data showed that the obtained centroids gained a stability of at least 100 000 error pairs in the learning dataset.

The second application consists of the quality assessment of the state-of-the-art coupled physical and biogeochemical numerical model reanalysis data from Copernicus Marine Environment Monitoring Service for the period of 1993-2017. The 2-dimensional error space of salinity and dissolved oxygen as representatives of physical and biogeochemical models of the coupled model system was formed. Five clusters were selected using the Elbow cluster selection criteria after testing a different number of clusters. 62% of comparison points (total number of the points was 651 565) show a good match between the model and measurements. A somewhat reduced performance is geographically in the Gulf of Finland, Gulf of Riga and at the Danish straits, vertically within the redoxcline and at the bottom of the Gotland Deep, and seasonally during summer. The spatial distribution of bottom salinity and oxygen errors for different clusters shows that, although the model and data match is predominantly good, the share of overestimated oxygen concentration errors is still significant.

eCUDO.pl – Polish Oceanographic Data and Information System for improved exploration of Baltic data resources

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The growth of data volume managed by organizations involved in research in Environmental and Earth Sciences turned exponential within last years. Data covering domain of one's interest are distributed across variety of infrastructures, data centers, collections, and formats. This makes discovery of all available sources of data and their harmonization extremely challenging, and rising the assurance of FAIRness of data as the most emerging problem for data managers.

Consortium of organizations engaged in research and exploitation of marine resources, established as POLMAR, together with Scientific Consortium SatBałtyk, consisting of 7 organizations engaged in research and exploitation of marine resources, for many years has led actions targeting harmonization, integration and coordinated provisioning of environmental data resources. This initiative merges the most of the organizations involved in marine research and continuous acquisition of oceanographic data in Poland to conduct activities towards the deployment of operational state of the system delivering demanded oceanographic data and products to the users and is heading to establish Polish Oceanographic Data Committee.

The complexity of distributed system design forced by geographical topology and technology state of the datacenters infrastructures drives the innovation for the efficient management of extensive data infrastructures. Presented result of these works is system „Elektroniczne Centrum Udostępniania Danych Oceanograficznych eCUDO.pl" developed by project No POPC.02.03.01-00-0062/18-00 funded within the frame of Operational Programme Digital Poland for 2014-2020.

This system enables users with integrated tools for data analysis and to provide products based on information explored from diverse sources: archives, online data streams, satellite data, numerical models and fleet of autonomous measuring devices. Unified data formats and protocols will boost development of the services based on environmental data. Advanced services provided for clients (including data analysis services) extend availability of oceanographic data both to Polish and European organizations.

Thursday, Theme 1, from 16:00 – 17:30

Storm surges in the Baltic Sea: shallow lagoons at risk in the future

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Sea level rise (SLR) increases the likelihood of storm surges by shifting their frequency distribution to higher base levels. Along the German Baltic Sea coast, a number of shallow coastal lagoons are located which provide a natural protection against storm surges by significantly reducing the surge heights inside the lagoon compared to the open coast.

In this study we investigate the effect of SLR on storm surge heights by using a numerical model of the Western Baltic Sea with a resolution of 200 m. We find that SLR linearly increases storm surge heights at most areas of the open Western Baltic Sea coast, e.g., a storm surge of one meter height in the present time would increase to 1.2 m height at a SLR of 20 cm. For shallow lagoons on the other hand, the results suggest surge height increases of up to 30% additional to SLR, e.g., at a SLR of 20 cm the surge height inside the lagoon would increase to 26 cm. We investigate this behavior in further details with a one-dimensional model to study the parameter space using following lagoon parameters: surface area of the lagoon, depth and width of the connection to the Baltic Sea, friction, as well as varying surge shapes, and heights.

Our results highlight that additional (non-linear) surge height increase needs to be considered when evaluating and planning future coastal protection measures in shallow lagoons.

Long waves in the Port of Klaipėda

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The hazardouse situations in semi-enclosed water bodies and harbors mainly occur due the unexpected and rapid water level change. Thus cases are often induced by the impact of long waves or by resonance in small basins such as harbors or/and marinas excited by shorter waves. As result it can disrupt operational work of ports, damage small vessels and etc.

Even though Port of Klaipėda is a small port, strategically and geographically, it has several specific and unique features among the ports in the Eastern Europe. The port is located on the south-east coast of the Baltic Sea, in the Strait of Klaipėda, in the middle of the 12 km long and 1.5 km inlet where the width of the free-flowing part is 0.4 km.

The entire strait is not only the basis of the port aquatorium and a vital navigational artery from the Baltic Sea to the Curonian Lagoon, but also a complex water system that connects two water basins with different sizes, depth and properties include substantially contrasting salinity and density. Its quaysides are well sheltered from open sea waves but the port area still hosts dangerous water level oscillations which origin is still are not well defined. The aim of this study is to identify occurency and main characteristics of the long waves, with the period from minutes to several hours with the recognition of its origin and casuality.

The analysis of spectral composition of these oscillations is based on continuous pressure recordings with a frequency of 4 Hz in Port of Klaipėda during the stormy season December 2016–January 2017 and calm season in the June-August 2021. The majority of the energy of oscillations is concentrated in two frequencies bands. Considerable water level changes occurred owing to infragravity motions with periods >30 s (<0.03 Hz) and disturbances with the typical periods of wind waves at the Lithuanian coast with periods of 3–10 s (0.1–0.3 Hz). The highest peak in the wind wave frequency band corresponds to typical storm conditions in the Baltic Sea with periods 9–5 s. While the typical amplitudes of oscillations in this range were modest, particularly hazardous changes in the water level, with amplitudes >0.5 m, were created at lower frequencies. The recording reveals the presence of harbor oscillations with periods 30–200 s (0.005–0.03 Hz) and seiches of the Curonian Lagoon with periods >1200 s (<0.0008 Hz).

Re-evaluating Baltic Sea wave energy studies using a new estimate for wave energy in finite-depth

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There exists numerous studies of the wave energy resource of the Baltic Sea, all of them using various approximations that have not been properly validated. We present a new method to account for the impact of a finite water depth. This method is well suited for estimating the wave energy resource in marginal seas in cases where only bulk wave parameters are available, which is more often than not the case. We validate this method in the Baltic Sea and simultaneously quantify the errors of previously used simpler approximations. We combine results of our new approximation with power matrices of two wave energy converters (established by manufacturer) to estimate the efficiency and output of said converters for the Baltic Sea. These simulated outputs are compared to a nearby land-based wind park. Our results show that some of the previous estimates of the wave energy potential in the Baltic Sea might have been biased high.

Quasi-steady patterns of circulation in the Eastern Baltic Proper

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Circulation is a key player in the creation of physical and biogeochemical fluxes in the Baltic Sea. The main goal of the present work was to study the quasi-steady circulation patterns under different atmospheric forcing and stratification conditions. Six months of ADCP current measurements, two monthly underwater glider surveys, temperature, salinity and current recording in single-point moorings, and numerical modelling with GETM were arranged in the Eastern Baltic Proper.

The vertical velocity shear maxima and its temporal variability were strongly linked to locations of the seasonal thermocline and the halocline. Upwelling and downwelling cells were detected in the ADCP velocity profiles. Northward (southward) boundary current in the upper layer was observed at the eastern coast of the Baltic Proper in the case of southwesterly (northerly) wind. However, the geostrophic current primarily contributed to the meridional velocity at the boundary.

Quasi-steady, three-dimensional circulation patterns in zonal scale of 20-60 km were detected under different forcing conditions. The sub-halocline quasi-permanent gravity current with a width of 10-30 km from the Gotland Deep towards north to the Farö sill was detected in the simulation data and was confirmed by the Argo float trajectory. This current, from the Gotland Deep to the Farö sill, is important deeper limb of the overturning circulation of the Baltic Sea. The mostly northward flow occurred at the sill according to the simulation.

The circulation regime had an annual cycle due to seasonality in the wind forcing. The boundary current at the eastern coast of the Baltic Proper is more frequently northward during the winter period. The sub-halocline current towards the north was strongest in March-May when southwesterly winds were less frequent, and it was weakest in November-December.

Rip currents in the southern Baltic Sea coastal zone

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Rip currents, although they are regarded as rare events in the southern Baltic Sea coastal zone, are important part of the nearshore current system. Once initiated, these flows can significantly affect the morphodynamics due to the feedback mechanism and in specific hydro- and litomorphological conditions can cause changes in the local bathymetry. The studies conducted so far have confirmed that the conditions favorable for the generation of rip currents in that region is swell, characterized by fairly flat long waves. The main objective of this research is to analyse a possible change in the frequency of such wave conditions in the future due to climate changes. Described in the literature predictions of wave climate changes in this part of the Baltic Sea will be related to the results of the simulation of coastal zone currents with the use of XBeach numerical model under various wave conditions.

Circulation and transport in the Finnish Archipelago Sea

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The Finnish Archipelago Sea is a complex sea area with numerous small island and islets located between northern Baltic Proper and the Bothnian Sea. This otherwise shallow sea area, with mean depth of 19 m, is sliced with numerous deeper channels. These channels strongly steer the currents in the area, and the narrowness of the channels forces current speeds to rise into significant magnitudes.

Finnish Meteorological Institute has conducted numerous measurement campaigns since 2004 using Acoustic Doppler Current Profilers (ADCP's) to study currents in the Archipelago Sea. In our work, we present these measurements, located in 8 different channels within the sea. Most measurements cover 5 to 7 months (ice-free season), however some more recent measurements have covered the full year.

In most areas of the Archipelago Sea the mean current speed is between 0.04-0.01 m/s. The highest values exceed 0.4 m/s, but are limited to specific wind conditions. In the northeastern channel however, currents regularly reach magnitudes of 0.6 m/s and even 1.0 m/s currents have been measured. In our study we examine what type of conditions drive these extreme events. We also aim to determine to what extent we can use these measurements to study the water exchange across the Archipelago Sea.

Thursday, Theme 2, from 16:00 – 17:30

Amphipods' grazing and excretion loop facilitates *Chara contraria* persistence in a eutrophic lagoon

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Charophytes represent an important group of submerged macrophytes which are distributed from tropical to polar regions in freshwater, brackish and marine habitats. They form dense stands with a recognized structural and functional role in the ecosystems they colonize. Charophytes are capable of modifying both an abiotic environment and the wider biological community through non-trophic interactions in common with many other macrophytes. Such interactions include competition with other primary producers, the increase of the three-dimensional complexity of the benthic environment, the provision of a physical refuge to zooplankton and small fishes or serving as a substrate for specific periphytic assemblages. Promoting and maintaining biological diversity charophyte stands represent valuable ecosystems threatened by eutrophication-related phytoplankton and epiphyte blooms. Despite eutrophic conditions in transitional waterbodies such as the Curonian Lagoon, dense stands of several charophytes species, particularly of the genus Chara, can be found confined in shallow and illuminated sandy sediments. Here, charophytes stands support relatively high diversity and abundance of mesoherbivores and periphyton.

The mechanisms allowing the persistence of charophytes and associated benthic species in eutrophic environments are important but poorly studied. We analyzed the benthic primary production and respiration, and inorganic nitrogen (N) fluxes in a *Chara contraria* stand within a eutrophic estuary system (northern part of the Curonian Lagoon) via light and dark intact core incubations. Rates were contrasted with those measured in adjacent unvegetated sediments. Additionally, O_2 production was measured in fragments of *C. contraria* and in the associated community of epiphytes, whereas O_2 respiration and ammonium (NH_4^+) excretion rates were measured in incubation of amphipods (*Pontogammarus robustoides*) alone. The results from core incubations suggest high primary production and respiration within charophyte stands, resulting in pronounced daily O_2 variations in the overlaying water. The incubations of charophyte fragments and associated epiphytes indicate that the latter supports a major fraction of the benthic primary production. The large production of dinitrogen in the dark indicates the occurrence of denitrification, which is suppressed in the light due to primary producers-bacteria competition. On a daily basis, the charophyte stand was a sink for N via assimilative NH_4^+ uptake and a dark nitrate sink via denitrification. Interestingly, active NH_4^+ excretion by the abundant and active amphipods supported nearly 40% of the N uptake by the primary producers. We speculate that amphipods continuously feed on epiphytes growing on charophytes, favoring *C. contraria* persistence and recycling large amounts of N via herbivory and excretion that are immediately re-used by benthic primary producers. This grazing, excretion and assimilation loop may represent an example of macrofauna-macrophyte mutual facilitation and a mechanism easing *C. contraria* competition under eutrophic conditions.

Danish eelgrass meadows capacity of capturing and storing organic carbon and nitrogen

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Seagrass meadows provide many ecosystem services, but their ability to store significant amounts of organic carbon (C_{org}) in their sediments for long periods is currently a major focus given its potential to slow the pace of climate change. The C_{org} storage capacity of seagrass along the Danish coasts has been previously studied in the top 10 or 25 cm of sediment, however, C_{org} is also accumulated at deeper depths. This study assesses the C_{org} and nitrogen (N) stocks and accumulation rates in the top 50 cm of sediment underneath eelgrass (*Zostera marina*) meadows, at vegetated and nearby currently unvegetated plots located in protected and exposed sites of four Danish fjords. The C_{org} stocks in 0.5 m thick eelgrass sediments were not significantly different between vegetated (2.2 ± 0.4 kg C_{org} m^{-2}, mean ± SE) and unvegetated plots (3.13 ± 1.1 kg C_{org} m^{-2}) (Mann-Whitney U test, W = 33, p = 0.96). Our results indicate a lower C_{org} storage in the top 25 cm of sediment (1.16 ± 0.19 kg C m^{-2}) compared to a previous study for Danish eelgrass meadows (4.3 ± 1.18 kg C m^{-2}). Measurements of ^{210}Pb showed a lack of accumulation of excess ^{210}Pb which precluded an estimation of reliable C_{org} accumulation rates and suggested low rates of sediment accumulation in most cores. Only two cores from vegetated plots could be dated, revealing that C_{org} was accumulated at 14.6 and 41.3 g C_{org} m^{-2} $year^{-1}$ over the last decades. As for the N stocks, they were 0.22 ± 0.03 kg N m^{-2} at vegetated plots, and 0.23 ± 0.04 kg m^{-2} at unvegetated plots. The N accumulation rates over the last decades for the dated cores were 1.6 and 4.3 g N m^{-2} $year^{-1}$. Stable isotope mixing models indicated that the sedimentary organic matter below eelgrass meadows came mainly from allocthonous sources (~65-80%). Moreover, there were no systematic significant differences in soil C_{org}, N stocks, or seagrass contribution between vegetated and unvegetated plots in both exposed or sheltered fjord sites.

37% of the retrieved sediment cores reached deeper than 50 cm in the sediment. In these deeper cores, depth profiles of carbon and nitrogen content showed two or even three-fold increasing trends with depth below 50 cm. Moreover, the depth profiles of $\delta^{13}C$ and $\delta^{15}N$ in these longer cores pointed to a higher seagrass and lower allocthonous contribution with depth. In other words, depth profiles point to a decreased input of eelgrass-derived material and increased eutrophication in more recent sediment layers, suggestion that eelgrass beds have a reduced ability to function as a C_{org} and nutrient sink. Overall, our results showed that C_{org} stored in sediments of eelgrass meadows can be highly variable within and between fjords, likely driven by the interplay of many physical and ecological factors, and that current Danish eelgrass meadows are most likely less efficient than in the past in terms of C_{org} and N burial and storage.

Could the seagrass seed microbiome play a role in successful restoration of seagrass meadows?

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Seagrasses, marine flowering plants, form vast meadows in the coastal areas worldwide that are of substantial ecological and economical value. These vulnerable ecosystems are under threat due to climate change, eutrophication and other human influences. The plants live in close relationship with microorganisms – together they represent a functional unit, the holobiont. The seagrass holobiont as a whole reacts to environmental changes, but yet we know little about the interactions and the establishment of a healthy microbiome. As the microorganisms interact with the seagrass host during the whole life cycle already the seeds carry a microbiome that influences the most critical early life stages of the plant. While seed microbiomes of terrestrial plants and their influence on the host are well studied, this knowledge is lacking for seagrasses. We sampled eelgrass (*Zostera marina*) seeds, leaves and roots along the salinity gradient of the German Baltic Sea coast and and studied their epiphytic prokaryotic and eukaryotic microbial communities (16S/ 18S rRNA gene amplicon sequencing). Here we present insights to the microbiome of eelgrass along a salinity gradient regarding community structure and function. Further we take a closer look on the eelgrass seed microbiomes and highlight the implications it has for the germination of the seeds and the establishment of healthy seedlings, a prerequisite for recovery and restoration of seagrass ecosystems in the Baltic Sea and worldwide.

Exposing changing phenology of fish larvae by modeling climate effects on temporal early life-stage shifts

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Changing environmental conditions are influencing the seasonal timing in life history events of organisms. Such shifts in phenology are often linked to increasing temperatures that stimulate faster developments or earlier arrivals. This phenomenon has been demonstrated in terrestrial and aquatic realms, but data and knowledge are limited on how early life stages of fish are affected over long-term and broad environmental scales. Here, we analyze two decades (1974-1996) of size class-specific Baltic herring *Clupea harengus membras* L. larval data along the whole coast of Finland to expose shifts in phenology linked to changes in environmental covariates. We use a novel Bayesian hierarchical spatio-temporal hurdle model that describes larval occurrence and abundance with separate processes. Abundances are modeled with the Ricker population growth model that enables us to predict size-specific larvae groups in relation to the environment while accounting for population density dependence. We quantify shifts in phenology at multiple life stages, based on first appearances of smallest larvae (<10 mm) and by detection of higher proportions of larger larvae (>15 mm) appearing earlier than they have done historically. Our results show a strong signal in shifting phenology of the larvae toward an earlier development of 7.7 d per decade. Increasing temperature had a positive effect on the earlier development of larger larvae. Additionally, we highlight that the survival of larvae becomes more density dependent as their size increases. Our modeling framework can reveal phenological shifts of early life stages in relation to environmental change for survey data that do not necessarily cover the onset of reproduction.

Food web organisation of the fish community reflects prey availability in two protected areas of the western Baltic Sea

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Bottom trawling disturbs the physical and geochemical integrity of the seabed, harms benthic fauna and can negatively affect benthic community structure. Shifts in benthic community structure due to frequent trawling can alter the availability and composition of prey for fish. Here, we quantitatively compared the trophic organisation of the benthic community including demersal fish in two designated but not fully implemented Natura 2000 marine protected areas (MPA) in the exclusive economic zone of the German Baltic Sea, the Fehmarnbelt area in the Bay of Kiel and the Oderbank area in the Bay of Pomerania. We used stable carbon and nitrogen isotopes ($\delta^{13}C$ and $\delta^{15}N$, respectively) combined with stomach content analyses to assess the trophic organisations of benthic community of both food webs. We observed a greater range in $\delta^{13}C$ values in the benthic community in the Fehmarnbelt area compared to the Oderbank area. This indicates a higher diversity of prey species and more complex feeding pathways from benthos to fish, that was confirmed by stomach content analyses. The similar trophic position estimated using $\delta^{15}N$ values of individual benthic species suggested similar food chain length in the Fehmarnbelt and Oderbank areas. The food web structure and organisation within and in close proximity to the MPA were similar in both areas. Our results will help to evaluate the consequences of the exclusion of bottom trawling on food web organisation.

Juvenile fish associated with pondweed and charophyte habitat: a case study using upgraded pop-up net in the estuarine part of the Curonian Lagoon

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Submerged vegetation enhances heterogeneity of sublittoral habitats therefore macrophyte stands are essential elements of aquatic ecosystems to maintain a diverse fish fauna. Fish-habitat relations have been extensively studied in streams and coastal waters, but in lakes and estuaries are still underestimated. The aim of this study is to assess temporal (diurnal and seasonal) patterns of fish juvenile assemblages associated with common submerged macrophyte habitats, which have significantly spread during the recent decade in the upper littoral part of the Curonian Lagoon. The assessment was performed by means of upgraded pop-up net approach resulting in much precise sampling versus other techniques. The optimal number of samples (i.e. pop-up nets) required to cover >80% of the total number of fish species depended on the time of the day in both study sites: at least 7 and 9 nets in the evening (18-24 pm) in the Southern and Northern study sites, respectively. In total, 14 fish species were recorded, where perch and roach dominated (respectively 48% and 24%). From multivariate analysis, water salinity and seasonality (temperature or sampling month) were primary factors determining fish assemblage composition. The southern littoral area, less affected by brackish water conditions, hosted a higher number of species (13) than in the Northern site (8). In the latter site, brackish water tolerant species (three-spined and nine-spined sticklebacks, spiny loach, roach and round goby) were more abundant than in the Southern site. Perch and ruffe dominated in the Southern site. Spiny loach and nine-spined stickleback were more frequent in September, while ruffe, perch and roach occurred more in July. The diel dynamics of the common species such as perch, roach and ruffe followed the general pattern, but it was species specific and depended on the study site, habitat and month. The species composition between macrophyte habitats did not significantly differ; however, it differed from the results obtained in 2005 at both study sites indicating the importance of expanded charophyte stands during the last decade in the littoral zone.

Friday, Theme 1, from 11:00 – 12:15

The influence of different oxygen regimes on energy metabolism and ecological functions of *Mya arenaria*

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Coastal hypoxia is major stressor for shallow benthic sessile organisms. Hypoxia might negatively influence aerobic ATP production and energy-dependent functions such as bioturbation and bioirrigation. We exposed the soft-shell clam, *Mya arenaria*, a widely distributed bioturbator in the Baltic Sea, to constant hypoxia (~20% of air saturation), cyclic hypoxia (~10-50% of air saturation) and normoxia (~100% of air saturation). To mimic conditions that occur in coastal hypoxic zones, we changed the CO_2 and pH levels along with the oxygen levels. We assessed the influence of different oxygen regimes on respiration, bioirrigation capacity, digging performance, energy reserves (lipids, carbohydrates and proteins) and the mitochondrial electron transport system (ETS) activity of the clams. Oxygen regime had no effect on the whole-organism oxygen consumption. Lipids were an important fuel source for clams acclimated to constant hypoxia. Clams acclimated to cyclic hypoxia synthesised carbohydrates and proteins during their recovery phase and used them during the hypoxic phase. ETS activity increased in clams acclimated to cyclic hypoxia during the recovery phase. Clams acclimated to constant and cyclic hypoxia dug slower than their normoxic counterpartners. Bioirrigation capacity decreased in clams acclimated to constant hypoxia but not cyclic hypoxia. Our results indicate that acclimation to constant or cyclic hypoxia impede bioturbation and bioirrigation capacity of *Mya arenaria* and therefore might affect their ecological function in coastal ecosystem.

An estuarine port as a habitat: the first biological survey in a southern Baltic Sea estuary's port

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Ports are generally man-made constructions, but they are also aquatic areas supporting biological communities that are subject to diverse anthropogenic pressures. The impacts are produced, on the one hand, by routine activities such as ships' traffic, on- and offloading of goods, operations of shipyards (should these be situated within a port), pollution and littering, with the associated accumulation of chemicals in the water column and bottom sediments of port basins. On the other hand, ports themselves are a source of biological threats resulting from maritime transport known to be the major vector of non-indigenous species (NIS) transfer and introductions. Therefore, the port environment and its biota should be monitored for their chemical and biological pollution which might potentially affect the native fauna and flora. With this in mind, we carried out, in 2018, the first biological survey of two ports (Świnoujście and Szczecin) situated in the River Odra/Oder estuary (the Szczecin Lagoon), but receiving and servicing sea-going vessels. The Szczecin port is situated on the River Odra, about 100 km away from the coast, which makes it vulnerable to the introduction of NIS of both marine and freshwater origin; the introductions can be mediated by human activities, but may also result from natural dispersal. The Świnoujście port is situated at the terminal section of the River Świna (a connection between the Lagoon and the Baltic Sea's Pomeranian Bay) and is therefore more vulnerable to introductions of marine and brackish-water NIS. We surveyed both ports in April and August to arrive at an inventory of the phyto- and zooplankton, the benthic macro-infauna, and the epifauna growing on solid port constructions. We paid a particular attention to species that are non-native to the area, in accordance with the Ballast Water Management Convention (BWMC) and the HELCOM-OSPAR Joint Harmonized Procedure for BWMC exemptions. The inventory allowed us to determine the taxonomic richness of all the ecological categories considered and to plot the respective species accumulation curves. We compared the taxonomic composition with the list of the so-called species of concern (target species) that constitute a threat of neobiont introductions in the area. No such species were found in the phyto- and zooplankton. On the other hand, such species featured in both the epifauna and the macro-infauna. However, although considered non-indigenous in the Baltic Sea, the species concerned have been present, both in the Pomeranian Bay and the Szczecin Lagoon, for a number of years. Thus, their presence was not unexpected and did not result from a sudden introduction. The species accumulation curves for the phytoplankton and the epifauna did not reach the asymptote, indicating that the taxonomic inventories were not complete. On the other hand, the curves for the zooplankton and the infauna did reach the asymptote, suggesting a complete picture of the taxonomic richness of both groups being obtained by the survey.

Acknowledgement: We thank the Szczecin and Świnoujście Seaports Authority SA for funding the survey and the permission to use the survey data.

Variability in functional traits of Eelgrass (*Zostera marina*) in Sweden

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Seagrass meadows promote biodiversity and provide important ecosystem services (ESS) for coastal protection, climate change mitigation and biodiversity. The Eelgrass *Zostera marina* is the dominant species in the northern hemisphere. In the Baltic Sea it is under threat, as the size of its meadows sharply decreased from the 1980's, mainly due to coastal development and reduced water quality. Even if it is currently under protection, natural recolonization of meadows is slow due to limitations in dispersal and establishment. Beside meadow size, specific functional traits such as shoot density and length may alter the type of ESS provided.
An explicit spatiotemporal evaluation of trends in functional traits is lacking. However, several datasets including functional traits information and relevant abiotic variables as well as anthropogenic pressures have been independently developed and are currently available in various formats. For example, long-term eelgrass functional traits data in Sweden are included in the SHARKweb dataset, whereas relevant environmental variables such as light penetration in the water, temperature and wind speed are deposited in the Google Earth Engine collection. Here, we present a method to download and aggregate the relevant environmental variables from Google Earth Engine given the location and time of biological samples. Then, we show how these variables may help in explaining spatiotemporal functional traits trends. This approach allows the incorporation of relevant abiotic variables in biodiversity datasets to produce robust explicit spatiotemporal evaluation of changes in species functional traits.
The results will support decision makers in planning seagrass conservation and restoration. Furthermore, they provide information for coastal administrations wishing to raise awareness on seagrass meadows and their ESS in present and future conditions. Finally, as the abiotic variable datasets cover the entire globe and are publicly available, this approach can be easily transferred and generalized for larger scales and additional species.

Impacts of round goby invasion on benthic fauna in the Baltic Sea: the effects of prey preferences and individual variation

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The round goby (*Neogobius melanostomus*) is one of the most successful invasive species in the Baltic region, becoming a dominant benthic fish in large parts of the Baltic Sea. Round gobies fiercely compete with native species for territory and prey, and are well adapted to feeding on hard shelled organisms such as bivalves and gastropods. This work assess the impacts of round goby invasion and feeding behaviour on the benthic fauna communities in coastal and inlet waters of the south-west Baltic Sea.

First, using benthic invertebrate data (via the Danish national NOVANA marine monitoring programme database), we identify increases and decreases in the abundance of specific taxonomic groups before and after round goby invasion. Certain gastropod and bivalve taxa were most strongly impacted, for example the detected densities of Cardiidae bivalves and Neritidae gastropods fell approximately 98% within the Guldborgsund Strait in the years following invasion. Furthermore, we show that the taxa preferred by round gobies were more negatively impacted by the invasion than non-preferred taxa, highlighting that goby feeding preferences may drive changes community composition, structure and ecosystem function.

Next, we further explored round goby feeding behaviour by measuring individual-level differences in behaviour and diet. Using stable isotope analysis of food webs in Danish coastal environments, we measured among-individual differences in the feeding behaviour and trophic position of round gobies. The aim was to test whether individual gobies show differences in their diet preferences and therefore may have different impacts on prey communities. In a round goby population within the Guldborgsund Strait, our results show substantial variation in behavioural traits as well as their isotopic signatures, showing evidence of within-species diet specialisation in invaded areas. This work highlights that the specific feeding preferences of invasive species influence can influence impacts on invaded communities, and that among-individual differences in feeding behaviour may also influence these effects.

Studying stock separation mechanisms between spawning aggregations of the herring (*Clupea harengus*) in the Stockholm Archipelago

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Herring (*Clupea harengus*) is an essential "engine" of the Baltic Sea marine ecosystem. It constitutes an important food source and link of nutrients and energy between lower and higher trophic layers. The drastic increase of large-scale pelagic fishing along the Swedish east coast has caused much concern, including the risk of depletion of local herring subpopulations.

Fisheries management should, therefore, urgently ensure a better and more detailed knowledge of the Baltic Sea herring's population- and subpopulation structure, including how subpopulations are separated from each other. For marine fishes with free-floating early life stages, two partly mutual opposing, ecological mechanisms for population segregations have been suggested: **natal homing (philopatry)** of mature fish or **physical forcing** the dispersal of early life stages.

The herring population complex in the Stockholm Archipelago represents an excellent system to test hypotheses about population separating mechanisms. There is still a multitude of herring spawning aggregations with a varying degree of connectivity in this area. Genetic divergence can be expected to be low, especially between spawning aggregations within the archipelago, while some genetic differentiation may exist between spawning shoals off the coast and the inshore. Methods may, therefore, be needed to describe relatedness to a specific spawning area rather than biological uniqueness. We find that survey of otolith chemical contents in various herring spawning aggregations presents such an opportunity. Also, by studying herring larvae distribution over spring and autumn, we may concur how herring spawning is distributed between the inshore and offshore over time.

Friday, Theme 5, from 11:00 – 12:15

Marine Carbon Sinks in Decarbonization Pathways – A large scale German research mission on marine CDR options and its implications for the Baltic

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The IPCC Special Report "Global Warming of 1.5°C", represents a milestone and paradigm shift in the climate debate. The politically formulated target of a maximum global temperature increase "well below 2°C" at the COP 21 in Paris in 2015 created the demand to scientifically evaluate, within the framework of existing uncertainties, what will be required to meet this target. Most of the 2°C and practically all of the 1.5°C scenarios require, in addition to a drastic reduction of CO_2 emissions, substantial deployment of active carbon dioxide removal (CDR) from the atmosphere to reach net-zero emissions early enough and to compensate for remaining emissions.

Within the Research Mission "Marine Carbon Sinks in Decarbonization Pathways" (https://www.cdrmare.de/en/) of the German Marine Research Alliance (DAM), about 200 scientists will be involved in assessing marine CDR options, including e.g. blue carbon, alkalinity enhancement, subsedimentary CO_2 storage, and other options. An evaluation framework will be developed, addressing natural scientific, legal, ethical, political and economic criteria, in close collaboration with initiatives addressing CDR options on land.

Some of the marine CDR schemes bear the potential to be investigated or even pursued in the Baltic Sea area. One example is the investigation of carbon sequestration and storage in seagrasses. This includes not only the actual carbon stored, but also advanced studies of organic matter composition and its microbial turnover, as well as the investigation of possible co-benefits of seagrasses to ecosystems and society. The results are expected to provide useful information for future ecosystem-design approaches to enhance carbon storage in the coastal zone. Another CDR scheme relevant for the Baltic is the alkalinization of organic-rich shallow sediments or euxinic deep water bodies, including the potential use of calcium carbonate, with a possible positive feedback on phosphate storage by formation of carbonate fluorapatite (CFA). Alkalinization has a strong potential to increase the ocean's uptake of atmospheric CO_2.

The Baltic Sea science and stakeholder community has a long history in addressing man-made interventions, both intentional and unintentional. This talk intends to stimulate a debate on measures to enhance the carbon uptake and storage potential of the Baltic Sea, and to serve as a nucleus for networking in the pan-Baltic area, involving scientists and stakeholders alike.

Using river plumes to shape assessment units

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The Baltic Sea is characterized by strong gradients from coastal waters to deep basins visible in hydrodynamic parameters, but also in all eutrophication indicators. While these gradients are mostly induced by the freshwater and nutrient inputs of large rivers, they get further amplified by the depth differences. At once, HELCOM assessments like HOLAS need representative units to be conducted in a suitable manner. Defining the assessment units is thereby challenging due to the strong gradients. Within HELCOM the assessment units got therefore adjusted several times in the past and nowadays a separation of Bornholm Basin into two parts is discussed. Furthermore, the assessments themselves are partly biased as many monitoring stations are located in the usually not-representative shallow areas. These areas show the highest concentrations of all eutrophication indicators due to the strong river impacts.

To identify the river plume area, a novel, model-based approach was developed and applied first to analyze the spatial and temporal dynamics of the Oder/ Odra plume. Based on the results and previous studies to trace the nutrients imported by the Oder/ Odra, a reshaping of the HELCOM assessment units in the southern Baltic Sea is suggested. Key component is thereby the introduction of a new unit for the Pomeranian Bay, representing the region mostly affected by the Oder/ Odra plume and stretching up to Rügen Island and along the Polish coast.

While our approach can be applied to all parts of the Baltic Sea, it was exemplarily conducted to the HELCOM assessment unit Bornholm Basin, where strong spatial gradients result in a bias of the present day eutrophication status. While the assessment unit itself has a mean depth of 46.5m (standard deviation 23m), many monitoring stations are located in the not-representative shallow area (below 20m), which is affected strongest by the Oder/ Odra. As long as the present state of the entire assessment unit is determined by using purely the monitoring stations, the eutrophication assessment will mostly overestimate the present state. To obtain more realistic present states, an adjusted monitoring program may get necessary in future, while at the moment an improved assessment method may get implemented, which incorporates the natural gradients properly.

Finally, using the existing, adopted and harmonized GES thresholds for Bornholm Basin, suitable target values are presented for the new assessment unit Pomeranian Bay, as well as for the remaining part of Bornholm Basin. The GES thresholds incorporate the spatial gradients and peculiarities between the different assessment units and are derived from the model-based reconstruction of the pre-eutrophic state around 1960. The proposed GES thresholds are substantially higher for Pomeranian Bay compared to the original Bornholm Basin unit and lower for the remaining part of Bornholm Basin.

Seasonal and long-term hypoxia in the western Baltic Sea – a modeling approach

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Oxygen deficiency in coastal seas as an indirect consequence of eutrophication is one of the most severe threat to marine ecosystems. The Baltic Sea exhibits the largest hypoxic areas (oxygen concentrations <2 mg/L) worldwide. Therefore, perennial hypoxia in its deep basins has long been a component of environmental assessments. In contrast, seasonal hypoxia in shallow areas of the western Baltic Sea is not a common subject of assessments, although increasingly observed in the last decades. Current in-situ measurements of dissolved oxygen cannot provide the high spatio-temporal resolution needed to fully assess highly dynamic seasonal hypoxia. Therefore, the duration and extent of seasonal hypoxia is uncertain or even unknown due to scarce data distribution.

Using a long-term simulation of oxygen concentrations from a coupled hydrodynamic biogeochemical model (MOM-ERGOM), we looked at the development of seasonal hypoxia in the western Baltic Sea. Thereby we analyzed different metrics (addressing the affected area, water volume and time periods) and critical oxygen concentrations for exemplary assessment units on sub-basin level as defined by HELCOM. Our results show that the frequency and extent of hypoxic situations have continually increased in the second half of the 20st century and slightly decreased in the last two decades. In the western Baltic Sea, the Bay of Mecklenburg is most affected by hypoxia, followed by Kiel Bay. Critical periods of hypoxia as well as the spatial extent in the bottom water layer were highly variable among the assessment units. Seasonal variability of hypoxic situations was stronger than inter-annual variability. The long-term analysis from the 1950s to present days shows that, likewise to nutrients and chlorophyll-a, the situation in the 1950s can be regarded as good status, including naturally occurring oxygen deficits in the western Baltic Sea. Although, the hypoxia status is improving it is still far from being good. Our current model set-up with a spatial resolution of 3 NM proved to be well suited for the analysis. Nevertheless, at several stations modeled oxygen concentrations are lower than the measured ones. Further model refinements as well as the handling of shortcomings of in-situ data, which partly fails to observe the very low oxygen concentrations close to the seafloor, are thus required in future studies.

In sum, seasonal hypoxia is a suitable indicator for describing the ecological status of the western Baltic Sea. In-situ data alone does not provide a sufficient spatio-temporal resolution to comprehensively evaluate seasonal hypoxia in the water body. The combination of model simulations and in-situ observations are thus a possibility to overcome these deficits and enable the use of seasonal hypoxia as a powerful eutrophication indicator in shallow areas.

Measuring the Impact of Physical Geographical Factors on the Use of Coastal Zones Based on Bayesian Networks

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Coastal regions of the Baltic Sea are among the most intensively used worldwide, resulting in a need for a holistic management approach. Therefore, there is a need for strategies that even out the seasonality, which would ensure a better utilization of natural resources and infrastructure and improve the social and economic conditions.

In this study present an approach to identifying the social, economic, and environmental factors influencing the sustainability of coastal resorts. To assess the effectiveness of coastal zone planning processes concerning sustainable tourism and to identify and substantiate significant physical geographical factors impacting the sustainability of South Baltic seaside resorts, several data sets from previous studies were compiled. Seeking to improve the coastal zone's ecological sustainability, economic efficiency, and social equality, a qualitative study (content analysis of planning documents) and a quantitative survey of tourists' needs expressed on a social media platform and in the form of a survey, as well as long-term hydrometeorological data, were used. To combine existing data and extract new knowledge to sustainable coastal zone planning a Bayesian Network framework was used.

The results of this study may be used to advise local governments on a broad spectrum of Integrated Coastal Management matters: planning the development of the beaches and addressing the seasonality of use, directing investments to improve the quality of the beaches and protect them from storm erosion, and maintaining the sand quality and beach infrastructure. The lessons learned can be applied to further coastal zone management research by utilizing stakeholders and expert opinion in quantified current beliefs.

InfoWas – Developing an Information System for Water Quality in the North and Baltic Seas

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Persistent oxygen deficiency zones in the Baltic Sea are a common phenomenon in regions with sluggish ventilation and high salinity gradients. However, the frequency of seasonal and temporary oxygen deficiency zones, occurring in coastal areas of both the Baltic and the North Sea, has increased over the last years. Thus, the development of a common oxygen indicator for both seas will help to identify and forecast localised areas defined by sporadically evolving low oxygen concentrations. Moreover, excessive sinking-out of organic matter originating from surface phytoplankton blooms speed up the consumption of oxygen in the bottom waters. Nowadays, expanding algal blooms caused by over-fertilisation of the Baltic increasingly become hazardous to organisms and humans. So-called harmful-algal-blooms (HABs) can negatively affect the environment, tourism and fishery, as well as environmental agencies and NGOs by causing ecological and economic consequences. Thus, it is of great importance to develop an information system of water quality (InfoWas) by combining up-to-date information on the condition of the Baltic and North Sea in compliance with the Marine Strategy Framework Directive (MSFD).

Here we will develop the InfoWas-System via an assimilative model approach. This comprises the integration of in-situ, remote sensing and model data in order to extend the operational physical-biogeochemical model (HBM-ERGOM) at the BSH with the Parallel-Data-Assimilation-Framework component (PDAF) developed at the Alfred-Wegener-Institute (AWI). The assimilation of near-real-time in-situ and remote-sensing data allows for high precision model-outputs and will thus strengthen the InfoWas-System forecasts of potential algal blooms and oxygen-deficiency zones in the near future. This will help to inform environmental agencies and the public of potentially upcoming harmful events and to act in advance in order to diminish environmental and economic consequences.

Poster presentations

Theme 1

Dane River compound flood risk if Baltic Sea level rise due to climate change

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As in other parts of the world, research on climate change is now of major interest in Europe, including the Baltic Sea region. As the result of continuing in the 21st century for air and water warming and rising water levels, the vulnerability of the ecosystem makes the Baltic Sea region coastal areas particularly susceptible to climate change. The importance of climate change adaptation is accepted worldwide, highlighting the lack of preparedness for managing today's emergencies. The new EU Strategy for Adaptation to Climate Change (2021) emphasizes the need to consider climate considerations and the perspective of future risks when planning urban spatial development. Due to climate change, extreme floods are projected to increase in the 21st century in Europe's river basins. As a result, the threat is growing to the areas adjacent to today's flood risk areas. The geographical object of this study is the lower reaches and mouth of the Dane River, where the river flows through the city of Klaipeda and flows into the Klaipeda Strait, which connects the Curonian Lagoon with the Baltic Sea. The human economic activities affected the mouth of the Dane significantly due to the long-running intensive shipping, navigation, dredging, and berth reinforcement. According to the published climate and Baltic Sea water level scenarios, the climate impact would increase the water level by 1 meter. As the average water level in the Baltic Sea and Klaipeda Strait rises, so does the water level in the lower reaches of the Dane River. In such a case, in Klaipeda, the greatest hazard of compound floods would occur. The floods in the lower Dane can be classified as compound floods because it is affected by falling precipitation in its basin, fluctuations in the water level of the Curonian Lagoon, and the Baltic Sea storm surge. Such an extreme phenomena can cause significant damage to the infrastructure of Klaipeda port city, as extreme floods of the Dane River may be affected by a further rise in the water level of the Baltic Sea due to climate change. The study aims to assess the risk of flooding of the Dane River in the territory of Klaipeda city, using the probabilities of the water level of the Klaipeda Strait and the flow of the Dane River when the Baltic Sea level rises by 1 meter due to climate change. These research results confirm that, in the long run, climate change will significantly impact the settlements of the south-eastern Baltic Sea coast. The assessment of the future flood risk of the Dane River due to climate change is helpful for the adoption and application of infrastructure solutions and the identification of the necessary flood protection measures.

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Ecosystem services in the Lithuanian coastal zone under climate change: a modelling study

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The aim of this study is to predict the future ecosystem services (ES) in coastal Lithuania by applying a wide set of multidisciplinary modelling and prediction tools. The study region is located at the delta of the Nemunas River, where hydrological conditions are governed by rivers discharge, with expected floods in early spring, and an annual mean river discharge of ~500 m^3/s. We have mapped the current ES of the area, where 11 Provisioning services, 12 Regulation, and Maintenance services and 11 Cultural services (according to CICES classification) were identified and assessed, using the ES potential matrices.

The modelling study was focused on the hydrological and water quality conditions of rivers in the study area under the "business as usual" land management and climate change scenarios based on the RCP4.5 and RCP8.5. A user-customized programmable software system, tailored for building SWAT models according to the hillslope discretization scheme with an advanced HRU definition procedure, was utilized. The SWAT models were calibrated and validated for monthly and daily discharge, sediment and nutrient loads. Five sets of global 0.5° General circulation models (GCM) data were originally extracted from the Inter-Sectoral Impact Model Inter-comparison Project, bias-corrected using statistical downscaling against the set of observed data using the Climate Change Toolkit and used to predict future flows and water quality parameters. The SWAT model was linked with the Curonian Lagoon hydrodynamic model (SHYFEM) to assess the changes in the Water Residence Time (WRT) of the lagoon.

The projected changes for short-term (up to 2050) and long-term (up to 2100) periods indicate a shift towards higher winter discharges of rivers and a net increase in nutrient load, associated with current landuse management and increased soil freeze-thaw cycles with more precipitation falling as rain in winter months in the future. The resulting river discharge shift might indicate a transformation in the exchange mechanisms of the Curonian Lagoon, with the higher exchange between the lagoon and the sea in winter and lower in summer. This, in turn, will increase the difference in WRT, lowering already low WRTs in winter even more and increasing already high WRTs in summer. These and other possible environmental changes will have direct impact on some of the ES diminishing or enhancing their potential.

This project has received funding from European Social Fund (project No 09.3.3-LMT-K-712-01-0178) under grant agreement with the Research Council of Lithuania (LMTLT).

Invasive Round Gobies (*Neogobius melanostomus*): Impact on Benthic Fauna in Latvian Coastal Waters

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Stony reefs are one of the most ecologically valuable habitats on the Latvian coast of the Baltic sea. It hosts invertebrates, fishes, plants and birds. The most abundant and biotope forming specie is mussel *Mytilus trossulus* accompanied with other benthic macrofauna. Furthermore, the euphotic zone hosts diverse macroalgae communities dominated by *Furcellaria lumbricalis*, *Coccotylus truncatus*, *Battersia arctica*, etc. Invasive fish round goby *Neogobius melanostomus* was first observed in the Latvian waters in 2002, while, already in 2012 it has established predominant populations and currently is found in the entire coastal zone. Monitoring of Latvian Marine Protected Area Nida-Perkone in 2014 showed that mussel biomass in the coastal areas has decreased by 5 times in comparison to 2006. Our hypothesis is that the main predatory impact of round goby primary fell on the benthic filter feeding mussel *M.trossulus* until complete depletion of this resource. Consequently, decreased mussel populations provide lower filtering capacity and accordingly the nutrient and particle retention capacity in biota and sediments. Decreased particle retention in turn decreases the water transparency in the coastal area resulting in further negative impacts on the growth of perennial macroalgae, like *F.lumbricalis* and others.

We used visual observations, video recording data, sampling by scientific divers and round goby stomach analysis. Our results showed that all the fish had at least food traces in their stomachs where invertebrates and seaweed were dominant items. Empty or almost empty stomach were in 59% of the samples. Diet of round goby (N=250 in summer 2019, size 8.5-20.5cm) in Latvian coastal waters consisted of invertebrates – *M.trossulus* (from traces to 722 mg/WW, present in 33% of the samples), *Amphibalanus improvisus* (from traces to 224 mg/WW, present in 20% of the samples), other crustaceans – *Gammarus* sp., *Corophium* sp. etc. (from traces to 88 mg/WW, present in 50% of the samples) and polychaeta – *Hediste diversicolor* (present in 12% of the samples). Soft sediment specie *Limecola balthica* was also identified in the stomach of Round goby in 10% of the samples ranging up to 575 mg. In some cases, cannibalism traces were found. Around 50% of fish had swallowed macroalgae and most abundant species found in round gobies stomach were *F.lumbricalis, Vertebrata fucoides*, *C. truncatus*, *Fucus vesiculosus* and *B.arctica* that indicates feeding place preferences near the shore in euphotic zone covered with algae. Benthic macro fauna samples from hard substrate habitats were collected in the same area in the depth range from 6m to 21m. Results showed that *M.trossulus* population recovered in stony habitats. Small size *M.trossulus* were abundant in every sample. The dominant size group was 0-5mm (up to 1600 ind./m²) and 5-10mm (up to 2500 ind./m²). Size groups 1-2cm, 2-3cm and 3-4cm were represented only by max 70 ind./m² but mostly some scarce individuals. *A.improvisus* and other crustaceans were found in all the samples.

In conclusion we suggest that *N.melanostomus* population has stabilized in Latvian coastal waters due to intensive fishing and resource limitation, using variety of food objects and allowing regrowth of mussel *M.trossulus* population thus resetting the stony reef ecosystem.

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The Baltic Sea Climate Change Fact Sheet 2021

[1]HELCOM-Baltic Earth Expert Network Climate Change (EN Clime)

[1]Affiliations available in the Climate Change Fact Sheet:
https://helcom.fi/media/publications/Baltic-Sea-Climate-Change-Fact-Sheet-2021.pdf

To provide a better understanding of the effects of climate change in the Baltic Sea, Baltic Earth and HELCOM have recently published the first Baltic Sea Climate Change Fact Sheet. The publication compiles the latest available science on climate change in the region.

The Fact Sheet provides a complete yet concise and easy to read publication, providing a summary for policy makers on how climate change is currently affecting the Baltic Sea and about what we can expect to happen in the future. It intends to help policy makers include climate change considerations in their work and decisions, and also seeks to inform the public about the effects of climate change in the Baltic Sea.

Jointly developed by Baltic Earth and HELCOM, the Fact Sheet contains information about 34 parameters ranging from air and water temperature to marine and coastal ecosystem services, grouped into six different categories: energy cycle, water cycle, carbon and nutrient cycles, sea level and wind, biota and ecosystems, human activities, and services.

According to the fact sheet, in the Baltic Sea, water temperature and sea level will rise, and sea ice cover will decrease – in turn affecting ecosystems and marine species, as well as maritime activities such as shipping, fisheries and aquaculture. For example, water temperatures of the Baltic Sea have been increasing during the past 100 years and are projected to further increase during the 21st century, and current projections suggest a largely ice-free Baltic Sea during normal winters by the end of the century.

The fact sheet is a summary of the regional counterpart, the Baltic Earth Assessment Reports, of the worldwide reports of the Intergovernmental Panel on Climate Change, empowering decision makers to carry out timely, ambitious and coordinated climate action.

About 100 experts from the entire Baltic Sea region were involved in the making of the fact sheet, which was developed by the Joint Climate Change expert network (EN CLIME) run by Baltic Earth and HELCOM. The Baltic Sea Climate Change Fact Sheet is expected to be updated every seven years.

Numerical modelling of ice thermodynamics and its future projections in the southeastern Baltic Sea (the Curonian Lagoon)

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In this study, we present a deterministic numerical modelling application for the ice thickness projections in the largest lagoon in Europe – the Curonian Lagoon, located in the south-eastern part of the Baltic Sea. The proposed ice thermodynamic model gives satisfactory results for simulating ice thickness evolution in this freshwater lagoon (mean R=0.92, RMSE=6 cm), although, model's capability to produce good thickness results highly depends on the accuracy of the forcing data. Nonetheless, independently of the model input data, the overall number of ice days is overestimated by on average 1 month, due to the lack of the dynamic component in the modelling system this way producing sporadic short freezing events of very thin ice, which are not usually recorded in the coastal stations.

The coupled ice and finite element hydrodynamic modelling system SHYFEM results revealed that it is not fully able to represent the real ice cover distribution as seen in the remote sensing (Synthetic Aperture Radar) images, due to the above-mentioned lack of dynamics in the ice modelling. This is evident during thin ice formation or decay events, when the wind forcing plays a significant role in distributing the ice. Under the changing climate and projected air temperature increase and ice thinning, the modelling of aerial ice thickness distribution based solely on thermodynamics might not be sufficient.

Nevertheless, model's application for studying climate change impact, revealed that the changes in the near future (2021-2040) are similar under both RCP4.5 and RCP8.5 scenarios, while in the far future (2081-2100) the difference of these scenarios is more evident. The ice model estimations show that the maximum ice thickness could decrease by 20-25% in the near future, while in the far future it could decrease by up to 55% under RCP4.5 and 80% under RCP8.5 scenario, compared to the historical period (1985-2005). The ice season duration could decrease by 15% in the near future, while by the end of the century it could decrease by 30% under RCP4.5 or 57% under RCP8.5 scenario compared to the historical period. The changing ice cover and season conditions will have a strong impact on not only the hydrodynamics and exchange processes in the Curonian Lagoon, but also to the overall ecosystem of it, as well as the fisheries and tourism sector.

The Baltic Earth Assessment Reports (BEAR)

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One of the goals of Baltic Earth has been the establishment of assessment reports of the current state of the science in different research fields in the Baltic Earth context, similar to the BACC approach for climate change. Now, 8 years after the founding of Baltic Earth, a series of extensive assessment reports, called BEAR (Baltic Earth Assessment Reports), is finalized and currently being published. For each of the Baltic Earth Grand Challenges, plus some additional relevant topics, a team of experts from the Baltic Earth network has wrapped up the current state of knowledge in the respective research fields, including uncertainties and gaps in knowledge. The 10 Baltic Earth Assessment reports are:

Salinity dynamics of the Baltic Sea
Biogeochemistry of the Baltic Sea
Natural hazards and extreme events in the Baltic Sea region
Sea level dynamics and coastal erosion in the Baltic Sea region
Human impacts and their interactions in the Baltic Sea region
Climate change and the Baltic Sea ecosystem
Coupled regional Earth system modelling in the Baltic Sea region
Atmospheric regional climate projections for the Baltic Sea Region until 2100
Oceanographic regional climate projections for the Baltic Sea until 2100
Climate Change in the Baltic Sea Region: A Summary

The reports are being published open access as a Special Issue in *Earth System Dynamics* and are very briefly summarized on the poster.

https://baltic.earth/ bear/
https://esd.copernicus.org/articles/special_issue1088.html

Natural Hazards and Extreme Events in the Baltic Sea Region

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A natural hazard is a naturally occurring extreme event that has a negative effect on people and society or the environment. Natural hazards may have severe implications for human life and they can potentially generate economic losses and damage ecosystems. A better understanding of their major causes, probability of occurrence, and consequences enables society to be better prepared to save human lives, and to invest in adaptation options. Natural hazards related to climate change are identified as one of the Grand Challenges in the Baltic Sea region. We here summarize existing knowledge about extreme events in the Baltic Sea region with the focus on the past 200 years, as well as future climate scenarios. The events considered here are the major hydro-meteorological events in the region and include wind storms, extreme waves, high and low sea level, ice ridging, heavy precipitation, sea-effect snowfall, river floods, heat waves, ice seasons, and drought. We also address some ecological extremes and implications of extreme events for society (phytoplankton blooms, forest fires, coastal flooding, offshore infrastructures, and shipping). Significant knowledge gaps are identified, including the response of large-scale atmospheric circulation to climate change and also concerning specific events, for example, occurrences of marine heat waves and small-scale variability of precipitation. Suggestions for future research include further development of high-resolution Earth System Models and the potential use of methodologies for data analysis (statistical methods and machine learning). With respect to expected impacts of climate change, changes are expected for sea level, extreme precipitation, heat waves and phytoplankton blooms (increase), and cold spells and severe ice winters (decrease). For some extremes (drying, river flooding, and extreme waves), the change depends on the area and time period studied.

Preliminary Pb isotope stratigraphy of two Baltic Sea discoidal ferromanganese concretions

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The Baltic Sea ecosystem is highly vulnerable to excess nutrient load, eutrophication, hypoxia, and global warming. To generate reliable projections on the future development of the Baltic Sea, it is of utmost importance to record the natural variability and understand the mechanisms influencing the sea environment changes through time. Previous research on long-term ecosystem evolution within the Baltic Sea has mostly focused on deep areas of the sea due to lack of suitable long sediment records in coastal sea areas. Coastal sea areas, however, can be best described as filters, and they therefore have a focal role in the biogeochemistry of riverine nutrients and suspended particles during their transport to open sea. Moreover, these coastal filter processes occur over wide areas, due to the shallow nature of the Baltic Sea.

Ferromanganese concretions are abundant in many parts of the coastal Baltic Sea and hence provide an important yet underused archive to investigate the shallow sea areas in detail. Ferromanganese concretions form through authigenic precipitation of iron and manganese oxyhydroxides at an unusually fast growth rate, which allows the production of high-resolution proxy data. When formed hydrogenetically, i.e. directly by biogeochemical precipitation from the water column with the building blocks mainly originating from the surrounding catchment area, the acquired proxy data from the concretions provide great potential to investigate high-resolution basin scale environmental changes.

Here we show preliminary high-resolution LA-SC-ICP-MS Pb isotope ($^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, $^{208}Pb/^{204}Pb$) results of two discoidal ferromanganese concretion samples from the Mecklenburg Bay and from the western Gulf of Finland. Pb has a relatively short residence time in the ocean and hence reflects local inputs, mainly weathering intensity and type, due to incongruent release of Pb during weathering processes of continental rocks. Depending on the source of the weathering products, the Pb isotope signature can be variably radiogenic. The variation in these isotopes therefore can reflect variations in weathering intensity and/or changes is weathering product provenance. Our results show isotope ratio compositions that vary through time in the studied two concretions and approximately plot as binary mixing of two endmembers. While the topmost layers of the concretions probably reflect anthropogenic influence, the deeper parts likely mirror the ambient climatic conditions of the catchment area and show the high-resolution secular variation in the weathering characteristics.

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Theme 2

Stronger effect of species identity than shading on aquatic plant community productivity and interspecific competition

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Competition is one of the major factors structuring plant communities. Species with similar traits generally compete more intensely and have more similar yield than functionally different species, which often respond differently to environmental change. However, little is known about how the interacting species' traits influence the effect of environmental change on interspecific competition. By affecting the productivity of functionally different species, environmental change can lead to competitive imbalance, favoring stress-tolerant species. In the Baltic Sea, reduced water clarity due to eutrophication has altered the aquatic vegetation communities during several decades. We used a mesocosm experiment with three aquatic plant species common in the Baltic Sea, to test how aquatic plant community productivity and competition asymmetry (the absolute difference in reductions in yield relative to monocultures of two interacting species) were affected by functional dissimilarity, shading and species identity. Community productivity decreased and competition asymmetry increased with functional dissimilarity of the interacting species, which was likely explained by the traits of the superior species, such as specific leaf area, maximum canopy height and primary production rate. Community productivity was not affected by shading while competition asymmetry was higher in shaded than ambient conditions. Individual species yield depended on species identity and species combination. Only the shortest species was negatively affected by shading. Together, these results suggest that nonrandom species loss following environmental change can be caused by competitive exclusion, in addition to a direct effect of abiotic filtering.

Key words: submerged aquatic vegetation, biotic interactions, competition, functional dissimilarity, species identity, shading, Baltic Sea

Does Temperature Affect the Production of Halogenated Natural Products in Baltic Macroalgae? A Comparison of 2017 vs. 2018.

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Marine macroalgae are used worldwide for human consumption, animal feed, cosmetics, agriculture and biofuels. In addition to beneficial nutrients, macroalgae contain halogenated natural products (HNPs), some of which have toxic properties similar to those of well-known anthropogenic contaminants[1]. Climate change will impact the abundance and species distribution of macroalgae, as well as production and environmental pathways of HNPs[2]. Brown and red macroalgae species were collected from the Baltic Sea near Gävle, Sweden in the summers of 2017 and 2018, shortly after the weeks of peak air temperatures. The macroalgae were analysed for bromoanisoles (BAs) and methoxylated bromodiphenyl ethers (MeOBDEs). Compounds were extracted by soaking in methanol or methanol-dichloromethane, cleaned up on Florisil and determined by gas chromatography with mass selective detection (GC-MSD)[1].

The ΣBAs ranged from 1.5 to 9.3 ng g^{-1} wet wt., with higher abundance of 2,4,6-triBA compared to 2,4-diBA. Identified tetrabrominated MeOBDEs were 6-MeO-BDE47 > 2'-MeOBDE68, and structurally unidentified tribromo- and tetrabromo-MeOBDEs were also found. The ΣMeO-BDEs ranged from 0.10 to 0.88 ng g^{-1} wet wt.

The summer of 2018 was marked by higher air and water temperatures compared to 2017. Most, but not all, macroalgae species showed higher concentrations of the studied HNPs in 2018. If temperature is responsible for the observed HNPs increase, the effects may be species-dependent. Release of light halocarbons by macroalgae is affected by many environmental factors, including temperature, irradiance, predation, pH, desiccation, nutrient levels and salinity[3]. Further research, including the effect of multiple stress factors, is needed to understand how Baltic macroalgae and HNPs production will respond to climate changes.

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The effect of coastal upwelling events on the fish assemblages at the SE Baltic Sea Coast

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Coastal upwelling is responsible for the changes of sea surface temperature, salinity and nutrient concentrations that are very closely linked to the functioning of the marine coastal ecosystem. In turn, it can have a significant impact on primary production intensity and affect the entire food chain from zooplankton to fish, birds and marine mammals. In the Baltic Sea, upwelling can be observed all along the coasts with a sustained wind in almost any direction. Bearing in mind that Baltic coastal waters are intensively used for regionally important commercial fishery, possible impacts of upwelling events might affect the fish community and, at the same time, can potentially impact fishing efficiency and commercial catches during certain upwelling periods.

Under the presence of northerly winds, upwelling is rather frequently observed at the South-Eastern (SE) Baltic coast. Therefore, we aim here to better understand the importance of coastal upwelling on biological processes, and how it may affect fishing stocks, gillnet fishery and the reliability of fish community indices-based environmental monitoring. For this, coastal fishing efficiency due to short-term upwelling events was analysed coupling long-term (2000-2019) satellite SST data and scientific and commercial gill-net fishery data in Lithuanian Baltic coastal waters. The analysis of the fish catch data indicate that upwelling might influence the diversity of the fish community as during its events 1-2 main species are predominant while before upwelling the fish community is more diverse. In addition, our results suggest that upwelling can influence the assessment of the ecological status of coastal waters. According to fish indicators in 25-30 % of analysed cases Good Environmental Status indicators were influenced by the presence of upwelling and the environmental status has changed from what was observed before the upwelling event. This implies that if the fish community surveys are performed under monitoring programmes with temporally limited sampling and the evaluation of environmental status coincide with upwelling-impacted fish community, it may potentially lead to misinterpretation of Good Environmental Status indicators.

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Effect of eutrophication on ecosystem functioning in Baltic Sea lagoons.

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Eutrophication is one of the major threats in the Baltic Sea and can alter the functioning of the entire ecosystem through bottom-up control. Constraining changes in nutrient status and its integrated impact on the entire food web is of major interest for ecosystem management. Our work is done within the collaborative Blue Estuaries project. We focus on two lagoons of the German Baltic Sea, the Szczecin lagoon and Greifswalder Bodden, both impacted by nutrient from the Odra River. Our goals were 1- to assess the recent temporal trend in eutrophication in the two lagoons using stable nitrogen isotopes of sediment ($\delta^{15}N_{sed}$) as a tracer of nitrogen source, along sediment cores going back to the 1930s, and 2- to evaluate how eutrophication influences the functioning of these ecosystems, using ecological network analysis (ENA). We observed significant temporal trends in $\delta^{15}N_{sed}$ which differed between the lagoons, suggesting variation in the source and fate of nitrate entering the coastal environment and impacting the primary production at the base of the food web. ENA allows the detection of indirect cascading effects of changes at the base of the food web on the entire system but requires large datasets including biomass and energy budget of all food web compartments from phytoplankton to predators. Once the model is completed, it provides significant insights into fundamental ecosystem properties such as stability and resilience. We expect that, along a eutrophication gradient, the food web in the estuarine lagoon (i.e., Szczecin Lagoon) will be more stable due to a higher recycling and more resilient due to higher redundancy and lower diversity in its flow network, compared to the Baltic influenced lagoon (i.e., Greifswalder Bodden). We present preliminary results on the comparison of the two lagoons in terms of primary production, and consumers (e.g., fish and bird) abundance and biomass. Our results will have implications for the development of the science-based recommendations for sustainable development and use of estuarine systems.

The importance of genetic diversity in the marine diatom *Skeletonema marinoi* during and after antibiotic stress

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Phytoplankton play a central role in global biogeochemical cycles and are the foundation of most marine food webs. Therefore, it is vital to understand which factors affect phytoplankton growth and bloom dynamics. Both abrupt anthropogenic disturbances and long-term environmental changes related to climate change in the Baltic Sea can subject phytoplankton to direct and indirect stress, which may have consequences for the entire ecosystem. Previous studies suggest that genetic diversity in marine phytoplankton buffers against negative effects from stressors, such as reduced salinity, elevated temperatures and grazing. However, the importance of genetic diversity has not been investigated during stress caused by a disruption of the bacterial community associated with phytoplankton. It is widely known that phytoplankton, especially diatoms, harbor bacterial communities playing a beneficial, and sometimes even crucial role for growth and survival of diatoms. In this experimental study we investigated the role of the associated bacterial community and genetic diversity in the marine diatom *Skeletonema marinoi*. This model species often dominates the spring bloom community in the Baltic Sea. To study the importance of the associated bacterial community for *S. marinoi*, two stress treatments consisting of a combination of antibiotics were used. To investigate the role of genetic diversity during and after antibiotic stress, we compared the response of mono- vs. multiclonal populations. The addition of antibiotics resulted in a strong negative effect on the growth of *S. marinoi*. Genetically diverse populations showed significantly better recovery from antibiotic stress compared to monoclonal cultures. The different isolates also showed phenotypic differences in some of the measured growth parameters in accordance with previous studies. The results obtained in this study emphasize the importance of genetic diversity in phytoplankton during severe disturbance of the interaction between the diatom and the associated bacterial community. Our results also highlight the need for more studies investigating the importance of interactions between phytoplankton and other microorganisms in the Baltic Sea. Such studies are urgently needed in order to predict the response of phytoplankton communities to ongoing environmental change.

SEABED SUBSTRATE DATA OF EUROPEAN SEAS - EMODnet Geology

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Seabed substrate is one of the key elements shaping the physical structure of benthic habitats. Thus, seabed substrate data is essential for various purposes, including sustainable marine management, conservation, and research. With increasing marine and coastal anthropogenic activities, and resulted challenges, there is urgent need for easily accessible and reliable data on marine environment.

The EMODnet (European Marine Observation and Data network) Geology project aims to address this demand and has been collecting and harmonising marine geological data from the European sea areas at different scales within subsequent projects running since 2009. The partnership includes 40 marine organisations from 30 countries, mainly the marine departments of the geological surveys of Europe.

The latest update of the EMODnet seabed substrate products was released in September 2021. In addition to previously released maps at scales 1: 1 000 000, 1: 250 000, 1:100 000, 1:50 000 and 1:25 000, the updated data products include now new scales from 1:70 000, to as detailed as 1:1500. Both updated and new maps include data from the Baltic Sea. Further, the coverage of the broad scale data product has expanded to new sea areas and includes the Caspian Sea at scales 1: 1 000 000/5 000 000.

The EMODnet Geology project is funded by The European Climate, Environment and Infrastructure Executive Agency (CINEA) through contract EASME/EMFF/2020/3.1.11 - Lot 2/SI2.853812_EMODnet – Geology.

Identification and mapping of reef biotopes using underwater imagery in southeastern Baltic Sea

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Reef habitat types are valuable for EU member states according to protected habitats designated by NATURA 2000 network. In the Lithuania marine area, southeastern Baltic Sea, 4 biotopes associated with reefs are currently identified: cobble and boulders dominated by epifaunal *Mytilus trossulus* and *Amphibalanus improvisus*; boulders with perennial red alga *Furcellaria lumbricalis*; moraine ridges with mussels *Mytilus edulis trossulus* and barnacle *Amphibalanus improvisus*; boulders with mobile Amphipods. The most valuable habitats proven to be hard bottom reefs with perennial red algae *Furcellaria lumbricalis*. From the geomorphological point of view, important reefs are moraine ridges with mussels *Mytilus edulis trossulus* and barnacle *Amphibalanus improvisus*. Moraine reef habitats in the Baltic Sea are unique in the Lithuanian territorial sea near Palanga. The area of bottom habitats is about 20 thousand hectares, but reefs are common in only 1 % of the territorial sea. Reefs located in the coast are the key components of the marine ecosystem since it is a shelter for many associated crustaceans (e.g. *Gammarus* spp., *Jaera albifrons*, and *Idotea baltica*), natural spawning substrates for fish (e.g. Baltic herring *Clupea harengus membras*) as well as one of the main feeding grounds for wintering and/or migratory birds including the red-throated diver (*Gavia stellata*), black-throated diver (*Gavia arctica*), long-tailed duck (*Clangulahyemalis*), and many more. In the offshore area, the biotope of cobbles and boulders dominated by epifaunal *Mytilus trossulus* and *Amphibalanus improvisus* located in two northern parts (Klaipėda Bank and Klaipėda-Ventspilis plateau) and one on the southern part (Sambian Plateau).

The status of benthic biotopes, including reefs, is determined by the Marine Strategy Framework Directive (MSFD) under Descriptor 1 (Biodiversity) and Descriptor 6 (Sea-floor Integrity). MSFD requires the spatial extent of the habitat type affected and to monitor changes over the years. This prompts us to look for detail and efficient ways for reef biotope mapping. However, reef biotope mapping techniques differ at circalittoral and infralittoral areas, where the former one is usually assessed by SCUBA diving techniques, while at circalittoral, this commonly used sampling technique is limited due to deep depths and grab samples are not suitable for hard bottoms. It suggests that the integration of remote methods is needed to cover areas inaccessible for divers or grab sampling. We choose the underwater imagery (UI) technique as a rapid and effective method suitable for biotope identification according to the HELCOM Underwater biotope and habitat classification system (HELCOM HUB). At present, detailed and spatial monitoring is being conducted using acoustics and underwater video at infralittoral and circalittoral Lithuanian marine areas with a grid covering 300x300 meters in the coastal zone and 1 nautical mile grid offshore. After reef biotope mapping at a fine spatial scale, we will help to accomplish MSFD descriptors related to habitat extent. On top of this, collected underwater video data will be used for deep learning as training materials to develop various tools for automatic analysis of UI for machine vision and pattern recognition. In the future, automatic UI analysis will significantly simplify hard bottom analysis.

Multi-species spatiotemporal distribution of fish larvae in the Kattegat

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Sympatric species share a common habitat, but seldom life-history traits, where spawning time, location and behavior can vary greatly. Although Kattegat is a small transition sea between the saline North and brackish Baltic Seas, biotic and abiotic factors vary significantly, where water advection affects salinity and ichtyoplankton composition, depending on origin. This variation complicates mapping of spawning areas, as the spatiotemporal presence of ichtyoplankton is controlled by spawning time, location and advection speed and direction through Kattegat.

In my PhD thesis, I am mapping the spatiotemporal distribution of fish spawning areas and exploring how these vary across species. This work is based on field observations, laboratory analysis of samples as well as biophysical modelling. Here, I will present the results of my ichtyoplankton surveys. Five survey cruises were completed in the spring of 2021, each sampling at 15 predetermined stations, evenly distributed throughout the Kattegat. Ichtyoplankton was sampled at several depths by the use of multi-net trawling to capture location and density variability with depth. All sampled fish larvae are being morphologically identified (preliminary results: >20 species), counted and measured for length. Here I am testing the hypothesis that length and abundance curves vary with species, time, and horizontal and vertical position.

Future work includes conducting daily increment on otoliths in order to estimate age (days) of all larvae. Finally, I will use observations and analysis coupled with physical forcing in an individual-based model (IBM) to backtrack the location of each larvae through its lifetime, in order to identify place of hatching, followed by egg fertilization/spawning location for each individual. Congregation of larvae trajectories will help identify species-specific spawning time and hotspots within Kattegat, as well as estimate the magnitude of larval drift from the North and Baltic Sea. Ultimately, this will strengthen our knowledge of fish spawning within the Kattegat, as well as identify important times and locations for spawning and early life history stages in both exploited and unexploited fishes, useful for ecological interactions and potential restriction of fisheries.

Panmixia within the Baltic Sea: high genetic connectivity between epilithic and free-living marine macroalga *Fucus vesiculosus*

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Marine populations with low genetic diversity are at greater risk of being affected by changing environmental conditions and anthropogenic pressures, particularly those within ecologically and geographically marginal environments. Poor population connectivity can further elicit harmful effects in response to these detrimental pressures.

As a foundation species, *Fucus vesiculosus* provides critical habitat for a multitude of fauna and flora, alongside important ecosystem functions and services. Despite the integral nature of this macroalga within the species-impoverished Baltic Sea, both historical and ongoing population declines have been documented throughout much of its distribution. Thus it is imperative to improve our understanding of the genetic resources represented by the species.

We used multi-locus barcode sequencing to investigate the genetic diversity, population structure and connectivity of *F. vesiculosus* within the Baltic Sea; with specific focus on the two lifestyles: epilithic and free-living.

For the first time using genetic techniques, we confirm that the Baltic Sea free-living *Fucus* can be designated as *F. vesiculosus*. The two lifestyles represent similar genetic resources, with high connectivity and little genetic differentiation.

We demonstrate a pattern of barrierless gene flow in much of the Baltic Sea though areas of restricted gene flow do occur. Consequently the Baltic Sea *F. vesiculosus* population is generally panmictic with sporadic localised areas of isolation. The overall genetic diversity is low with geographic extremes to the north and south displaying fixed populations, whilst central populations demonstrate greater genetic diversity. Unique genetic resources are present within the Baltic Sea, indicating that it is a source of important genetic variation for the species.

Fucus vesiculosus has broad dispersal capabilities suggesting a potential resilience of natural populations to changing conditions. This also poses favourable outcomes for future restorative measures. Overall *F. vesiculosus* populations within the Baltic Sea show potential for adaptation to changing conditions due to high connectivity and areas of unique genetic diversity.

Salinity modifies the effect of resource availability on phytoplankton communities

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Salinity is an important driver structuring phytoplankton communities in the Baltic Sea. Salinity can also influence resource uptake by increasing metabolic rates required for osmotic adjustment. Thus, interaction between salinity and nutrient availability is expected to change community structure by altering phytoplankton traits determining resource competition. This is a particularly relevant area of study for the Baltic Sea due to its predicted future freshening.

We investigated changes in traits distribution in artificial communities of ten diverse phytoplankton species grown under different combinations of salinity (0, 5, 12 and 24 psu), N:P ratio (2, 10, 16 and 80) and light (10 and 130 $\mu molm^{-2}s^{-1}$). A three-way interaction between light, N:P and salinity influenced community traits associated with resource competition, as well as presence and proportions of phytoplankton taxa. Light limitation inhibited phytoplankton growth under all salinity conditions and increased the dominance of a diatom *Phaeodactylum*. Growth rate of communities was higher under high light, but also more variable between salinity conditions. Strongest negative effects of nutrient limitation (N, P, and both nutrients together), both on growth rate and taxonomic diversity, were observed in the highest salinity treatment. In the freshwater treatment with the highest proportion of green algae *Monoraphidium*, N-limitation did not inhibit phytoplankton community growth and P-limitation had more profound negative effect on community performance.

Our results emphasise the importance of a trade-off between salinity and resource limitation in functioning of phytoplankton communities, and suggest that future freshening of the Baltic Sea might shift phytoplankton dominance structure.

The influence of environmental conditions on mesozooplankton diet

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Plankton community consists of diverse species that interact in many different ways and estimation of species interactions in nature is challenging. There is limited knowledge on how plankton interaction networks are influenced by environmental conditions, in part because of limited understanding of zooplankton feeding strategies and factors affecting plankton trophic interactions.

In this study, we used DNA barcoding methodology to investigate the complexity of trophic interactions in mesozooplankton predators and the influence of environmental conditions on their feeding behaviour. To determine the effect of abiotic conditions, we collected samples across the Baltic Sea gradient of salinity and temperature. We found that mesozooplankton strategy varies between mesozooplankton species but also within species across environmental gradients. Some species such as *Temora* are consistently using a selective strategy, while diets of *Centropages* and *Acartia* vary between stations. They feed on a wide range of prey items in less salty waters, indicating of opportunistic feeders, but are more selective at marine stations.

Our study helps to understand the spatial and temporal complexity of plankton species interactions. Due to the central role of the plankton in marine waters, a better comprehension of the spatial and temporal variability in species interactions helps to better estimate fluxes to benthic and pelagic predators.

Bioassays and biomarkers approach to detect targeting reproductive variables of the benthic amphipod *Monoporeia affinis* to assess environmental health of the Gulf of Riga (eastern Baltic Sea)

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New tools and approaches to identify emerging risks in nature are based on early warning system (EWS) technology. In the case of contaminant stressors, an understanding of chemical modes of toxicity can be linked with diagnostic markers of aquatic animal physiology to help understand the health status of aquatic organisms in situ. Amphipod embryo malformation is a general biomarker for various types of contaminants, and it can provide a wide and comprehensive assessment of all potentially toxic chemicals in the natural habitat. The scientific objective is to identify biomarkers and ecotoxicological approach to detect reproductive disorders in amphipods as screening tools. The aim of this study was to assess how biomarkers can be used in complex analyses to determine the potential risks to the environment combining laboratory ecotoxicity studies with reproductive disorders in natural populations.

Sediments with amphipods for microcosms experiments (8 stations) and sediments for bioassay studies (6 stations) were collected in the Gulf of Riga (GoR) from 20-40 m depth and >40 m depth, respectively. The effects of amphipods survival and reproductivity were detected in the laboratory conditions. Duration of experiments of acute toxicity tests were 14 days, but chronic tests were conducted for 42 days.

High survival rate was observed at all study sites with *Monoporeia affinis* (80–100%) in acute toxicity tests. Based on the amphipod survival rates in the chronic toxicity tests 21% of the GoR sediment stations were assessed as high quality, 36% - good, 29% - moderate and rest of the sites (14%) were assessed as poor/very bad. High reproductivity values (29-51 gravid females), survival rate (>90%) and also high reproductive disorders (0,9-3,1%), measured as percentage (%) of malformed embryo per females of *M. affinis* were detected in the microcosms studies.

M. affinis in bioassay studies showed less reproductivity than in the microcosms experiments (4-6 female per station). Malformed embryos varied in the range of 2,3-6,1% and were detected only in the 50% stations. Enzymatic biomarkers (AChE, CAT and GST) of microcosmos and bioassay studies showed significant differences between stations and test exposure time. However, significant correlation between reproductive disorders and integrated biomarker index (IBR) values were not detected. In general, our results indicated good or moderate status of environmental health of the Gulf of Riga ecosystem.

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Metabolic challenges in Baltic Sea fishes disentangled by the carbon isotope composition of otoliths

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Climate change, disease, and hunger are likely to have metabolic consequences for Baltic Sea fishes. We present how the isotopic composition of otoliths (ear stones) can be used to explore the effects of environmental stressors, such as increasing water temperatures, parasite load, and salinity variations, on the metabolic rate of Baltic Sea fishes.

Water temperatures in the Baltic Sea are expected to increase by 2-4°C, resulting in an increased field metabolic rate, which reduces the survival and distributional range of fish. Additionally, warmer waters make fish more vulnerable to parasites and diseases. In particular, the seal worm (*Pseudoterranova decipiens*) affects cod condition. Low oxygen levels, which are increasingly observed in the Baltic Sea, also negatively affect the field metabolic rate of fish. However, the metabolic impact of these changes are not easily predicted.

Otoliths are paired calcified (aragonite) structures used for hearing and balancing. They can be found in all teleost fish. Coupled with age or date of catch, they provide chronological records that can be used to reconstruct a fish's life and temperature/ metabolic history as otoliths grow continuously from hatching to death. Recent studies have shown that the carbon isotope composition of otolith aragonite is a reliable proxy to back-calculate the field metabolic rate (FMR) of fishes. FMR is the sum of all energy expenses an organism encounters in the wild and thus the relevant ecophysiological metric with which to gauge the impact of environmental stress on the metabolic performance of fishes.

With this poster, we highlight the analysis of otolith carbon isotope composition and how it can be used to investigate metabolic changes in Baltic Sea fishes due to environmental change.

Common macrofauna with different lifestyle harbor unique microbial communities

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Filter and deposit feeders generally dominate the benthic communities in coastal ecosystems and thereby represent key players in regulating benthic biogeochemical processes. These functional groups may also host complex microbiomes, which together form biological and ecological units (holobionts). However, so far it remains poorly explored to what extent functional behaviour and environmental settings determine the microbiome composition.
We used a 16S r-RNA gene sequencing to explore the taxonomic and functional diversity of microbiota associated to the most abundant clams and polychaetes in two estuarine locations, i.e., the oligotrophic (northern Baltic) and eutrophic (north-eastern Adriatic) estuaries.
The diversity of bacteria in clams and polychaetes differed substantially from ambient benthic environment in both estuarine locations, confirming unique assemblages harbored by animals. Polychaetes were primarily dominated by Bacteroidetes and Proteobacteria lineages, whose relative abundance within the community varied between locations. On contrary, specificity of clam's microbiota depend on the geographical location. Notably, however a considerably large number of operating taxonomic units (OTU) in clams resulted to any bacteria phylum. The identified OTUs in both clams and polychaetes were also associated with metabolic functions, including the nitrogen cycling processes. This study suggests that invertebrate–bacteria associations could be specific and may contribute to the benthic functioning.

Occurrence and spatial distribution of microplastics in the surface waters of the Baltic Sea and the Gulf of Riga

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The study is comparing microplastic debris distribution and composition in the Gulf of Riga and the Eastern Gotland Basin, Baltic Sea. Samples from 44 stations were collected from coastal and open water sites using Manta trawl (mesh size 300 μm). The natural organic material was digested sequentially with sodium hydroxide, hydrogen peroxide and enzymes. Thereafter, micro-debris (16,315 particles) was identified by visual analysis and 5285 particles were analyzed with Attenuated Total Reflection Fourier Transform Infrared spectroscopy method. The abundance of particles varied from 0.09 to 4.43 particles per m-3. The fibers accounted for 66.1% of all encountered particles while the fragments for 30.2%. The predominant polymer types were polyethylene (77.9%) and polypropylene (11.1%). The relative proportion among polymer types varied considerably from station to station. The encountered concentrations of micro-debris were well in range of values reported from other regions of the Baltic Sea.

Transport of microplastics from coastal to basin scale in Daugava - Gulf of Riga - Baltic Sea system

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Plastic usage is increasing in recent decades which causes more intense concerns of increasing microplastics into the seas. Most of the microplastics are released by estuaries of major rivers with are usually located in urban areas with high load of waste water treatment plants. Therefore, it is important to consider the path of microplastics from the estuary scale to basin scale. As a particular example, Daugava estuary - Gulf of Riga - Baltic Sea system is considered with special interests on southern part of Gulf of Riga, where Daugava river is the major fresh water source. Additionally, Kisezers and Jugla lakes are included in the estuary domain in order to consider longer residence times in the coastal system. Microplastics are treated as passive tracers which are affected by biofouling in the presence of CHL-a. Biofouling will eventually lead to sinking of microplastics and its sedimentation to the seabed. Microplastic transport is largely affected by the currents. Moreover, the currents in the river estuaries and in transition zone are of high importance. Therefore, a multiscale nested setup of Daugava estuary - Gulf of Riga - Baltic Sea is constructed by using the HIROMB-BOOS Model (HBM). The two-way nesting applied in this model allows seamless transition from inland water to estuary and then to basin scale. Model results are studied in period from 2017 to 2021 with different parameters in the Daugava estuary. Results are compared with microplastic observations in Gulf of Riga, particularly with series of observations in summer-autumn of 2018 by Latvian Institute of Aquatic Ecology. River run-off is derived from high-resolution pan-European hydrological model E-hype. Because the run-off of Daugava river is largely determined by Riga Hydro Power Station with particular daily and weekly pattern of the operation, then run-off of Daugava is treated specially according to the data from the Power plant. The influence of biofouling and sedimentation in the estuary domain is studied as well. The comparison with available microplastic observations in Gulf of Riga show that inclusion of estuary domain does not provide essential improvement in the model quality, but much higher number of microplastic observations are required for better assessing of microplastic pathways. Backtracking from the transects of observations is performed in order to estimate the most presumable fresh water source of the plastics and time interval required to reach the observation point. Both model and observations show that microplastic concentration decreases with distance from the river source. Nevertheless, the stochastic character of the microplastic observations is too high especially in nearshore locations for more sensitive parameter studies.

Sediment stratigraphy studies reveal variable POP concentration trends in the Baltic Sea environment

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There is an urgent need in practically all international conventions (Stockholm Convention on POPs, Minamata Convention on Mercury, LRTAP, OSPAR, HELCOM) and EU legislation to show the effectiveness of the already implemented regulation of the most dangerous substances.

Sediment core studies are a cost-effective method to reveal the recent history of substances with high affinity to particle phase. This method has been used in different fora for decades but has been somewhat forgotten at least in Europe in regulatory monitoring in the 2000's, due to focusing on quality standards based on water and biota. However, sediment core sampling and analyses may actually be much easier to harmonize between countries, compared e.g. to differences in food web structures affecting the species selection for monitoring.

The concept is based on sampling of short sediment core (height of ca. 10 to 30 cm) which is cut to1–2 cm thick subsamples. Based on chemical analysis and Pb210 and/or Cs137 -dating of these samples the concentration trends of contaminants and their sedimentation rates can be assessed.

We have analysed and dated sediment cores from the Gulf of Finland for PAHs, PCBs, PCDD/Fs, PBDEs and PFASs.

The results show declining concentrations for most of the contaminants, especially for PAHs, PCDD/Fs and PCBs over the last couple of decades. This indicates that restrictions previously set have been effective and have had impact on contaminant levels in the environment. However, results also reveal recent increase in concentrations of several long-chained PFASs, e.g PFOS, PFUnDA and PFTrDA. Also, the results indicate the substitution of restricted PFOS by other PFASs and support the need of regulation of PFASs as a group, rather than as individual compounds.

Scientists and Exercise for Health

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Looking at the bigger picture, exercise for health and the economy go hand in hand. Never has an exercise for health been so high on the agenda of governments' public health strategies (Health Matters, 2020) worldwide, with many currently imposing national lockdowns or harsh restrictions on the movement of their people. One also needs to acknowledge the total social and economic value of being involved in community sport and physical activity (Sport England). While exercise for health has been widely researched with the reference to public health and sports, a gap exists in the field of environmental science *scientific* communities. Indisputable, exercise for health should too play an important role in scientists' lives if they are to carry out their scientific work productively while staying healthy during these difficult times. Like in other fields, environmental scientific research involves spending too much time sitting and writing, not exercising enough and often requires working in harsh climatic conditions. Without realising it as well as forgetting to look after own health, this can easily disrupt scientists' professional lives. This argument provides a rationale for the poster, that is, to explore scientists' perceptions and attitudes toward exercise for health within the research community of the Baltic Sea region. Using the analogy of a team sports fitness coach whose task is to ensure that athletes are fit for play, the same could be applied to the scientists. How well do they look after their minds and bodies? How healthy is their diet? How fit are they for work? While reflecting on their fitness practices, participants will have an opportunity to share experiences and complete short health-based questionnaires as a part of ongoing research into this theme. The findings may not only give us an interesting insight into the linkage between the scientific community and exercise for health in the Baltic Sea region but may also increase the awareness of this research theme as well as generate practical ideas that may find a home amongst the research institutions beyond.

Caffeine and selected pharmaceutical residues in the southern Baltic Sea waters – Gulf of Gdańsk case study

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The presence of several types of chemicals of emerging concern (CECs) in Waste Water Treatment Plant effluents is well acknowledged and is known to pose a potential threat to the receiving environments including coastal zones. An important and diverse group of CECs are pharmaceutically active compounds, including antibiotics, non-steroidal anti-inflammatory drugs (NSAIDs), and antiepileptic drugs. Another group of CECs that may pose adverse effects to marine organisms is lifestyle products like caffeine. Due to the present knowledge presence of many CECs has been detected in the Baltic Sea waters, nevertheless, detailed information about spatial and temporal differences in CEC concentrations is hardly available.

In the present study, the Gulf of Gdańsk has been considered as a case study. The objectives of performed investigation included evaluation of temporal and spatial distribution of selected CEC concentrations in the studied area, identification of the most important sources of target compounds, and assessment of their ecotoxicological risk through the determination of risk quotient (RQ). Target CECs were selected based on previous studies and included carbamazepine, diclofenac, sulfamethoxazole, and trimethoprim. A new compound, not investigated earlier in the Gulf of Gdańsk waters was caffeine (a possible tracer of wastewater contamination due to its nearly ubiquitous consumption by humans). About 70 samples of surface and near bottom waters have been collected at several sites located in the Gulf of Gdańsk, from the Vistula river and from smaller rivers discharging to the Gulf. The samples were collected in spring 2018 and 2021 and analyzed for the presence of target compounds. BAKERBOND® Speedisks (H2O-Philic DVB) were used for the solid-phase extraction. The extracts were analyzed with the use of LC–ESI-MS/MS method. Isotopically-labeled standards were used as internal standards. Caffeine was the most often detected compound (100% detection), followed by carbamazepine (95% detection) and sulfamethoxazole (66%). Diclofenac and trimethoprim were detected in only a few samples. The range of measured concentrations was quite wide depending on the compound, location of sampling site and sampling period. Nevertheless, continuous presence of analysed CECs in the investigated area was observed. The measured concentrations were compared to a predicted no-effect concentration. PNEC was estimated using available lietarature data and/or acute or chronic toxicity data for algae, invertebrates and fish in accordance with the rule to consider the worst case scenario. Considering that caffeine and carbamazepine were the most often detected compounds in the water samples it can be concluded that the presence of these CECs in waters in the investigated area is of significant ecotoxicological relevance.

Ionic liquids – a potential threat to the marine microorganisms

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The widespread presence of emerging contaminants is a potential factor contributing to the deterioration of freshwater and marine ecosystems. Ionic liquids (ILs) are a class of organic salts that have gained lots of attention over recent years due to their potential applications in industrial areas. However, due to their unique physicochemical properties and resistance to biodegradation, they are considered possible water micropollutants.

Presently, regulatory risk and hazard assessments are mainly based on the evaluation of the effects of individual chemicals. Yet, ecosystems are exposed to multi-component micropollutant mixtures. The interactions between those pollutants and their continuous presence in the aquatic environment can cause an increase in the overall threat to living organisms and result in unforeseen negative effects. Therefore, there is a need for more information on reactions of a wide range of marine species of cyanobacteria, diatom, and green algae to different types of harmful agents and their mixtures to accurately evaluate their impact on the primary production.

The presentation aims to give a general overview of the challenges and potential risks associated with the presence of xenobiotic mixtures in the aquatic environment. 1-dodecyl-3-methylImidazolium bromide (IM1-12Br) as a representative of ionic liquids- potential water micropollutants and oxytetracycline (OTC) -pharmaceutical- already found on the wide-scale in the aqueous environment including the Baltic Sea were employed as target compounds. The results of the chronic exposition of microorganisms present in brackish coastal waters and open Baltic Sea basin including green algae *Chlorella vulgaris*, cyanobacteria *Microcystis aeruginosa*, and diatom *Phaeodactylum tricornutum* to these two compounds are presented. Standard measurements (e.g. optical density) were combined with photosynthetic parameters evaluation. The variations in chlorophyll *a* fluorescence kinetics defined as O, J, I, and P steps of redox states of photosystems PSI and PSII directly related to electron transfer efficiency were quantified. The information on the photosynthetic activity of the target microorganisms improves the understanding of the modes of action of Ils. Moreover, the report for the first time provides information on the mixture effects of ionic liquids and other organic micropollutants. It is particularly important in terms of assessing and predicting the adverse effects of xenobiotics on phytoplankton community structure and functioning.

LainePoiss®— a lightweight and ice-resistant wave buoy

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Wave buoys are a popular choice for measuring sea surface waves, and there is also an increasing interest for wave information from ice-covered water bodies. Operational wave buoys are large and therefore expensive and inconvenient to deploy. Many commercially available devices cannot measure short waves and are not tested in ice. We have developed LainePoiss (LP)—an ice-resistant and lightweight (3.5 kg) wave buoy, which measures waves up to 1.28 Hz. LP has a rechargeable battery with at least 2 months of operation and transmits wave parameters and spectra over cellular or satellite networks. LP has undergone extensive validation in the field (e.g., the bias in significant wave height was 0.01 m) and in a wave tank both in moored and drifting setups (incl. also Unmanned Aerial Vehicle deployments from shore and from ice). A month-long experiment where three LP's were deployed in ice in the Gulf of Riga showed that LP can survive ice and measure waves in ice. Still future development is pursued, since the low frequency part of the spectrum suffers from some artefacts stemming from sensor noise.

EMODnet Ingestion and safe keeping of marine data

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The European Marine Observation and Data Network (EMODnet) consists of more than 160 organisations that together work on assembling, harmonising and making marine data, products and metadata more available to public and private users. This Data Ingestion portal facilitates additional data managers to ingest their marine datasets for further processing, publishing as open data and contributing to applications for society.

The EMODnet members are national and regional marine and oceanographic data repositories and data management experts from Europe. They have arrangements and infrastructures in place at national, international and European level for providing long term stewardship and access to marine and oceanographic data as collected by research, monitoring and survey programmes from more than a thousand data originators from public, research and private sectors.

The EMODnet Data Ingestion portal seeks to identify and to reach out to other potential providers in order to make their data sets also part of the total offer. This can concern historic data sets that can become part of the large European archives that might be of use for many applications. This can also concern operational oceanography data streams from monitoring platforms that can become part of the European operational oceanography data exchange for feeding forecasting models and supporting various operations.

The EMODnet Data Ingestion portal aims at streamlining the data ingestion process so that data holders from public and private sectors that are not yet connected to the existing marine data management infrastructures can easily release their data for safekeeping and subsequent distribution through EMODnet.

The focus is to pick up legacy/'sleeping'/old datasets that are in danger of being lost. Here are presented the ideas behind the portal and the marine researches and managers are encouraged to submit their data through the EMODNET Ingestion portal.

Drone-based characterization of seagrass habitats in the tropical waters of Zanzibar

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Unmanned Automatic Vehicles such as drones are increasingly being applied as an alternative to more costly, time-consuming traditional mapping approaches for submerged aquatic vegetation (SAV). We applied aerial drones in combination with underwater photos to map habitat conditions and assess ecosystem health of nine nearshore seagrass-dominated areas along the coastline of Unguja Island, Zanzibar situated in the West Indian Ocean (WIO). Corrected images were classified using a maximum likelihood algorithm to distinguish the total cover of SAV, sand, corals, rocky, macroalgae, and cover of dominant seagrass species. Drone images were furthermore used to determine the level of habitat fragmentation based on different seascape metrics. Additionally, we integrated data extracted from *in-situ* underwater images on sea urchin abundance, epiphytic cover and dead leaves to further characterize the nine sampled areas. Multivariate analysis was then applied to determine the similarity of areas and classify these according to their ecosystem health status, relevant for coastal management and future research. A total of 724 ha in nine nearshore areas were mapped, of which SAV covered 55%, corals 9%, bare 31% and macroalgae 5%. Nine seagrass species were observed and mean species occurrence was 6. The moderate dominant cover class of 40-70% had highest cover share of 19.8%. Variation with depth gradient indicated decrease in both the abundance from 30% at 1-2m towards 1.6% between 5-6m, with significant variation among the species. In addition, seascape metrics such as number and size of patches indicated higher levels of fragmentation associated areas with low share of percent cover. In two sites where sea urchins were apparent, a negative relation (r^2 = 0.9, $p<0.01$) with SAV cover, suggested a strong impact. Overall, the classified maps had an accuracy of up to 87%. Multivariate analysis of cover data, measures of SAV fragmentation and sea urchin density suggested significant differences in the biotic features of the 9 sites despite of considerable inter site variability. Importantly, there was a clear distinction between sites near the main coastline, and sites further off shore around small Islands, which for many parameters seems less disturbed by human activity. Our study demonstrated the robustness of drone for mapping seagrass health in tropical waters providing a suite of important data relevant for coastal ecosystem monitoring in the WIO region.

Assessment of marine data from heterogenous databases using Data Assimilation System

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Originally the Data Assimilation System (DAS) has been developed as a client program to communicate with the Baltic Environmental Database (BED) which has been initiated in 1990 by Fredrik Wulff in the Department of System Ecology, Stockholm University as a part of the project “Large-scale Environmental Effects and Ecological Processes in the Baltic Sea”. DAS extracts data from the database and constructs three-dimensional gridded fields of the selected oceanographic variables by interpolation. Gridded data can be analysed and visualized in different ways (map of spatial distribution, cross-sections, vertical profiles, calculation of water masses with certain characteristics).

Later, several other online databases from different institutions (Leibniz-Institute for Baltic Sea Research, Aarhus University, Finnish Environment Institute, Finnish Meteorological Institute, Swedish Meteorological and Hydrological Institute) were made available for DAS using a data portal which requests and harmonizes received data.

In recent years many oceanographic datasets were made available for downloading. Often such data are provided for personal use only and therefore cannot be included as a server-based database available for the data portal. To overcame such problems a new version of DAS allows to request data from remote databases using the data portal and from the local databases as well. DAS uses a popular SQLite database engine and a simple database structure. Users can convert their data in the specified format by developing a program using popular programming languages like Python, R, Java and others.

Oceanographic monitoring data gathered by HELCOM Contracting Parties within the COMBINE monitoring programme are hosted by The International Council for the Exploration of the Sea (ICES) and can be downloaded from the ICES data portals. To work with these data DAS has a built-in tool which converts downloaded dataset into local database and adds it to the list of databases for querying the data.

This approach makes it possible to aggregate data from different sources and construct a specific, problem oriented local database.

Regionally Extended Shared Socioeconomic Pathways for the Offshore Wind Industry in Finland

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Offshore wind energy is increasingly becoming an important part of European and global low-emission power systems. The aims of this paper are to create a shared understanding on the major drivers of offshore wind development in Finland and to explore how these drivers, and opportunities for the entire industry, may develop over the 21st century, under different global futures. This research develops extended Shared Socioeconomic Pathway (SSP) narratives for the offshore wind industry by using a virtual participatory workshop with expert stakeholders. According to our results the five key drivers shaping the prospects of offshore wind development are public acceptability of offshore energy, global and national demand for low-emission energy, technological development and relative competitiveness of offshore energy, availability of space and wind resources, and energy markets and transmission infrastructure. Nationally extended SSP narratives, building on these key drivers, describe a wide range of alternative future risks and opportunities for developing offshore energy. Under sustainable development (SSP1), offshore wind is likely to soon become a major source of energy in the area, if developed in a balanced manner alongside other uses of the marine space. Under fossil-fuelled development (SSP5), offshore wind grows slower and may experience rapid uptake only in the latter half of the century. Under the regional rivalry scenario (SSP3), the need for local energy sources drives the national energy policies and may create new opportunities for offshore wind. Under the inequality scenario (SSP4), local municipalities and the residents decide on locations of new wind turbines and the overall magnitude of future offshore wind.

Keywords: Scenario narratives, renewable energy transition, renewable energy, participatory planning,

An early warning system on invasive alien species in the Baltic Sea ports: from idea to the implementation

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Shipping facilitates the transportation of over 90 % of the world's commodities and eventually transfers ~10 billion tons of ballast water (Ghosh and Rubly, 2017; Khandeparker and Anil, 2017). Based on the analysis of data stored in the information system on aquatic non-indigenous and cryptogenic species AquaNIS (2021) 29 out of 60 (48%) of non-indigenous species (NIS) introduced to the Baltic Sea in the 21st century, were likely transported by ships' ballast water and sediments.

Recently the International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWMC) (IMO, 2007) came into force, which aimed at reducing the spread of harmful aquatic organisms and pathogens (HAOPs) with ships' ballast water. The effective implementation of BWMC in the countries includes a wide range of stakeholders from port authorities, ports state control, local environmental agencies, ship owners and etc. In cases when in the port and port vicinities the detection of HAOP is assessed, the crucial step in ballast water management is a warning signal service (Early et al. 2016) to the associated stakeholders and institutions.

Klaipeda University has developed a new AquaNIS Early Warning System (EWS) model, based on introduction records of IAS in the ports, for predicting the possible risk to environment and human health. The specific goals of the early warning are firstly to warn vessels to prevent loading of ballast water when critical biological conditions occur in ports and surrounding areas i.e. outbreaks of HAOP. Secondly, to warn a port, environmental and health authorities when NIS or pathogens are present in ports or surrounding areas to enable management activities. Such early warning system with risk assessment tools are integrated into online systems AquaNIS (AquaNIS, 2021), for timely communication of findings of HAOPs to all relevant authorities in countries to ensure that there is sufficient time for the response measures and the roles of all actors are clearly defined.

The AquaNIS early warning system was presented for the Baltic sea stakeholders who are associated with marine environment and industry. After the presentation of this system, Baltic associated stakeholder were asked to assess the developed system in order to identify advantages and disadvantages of the system. Development of communication mechanism integrating rapid ballast water sample analysis and online data platform is crucial for the prevention and management of the spread of HAOP.

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