Rostock. Meeresbiolog. Beitr.	Heft 34	44-52	Rostock 2025

Daniela GLÜCK[1*], Kira PREUSCH[2]

[1*] Department Aquatic Ecology, University Rostock, Albert-Einstein-Straße 3, 18059 Rostock
daniela.glueck@uni-rostock.de

[2] Department Aquatic Ecology, University Rostock, Albert-Einstein-Straße 3, 18059 Rostock
kira.preusch@uni-rostock.de

Sand nourishments do not foster diaspore accumulation on exposed sandy coasts at the German Baltic Sea coast

Abstract

Coastal protection measures, such as sand nourishments and groynes, are widely implemented along the German Baltic Sea coast to mitigate erosion. It is already known that these structures can have an influence on underwater vegetation by determining its distribution or colonization. However, their impact on macrophyte seed banks remains largely unexplored. This study investigates whether sand nourishments introduce or redistribute algal diaspores and macrophyte seeds in coastal ecosystems. Sediment samples were collected before and after a sand nourishment in Ahrenshoop and compared to control sites in Graal Müritz. Of 375 samples analysed, only three diaspores were found: two spores of *Ruppia maritima* L. (only one viable) and one spore of *Zannichellia palustris* L., all in Ahrenshoop. No diaspores were detected at the control sites in Graal Müritz. The low abundance suggests that sand nourishments do not significantly contribute to diaspore dispersal. This is most likely due to the overall low abundance of diaspores and seeds at exposed coastal stretches. Instead, high wave exposure and sediment mobility might limit the seed accumulation in these ecosystems. While coastal protection structures may not influence seed banks, restoring macrophyte communities remains crucial for nature-based coastal protection, requiring viable seed banks or transplantation efforts.

Keywords: coastal protection, sand nourishment, groynes, sediment analysis, biodiversity, macro algae

1 Introduction

Coastal zones are highly dynamic ecosystems constantly changing due to the effects of various environmental influences, such as wind and waves (STAUN 2009). This can lead to erosion on exposed coastal stretches. As a result, coastal protection measures have been implemented. Two of the most commonly used coastal protections measures at the German Baltic Sea coast are sand nourishments and the construction of groynes, reported by the STAUN (2009). Groynes protect around 79 km of the German Baltic Sea coast, while sand nourishments are implemented regularly for 69 km of coastline. During a sand nourishment, sediment is hydraulically extracted from marine sand deposits using suction dredgers and transported to the beach as a water-sand mixture through pipeline systems (KORTEKAAS et al. 2010). As the sand settles, the water is directed back into the sea. Subsequently, the sand is incorporated into the dune, beach and shallow water areas using excavators and bulldozers. Due to alongshore sediment transport, sand nourishments need to be repeated, with the average interval between nourishment events typically ranging from 8 to 10 years (STAUN 2009).

Sand nourishment operations can induce significant alterations in coastal habitats and their associated faunal and floral communities. Potential impacts are the loss or the modification of coastal habitats by destroying and covering the native habitats and additional nutrient inputs (GRUNEWALD 2006, JORDAN & FRÖHLE 2022, SCHOONEES et al. 2019). These changes result from direct mechanical impacts but also from interventions in the dune succession. Additionally, deposited sediments exhibiting physicochemical properties that differ from the original beach material, can lead to further habitat degradation (GLUECK et al. 2024). Furthermore, the effects of sand nourishments can extend to distant ecosystems, including seagrass beds or macrophyte communities through generated sediment plumes that increase turbidity (GLUECK 2023).

The distribution of algal diaspores and macrophyte seeds in the Baltic Sea is influenced by various factors, including ecological parameters such as the species and the diaspore or seed morphology but also dependent on seasonal variations and hydrological conditions (VAN DER PIJL 1982). Diaspores of algae are commonly found in shallower, coastal areas and brackish water regions that receive inputs from rivers and streams. Coastal areas, shallow bays, river mouths, and brackish water regions are particularly favourable habitats for algal diaspores within the Baltic Sea (STEINHARDT & SELIG 2007, STEINHARDT & SELIG 2009). Although macrophytes in the Baltic Sea typically can be found in sheltered areas, their diaspores could be transported either by natural alongshore sediment transport, or by anthropogenic forces. Sand nourishments lead to the relocation of larger sediment masses along the coast, however, currently no detailed investigation exists regarding the implications of sand nourishments for the introduction or distribution of diaspores and seeds on the Baltic coast.

To provide valuable insights into this topic, the following present study contains an analysis of sediment samples after a sand nourishment in search of seeds and diaspores to address the following questions: (i) is there an input of diaspores and seeds after a sand nourishment and if so (ii) which diaspores and seeds are introduced?

2 Methodology

The sediment samples were taken from Ahrenshoop and Graal Müritz, two small municipalities at the German Baltic Sea Coast (Figure 1, Ahrenshoop: 54° 22' 50.57'' N 12° 25' 16.51'' E and Graal Müritz: 54° 15’ 34.41’’ N 12° 14’ 30.69’’ E). The distance between the two cities is about 15 km.

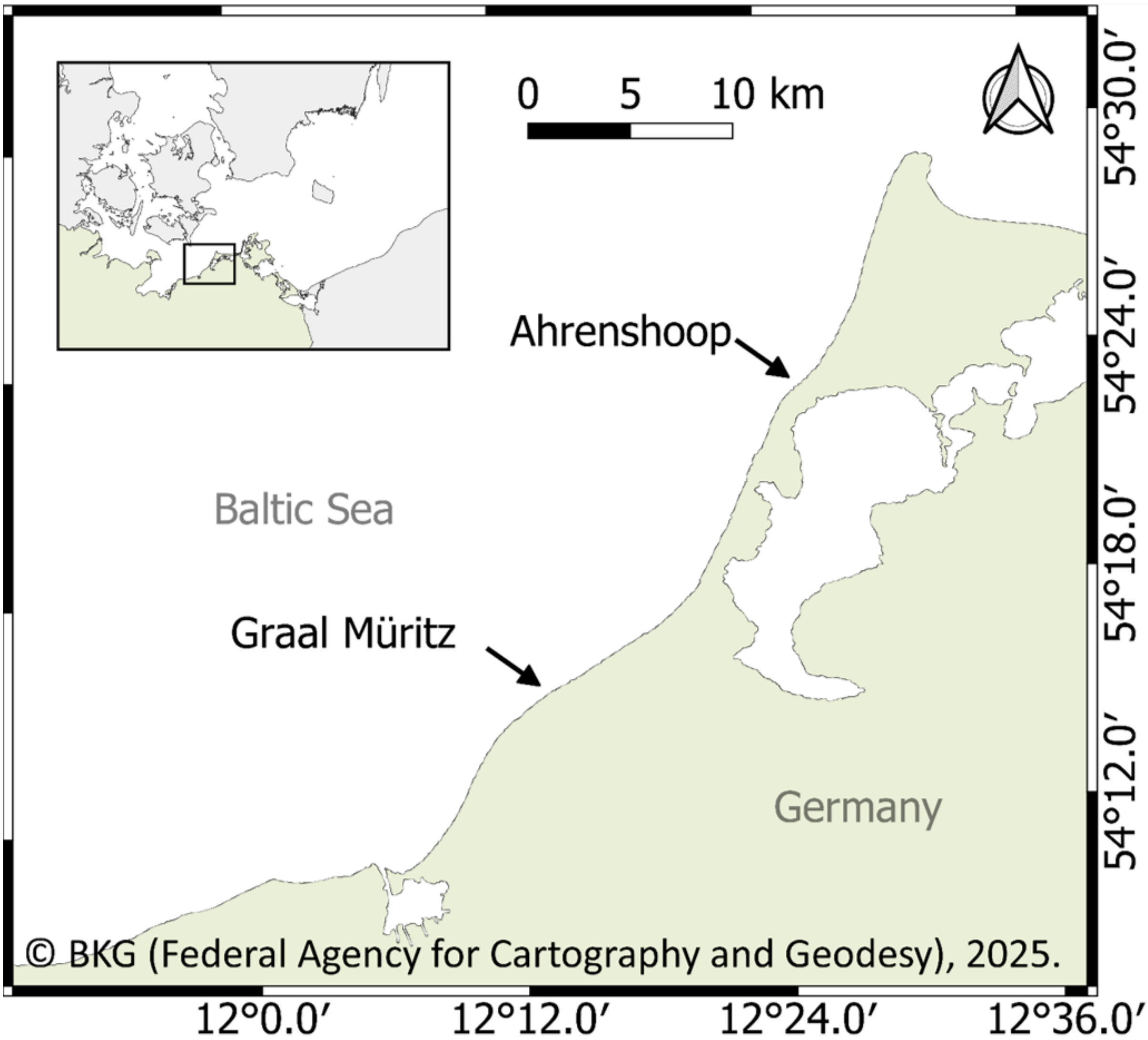

Fig. 1 Map of the sampled beaches in Germany. In Ahrenshoop, both sand nourishment and groynes are installed as coastal protection measures. In Graal Müritz, groynes are only installed at some beaches but also unprotected sites were sampled.

In Ahrenshoop there was a sand nourishment in winter 2021/2022 for coastal protection reasons. Around 600,000 cubic meters of medium sand was extracted approximately 10 km from the coast from a sand deposit and nourished on almost 4.5 km of coastline. The nourished sand was then deposited on the beach and the dune slope by heavy machinery (Figure 2). Additional groynes are installed at the beach. In Graal Müritz, samples were taken from a site with groynes as well, but also from a control site without any coastal protection measures.

Fig. 2 Photos of the sand nourishment in Ahrenshoop. Sand is nourished onto the beach with water through a pipe system from a ship and then distributed from there using heavy machinery. Left picture taken by Jan Tiede, right picture taken by StALU MM.

Sediment samples were taken from the upper 20 cm of the sediment at the dune, beach and in the shallow water at different water depths (1 / 2 / 3 m), see Figure 3. The number of replicates was n = 5. When groynes were present, the samples were taken at both sides of the groynes and behind the groynes. In Graal Müritz, only one sampling was performed (07.04.2021). In Ahrenshoop, the sampling was performed before the nourishment, on 11.08.2021, and after the nourishment, following the timetable: one week after (16.02.2022), one month after (14.03.2022), three months after (19.05.2022), six months after (11.08.2022) and more than one year after (15.05.2023). The sediment was dried for 4 h at 105 °C until constant dry weight and sieved through sieves with different mesh sizes. Samples from the mesh sizes 1 / 0.8 / 0.5 / 0.2 mm were kept for diaspore analysis. Smaller grain sizes were not analysed. The analysis was performed by visual inspection using a microscope (Olympus SZX2-ILLT, Olympus Inc., Tokyo, Japan). The diaspores were identified using the determination keys of VEDDER (2004) and KRAUSE (1997). Overall, 375 sediment samples were analysed.

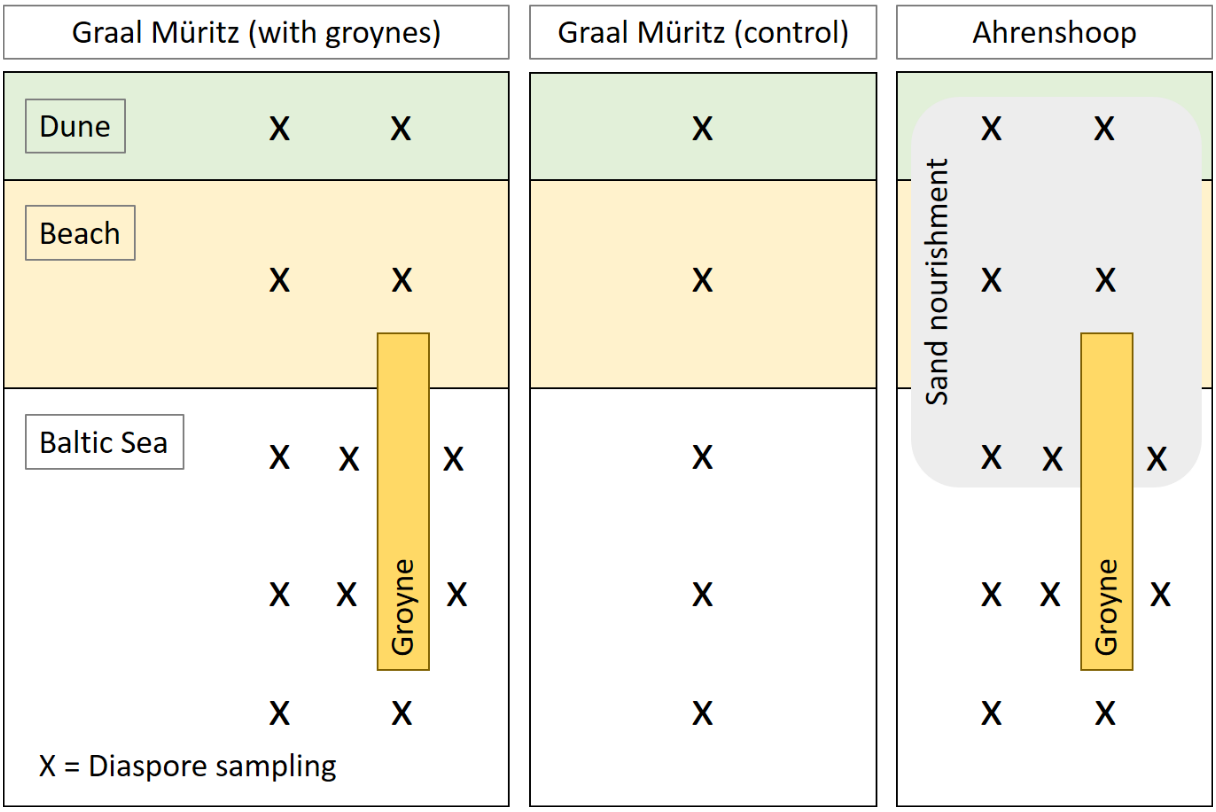

Fig. 3 Schematic graphic of the sampling position at the sites in Graal Müritz (one site with groynes, one site without) and Ahrenshoop. In the Baltic Sea, the sampling was performed at three water depths (1 / 2 / 3 m).

3 Results

Only spores of two different species were found in the sediment samples (Figure 4): *Zannichellia palustris* and *Ruppia maritima*. Only one spore of *Ruppia maritima* was unharmed and intact, the other spores were open and empty. All spores were found in only two samples from Ahrenshoop. Both *Ruppia maritima* spores were found in the same sample from one month after the nourishment (1 m water depth, left side of the groyne). The *Zannichellia palustris* spore was found in a sample one year after the nourishment (3 m water depth, behind the groyne). At the control site, Graal Müritz, no spores were found in the sand samples.

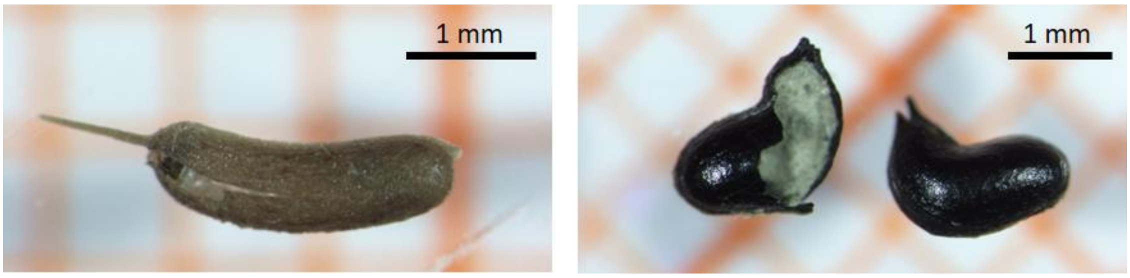

Fig. 4 Diaspores found in the sediments at Ahrenshoop. Left picture is *Zannichellia palustris*, right picture is *Ruppia maritima*. Only the right spore of *Ruppia maritima* was unharmed. The other two spores were open and empty.

4 Discussion

Aquatic macrophytes distribute by vegetative growth and sexual reproduction. The results of the sexual reproduction are diaspores, e.g. seeds and oospores, which accumulate in the sediment and can form seed banks. Most diaspores are found near the vegetation stands. This correlation between plant coverage and seed banks was detected by a number of scientists (GRILLAS et al. 1993, HUTCHINGS & RUSSELL 1989, VAN DEN BERG et al. 2001) and also applies to the Baltic Sea (STEINHARDT & SELIG 2007, STRAGAUSKAITĖ et al. 2021). But the diaspores can also be transported away from the producing organism by waves and currents, with increasing dispersal distance with decreasing vegetation cover (BAKKER et al. 1996, STEINHARDT & SELIG 2007). Nevertheless, this dispersal process occurs only limited in nature (STRAGAUSKAITĖ et al. 2021).

In Zingst (54° 26' 26.14'' N 12° 41' 38.14'' E), near the sampling area of this study, diaspores of the species *Chara baltica* var. *liljebladii* (Wallman) H.Schubert, Blindow & K.Weyer 2015 were found in the past (HOLZHAUSEN et al. 2015). But besides macro algae growing attached to the coastal protection measures (e.g. groynes), no macrophytes and only very few diaspores were found in the sampling areas in Ahrenshoop and Graal Müritz. The seagrass species *Zostera marina* L. was last reported before 1900 (SCHUBERT et al. 2014) in this region. During the samplings, no traces of seagrass besides the occasional occurrence of beach wrack was reported. Although all diaspores were found after the sand nourishment, only one of those was considered viable (intact) and no seagrass seeds were detected. In other parts of the Baltic Sea, sediments showed very high numbers of diaspores. These numbers can exceed up to 90.000 per m² and are dominated by oospores and seeds of *Potamogeton pectinatus* L., s. str., *Ruppia maritima*, *Zostera marina* and *Zannichellia palustris*. (NOWAK et al. 2018, STEINHARDT & SELIG 2007). Many of the abiotic factors at these sites were similar to the conditions found during the sampling, e.g. water depth, sediment sampling depth and salinity (NOWAK et al. 2018, STEINHARDT & SELIG 2007). However, there is one major difference: the exposure to waves and currents. All samples with higher numbers of diaspores came from sheltered sites of the coast, such as lagoons, whereas the samplings of this study were performed at exposed coastal areas. In the Baltic Sea, west and southwest winds are dominating the climate (TIESEL 1995) resulting in a clearly pronounced alongshore current (FENNEL 1995). The coast of Ahrenshoop and Graal Müritz faces northwest (Figure 1) and is therefore exposed to the weather. The connection between wave exposure and macrophyte communities and their seed banks has already been established in the Baltic Sea (STEINHARDT AND SELIG 2007, STEINHARDT AND SELIG 2009, NOWAK et al. 2018) but not yet verified by sampling. Hydrodynamics is one of the most important environmental variables determining the patterns of diaspores (STRAGAUSKAITĖ et al. 2021), transporting oospores to non-exposed, calmer areas. However, waves do not only affect the submerged macrophytes (BLINDOW et al. 2016) but they also increase sediment mobility. Sediment mobility has an impact on accumulation and burial of diaspores and results in more abundant diaspores in less mobile sediments (INGLIS 2000, NOWAK et al. 2018). This is also applicable for terrestrial plants on the dune where wind is the main factor influencing the seed dispersal: if seeds are buried too deep, the seedling emergence was decreased but also stronger wind lead to an overall smaller seed bank (LIU et al. 2011). The reason for the very low number of diapores found during the sampling is therefore not necessarily the presence of the coastal protection measures, but the exposition of the sampling sites. All of them are exposed to the open Baltic Sea and the hydrodynamic conditions are dominated by waves and currents – which is the cause for the installation of the coastal protection measures. Although these measures might not influence the seed banks, they could still benefit from macrophyte communities. Especially seagrass is considered to be able to support coastal protection as the plants form dense meadows where sediment erosion is inhibited and waves are dampened (KOCH et al. 2009). This kind of coastal protection is called nature-based solution. Legal regulations for a sustainable management of aquatic ecosystems in Europe (EUROPEAN UNION EU-WFD 2000) stipulate the restoration of degenerated ecosystems such as seagrass meadows, but suitable conditions must also exist for this. Macrophyte communities can only be restored either by transplantation from viable plants or by activation of seed banks - if the latter one is existing and intact (BAKKER et al. 1996, BONIS & GRILLAS 2002, HOLZHAUSEN et al. 2018, NOWAK et al. 2018). In this study, exposed sandy coasts at the German Baltic Sea coast do not accumulate diaspores or seagrass seeds after sand nourishments. A natural restoration by activation of a seed banks is therefore not possible in this areas.

5 Conclusion

The findings of this study indicate that sand nourishments do not significantly contribute to the introduction or accumulation of macrophyte diaspores in coastal areas of the German Baltic Sea. While a few diaspores were detected in the sediment following nourishment, their numbers were extremely low, and only one was intact. The primary factor influencing the presence and dispersal of macrophyte diaspores appears to be hydrodynamic exposure rather than the coastal protection measures themselves. Strong wave action and sediment mobility in these exposed sites likely prevent the establishment of seed banks, in contrast to more sheltered areas of the Baltic Sea where higher diaspore densities have been reported. Although the investigated coastal protection measures do not seem to promote the accumulation of diaspores, the potential role of macrophyte communities in stabilising sediments and mitigating coastal erosion should be further investigated as part of nature-based solutions in coastal management strategies.

Zusammenfassung

Küstenschutzmaßnahmen wie Sandaufspülungen und Buhnen sind an der deutschen Ostseeküste weit verbreitet und sollen Erosion mindern. Es ist bereits bekannt, dass diese Strukturen einen Einfluss auf die Unterwasservegetation haben können, indem sie deren Verteilung oder Besiedlung bestimmen. Ihre Auswirkungen auf die Makrophyten-Samenbanken sind jedoch noch weitgehend unerforscht. In dieser Studie wird untersucht, ob durch die Sandaufspülungen Diasporen von Algen und Samen von Makrophyten in Küstenökosysteme eingebracht oder umverteilt werden. Es wurden Sedimentproben vor und nach der Sandaufspülung in Ahrenshoop entnommen und mit Kontrollstellen in Graal Müritz verglichen. Von 375 analysierten Proben wurden nur drei Proben Diasporen gefunden: zwei Sporen von *Ruppia maritima* (nur eine davon lebensfähig) und eine Spore von *Zannichellia palustris*, alle in einer Sedimentprobe aus Ahrenshoop. An den Kontrollstandorten in Graal Müritz wurden keine Diasporen nachgewiesen. Die geringe Häufigkeit deutet darauf hin, dass Sandaufschüttungen nicht wesentlich zur Ausbreitung von Diasporen beitragen, was

jedoch höchstwahrscheinlich auf die generell geringe Abundanz von Diasporen und Samen an exponierten Küstenabschnitten zurückzuführen ist. Die hohe Wellenexposition und Sedimentmobilität könnten die Samenakkumulation dort einschränken. Auch wenn die Küstenschutzstrukturen keinen Einfluss auf die Samenbanken haben, bleibt die Wiederherstellung von Makrophytengemeinschaften für den naturbasierten Küstenschutz von entscheidender Bedeutung, was lebensfähige Samenbanken oder Transplantationsbemühungen erfordert.

Acknowledgement

The authors are thankful to the BMBF ("Bundesministerium für Bildung und Forschung" / Federal Ministry of Education and Research) for funding the project, grant number FKZ 03F0860F project ECAS Baltic. Special thanks go to the StALU MM (Staatliches Amt für Landwirtschaft und Umwelt Mittleres Mecklenburg), Germany, for exceptional communication and cooperation. Many thanks also go to the Centrum for Scientific Diving, University Rostock, for the support of the fieldwork and to the student workers Hilal Hoefer and Greta Winkler.

References

European Union EU-WFD, 2000. Directive 2000/60/EC of the European Parliament of the Council of 23 October 2000 establishing a framework for Communities in the field of water policy. Official Journal of the European Communities L327: 1-73.

Bakker, J. B., P. Poschlod, J. Strykstra, R. M. Bekker & K. Thompson, 1996. Seed banks and seed dispersal: important topics in restoration ecology. Acta Botanica Neerlandica 45: 461–490.

Blindow, I., S. Dahlke, A. Dewart, S. Flügge, M. Hendreschke, A. Kerkow & J Meyer, 2016. Long-term and interannual changes of submerged macrophytes and their associated diaspore reservoir in a shallow southern Baltic Sea bay: influence of eutrophication and climate. Hydrobiologia 778: 121-136.

Bonis, A. & P. Grillas, 2002. Deposition, germination and spatio-temporal patterns of charophyte propagule banks: a review. Aquatic Botany 72: 235-248.

Fennel, W., 1995. Wasserhaushalt und Strömungen. [Water regime and currents]. In Rheinheimer, G. (ed), Meereskunde der Ostsee. [Oceanography of the Baltic Sea], 2. Edition. Springer, Berlin: 56-67.

Glueck, D., 2023. Comparison of high turbidity events: Sand nourishments and storm events on sandy beaches at the Baltic Sea, Germany. Marine pollution bulletin 194: 115389.

Glueck, D., U. Schiefelbein & H. Schubert, 2024. Ecological Impacts of Coastal Protection on the Vegetation of Sandy Coasts at the German Baltic Sea Coast. Coasts 4: 437-453.

Grillas, P., P. Garcia-Murillo, O. Geertz-Hansen, N. Marbá, C. Montes, C. M. Duarte, L. Tan Ham & A. Grossmann, 1993. Submerged macrophyte seed bank in a Mediterranean temporary marsh: abundance and relationship with established vegetation. Oecologia 94: 1-6.

Grunewald, R., 2006. Assessment of Damages from Recreational Activities on Coastal Dunes of the Southern Baltic Sea. Journal of Coastal Research 225: 1145-1157.

Holzhausen, A., P. Nowak, C. Niedrig, M. Feike & H. Schubert, 2015. Morphometry of *Chara aspera, C. canescens*, *C. baltica* var. *baltica*, *C. baltica* var. *liljebladii* and *C. intermedia* oospores: Local variation versus taxonomic differences. Aquatic Botany 120: 60-66.

Holzhausen, A., C. Porsche & H. Schubert, 2018. Viability assessment and estimation of the germination potential of charophyte oospores: testing for site and species specificity. Botany Letters 165: 147-158.

Hutchings, M. J. & P. J. Russell, 1989. The seed regeneration dynamics of an emergent salt marsh. Journal of Ecology 77: 615-637.

Inglis, G. J., 2000. Disturbance-related heterogeneity in the seed banks of a marine angiosperm. Journal of Ecology 88: 88-99.

Jordan, P. & P. Fröhle, 2022. Bridging the gap between coastal engineering and nature conservation? Journal of Coastal Conservation 26.

Koch, E. W., E. B. Barbier, B. R. Silliman, D. J. Reed, G. M. E. Perillo, S. D. Hacker, E. F. Granek, J.H. Primavera, N. Muthiga, S. Polasky, B. S. Halpern, C. J. Kennedy, C. V. Kappel & E. Wolanski, 2009. Non-linearity in ecosystem services: temporal and spatial variability in coastal protection. Frontiers in Ecology & Environment 7: 29-37.

Kortekaas, S., I. Bagdanaviciute, P. Gyssels, J. M. A. Huerta & A. Héquette, 2010. Assessment of the Effects of Marine Aggregate Extraction on the Coastline: an Example from the German Baltic Sea Coast. Journal of Coastal Research 51: 205-214.

Krause, W., 1997. Charales (Charophyceae). In Ettl, A., G. Gärtner, H. Heynig & D. Mollenhauser (eds), Süßwasserflora von Mitteleuropa [Freshwater flora of Central Europe]. Gustav Fischer, Jena: 202.

Liu, H.-L., X. Shi, J.-C. Wang, L.-K. Yin, Z.-Y. Huan & D.-Y. Zhang, 2011. Effects of sand burial, soil water content and distribution pattern of seeds in sand on seed germination and seedling survival of *Eremosparton songoricum* (Fabaceae), a rare species inhabiting the moving sand dunes of the Gurbantunggut Desert of China. Plant Soil 345: 69-87.

Nowak, P., T. Steinhardt, U. von Ammon, H. Rohde, A. Schoor, A. Holzhausen, R. Schaible & H. Schubert, 2018. Diaspore bank analysis of Baltic coastal waters. Botany Letters 165: 159-173.

Schoonees, T., A. Gijón Mancheño, B. Scheres, T. J. Bouma, R. Silva, T. Schlurmann & H. Schüttrumpf, 2019. Hard Structures for Coastal Protection, Towards Greener Designs. Estuaries and Coasts 42: 1709-1729.

Schubert, H., T. Steinhardt & A. Schanz, 2014. Monitoring Makrophytobenthos - Dokumentation von historischen und rezenten Seegrasvorkommen für die Bewertung nach WRRL und MSRL entlang der Ostseeküste Mecklenburg-Vorpommern. Forschungsbericht im Auftrag des Landesamts für Umwelt, Naturschutz und Geologie Mecklenburg-Vorpommern, 44 pp.

StAUN (Staatliches Amt für Umwelt und Natur Rostock [Rostock State Office for Environment and Nature]), 2009. Regelwerk Küstenschutz Mecklenburg-Vorpommern (Übersichtsheft). Grundlagen, Grundsätze, Standortbestimmung und Ausblick [Regulations for coastal protection in Mecklenburg-Vorpommern (overview booklet). Basics, principles, assessment and outlook]. Ministerium für Landwirtschaft, Umwelt und Verbraucherschutz Mecklenburg-Vorpommern [Ministry of Agriculture, Environment and Consumer Protection Mecklenburg-Western Pomerania] (ed), 110 pp.

Steinhardt, T. & U. Selig, 2007. Spatial distribution patterns and relationship between recent vegetation and diaspore bank of a brackish coastal lagoon on the southern Baltic Sea. Estuarine, Coastal and Shelf Science 74: 205-214.

Steinhardt, T. & U. Selig, 2009. Comparison of recent vegetation and diaspore banks along abiotic gradients in brackish coastal lagoons. Aquatic Botany 91: 20-26.

Stragauskaitė, V., M. Bučas & G. Martin, 2021. Distribution of Charophyte Oospores in the Curonian Lagoon and their Relationship to Environmental Forcing. Water 13: 117.

Tiesel, R., 1995. Das Wetter. [Weather]. In Rheinheimer, G. (ed) Meereskunde der Ostsee. [Oceanography of the Baltic Sea], 2. Edition. Springer, Berlin: 46–55.

van den Berg, M.S., H. Coops & J. Simons, 2001. Propagule bank buildup of *Chara aspera* and its significance for colonization of a shallow lake. Hydrobiologia 462: 9-17.

Van der Pijl, L, 1982. Principles of Dispersal in Higher Plants. Springer, Berlin: 214-216.

Vedder, F., 2004. Morphologie und Taxonomie rezenter und subfossiler Characeen-Ooosporen aus der Ostsee [Morphology and taxonomy of recent and subfossil oospores of charophytes out of the Baltic Sea]. Rostocker Meeresbiologische Beiträge 13: 43-54.