Walls or the wall, that is the question

Vallar eller vallen, det är frågan

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Abstract

A world with multimeter sea level rise is likely to be a world riddled with storm surge barriers. One cannot with certainty tell if or when our world will experience such magnitudes of sea level rise, but we can infer that certain geographical locations offer alternative options to local storm surge barriers. Here, the Baltic Sea is discussed. The Baltic Sea is connected to the open ocean by the narrow and shallow Danish Straits. Closing these straits would require building a seawall of about half the length of the longest seawall in existence today. Closing the sea would create a freshwater lake, a configuration the Baltic Sea had until about 8000 years ago. Given that the scale of the seawall needed to enclose the Baltic Sea is smaller than a number of seawalls already in existence, it is argued that the question is not if an enclosure could be built, but at what magnitude of sea level rise its construction would be preferable to other adaptation measures with smaller environmental footprints. It is found that different countries would likely have different opinions about this given their differing levels of exposure.

Keywords: Sea level rise, Seawalls, Dikes, Adaptation, Flooding

Sammanfattning

En värld med flera meters havsnivåstigning är högst sannolikt en värld full av översvämningsskydd. Man kan inte med säkerhet veta när eller om så stora havsnivåstigningar kommer upplevas i vår värld, men man kan med säkerhet säga att vissa platser erbjuder alternativ till lokala översvämningsskydd. Här diskuteras Östersjön, som är sammanlänkad med det öppna havet genom trånga och grunda sund. För att stänga dessa sund skulle en havsvall kunna konstrueras vars längd skulle behöva vara ungefär hälften av den längsta havsvallen som existerar idag. Att stänga sunden skulle transformera Östersjön till en färskvattensjö, någonting den var för ungefär 8000 år sedan. Givet att den föreslagna vallen är mindre än ett antal havsvallar som redan existerar, så argumenteras det för att frågan inte är om en sådan vall skulle kunna byggas, utan hur högt havsnivån måste stiga för att en sådan vall skulle vara att föredra över andra åtgärder med mindre miljökonsekvenser. Givet att utsattheten för havsnivåhöjning är väldigt olika i olika länder är det sannolikt att det optimala konstruktionstillfället inte ens approximativt kommer sammanfalla för olika länder.

Introduction

Enormous sums are spent every year on mitigating climate change and on climate adaptation. As an example, The EU's 2021-2027 long-term budget, together with the NextGenerationEU recovery instrument, amounts to 1.8 trillion euro in 2018 prices, of which the European Commission claims that 30% will be spent to fight climate change. The massive spending is a consequence of similarly enormous projections of future damage. The Horizon 2020 funded COACCH project estimated that the largest impact would come from flooding induced by sea level rise that could "lead to damages in excess of 100 billion euro per year by the 2050s, even under a moderate warming scenario (RCP4.5)" in current prices and with no adaptation in place (the COACCH project, 2021). Toward the end of the century in a very high emission scenario with an extreme ice-sheet melt projection, Vousdoukas et al. (2018) projected that the annual flood damage in Europe could exceed a trillion euro, also this estimate in the absence of adaptation. Fortunately, Vousdoukas et al. (2020) found that a large percentage of the projected damage could be avoided by raising coastal flood defenses and that such constructions would have favorable cost to benefit ratios.

When both the potential problems and the allocatable resources are vast it should come as no surprise that a number of megaprojects have been suggested to tackle the issues related to sea level rise. One such proposal is to attempt to curtail sea level rise through geoengineering of polar glaciers (Moore et al., 2018). Another suggestion is to turn the whole North Sea into a giant lake, through construction of seawalls between Norway and Scotland and between England and France (Groeskamp and Kjellsson, 2020). Both of these proposed projects would, if they were ever constructed, be civil engineering on a scale never undertaken before, and they would have to be done, at least, partly over very rough seas hundreds of meters deep. Enclosing the Baltic Sea on the other hand, would require a seawall that is only about half the size of the biggest already in existence. Moreover, the construction could be done over shallow straits and in comparably sheltered conditions.

Sweden and Denmark are connected by three straits: Öresund, the Great Belt and the Little Belt that are at their narrowest 3.5, 12 and 0.7 km wide respectively, see Fig. 1. These straits are also already connected by bridges and they are shallow, some tens of meters is the maximum depth. The total length of seawall that would have to be constructed to enclose the Baltic Sea, would as mentioned before only be about half the length of the longest seawall in existence today. The two longest currently existing seawalls the Saemangeum Seawall (finished in 2010) in South Korea and the Afsluitdijk (finished in 1932) in the Netherlands are both in excess of 30 km long. For comparison, the proposed seawall needed to enclose the North Sea would be 637 km long (Groeskamp and Kjellsson, 2020). Moreover, the average height of the Saemangeum Seawall is 36 m, which would more than suffice for a Baltic seawall even in a world with multiple meters of mean sea level rise. Moreover, the construction cost for the Saemangeum Seawall of 1.83 billion euro (2018 value) (Groeskamp and Kjellsson, 2020), is within the range of what the city of Gothenburg (with 600000 inhabitants) on the Swedish west coast expects to spend on floodgates (SWECO, 2023). In comparison to the high estimates of future damage and the enormous property values at stake, the building cost of a Baltic seawall would be negligible. The central banks of Sweden and Denmark estimated respectively that about 5% of properties in southern Sweden and 13% of those in Denmark would be exposed to flooding during severe storms in 2100, if the mean sea level rose according to the projection for the very high emission scenario RCP8.5 (Nationalbank, 2019; Danielsson, 2020).

For comparison, it is also worth noting that the Saemangeum Seawall was built to create about 400 km^2 of farmland and a freshwater reservoir. The values at stake around the Baltic Sea coast are of course many orders of magnitude greater, and not just economical but also architectural and cultural, including several world heritage sites.

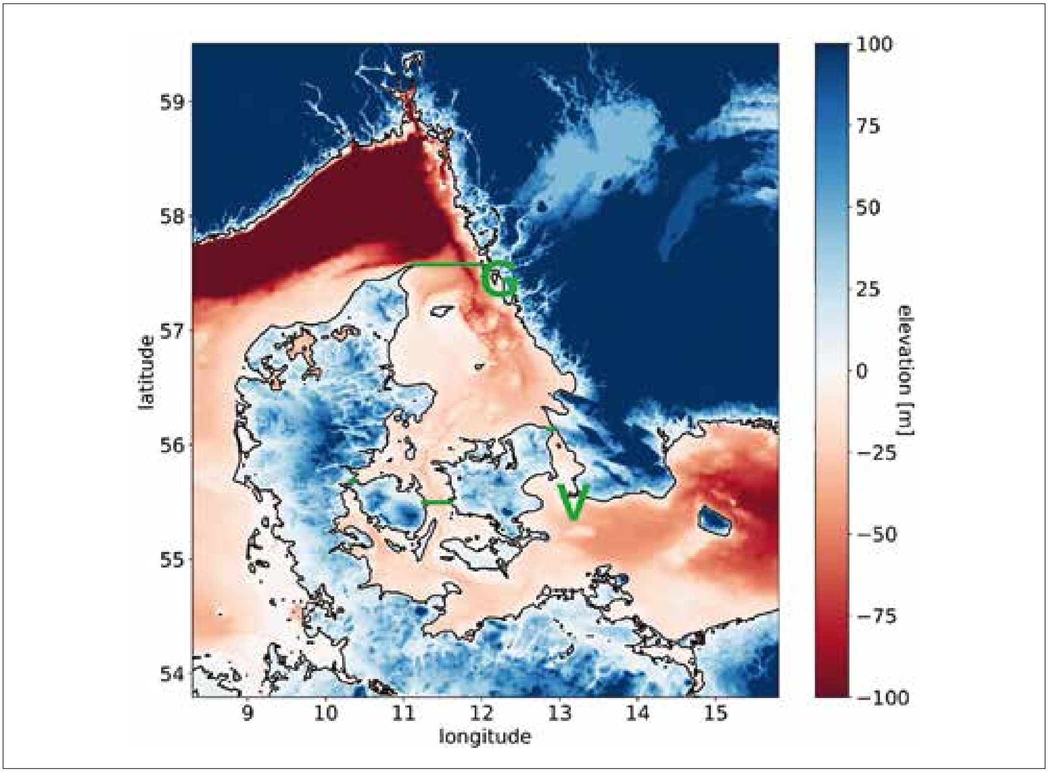
A list of potential marginal seas that could host enclosure dams, including the Baltic, was given by Groeskamp and Kjellsson (2020). The geographical conditions for creating a cost efficient enclosure around the Baltic Sea are very favorable in comparison to the others. Only the Black Sea, which is connected to the Mediterranean by even narrower straits is likely to have better geographical conditions. Both these basins also share that they have a freshwater surplus, that is the sum of the precipitation and river run-off over the basins is larger than the evaporation. This is an under-appreciated factor, which may be even more important than the size of the seawall that has to be constructed, for whether a marginal sea would make a good target for an enclosure. For example, if one closed the strait of Gibraltar the volume of the Mediterranean Sea would diminish with time and the salinity would increase over time since the basin has a freshwater deficit and sea-salt does not evaporate. The volume budget could be closed by letting ocean water, which contains about 35 ‰ salt, flow into the Mediterranean through the enclosure at the strait of Gibraltar. However, closing the salt budget is much more difficult, and would require a desalination operation far beyond the scale of anything in the world today.

Given the favorable geographical conditions; the big question in the Baltic case is not if an enclosure could be built, but at what magnitude of sea level rise its construction would be preferable to other adaptation measures with smaller environmental footprints?

Mean sea level change

Sea level rise projections diverge widely depending of emission scenario, time frame, location and several other factors. The *likely* ranges of the medium confidence projections for global mean sea level rise in the IPCC's sixth assessment report (AR6) range between 0.28 m and 1.01 m until 2100 and 0.37 m to 1.88 m until 2150. The lower bound is for the *likely* range of

Figure 1. Topographic map of the area with the proposed placements. The two alternative locations for a Baltic seawall are marked with green lines. The V shows the location of the municipality Vellinge, where Sweden's first seawall will be built. The G marks the location of Gothenburg where a pilot study for floodgates has been done. Elevation data comes from NOAA's ETOPO Global Relief Model.



the SSP1-1.9 projection and the upper bound is on the *likely* range for SSP5-8.5. The middle of the road scenario SSP2-4.5 has a median projection of 0.56 m until 2100 and 0.92 until 2150 (Fox-Kemper et al., 2021). Apart from the medium confidence projections there are also low confidence projections. These projections have their ice sheet contributions to sea level rise taken from some of the highest estimates in the published scientific literature (Bamber et al., 2019; DeConto et al., 2021). Taking also these projections into considerations gives *likely* ranges of 0.28-1.6 m for 2100 and 0.37-4.82 for 2150 (Fox-Kemper et al., 2021).

The relative sea level rise (sea level change relative to land) is slower in the Baltic Sea than in the global average for two primary reasons. Firstly, because a large part of the coast still experiences significant postglacial land uplift (Vestøl et al., 2019) and secondly, because the relative proximity to Greenland ensures that melt from Greenland has a comparably small effect on the local sea level (Hieronymus and Kalén, 2020). Both these effects have their maxima in the northern Baltic Sea, where many locations expect to see a relative sea level fall until the end of the current century even in very high emission scenarios (Hieronymus and Kalén, 2020). The land uplift has its maximal rate of about 10 mm per year on the Swedish coast of the Bothnian Sea.

On the Southern shores of the Baltic Sea the land uplift rate is close to zero, and even negative in some areas, yielding sea level rise that, in magnitude, is similar to that seen in globally averaged projections.

Even though the projected mean sea level change for large parts of the Baltic Sea shores are significantly lower than for other locations, the large range given in published sea level projections still enables very considerable sea level rise also in its northern parts in the coming decades and centuries. For context, Johansson et al. (2014) estimated that the Finnish coast would see around 80% of the globally averaged sea level rise until 2100. The relative sea level rise in Finland will, however, be smaller than 80% of the global average, because of land uplift. However, in the unlikely circumstance that multimeter sea level rise were to occur in the next few hundred years, large areas in the northern Baltic would also be affected by very considerable sea level rise.

In a longer time frame it is very likely that even a modest warming in line with the Paris agreement will lead to multimeter sea level rise. It was assessed in AR6, although with low confidence, that "Over the next 2000 years, global mean sea level will rise by about 2 to 3 m if warming is limited to 1.5°C, 2 to 6 m if limited to 2°C and 19 to 22 m with 5°C of warming, and it will continue to rise over subsequent millennia" (Fox-Kemper et al., 2021). Such mean sea level changes would lead to considerable permanent land loss, at least, in areas with low or negative land uplift rates.

Local or non-local protection

As a part of the Swedish Meteorological and Hydrological Institute's expert group on sea level rise I occasionally get to meet city planners from coastal municipalities in, mostly southern and central, Sweden. Till date, I have never met a planner from a municipality where no form of seawall, flood gate or some other form of hard protection has been, at least, discussed. In my home city, at least two locations of possible sea walls, one of them being several kilometres long, have been proposed. As mentioned in the introduction, the city of Gothenburg (marked with G in Fig. 1) has already made a pilot study for constructing flood gates, with cost estimates similar to those for the Saemangeum Seawall (SWECO, 2023). Currently a seawall building project has started in southern Sweden in Vellinge municipality, (marked with V in Fig. 1). The seawall to be built is over 20 km long and the estimated cost is at least 200 million Swedish crowns (Dagens Industri, 2021). This single small Swedish municipality is thus building a seawall that is longer than the wall that would be needed to protect the whole Baltic Sea from flooding. The scale of the project is of course smaller as Vellinge's seawall will be built on land. However, also a seawall that is even larger than that needed to enclose the Baltic Sea has in fact already been built in the area. The 25 km long St. Petersburg flood protection barrier in the Gulf of Finland was opened to the public in 2011. Its construction including sluices, highways, flood gates, tunnels and a viaduct costed approximately 3 billion dollars (Hunter, 2012). It's also worth noting that the St. Petersburg flood protection barrier was built to protect a single city, albeit the largest in the area, from flooding. Moreover, while St. Petersburg is the largest city in the area by a considerable margin it is also situated in the Baltic country with the lowest GDP per capita (IMF, 2023). Similar amounts can thus be expected to be spent on coastal protection also by much smaller cities in richer countries, as is also evidenced by the aforementioned pilot study for Gothenburg (SWECO, 2023).

Judging from both from future plans and past preferences it seems clear that, at least, for densely populated areas there is overwhelming support for installing hard protection over retreat in circumstances when the flood risk becomes uncomfortably large. A general preference for protection over retreat is also evident in the Netherlands whose entire coast is more or less a flood prevention engineering project (Wiering and Winnubst, 2017). The entire Baltic Sea coast, being much longer and less densely populated than the Dutch one could unlikely all be protected with local walls. Nonetheless, it stands to reason that in a world with multimeter sea level rise the Baltic Sea should be expected to be a place with either very many walls or a single enclosure wall, as the title of the manuscript suggests. It is equally obvious that an enclosure wall would be a much more cost efficient option than having every densely populated area building their own seawall and related infrastructures such as floodgates, sluices and roads. The environmental consequences of having many local versus one enclosure wall are, however, different and one could favor either option depending on preference.

Freshwater and environmental effects

The Baltic Sea is brackish because the precipitation and river run-off coming into the basin is much larger than the evaporation. The excess freshwater input is balanced by a net outflow from the Baltic Sea through the Kattegat and into the open ocean. If a wall was to be built across the Kattegat this volume would have to be pumped out of the Baltic Sea. The net freshwater input to the Baltic is about $Q = 16000 m^3 s^{-1}$ (Hordoir and Meier, 2010). The power needed to lift this vol- ume every second say 10 m is given by $P = \rho g h Q$, where P is power, $\rho = 1000 kgm^{-3}$ is density, $g = 10 ms^{-2}$ is the gravitational acceleration and h = 10m is the height. Plugging the numbers in gives 1600 MW, which is similar to what the power production was in the now discontinued Swedish nuclear power station Barsebäck, which is located near the Swedish side of the proposed placement. Pumps, of course, do not operate at a hundred percent efficiency, but the back of the envelop calculation shows that there is no outlandish power consumption required. The worlds largest offshore wind farms also start to have, at least, nameplate capacities approaching this number (Mytilinou and Kolios, 2019). Moreover, the West Closure Complex pumping station, the largest currently in operation, has a capacity to pump 550 m^3/s (Orleans, 2015). Thus, 29 such stations could handle the pumping needs for the proposed Baltic enclosure. It is also worth noting that pumping means that the sea level within the Baltic Sea can be controlled. This has some benefits. For example, that the position of the shoreline can be determined and that the water level can be lowered to hinder flooding during the stormy winter season, when sea level extremes typically occur (Männikus et al., 2020).

More problematic are the environmental effects. Overtime closing the Baltic Sea off from the open ocean would transform it into a freshwater lake, which it was about 8000 years ago (Björck, 1995) and which its northern parts may become again in 2000 years owing to land uplift (Tikkanen and Oksanen, 2002). In some cases, it can take a very long time for seas being closed of from the ocean to become fully fresh. This is evidenced by some lakes holding relic salt water layers for millennia (Scheifele et al., 2014). In the case of the Baltic Sea it would likely not take that long. The turnover time of the Baltic Sea based on its freshwater input and volume is between 30-40 years (Meier and Kauker, 2003). However, since the Baltic Sea is strongly stratified the turnover time for water below the permanent halocline is longer. Reissmann et al. (2009) noted that during stagnation periods (periods with no notable inflows of high salinity Kattegat water) the salinity at 200 m declined by about 1% per year. This would give a turnover time of about 100 years for the deep water. In reality, it would not take quite as long given that the halocline would collapse at some point, which would enable winter convection to reach the deep waters. The time scale for the deep water to lose its salinity could also be shortened artificially by pumping water from the surface to the deep layer (Stigebrandt and Gustafsson, 2007). Stigebrandt and Gustafsson (2007) estimated that such a pumping project would cost around 200 million Euros. Indicating that the transformation into a freshwater basin could be accelerated at a prize tag that compared to the rest of the project would not be excessive.

Needless to say, turning the Baltic Sea into a freshwater lake would be an ecological disaster and many species adapted to their currently brackish environment would likely not be able to survive in freshwater. However, the severity of that argument is lessened considerably by the fact that the whole premiss for turning the Baltic Sea fresh is itself an ecological disaster. In a world with multimeter sea level rise the currently brackish Baltic Sea would turn much saltier. Hordoir et al. (2015), estimated using an ocean model that the deep salinity in the Baltic would increase by more than one g/kg over a few decades for one meter of sea level rise. Moreover, one should not expect the salinity increase to scale linearly with sea level rise. Rather, I would expect a steeper scaling and ultimately a transition toward a Kattegat like Baltic Sea to occur. Currently, it is not known at what sea level the Danish Straits would lose their ability to hold high saline Kattegat water from constantly intruding. Modelling studies could, of course, be done to pinpoint potential thresholds that mean salinity might have to sea level rise, should the issue ever become important to a decision process. Other environmental consequences that would undoubtedly occur in a world with multimeter sea level rise is that: the shoreline would retreat, the water temperature would be much higher and the sea ice extent much smaller. In light of this, it it highly likely that many species currently living in the Baltic Sea would not be able to thrive in either a warm freshwater lake or a warm and salty marginal sea.

The most severe environmental problems in the current Baltic Sea is arguably hypoxia. The deeper parts of the Baltic Sea are frequently without oxygen. During autumn 2018, 24% of the Baltic proper bottom water was anoxic, while 33% was hypoxic (Almroth-Rosell et al., 2021). The hypoxia is driven by eutrophication and poor ventilation and it is likely to worsen as a consequence of global warming (Breitburg et al., 2018). The Baltic Sea's strong permanent halocline limits vertical mixing and the main supply of oxygen to the deep waters today comes with sporadic deep water inflow events. If the Baltic Sea was turned into a freshwater lake, there would be no halocline to limit vertical mixing, and winter convection would renew deep waters every year. A better ventilated Baltic may also be more efficient at exporting nutrients out of the basin, given that the exchange between nutrient rich deep water and the nutrient poor surface water (that would be pumped out) would be larger. A case could thus be made that hypoxia might be less of a problem in a freshwater Baltic Sea. Needless to say, one would have to make careful studies aided by ocean-biogeochemical models to quantify both the biogeochemical and physical state of the Baltic Sea in a world with multimeter sea level rise both with and without an enclosure wall to be able to make a good judgement on which state one prefers. That is, however, well beyond the scope of this article.

An obvious benefit with a freshwater Baltic is a much improved availability of water both for drinking and agricultural needs. Even the Baltic's biggest islands suffer from a freshwater shortage in the summer months (Foghagen and Alriksson, 2023). A shortage that is likely to be exacerbated in a warmer and saltier future. Freshwater for such needs could, of course, also be acquired through the installation of more desalination plants. However, desalination is a costly operation owing to its large energy consumption.

Demographics & Economic considerations

The Baltic Sea area has a sizable population. 85 million people live in the drainage area, more than 26 million live within 50 km of the coast and 15 million people live within 10 km of the coast (Sweitzer et al., 1996).

The thirty largest coastal cities in the area are home to over 16 million people (Wikipedia, 2023). To calculate these numbers I have used the urban population when available and otherwise the population within the city limits. The number would have been even higher if the metropolitan area population had been used. The degree of exposure obviously varies substantially between inhabitants of the same city, but nevertheless it is obvious that tens of millions of people would be affected directly or indirectly in the case that multimeter sea level rise was to occur in the Baltic Sea. In Sweden alone, it has been estimated that 230000 homes (7.5% of all homes) are located within three km of the coast and no more than five m above sea level (Danielsson, 2020). In Denmark the situation is significantly worse as more than 15 % of mortgaged assets are found on land situated no more than 2.5 m above sea level (Nationalbank, 2019).

Having established that there are plenty of people to split the bill it is now time to estimate what a seawall across the Danish Straits might cost. However, before we proceed it seems prudent to quote the so called iron law of megaprojects: "over budget, over time, over and over again" (Flyvbjerg, 2014), as a reminder that any given estimate is likely to be too low. The same could of course be said about large scale local seawalls. So the fact that mega projects often go over budget is no argument for building local walls instead of an enclosure wall.

Groeskamp and Kjellsson (2020) estimated a building cost of 250–550 billion euros for their proposed North Sea enclosure wall, using estimates of costs from much smaller structures such as the Saemangeum seawall and assuming their construction costs per meter or volume would be the same. For a project like the here proposed Baltic seawall that is considerably smaller than some of these existing structure that might be a useful estimate. For a North Sea wall, which is very much larger than any seawall ever constructed and also situated over much deeper waters my personal belief is that such estimates are much too optimistic.

For want of a better methodology we nevertheless proceed along a similar path. The proposed Baltic seawall is about half as long as the Saemangeum seawall indicating that it might cost around 900 million euro to construct. The amount of freshwater having to be pumped out of a Baltic Sea enclosure is about 0.4 of that having to be pumped out of a North Sea one. Using numbers from Groeskamp and Kjellsson (2020), the pumping stations may cost anywhere between 8 and 13 billion euros. That is, the wall and the pumping stations together might cost between 4.5 and 14 times more than the city of Gothenburg expect that they might spend on floodgates, and between 3 and 4.6 times what St Petersburg has already spent on its flood protection barrier (Hunter, 2012; SWECO, 2023). Having no good estimate of the maintenance cost of protecting a very large sea wall against weathering, we note that if it scales with volume (length) it would about 200 (40) times more expensive to maintain a North Sea seawall than a Baltic Sea one.

Even though, these estimates are no more than ballpark numbers of what a Baltic seawall might cost, three things are evident: 1) building a Baltic Sea enclosure wall would be much cheaper than every city building its own protection, 2) the property values a wall would protect are orders of magnitude higher than its building cost and 3) a Baltic seawall would cost a small fraction of a North Sea seawall and it would be a much lower risk project. 1) and 2) are important for decision makers in the Baltic Sea countries, 3) on the other hand tells us something about the level at which Baltic Sea decision makers might be willing to contribute to a possible North Sea wall instead of one in the Baltic Sea. From an economic point of view it is clear that at sufficiently high sea level rise, decision makers in the Baltic Sea area should prefer an enclosure wall to very many local walls. Moreover, although from the perspective of protection a non-local wall might just as well be placed in the North Sea as in the Danish Straits, the willingness of decision makers from Baltic countries to pay for a much more expensive and risky project should be severely limited by the existence of a much cheaper and simpler option closer to home.

International considerations and alternative locations

Even though it is evident that plenty of both resources and money could be saved by building one Baltic enclosure wall instead of having every municipality building their own protection, the highly spatially varying rates of projected sea level rise could prove a hindrance for such cooperation. A city on rocky shores in the northern Baltic with very few low laying properties and considerable land uplift will not have the same or even a similar optimal time of investment as a low lying city in the southern Baltic with erosion and perhaps even current flooding problems. This problem would, of course, be even more difficult to tackle for a North Sea than a Baltic Sea enclosure wall. Moreover, turning the Baltic Sea into a freshwater lake would have many other consequences for the environment, fishing, shipping and many other sectors. Taken together, such considerations would undoubtedly require the matter to be lifted from the municipal to the international level.

Another potential hindrance for a cooperative effort is that the most obvious location to place a Baltic enclosure wall is the Danish straits between Sweden and Denmark. However, that placement would leave the majority of the Danish coast as well as the Swedish west coast unprotected. The incentives for construction for these two necessary countries are therefore perhaps weaker than for countries that get more protection out of this placement. For this reason a second alternative placement is marked on the map in Fig. 1. This placement would protect much larger parts of Denmark and Sweden, although it should be pointed out that for the Danes both locations would have to be complemented with large scale coastal defences on their North Sea coast. A more northerly placement in Kattegat would require a much longer wall, about four times longer than a wall in the Danish Straits. If the building costs can be assumed to scale with the size of the seawall, the total project would, however, not be much more expensive with a more northerly location. This is because over 90% of our estimated construction costs would be the pumping stations and those costs would be similar for both locations. Moreover, a wall in the Danish Straits would likely have to be complemented with walls on the Danish islands of Zealand and Fyn, which would not be necessary with a more northerly placement. The northern placement is also mostly over shallow waters, but there is a trench on the Swedish side where depths approach one hundred meters. Without question a seawall in northern Kattegat would be a project much closer in scale to existing seawalls than to the proposed North Sea enclosure wall. However, it would also be considerably larger than any seawall in existence and thus clearly a riskier project than building a seawall in the Danish straits. Alternative placements across the Skagerak between Denmark and Norway, would require a much longer wall being constructed over much deeper waters. Thus, it would require a project more on the same scale as the proposed North Sea enclosure wall. Given that a Skagerak wall would protect a much smaller and less densely populated area than a North Sea enclosure, it is unlikely to be a practical solution.

Conclusions

Different arguments can be made favoring either local walls, an enclosure wall or simply retreat to higher grounds as a response to catastrophic sea level rise. From an economical perspective it seems undeniable that for a large and fast enough sea level rise, an enclosure wall is the best option. However, how fast and how large the rise would have to be for an enclosure wall to be economically favorable over a combination of local protection and retreat has no simple answer. This is because the exposure, both in terms of how the current building stock is located in relation to the mean sea level and in terms of the magnitude of the projected mean sea level rise, is very different for different countries and cities. When considered from a wider perspective than the economical, it is obvious that a best option in an objective sense does not exist as no common scale on which different consequences can be weighed exists.

Hieronymus (2021) showed that conditioning adaptation on mean sea level rise was an effective way of minimizing flood risk for Stockholm. The same conclusion can, using similar techniques as Hieronymus (2021), almost certainly be drawn for many other sites. However, the mean sea level at which a city will want to start adapting is unique to each city, and so is the time when that level is reached. From a safety perspective, retreat to higher grounds is undoubtedly safer than sheltering behind a seawall. However, it is also undeniable that this fact has not stopped people from settling on land well below even the current sea level.

From an environmental perspective one could probably argue in favor of either option as there is no consensus on what the optimal state of the Baltic should be. At least, when granted that an undisturbed preindustrial state is not an option that is compatible with fast and large mean sea level rise. Instead it is evident, that a Baltic Sea experiencing multimeter sea level rise would be under many severe environmental stresses and that many species that currently live there would likely not be able to thrive regardless of the chosen form of coastal defense.

In a recent study Rasmussen et al. (2023) discussed why certain coastal defense megaprojects in the US got built while others did not. Those authors concluded: " that storm surge barriers are politically challenging climate adaptation options because of modern environmental laws that provide avenues for expression of oppositional views within the decision process and the allure of alternative options that are more aesthetically pleasing and cheaper and faster to implement.". It should be noted that the alternative options alluded to by Rasmussen et al. (2023) were rather artificial reefs and nature based solutions than local storm surge barriers. That is, the alternatives they considered are more aimed at dissipating wave energy and redirecting water than protecting against multimeter sea level rise. However, their finding that the general public prefers protection that is more aesthetically pleasing, cheaper and faster to implement than its alternative, seems reasonable to assume to hold also for the question of many local walls versus one enclosure wall.

In terms of aesthetics it is obvious that hundreds or even thousands of kilometers of ugly storm surge barriers obstructing the view of the ocean is an unwanted feature in the coastal landscape, and thus that an enclosure wall is preferable to many local ones. The same conclusion is evident also from economic considerations, given that the sea level rise is large and fast enough that many need protection at a reasonably similar time. The speed of implementation, however, could certainly be slower given the level of international cooperation that would have to happen to get such a project running.

In many ways, the case made here for a Baltic enclosure wall is, in fact, an excellent case for building more aesthetically pleasing, cheaper, and faster to implement nature based flood protection instead of seawalls in the short term. In the long term, if we experience very considerable sea level rise such structures offers little protection. However, catastrophic sea level rise is certainly no certainty and the combination of a somewhat temporary solution with the option of a cost effective more permanent solution in the future would buy the decision makers considerable time. Time that might prove very valuable as our understanding of ice-sheet dynamics, committed sea level rise and future emission trajectories might change considerably in the coming decades. Turing the Baltic Sea into a lake and later finding it unnecessary would obviously be a horrible form of mal-adaptation that should be avoided even at great costs. Conditioning the seawalls construction on having large and fast sea level rise is a good protection against this form of mal-adaptation. However, the later one can make the decision on whether to build or not, the better one will know just how large and fast sea level rise to expect.

Even though sea levels high enough to motivate the construction of an enclosure wall are highly unlikely to be seen in the next few decades. It would be useful to already now start international discussions about how future flood protection could best be constructed for the Baltic Sea countries. For an enclosure wall to be a viable option for countries other than perhaps Sweden and Denmark, that have the land surrounding the wall, requires a great deal of trust. Trust that construction would be initiated when they needed it, and that an agreement to build would survive a long sequence of changing political leadership in multiple countries. There are of course also many other international issues that would have to be agreed upon, not least in shipping and maritime trade. Even if a sluice was built into the proposed seawall it would clearly be a hindrance to the freedom of navigation and the country controlling the sluice would have a strategic advantage, just to name two.

Whether such profound issues can be overcome is anyone's guess. The potential gains in avoiding massive land loss, flood risk and enormous land based storm surge barriers is at least a strong incentive to investigate. Mitigation is, of course, the best approach to avoiding both local and enclosure walls, but it may not be enough. Moreover, mitigation is by nature a global undertaking. How well it will succeed is far beyond the control of the Baltic Sea countries. Adaptation is therefore a necessary part of national strategies for dealing with climate change, and if we are unfortunate it could require massive scale civil engineering projects. To our advantage is, at least, that our geographical location admits a solution where such a project can be on a much smaller scale than almost everywhere else.

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