VALUE AT RISK IN THE BLUE ECONOMY

Piloting a Systems Modeling Approach to Explore Sustainability Pressures and Financial Risk

WWF

METABOLIC

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FOREWORD

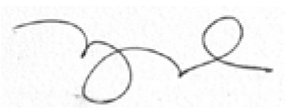
The current decade has seen an escalating interest in the blue economy, encompassing all economic activities that rely on the marine and coastal environment, with ocean-based economic activity projected to double by 2030 (OECD, 2016). Whilst the goods and services provided by the blue economy have conservatively been valued at over USD 2.5 trillion per annum (Hoegh-Guldberg et al. 2015), the IPCCs ***Special Report on the Oceans and Cryosphere in a Changing Climate***, ***2018 Living Planet Report*** (IPCC, 2019) and ***2019 IPBES report*** (IPBES, 2019) provide strong evidence that the impacts of climate change and human activity are severely eroding ocean health and with it the resource base on which society and business depend.

These warnings are also being strongly articulated across the business sector. A report released earlier this year by Goldman Sachs and the Global Markets Institute highlighted the economic and environmental costs of flooding and erosion to coastal communities and infrastructure (Hindlian et al., 2019). Mark Carney, Governor of the Bank of England, has repeatedly cautioned that climate change will directly impact financial systems (Partington et al., 2018; Bank of England, 2018), and central banks all over the world are also acknowledging climate change as a source of systemic financial risk (NGFS, 2018). We must therefore question how future development ambitions will be met.

Despite these concerns, there continues to be a lack of understanding or acceptance of the risks of business-as-usual investments by many public and private sector leaders. If we continue to extract ocean resources at the current pace as well as invest in GHG-intensive sectors, we increase the risk of “stranded assets” materialising in portfolios, i.e. through assets suffering unanticipated or premature write-offs, downward revaluations or conversions to liabilities. It is imperative that financial institutions assess and manage marine-related financial risks and assess and disclose their portfolio’s impact on ocean resources and ecosystems, as they do for climate change, to ensure investments in the Blue Economy are targeted at the most sustainable pathways possible.

WWF is actively working with partners, including the European Commission, European Investment Bank, World Resources Institute and the UN Environment Finance Initiative, towards the broad adoption and implementation of the ***Sustainable Blue Economy Finance Principles***, (WWF, 2018) the world’s first financial framework to guide sustainable management of assets and investments within the blue economy. Furthermore, WWF, together with World Economic Forum and AXA, has also recently explored how nature-related risks to business and finance can be identified, quantified and managed (WWF & AXA, 2019). This current study aims to advance the implementation of the principles and nature-related risk management by initiating the development of a tool which aims to highlight the inherent financial risks associated with blue economy investments if ocean scenario data are not used to inform decisions.

If we are to secure a sustainable blue economy, one which maintains the stability of global ecosystems and the societies and economies that depend on them, it is essential that we continue to seek collaborative financial solutions through the creation of frameworks, data sources, tools and guidance. We therefore welcome your full engagement in further co-developing this innovative model and approach.



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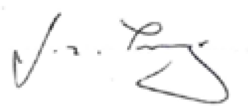

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"How inappropriate to call this planet *Earth* when it is quite clearly *ocean*."

- ARTHUR C. CLARKE

EXECUTIVE SUMMARY

Purpose

The Blue Economy is of key importance to the global economy: value created and supported by our oceans, seas and coasts, is estimated to be worth at least USD 24 trillion. However, the direct and indirect value generated by marine environments is increasingly under threat from environmental drivers. This poses a risk to current and future assets and revenues dependent on a healthy Blue Economy.

The relationships between environmental drivers and the Blue Economy are dynamic and nonlinear. Current approaches to evaluate the associated risks, such as Value at Risk (VaR) methodologies, are insufficient to account for such interactions, and the cumulative effects of drivers.

Systems modeling is an approach which can capture complex dynamics between parameters. We explore the potential of using this approach to model and calculate financial risks in the Blue Economy. This paper describes the first iteration of exploring the approach, where we modeled two sectors located in the Baltic Sea: ports (shipping) and fisheries.

Systems Modeling Outcomes

For ports, the main driver of risk is through damages from increasingly frequent and intense storms. Though the model accounts for the increasing occurrence of 100-year storms based on two different scenarios, the damages from this risk are not significant on a short time scale. On a long time scale, the risk is much higher, though the damages modeled do not outweigh the growth of assets and revenues over time, due to projections in increasing freight tonnage in the region.

Value associated with fisheries in the Baltic Sea is at a much higher risk, as fish populations are already under an enormous amount of pressure from habitat changes, climate change, and other pressures. Even within a shorter time period, the model outcomes show extensive loss of revenues and stranded assets. In the 15-year model run, revenue losses rise as high as 64% compared to the baseline year, while the total asset value that is stranded is around 12%. The outcomes are highly sensitive to the amount of fishing effort - potential fishing quotas, or financial incentives or disincentives could have a large effect on fish populations and value in the fisheries.

Value at Risk Outcomes

The Value at Risk (VaR) to a portfolio of equities is the difference, over time, in discounted cash flows from company dividends compared to the Business as Usual (BAU) scenario. Our Blue Economy VaR assessment tries to gauge whether, and by how much, the dividends are expected to be lower due to environmental drivers.

The results from the ports model indicate that the total VaR to the ports sector in the Baltic Sea region over 85 years is up to 2.21%, or €19.9bn. The results from our fisheries model indicate that the total VaR to fisheries sector in the Baltic Sea region over 15 years is 73%, or €1.32bn. We translated the sector-level VaR of the fisheries sector to a portfolio of a Swedish asset manager. There were no holdings with direct exposure to the fisheries sector of the Baltic Sea in the portfolio, but three holdings with a potential indirect exposure. The total VaR to the case study portfolio was 0.01% (€213k), most of which came from its holding in a diversified bank.

However, this figure very likely underestimates the total VaR to asset managers from the global fisheries sector, as most large fisheries companies are based in the Asia-Pacific region. As asset managers are inherently global stakeholders, one potentially valuable avenue for further research would be to extend the geographical scope of the model to include more major fisheries worldwide.

Key Conclusions and Next Steps

- A systems approach for Value at Risk assessment shows promise for further development as it adds the ability to look at cumulative impacts, tradeoffs and interactions, and nonlinear risk.
- This first exploration was limited by modeling only two sectors. The next step is to expand the approach to other sectors, including those indirectly related to the Blue Economy, such as real estate and manufacturing. On the longer term, our vision is to create a global model of all Blue Economy sectors.
- Additionally, our approach should be tested on additional portfolios and asset types to better understand its relevance for financial institutions.
- Data availability was (and will remain) a key barrier to such detailed modeling. In the long run, key partnerships are important to alleviate some data limitations.
- One of the key benefits of the approach is the potential for scenario modeling and understanding the impact of mitigation strategies, which can also be used as an engagement tool. If we achieve the long-term vision of a global model, then it can be used to evaluate the potential systemic impacts and tradeoffs of public and private policy scenarios in significant detail.

01

VALUE AT RISK IN THE BLUE ECONOMY

GROWING PRESSURES IN THE BLUE ECONOMY

The goal of this project is to explore the feasibility and usefulness of modeling financial risk in the Blue Economy using a systems model approach, rather than by incorporating environmental modules into traditional financial risk models.

The definition of the Blue Economy (BE) includes all sources of financial and non-financial value that humanity derives from marine environments, including the following list developed by the World Bank Group (2017):

Blue Economy

Harvesting and trade of living marine resources: Including seafood harvesting (and related sectors), harvesting of non-food bio resources, and marine biotechnology.

Extraction and use of non-living marine resources: Mining, oil & gas extraction, and freshwater production through desalination.

Use of renewable, non-exhaustible natural forces: Renewable energy from wind, waves, and tides.

Commerce and trade in and around the oceans: Transportation and shipping, coastal development, tourism and recreation.

Indirect contribution to economic activities and environments: Ecosystem services such as coastal protection, carbon sequestration, waste processing and biodiversity.

Many regions depend on the Blue Economy. It plays a crucial role in trade, tourism, and cultural heritage, as well as being a key area for growth in sectors such as marine renewable energy and biotechnology. In developing countries, fisheries play a crucial role in the economy and provide a key source of protein, as well as livelihoods to hundreds of millions of people. The Blue Economy was responsible for 31 million full-time jobs in 2010 (Accenture, 2017).

WWF has estimated that global ocean assets are worth at least USD 24 trillion, from direct outputs such as fisheries, to the value of trade and shipping, to coastal assets and carbon storage (WWF, 2015). For a full two thirds of these assets, it is critical that oceans remain healthy and productive. Beyond the direct financial value that oceans provide, there is an enormous amount of value inherent in ecosystem services: the oceans produce 50% of global oxygen, absorb 30% of CO_2 emissions, and absorb 93%

of heat arising from changes to the atmosphere. Coastal habitats buffer damages to coastal infrastructure and support biodiversity vital for tourism (Accenture, 2017). The risks associated with loss of marine natural capital are therefore many and varied, with implications for our global ecosystem beyond the confines of the Blue Economy.

Changes in global natural systems present new risks for the value of the Blue Economy. Some of the key drivers include:

Key drivers

Marine pollution such as ship coatings, ghost gear, plastics, and other hazardous substances from marine and terrestrial activities, which impacts fisheries, tourism, and even shipping itself. In particular, plastics pollution has been a key topic of discussion, further brought into public focus by the estimation made in 2016 that there will be more plastic in the ocean than fish (World Economic Forum, 2016).

Ocean warming effects on marine habitats and ecosystems, which impacts fisheries and other species through changes in oxygen concentration, shifts in primary production, migratory shifts, and changes in ocean circulation and stratification (Free et al., 2019).

Salinity change driven by climate change will have dramatic impacts on species distribution in the Baltic Sea, successful spawning efforts, and the overall growth of key fish populations (Meier et al, 2006).

Sea level rise and increased frequency and intensity of storms, which threaten ports and other coastal infrastructure.

Development of coastal regions and estuaries and coastal sand and gravel extraction, which impact fisheries, tourism, and coastal infrastructure through habitat disruption and a loss of storm buffering capacity.

Land-use change and agriculture further inland, which affects fisheries and coastal tourism through nutrient cycle disruptions (organic enrichment) and erosion to waterways.

Disturbances to seabeds which affect fisheries and tourism, from fishing equipment and practices, to sand and gravel extraction.

Overexploitation of fish, which threatens the long-term sustainability of fisheries.

Overall, the drivers can be grouped into three categories: impacts from (coastal) development (urban areas, ports, infrastructure, renewable energy, etc.), impacts from production and logistics systems (e.g. fishing, aquaculture, agriculture, extractive industries, industrial activities, forestry, shipping & transportation), and impacts from climate change.

Climate change in particular poses a major challenge as the overall impact is still poorly understood, due to all of the systemic interdependencies, feedback loops, and tipping points, which translate to nonlinear patterns of risk development. Overall, the risk to manageable assets from climate change has been estimated at USD 4.2 trillion (out of a total global stock of USD 143 trillion of assets) and up to USD 13.8 trillion with more significant warming (Economist Intelligence Unit, 2015).

This project was established to explore whether environmental impacts in the Blue Economy might result in financial risks to asset managers. While approaches exist to estimate the risk from such drivers to asset value and revenues, there are some shortcomings associated with existing models, described in the following section. In this summary report, we describe an exploratory approach of using system dynamics modeling to evaluate the Value at Risk (VaR) associated with the Blue Economy.

CURRENT VALUE AT RISK (VAR) ASSESSMENTS

One of the main responsibilities of asset managers is to manage risk, and Value at Risk (VaR) is a key metric for assessing the risk of an investment (Damodaran, 2007). VaR measures how much a portfolio stands to lose over a given time period at a certain confidence level. It answers the question, “What is the maximum that an investment can expect to lose in given circumstances?” VaR provides a consistent way to measure risk across different investment activities. It is a useful risk metric because it is able to express the risk to a holding or portfolio in clear dollar terms or as a percentage, making it easy to understand, and meaning it requires little additional interpretation (unlike, for instance, volatility, which differs per sector). Importantly, regulators such as the Bank of International Settlements recommend it.

There are roughly two approaches to modeling the financial risk of environmental impacts: top-down or bottom-up (Economist Intelligence Unit, 2015). The top-down approach, which is by far the most common method and is used by, among others, the Fish Tracker Initiative in their Empty Nets report (McCarron et al., 2017), integrates relevant environmental impact data such as emissions or climate modules into a macroeconomic model. These Integrated Assessment Models (IAMs) are used to estimate the cost to the economy of environmental impact (usually climate change) by comparing rates of GDP growth over time under different scenarios. We call this a top-down approach because it starts from the perspective of the overall economy and estimates a reduction in aggregate economic activity resulting from certain high-level parameters.

A bottom-up approach starts with the impacts or drivers that influence economic activity, and models the effect of shifts in the parameters of those elements on the outcome of the overall system. It is less concerned with the impact of the environmental system on aggregate economic activity (i.e. GDP), than on attempting to model the relationship between different elements in the system and how they influence each other. The result is a more fine-grained, context-specific understanding of the interplay between environmental impacts and economic activity in a system such as the Blue Economy. However, this approach is significantly more model- and data-intensive, and it is not always certain that the added detail also leads to increased accuracy of the model.

Pitfalls and Shortcomings of VaR

There are two key disadvantages to common VaR methodologies used today. Firstly, most VaR methodologies used today assume that the risk probability distribution, or the risk that the value of an asset will fall below a certain threshold within a given time period, is normally distributed. While this may be adequate for short-term investments, this does not hold in the long term.

Secondly, most current VaR approaches assume that risks remain relatively constant over time, or that they develop in a more or less linear fashion, yet it is exactly the nonlinear nature of the environmental drivers that affect financial returns which we are trying to capture in our model. Integrating environmental drivers into common financial risk models is difficult due to the short (usually 5-year) time horizon that most such models are calibrated to (Naqvi et al., 2017). Because of this, financial risk models will tend to miss, and therefore underprice, well-documented nonlinear risks. These linear risks come in three forms: slow-building, de-anchoring, and point-in-time (see Figure 1 below). Slow-building risks are trends or events, such as climate change, which increase slowly but gain momentum over time in a nonlinear fashion. De-anchoring risks materialise when technological, regulatory, or socio-economic safeguards maintaining an artificial status-quo are removed, resulting in spiking exposure to incumbents reliant on that risk. Gasoline-powered car manufacturers are a good example of this, resulting from the sudden electric vehicle (EV) revolution. Lastly, point-in-time risks are those whereby a high-impact event is almost certain to happen at some point in the future, though it is uncertain when. Extreme weather events are a good example of this type of risk.

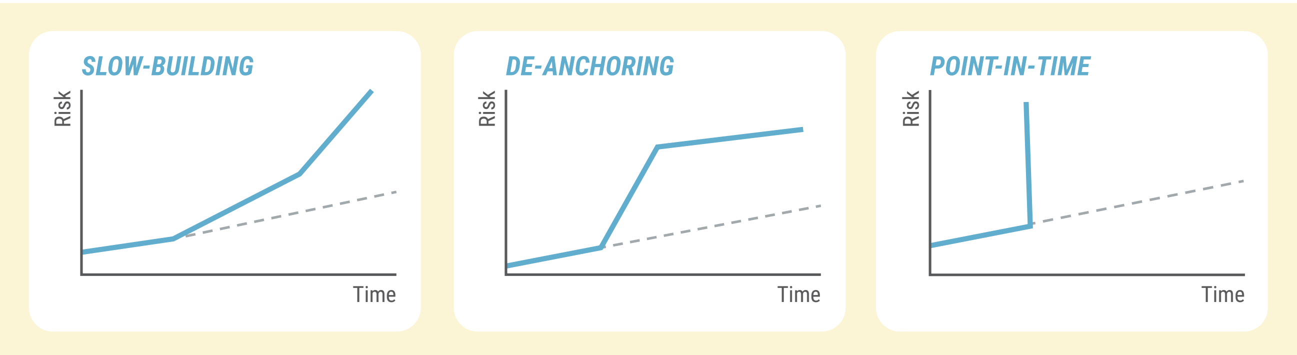


Fig. 1 Illustration of nonlinear risk

Background of Systems Modeling

System dynamics modeling originated in the 1950s, at first as a way to explore complex problems around corporate and management issues. The original creator, Jay Forrester developed a systems model at the invitation of the Club of Rome to explore different development scenarios to see at what point interconnected population, planetary, and production systems would be at risk of collapse.

Forrester developed the World3 model, in which global dynamics were simplified into several dozen variables in five main system clusters:

Food system

Industrial system

Population system

Non-renewable resources system

Pollution system

Some of the outcomes of the business-as-usual scenario were that key parameters, such as industrial output, food per capita, and population would peak in the early decades of the 21st century, followed by a sharp decline. While heavily criticized at the time, 40 years of tracking the actual development of these parameters has shown that the model produced relatively accurate results, well within ranges of uncertainty (Figure 2).

The outcomes of the study formed the basis for the groundbreaking book "Limits to Growth", published in 1972. The main message of Limits to Growth is that since planetary systems are finite, eventually growth in population and the economy will hit a limit and decline.

This example highlights some of the benefits of systems modeling, such as: the ability to model exponential changes driven by reinforcing feedback loops, dynamic relationships between parameters such as population and resources, and limits and tipping points. Additionally, systems modeling allows for evaluating scenarios, the effects of which can have cascading indirect effects through a system and be difficult to evaluate otherwise.

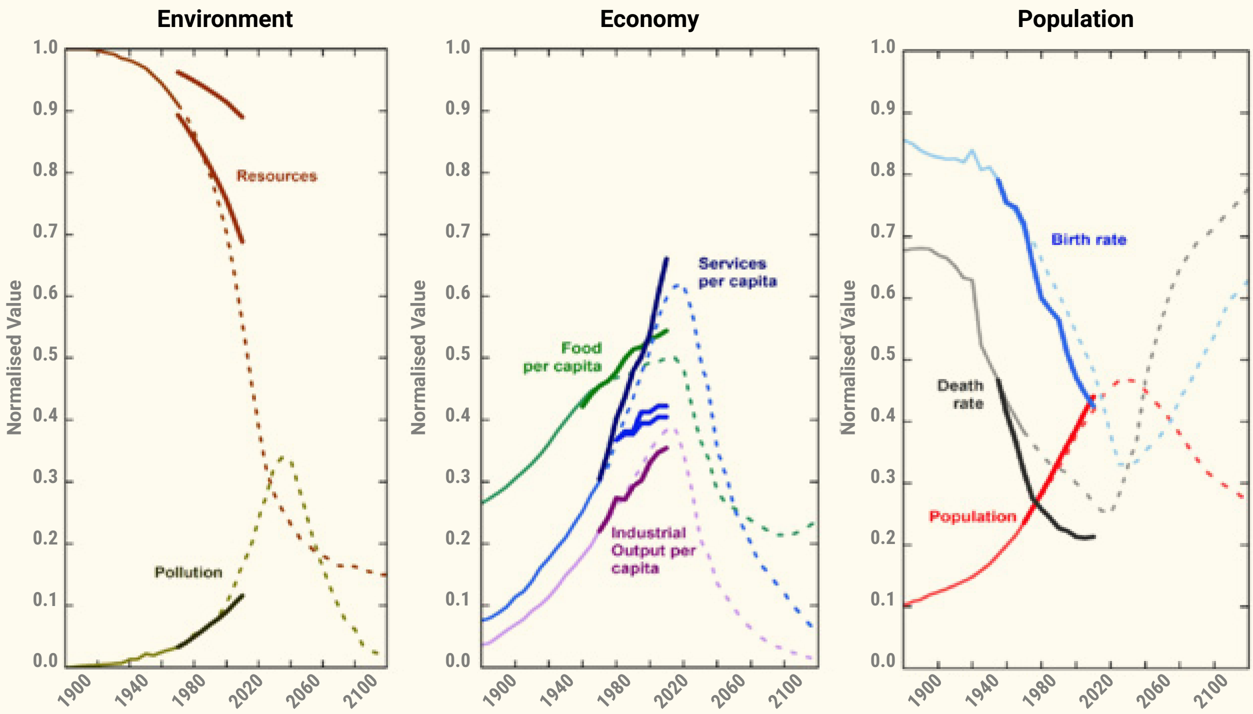


Fig. 2 Image from Turner (2012) - These graphs show the World3 Business-as-Usual model outcomes (dotted lines), along with 40 years of actual developments (dark solid lines)

INTEGRATING A SYSTEMS MODELING APPROACH

As mentioned in the previous sections, reinforcing mechanisms in systems can result in nonlinear outcomes that are difficult to model using traditional statistical assumptions. As the complex environmental drivers resulting in risk to Blue Economy assets and revenues are not linear or simple to model accurately, we decided to explore a method for using systems modeling in Value at Risk assessment. The key innovations of our approach are the ability to capture nonlinear environmental drivers and model scenarios with sensitivity to parameter values.

The aim of this project is to explore the feasibility and usefulness of modeling the financial risk to asset managers using a systems model of the Blue Economy, rather than by incorporating environmental modules into traditional financial risk models.

Our approach starts with the impacts or drivers that influence economic activity. We then model the effect of the shifting parameters of those drivers on the outcome of the overall system. Our focus is to model the relationship between different elements in the system and how they influence each other, rather than on the impact of the environmental system on aggregate economic activity (e.g. GDP). The result is a more fine-grained, context-specific understanding of the interplay between environmental impacts and economic activity in a system such as the Blue Economy.

Other Potential Applications for Systems Modeling in VaR Assessment

The focus of this exploratory study was to assess the VaR to asset managers from environmental drivers in the Blue Economy. Asset managers are indirectly exposed to environmental impacts in the Blue Economy through their holdings in financial institutions (FI). Yet they are able, to an extent, to diversify some of the risks in the Blue Economy. They largely deal with listed multinationals. Banks and insurance companies, whose activities tend to be much more embedded in the local economy, less so. Banks and insurance companies will likely have more exposure to the SMEs that make up a large share of the Baltic fishing sector.

Climate change and other environmental drivers are prominently on the agenda of FIs as one of the most significant risks to their businesses. As such, most FIs seek to incorporate these drivers into their financial risk models through so-called Integrated Assessment Models. Systems modeling is a versatile tool for achieving this. However, rather than 'plugging' environmental modules into a financial risk framework, they are integrated into one, seamless model.

One asset manager at a multinational financial services company whom we spoke with mentioned that a VaR model of the Blue Economy could be a valuable engagement tool for asset managers. There are two ways in which the model could be useful for that. In its current state, the model is useful for understanding how the system is likely to develop over time under certain conditions, and asset managers can use this information to engage with portfolio companies. Secondly, the model could be adjusted to help stakeholders - including asset managers - understand what mitigating strategies could be implemented to avoid unwanted outcomes (such as the collapse of fisheries) and what the costs and benefits of those mitigation strategies are.

The model might also be useful for other types of FIs, such as:

Banks

Banks are on the front line of most environmental risks. Most fishing companies, for example, in the Baltic Region are Small and Medium Enterprises (SMEs) that depend on bank financing, but are too small to be included in asset portfolios. Because of this, banks are likely to be very interested in the model to inform their financing strategies and to assess credit risk of clients. Ports require larger investments, but many still rely on financing from banks.

Because banks mostly deal with credit risk, the method of translating the sector-level VaR to a useful indicator for a bank will differ slightly to the method described above. This is because credit risk is more binary than equity risk - bank clients need to adhere to certain covenants around Loan-to-Value Ratios (LTVs) or Debt Service Coverage Ratios (DSCRs), and a violation of the covenants is often considered a default. VaR assessments for credit risk are therefore concerned with estimating the probability of a client violating covenants or outright defaulting, measured by the client's revenues in relation to a certain threshold, rather than the average revenues over time.

Insurance

Insurance companies are uniquely exposed to environmental risks. Millions of businesses buy insurance policies to protect their businesses every year. Extreme events could put insurance companies out of business if they don't adapt, or insurance could become unaffordable, creating an insurance gap that would have far-reaching repercussions across the economy. Additionally, as many insurance policies are renewed every year, point-in-time and de-anchoring events could have a major impact.

Insurance companies are in the business of assessing risk. However, actuarial science relies on past data to make predictions about the future. Though insurers have highly sophisticated models for assessing the financial risk of their clients, it is unlikely that they are able to fully capture the nonlinear risks from environmental drivers described above. Systems modelling could provide valuable benefits to their pricing models, and better understanding of environmental risk drivers could even help insurers stimulate mitigation strategies among their clients.

Project Finance

Project finance, the financing of long-term infrastructure, industrial projects, and public services, is another area where our model can provide valuable insights, as it is an area of finance that is exposed to both physical and transition risks. Large-scale coastal infrastructure projects are exposed to physical risks from Extreme Sea Level (ESL) events resulting from climate change. Similarly to how coal plants and cement factories with 40-year expected life spans are at risk of becoming 'stranded' if the world is to stay within the 1.5-degree carbon budget, assets in the Blue Economy are at risk of becoming 'stranded' if pressures on a sustainable Blue Economy are not alleviated.

Governments Bonds

National governments (meaning taxpayers) could be required to foot the bill for a large part of the financial damages caused by the environmental drivers covered in our model, especially if an increasing share of the economy becomes uninsurable. The effects of climate change, in particular, are projected to be significant. If the costs resulting from ESL events and other environmental impacts become too great, we may reach the point where the creditworthiness of governments could start to be at risk. This brings us full circle back to asset managers, for they are some of the largest purchasers of government debt.

02

VALUE AT RISK IN THE BLUE ECONOMY - A CASE STUDY OF THE BALTIC SEA

The Baltic Sea was selected as a first case study, as there is a lot of data and knowledge available for this region on environmental drivers of Value at Risk in the Blue Economy. The conditions of the Baltic Sea also make it interesting to explore from an impact perspective.

The Blue Economy of the Baltic Sea (excluding Russia) produces an added value of nearly USD 18.5 billion and is responsible for almost 400,000 jobs (WWF, 2015). The fastest growing sectors in the Baltic Sea's Blue Economy are offshore wind, aquaculture, and cruise transport, with growth rates between 2008 and 2010 above the EU average (20%, 13%, and 11%, respectively) (EUNETMAR, 2013). The Baltic Sea is currently one of the most traffic-intensive areas, accounting for up to 15% of global cargo transportation (EC - Maritime Affairs, 2018). Additionally, the amount of cargo (in Mtons) handled by Baltic ports is expected to double between 2010 and 2030 (WWF, 2015).

Around 68% of the added value is due to three major sectors: marine transport, coastal tourism, and fisheries. In this project, we built models for two of these, marine transport (focusing on ports) and fishing, to test the approach on two very different sectors. Tourism was also explored, but given the diverse range of activities associated with tourism (mainly by small businesses), this sector will be addressed at a later stage.

The following pages provide a high-level overview of the two systems models for illustration - for more technical details and a complete list of parameters, values, and reference data, please see the Appendix.

SYSTEMS MODEL FOR PORT REVENUE AND ASSETS RISKS

At a high level, the model for ports includes seven modules:

- **Freight transported:** Including growth rate over time
- **Port assets:** Value is modeled over time and grows along with the growth in freight
- **Port revenues:** Value is modeled over time and grows along with freight transported
- **Climate change:** A module estimating the change in probability of Extreme Sea Level (ESL) events over time
- **Damage from Extreme Sea Level (ESL) events:** Triggered randomly over time, based on the probability in the climate change module
- **Loss of Asset Value & Loss of Revenues:** Outflows of value triggered by ESL events

The key drivers of value in the Baltic port model are the growth in shipping demand and the impacts of Extreme Sea Level on Baltic freight ports' infrastructure and operations.

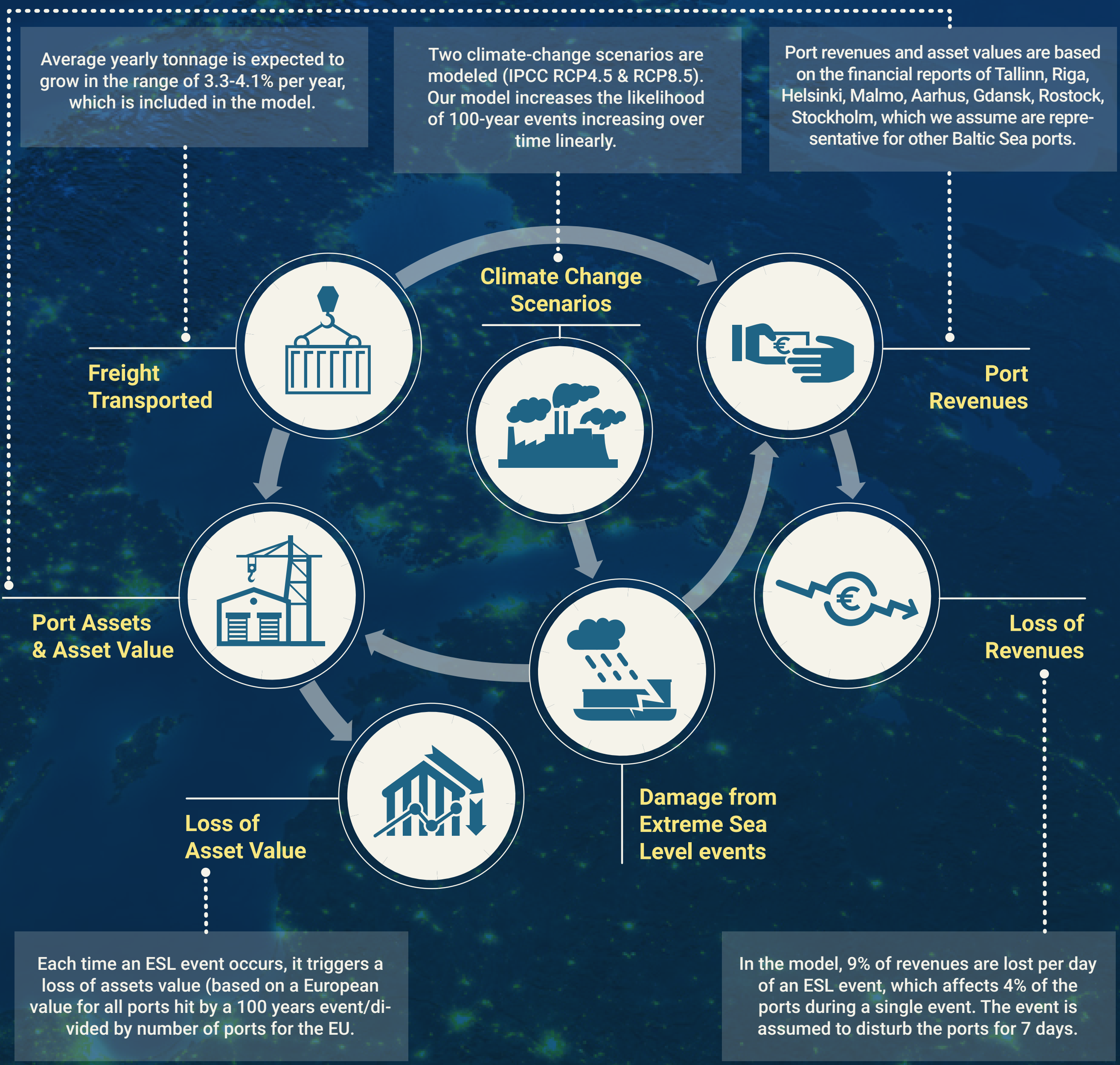


Fig. 3 **High-Level Overview of the Baltic Port Systems Model**

The Baltic ports model was run 100 times each for an 85-year period and a 15-year period, so that we could explore both the long-term outcomes that are considered under climate scenarios, as well as the outcomes more directly relevant for financial institutions.

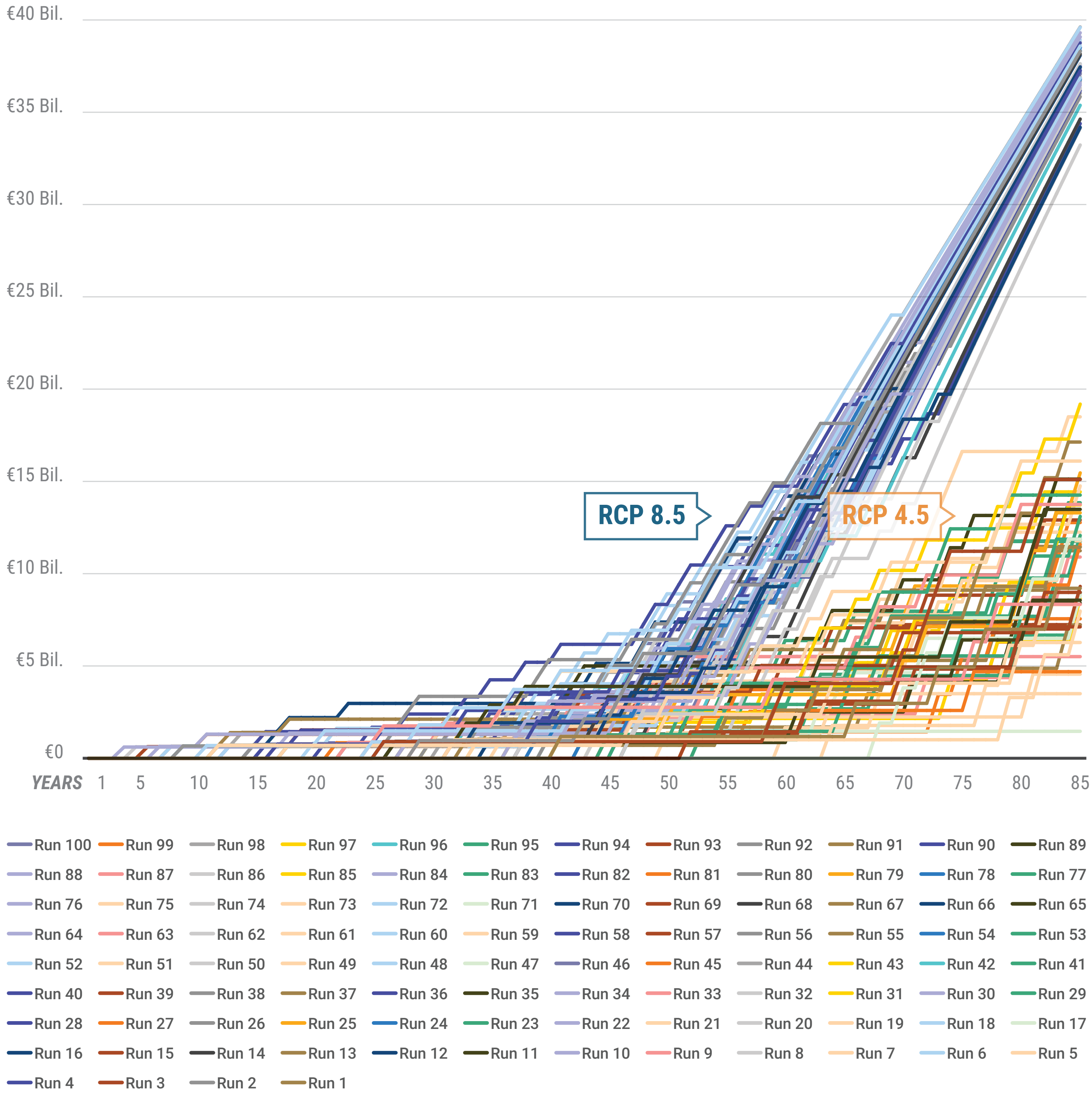


Fig. 4

Total Asset Value Loss Due to ESL Events. In the 85 year period, damage intensifies around the 40-year mark. We see a distinct difference between the outcomes for the two climate change scenarios, with port asset value more or less reaching a plateau in value as the damages from Extreme Sea Level (ESL) events hampers asset growth, while the more conservative climate scenario results in increasing damages over time, but not at the same catastrophic levels.

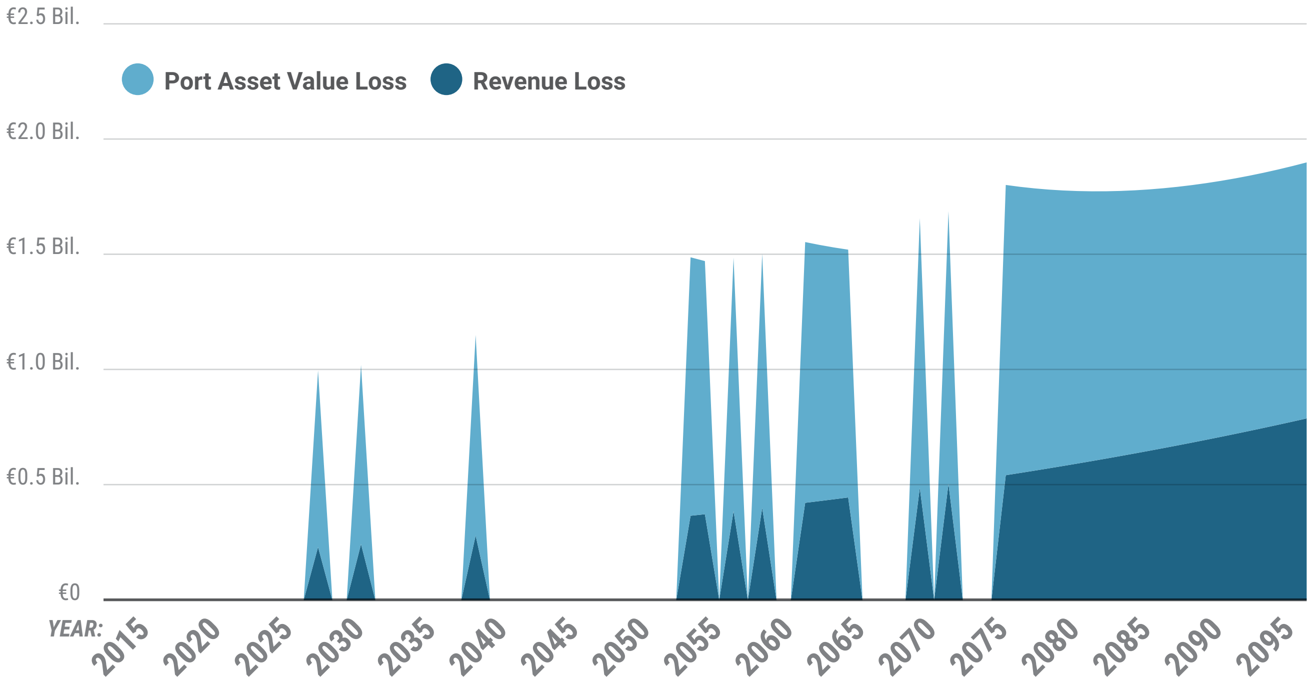


Fig. 5 **Yearly revenue and asset losses in the 85-year scenario.** Over a shorter period, the effect of individual ESL events is much more visible. In a run where an event is triggered there is a loss of assets and revenues. Over a 15-year period, only a handful of runs (out of 100) triggered the ESL event, and only one run had two events triggered, due to the low short-term risk of devastating ESL events. On the longer term, it is obvious that ESL events become more frequent, with later years experiencing revenue and asset losses regularly.

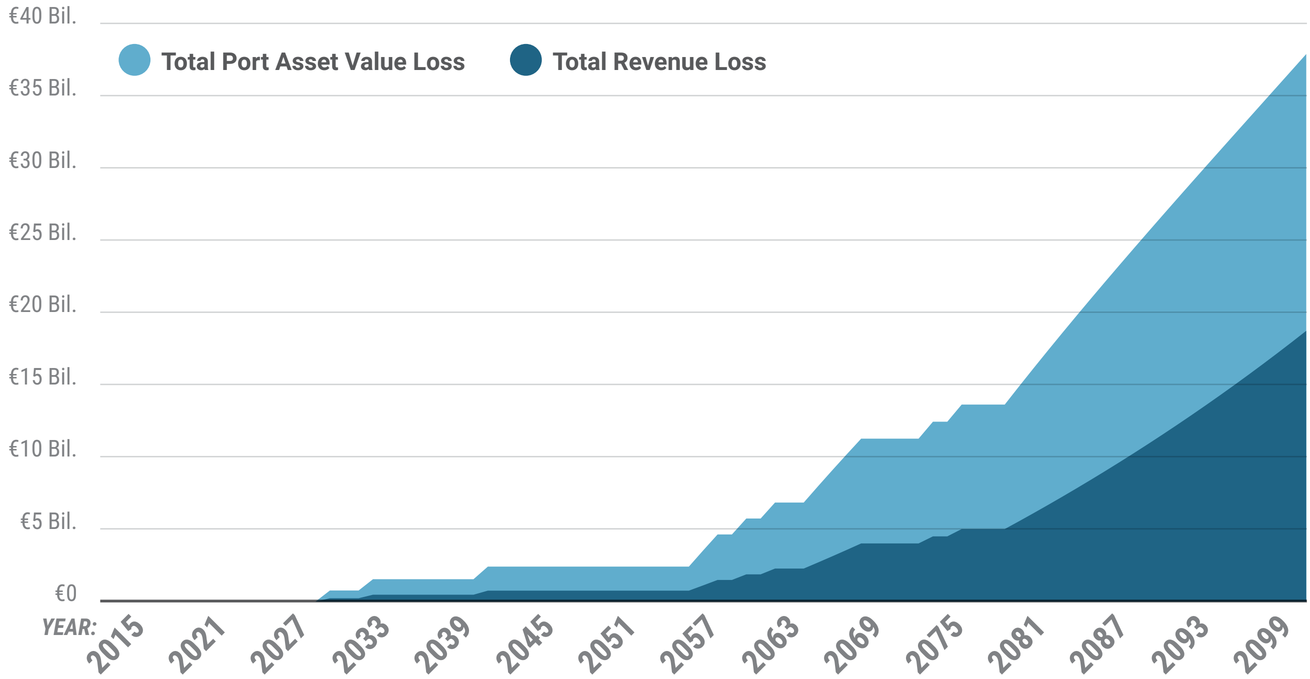


Fig. 6 **Cumulative modeled asset and revenue losses.** Over the short term, these value losses are relatively insignificant. In the longer term, they become more significant, accounting for a total revenue loss of 4% in 2100.

SYSTEMS MODEL FOR FISHERIES REVENUE AND ASSETS RISKS

The Baltic fisheries model was considerably more complex than the Baltic ports model, due to additional environmental drivers and the need to differentiate fish populations in specific regions of the Baltic Sea. The Baltic fisheries model was developed to include five populations of fish: sprat, herring (in two distinct regions), and cod (in two distinct regions). While we included as many key drivers as we could find reliable data for, it should be noted that other important drivers are still excluded from the model, due to a lack of acceptable data.

At a high level, the model for fisheries includes seven modules:

- **Drivers affecting birth rate:** Drivers which affect the replacement rate of the fish population stocks, such as habitat loss, temperature change, and egg predation.
- **Drivers affecting death rate:** Drivers which affect the death rate of mature stocks, such as predation.
- **Fish populations:** Starting with the current stock, fish populations are driven to change over time due to the drivers of death and birth rates, as well as fishing.
- **Fishing effort:** The rate at which fish are removed through fishing (including bycatch) and a policy scenario that increases or decreases fishing effort.
- **Fish landings:** Commercial and non-commercial fish landings. Commercial fish landing value drives the rest of the value chain in the model.
- **Revenues from fish value chain and fisheries value chain assets:** Modeling projected changes in the asset values of fishing boats and fish processing equipment, as well as the revenues along the full value chain.

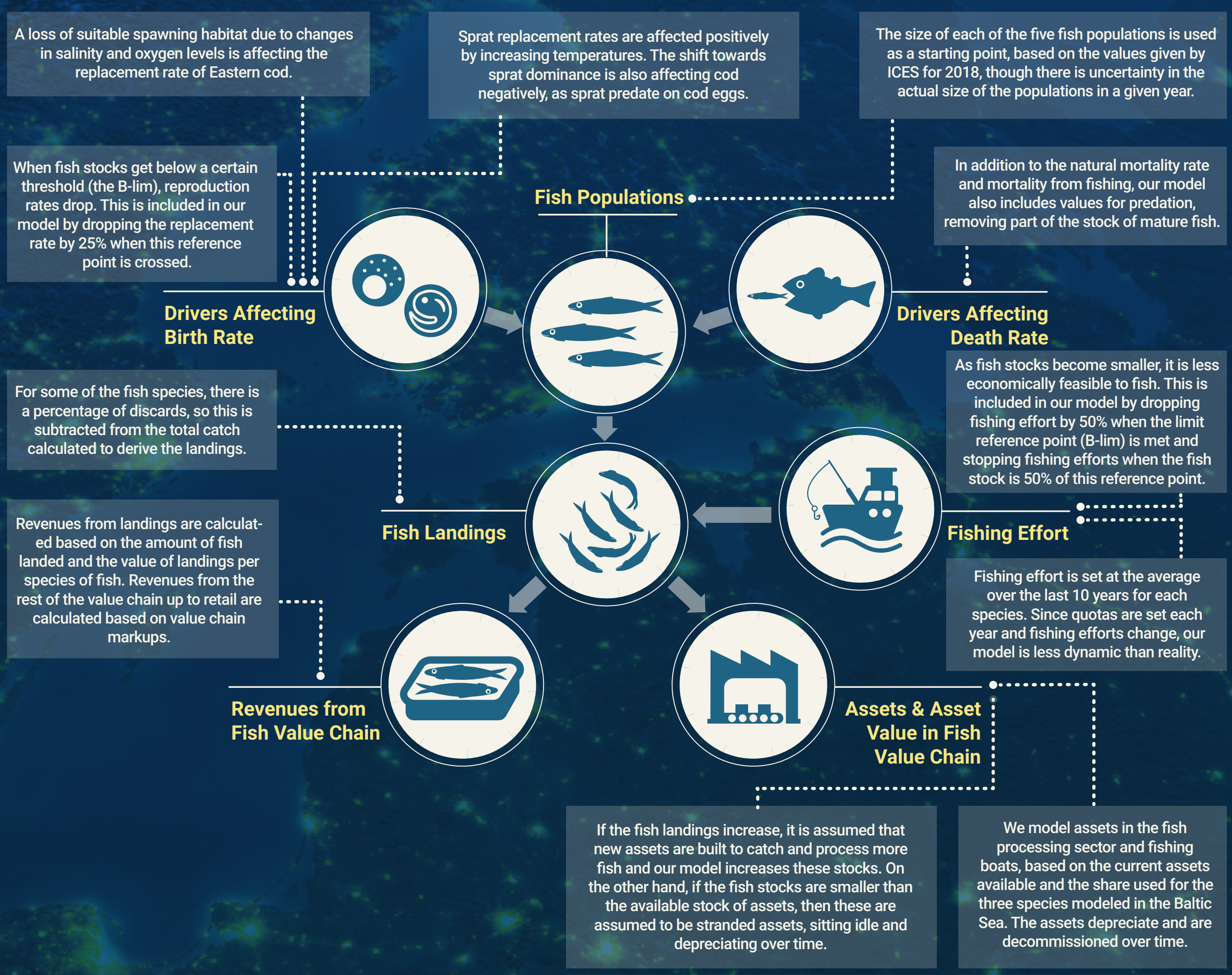


Fig. 7 **High-Level Overview of the Baltic Port Fisheries Model**

The key parameter we tested out was a policy scenario which increased or decreased fishing effort by (up to) 5%. Without the parameter, all of the fish populations decrease considerably within the 15-year period, reflecting the current trend seen in the Baltic Sea populations. By changing fishing rates by +/- 5%, we get a much higher variation in outcomes, with fish populations dropping faster or slower, and in the case where fishing of the Eastern cod is decreased by 5%, there is even a recovery of the population. Overall, the total value of landed fish decreases in this range, though in some scenarios (fishing reduced by close to 5%) it increases later as some populations begin to recover (assuming no other changes to drivers).

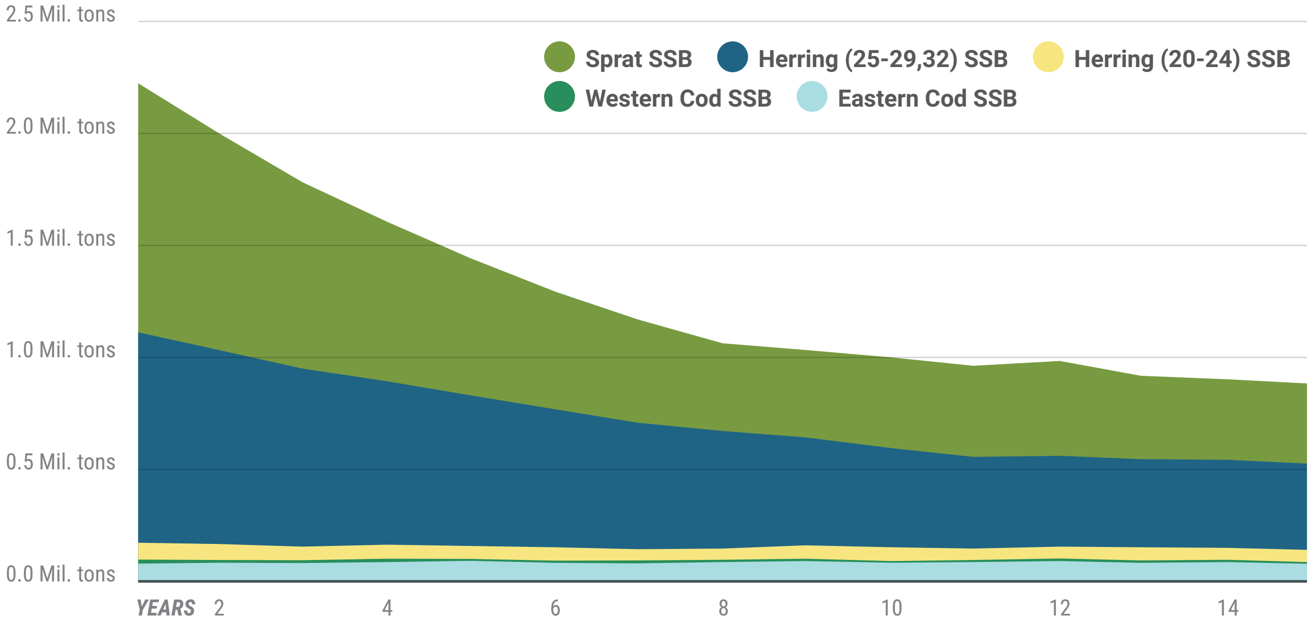


Fig. 8 **Model outcomes for total fish population development in 15-year period with no policy sensitivity analysis**

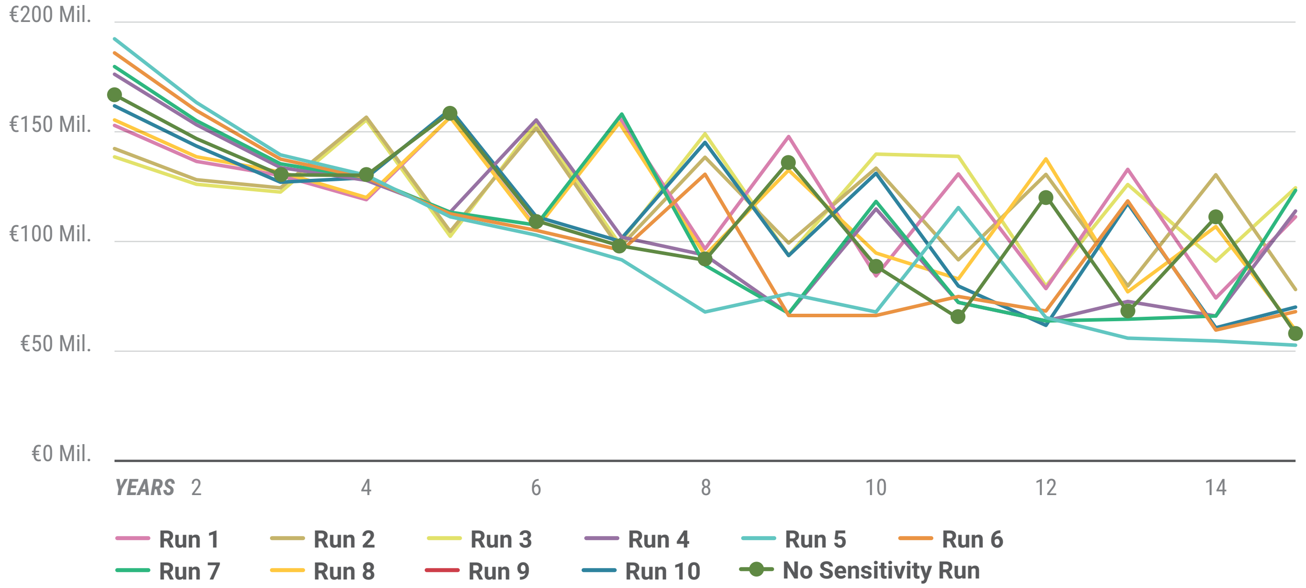


Fig. 9 **Total yearly revenues estimated for commercial landings from all fish populations combined,** with policy sensitivity analysis

The changes in fish populations (and therefore landed fish) drives losses of asset value and revenues in the seafood value chain.

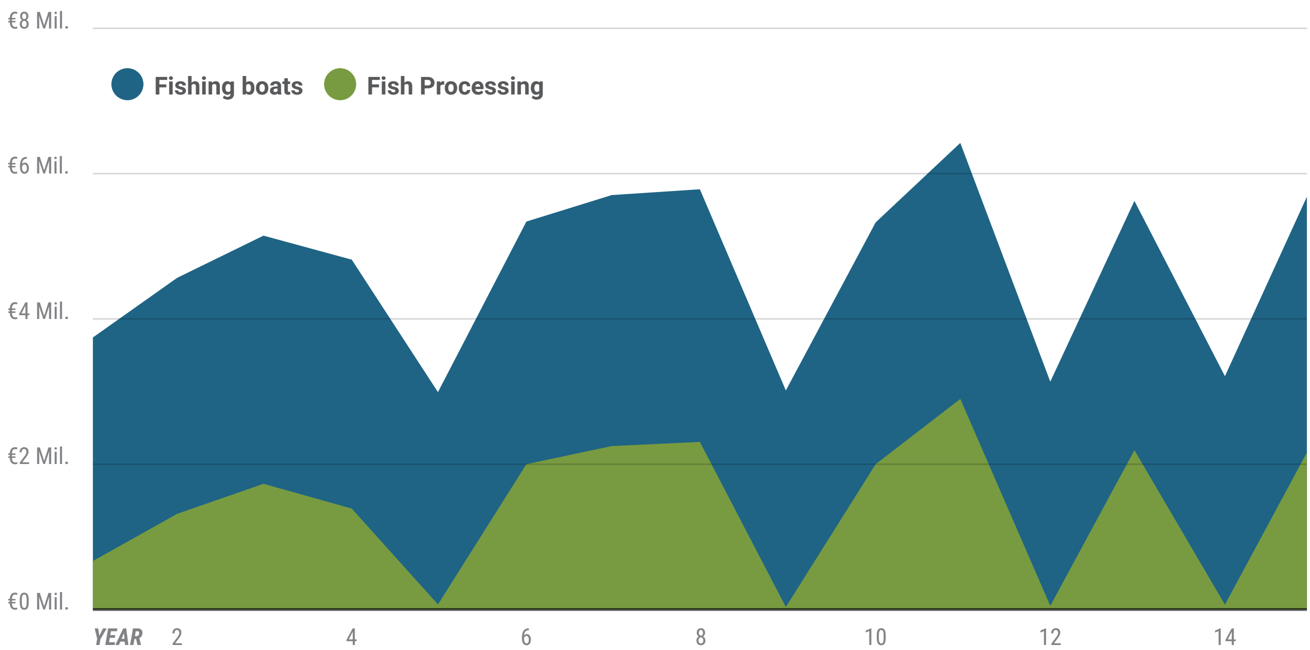


Fig. 10

Yearly asset value losses, or 'stranded assets' due to dips in fish populations that leave assets unused. Fish processing assets start at 170 mil. euros and 514 mil. euros for fishing boat assets, which means that in a given year, up to 0.8% of assets are stranded due to decreasing fish populations and around 12% of the value is stranded over the full period (excluding the value loss due to normal depreciation).

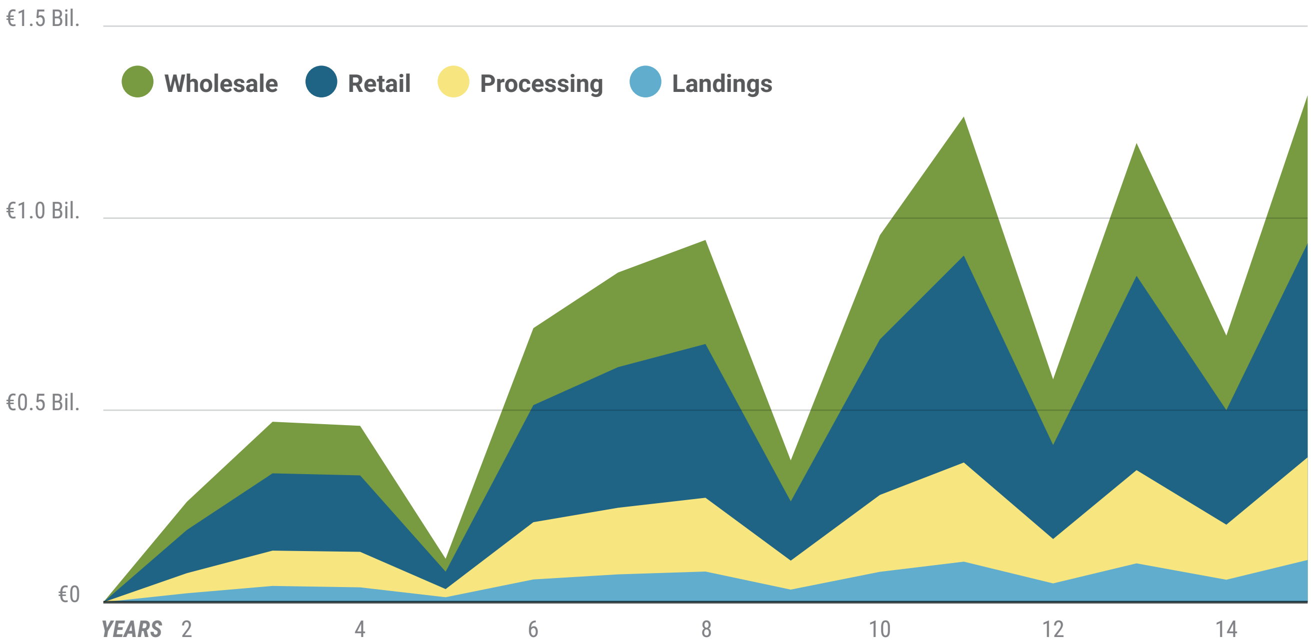


Fig. 11

Yearly revenue losses compared to baseline year of 2018. In the 15-year period, the revenue losses rise up to 64% of total potential revenues in a single year compared to the baseline year. This excludes the potential lost revenues in adjacent sectors, such as shipbuilding and repair.

03 OUTCOMES OF THE MODEL

The value of a company is calculated by discounting the future cash flows (dividends) from an investment back to the present. Dividends are generally assumed to grow at a steady rate over time, usually equal to GDP growth, and the discount rate is determined by the investor's cost of capital. The VaR to a portfolio of equities is the difference, over time, in discounted cash flows from company dividends compared to the business-as-usual (BAU) scenario. Our Blue Economy VaR assessment tries to assess whether, and by how much, the dividends are lower than expected, due to environmental drivers.

The output of the model shows how the revenues (revenues are used as a proxy for dividends in our model) and physical asset values of different Blue Economy-related sectors evolve over time. By simulating the model a large number of times, we are able to estimate the expected value of the revenues in a sector within a given confidence interval. Comparing this expected value to the baseline, which is set to the expected growth of the sector or, in case there is no data available, to the growth of the Blue Economy as a whole, gives us the total revenue lost due to environmental drivers. This is the VaR for the sector as a whole.

We are able to derive the VaR to an asset portfolio by aggregating the VaR to individual holdings. In turn, translating the sector-level VaR to individual assets requires three steps:

1. **Risk Identification -** Firstly, we need to identify which of the assets in the portfolio are exposed to the Blue Economy. We do this by matching the NACE and/or GICS codes (sector classification codes used by the European Union and S&P index respectively) of the sectors in the model to those of the assets in the portfolio. However, some NACE/GICS sectors may be only partially exposed to the Blue Economy, while some companies, notably financial institutions such as banks or insurance companies, are exposed indirectly. Also, many listed companies have diversified activities and therefore fall under multiple NACE/GICS codes. To capture this nuance, we have developed a risk analysis methodology for assessing the partial or induced risk of certain sectors to the Blue Economy,
2. **Risk Analysis** - Secondly, we assess the extent to which assets in a portfolio are exposed to the Blue Economy. Most large companies have different product or service types. For those companies that are partially exposed to the Blue Economy, we need to find out how much of their revenues are earned in Blue Economy sectors. Next, we need to find out the geographical distribution of their revenues. A manufacturing conglomerate, for instance, might earn a share of its revenues from shipbuilding, and a smaller share still from shipbuilding in the Baltic Sea. Financial accounts generally provide this information to a sufficient level of granularity. **The results from our model indicate that the total VaR**

to the Baltic fisheries sector (including retail and processing) over 15 years is 73%, or €1,32bn.

3. **Risk Quantification -** Thirdly, we calculate the expected Value at Risk to the individual holdings. For instance, if the manufacturing company earns 50% of its revenues from shipbuilding in the Baltic, and our model shows that the VaR in the shipbuilding sector in the Baltic Region is 10%, then the VaR to the manufacturing company is 5%.

The difficulty lies mostly in translating the sector-level VaR derived from the model to an equity portfolio. Very few companies included in the portfolio of large asset managers earn all their revenues from a single activity. Annual accounts of listed companies generally provide high-level data on the regional and divisional (product or service types) distribution of revenues and profits. However data availability, especially at the level of granularity required, remains a key constraint in translating the sector-level VaR to a measure of risk for individual assets. More granular disclosure on the distribution of revenues and profits across different business units within a holding company would greatly improve the accuracy of the analysis. Ideally, it would be possible to identify, or at least approximate with a high level of confidence, for each company the distribution of revenues across all NACE/GICS sectors.

Holdings of diversified banks are particularly problematic, as it is almost impossible to find accurate data on the amount of financing activity related to the Blue Economy. Banks only disclose aggregate lending by region, country, or type of credit instrument, but rarely by sector. However, as a proxy, we have assumed that banks lend to a representative distribution of the economy as a whole, and that the bank's revenues from the Blue Economy in the Baltic region are therefore equal to the total share of GDP from the Blue Economy in the region (in the Baltic Region this is 0.4%).

PORTFOLIO VAR ANALYSIS FROM PORTS

The ports model indicated that the total VaR over an 85-year period was around 2.1%, or €19.9bn. We used data from a portfolio of a Swedish asset manager to test the methodology on a real-world case study. In the USD 2bn Nordics-focused portfolio, there are no port operating companies. However, there is one machinery construction company (4.9% of the total portfolio by value) that has marine activities and one aerospace & defense company (0.5%) with marine activities.

The machinery construction company is a multinational conglomerate with multiple business units. The group's net sales from marine-related activities, including shipbuilding and repair, made up 4% of the total revenues of SEK 390bn.

If we assume that the company's shipbuilding activities are perfectly correlated with port revenues, the **VaR to the asset manager's portfolio** relating to the machinery production company is **0.0041% (or €82,467)**.

The aerospace and defense company is also a multinational conglomerate with multiple business units. The group's net sales from marine-related activities, including ship-building and repair, were 10% of the total revenues of SEK 23bn. Using the same assumptions as above, the **VaR to the asset manager's portfolio** relating to the aerospace and defense company is **0.0011% (or USD 22.824)**.

PORTFOLIO VAR ANALYSIS FROM FISHERIES

We also conducted a VaR assessment on the portfolio for the fisheries sector. The risk identification analysis showed that the portfolio contains no fishing or fish processing companies. There are three holdings that have potential exposure to the fisheries sector in the Baltic Region: a food retail company (0.68%), a second food retail company (0.46%) and a diversified bank (26.27%). All other holdings are either not exposed to the Blue Economy, or only indirectly exposed through other Blue Economy sectors.

The first food retail company is a conglomerate with numerous retail businesses as well as real estate and banking businesses. Sales from their retail stores was 97bn SEK in 2018, around 84.5% of the group's total. Because there is no data available on the distribution of supermarket revenues, it is difficult to assess how much of the retail revenues are marine-related. As a proxy for the share of their Baltic fish-related revenues, we use the total Baltic Blue Economy's GDP contribution (0.4%). If we assume that the company is unable to increase prices or find substitutes, the **VaR to the asset manager's portfolio** relating to the retail company is **0.0017%**. This means that 0.001% (or 97m SEK) of the retail company's revenues are at risk from environmental impacts in the Baltic Blue Economy, and by extension **0.0017%** of the asset managers holding in them (or **USD 33,998**). However, the real figure is likely far closer to zero as it is highly probable that the retail company can take mitigating actions, such as increasing prices following lower supply or, in the case of a collapse in fisheries, substituting local species with imported fish.

We use a similar assessment for estimating the VaR from the **second retail** holding. The annual revenues for 2018 were 48bn SEK. 100% of its revenues came from food retail. Again, we assume that 0.4% of its revenues by value came from Baltic fish sales. With a sector-level VaR in the retail sector of 73%, that translates into a **VaR to the asset manager of 0.0011% (or USD 22,511)**, with the same caveat about pricing and substitutes.

The bank generated 2018 interest income from commercial lending in the Baltic region of 15.8bn SEK, or 31.5% of its total income for the year. Assuming that its activities are across a representative proportion of the economy, its total share of Blue Economy-related income is 0.4%, or 0.6bn SEK. **The asset managers's fisheries-related VaR** from its bank holding is therefore estimated to be **0.03% (or $662k)**. For a further discussion on estimating the VaR to banks see section 4: Applications for Systems Modelling in VaR Assessment.

REFLECTION ON THE OUTCOMES OF THE MODEL

Our model indicates that the total VaR to the example portfolio that we assessed is around 0.01% (USD 213k). This number in itself may not be cause for concern for an asset manager. However, this figure comes with a number of caveats which are important to consider.

Firstly, the current case study is somewhat limited in geographical scope. Because there is relatively little investment in the fisheries sector in the Baltic Sea region, the outcome of this model is not necessarily representative globally. According to the Fish Tracker report (2017), revenues from listed fisheries companies are concentrated in only a small number of countries, and almost half (46%) of global revenues come from Japanese companies. As such, the outcome might look very different for a portfolio focused on the Asia-Pacific region. We therefore recommend extending the model to include all major global fisheries, so as to capture this spatial distribution of risk.

Secondly, the case study is limited in sectoral scope. As the relative VaR (0.01%) suggests, asset managers are quite adept at managing risk through diversification. However, according to the European Commission (2019), the direct extraction of marine living resources makes up only around 11% of the Blue Economy's total gross revenues. It is likely, therefore, that if all Blue Economy-related risks are considered together, the VaR to a representatively diversified asset portfolio could be more significant. It will likely also encompass a larger share of companies in an asset manager's investment universe, making it more difficult to diversify away the risk from the Blue Economy.

Thirdly, the model looks only at direct risk to revenues from environmental drivers, but in its current form doesn't include other types of risk to the business reputational risk, regulatory risk, technological risk, or transition risk. It also doesn't include important economic risks which might influence the results.

However, as discussed in the textbox 'Other Potential Applications for Systems Modelling in VaR Assessment', it might be that even considering the above caveats, the risk to asset managers is acceptable, but that the outcomes are nonetheless highly relevant for other financial institutions such as banks or insurers. Especially in the case of fisheries, where a large part of the economic activity is from SMEs, banks and insurers might serve as a first 'buffer' for asset managers. Extending the model to highlight the VaR to other financial institutions is an interesting avenue for future research.

04 CONCLUSIONS AND NEXT STEPS

REFLECTIONS

Systems Analysis for Value at Risk assessment shows promise for further development

This type of modeling allowed us to incorporate elements that would not be possible using traditional Value at Risk approaches, including a concept of "point-in-time" risks like Extreme Sea Level events, cumulative impacts, and tradeoffs and interactions between different parts of a sector. While there is still much room for growth and improvement, the approach has proven valuable and further exploration of the approach is warranted.

Sensitivity analysis allows for scenario modeling and understanding the potential of mitigation

Sensitivity analysis allows us to look at indirect systemic effects of ranges for a single variable or scenario. In addition to allowing us to test out dummy variable values, this provides us an opportunity for better understanding the effect of mitigation strategies on value. This was mentioned by one asset manager as a valuable characteristic of the model as it can be used as a tool for engagement.

This first exploration was limited by only exploring two sectors

In the scope of this project, we were only able to explore two sectors. By modeling additional sectors, we can dig deeper into scenarios and drivers that are cross-cutting in their implications for value, as well as more indirect and macroeconomic drivers from the Blue Economy sector activities. For the Baltic port model for example, very few environmental drivers are posing a (direct) risk to value. However, impacts of ports are drivers for value risk in other sectors such as fisheries and coastal tourism and when port activities are interrupted, then other sectors downstream (such as manufacturing) could also be affected.

Data availability was (and will remain) a key barrier to such detailed modeling, though there are ways to work around some data gaps

Data availability severely limited what could be included in the model. This points to a larger issue - while there is increasingly more data available on environmental drivers, data on value itself (e.g. assets and revenues), and therefore also the link between environmental drivers and value, is more limited. With more time, other key parameters for which data is unavailable could be explored further with sensitivity analysis on dummy variables.

Our approach should be tested on additional portfolios to better understand the relevance for financial institutions

In this first exploration, we only looked at the implications of the modeled risk of the two sectors for one asset manager's portfolio. In addition to including other sectors, other portfolios should be tested as exposure to risk in different sectors varies among portfolios.

NEXT STEPS AND OUTLOOK

In conclusion, the systems modeling approach has proven useful and relevant, though there are some adaptations needed to increase its relevance in a following iteration, including the following:

Sharing the findings with key stakeholders and networks

We would like to share the findings with key stakeholders and networks, such as data providers, commercial banks, other asset managers, and multilateral development banks (MDBs) to get feedback on the approach and its applications, in order to better tailor the approach and model to the needs of the financial sector. As part of this process, speaking with companies directly or indirectly affected by risk in the Blue Economy may also be valuable. Likewise, sharing with more vastly different stakeholders, such as public policy makers, who might also find value in such a model, may provide additional insights.

Applying the approach to further asset portfolios and exploring opportunities for engagement

Further application of the approach to existing portfolios will give us the opportunity to engage with key financial stakeholders, to generate additional data on revenue streams relating to the Blue Economy, and to discover additional hidden risks. Furthermore, asset managers have proposed that this model could be useful as an engagement tool. Highlighting risks facing holding companies could be a first step in mitigating root causes and transitioning to a more sustainable Blue Economy.

The approach should be compared to other Value at Risk assessments

Comparisons of our results with the outcomes of conventional Value at Risk approaches will help identify gaps in risk management in the financial sector and could be the foundation for back-testing and eventual stress-testing.

Taking the approach further in a second iteration, by including root causes, additional sectors, and exploring other asset types

In a second iteration, we would like to build on the existing model with more detail, for example incorporating key root causes that drive the model, such as population and consumption trends. Additionally, we will expand the approach to include additional sectors, including those related sectors (such as real estate) that are impacted indirectly if marine ecosystems die off. During this second iteration, we will also test out the Value at Risk assessment on other types of assets, such as bank loans, insurance, project finance, and government bonds.

On the longer term, our vision is to create a global systems model covering all Blue Economy sectors

The true value of a systems model lies in its ability to link together elements that are indirectly connected in meaningful ways. Not only are sectors within the Blue Economy related (e.g. if fisheries collapse, then fish processing, shipbuilding, ship repairs, and other sectors could follow), but regions are also interconnected in a global economy. So if capture fisheries collapse or are banned in one region, it could mean increasing fishing pressure on another region that ultimately leads to collapse there. This effect is called "burden shifting" and is one of the key reasons a systems approach is applied.

With an extensive, spatially differentiated model of the Blue Economy, the value as a tool for mitigation scenarios and exploring the implications of public and private policy on different scales vastly increases. The main barrier in achieving such a vision lies in data availability. Reaching this point would require establishing partnerships to ensure the correct data and knowledge is incorporated into the model.

Bibliography

1. **Accenture.** (2017). Principles for sustainable investment in the blue economy. Retrieved from https://ec.europa.eu/maritimeaffairs/sites/maritimeaffairs/files/principles-sustainable-investment-in-blue-economy-report_en.pdf

2. **Anderson, J., Contini, F., Virtanen, J., Carvalho, N., & European Commission. Joint Research Centre. Institute for the Protection and the Security of the Citizen.** (2012). The 2012 annual economic report on the EU fishing fleet (STECF-12-10). Publications Office.

3. **Andersson, A., Meier, H. E. M., Ripszam, M., Rowe, O., Wikner, J., Haglund, P., … Elmgren, R.** (2015). Projected future climate change and Baltic Sea ecosystem management. Ambio, 44, 345–356. https://doi.org/10.1007/s13280-015-0654-8

4. **Ankobiah, M.** (2001). Valuation of port assets : impact on the financial performance of port and the national economy. Retrieved from http://commons.wmu.se/all_dissertationshttp://commons.wmu.se/all_dissertations/71

5. **Anrooy van, R., Secretan, P., Lou, Y., Roberts, R., & Upare, M.** (2006). Review of the current state of the world aquaculture insurance. Rome. Retrieved from http://www.fao.org/3/a-a0583e.pdf

6. **Ansari, T. M., Marr, I. L., & Tariq, N.** (2004). Heavy Metals in Marine Pollution Perspective–A Mini Review. Journal of Applied Sciences, 4(1), 1–20. https://doi.org/10.3923/jas.2004.1.20

7. **Arora.** (2012). Anatomy of a port financing transaction. Retrieved August 30, 2019, from https://www.porttechnology.org/technical-papers/anatomy_of_a_port_financing_transaction/

8. **Asariotis, R., Benamara, H., & Naray, V. M.-.** (2017). Port Industry Survey on Climate Change Impacts and Adaptation, (18).

9. **Bank of England.** (2018). Transition in thinking: the impact of climate change on the UK banking sector.

10. **Bax, N., Williamson, A., Aguero, M., Gonzalez, E., & Geeves, W.** (2003). Marine invasive alien species: a threat to global biodiversity. Marine Policy, 27(4), 313–323. https://doi.org/10.1016/S0308-597X(03)00041-1

11. **Bax, N., Williamson, A., Aguero, M., Gonzalez, E., & Geeves, W.** (2003). Marine invasive alien species: a threat to global biodiversity. Marine Policy, 27(4), 313–323. https://doi.org/10.1016/S0308-597X(03)00041-1

12. **Burke, L., Reytar, K., Spalding, M., & Perry, A.** (2011). Reefs at Risk Revisited. Washington DC. Retrieved from www.wri.org

13. **Cao, X., & Lam, J. S. L.** (2019). Simulation-based severe weather-induced container terminal economic loss estimation. Maritime Policy and Management, 46(1), 92–116. https://doi.org/10.1080/03088839.2018.1516049

14. **Centrum Balticum.** (2016). The maritime cluster in the Baltic Sea region and beyond.

15. **Christodoulou, A., Christidis, P., & Demirel, H.** (2018). Sea-level rise in ports: a wider focus on impacts. Maritime Economics and Logistics. https://doi.org/10.1057/s41278-018-0114-z

16. **Clark, J. R., & Food and Agriculture Organization of the United Nations.** (1992). Integrated management of coastal zones. Retrieved from http://www.fao.org/3/t0708e/T0708E00.htm

17. **Copenhagen Malmo Port.** (2017). Copenhagen Malmo Port - Annual Report 2016.

18. **Copp, G. H., Russell, I. C., Peeler, E. J., Gherardi, F., Tricarico, E., Macleod, A., … Britton, J. R.** (2016). European Non-native Species in Aquaculture Risk Analysis Scheme - a summary of assessment protocols and decision support tools for use of alien species in aquaculture. Fisheries Management and Ecology, 23(1), 1–11. https://doi.org/10.1111/fme.12074

19. **Cottrell, R. S., Nash, K. L., Halpern, B. S., Remenyi, T. A., Corney, S. P., Fleming, A., … Blanchard, J. L.** (2019). Food production shocks across land and sea. Nature Sustainability. https://doi.org/10.1038/s41893-018-0210-1

20. **Döring, R., Carvalho, N., Guillen, J., & European Commission. Joint Research Centre.** (2017). The economic performance of the EU fish processing sector 2017 (STECF-17-16).

21. **EC - Maritime Affairs.** (2017). Towards an implementation strategy for the Sustainable Blue Growth Agenda for the Baltic Sea Region. Maritime Affairs, 1–95. https://doi.org/10.2771/706890

22. **Economist Intelligence Unit.** (2015). The cost of inaction: Recognising the value at risk from climate change. Economist Intelligence Unit, 63. Retrieved from http://www.eiuperspectives.economist.com/sustainability/cost-inaction/white-paper/cost-inaction

23. **Ecorys.** (2013). Study in support of policy measures for maritime and coastal tourism at EU level. Rotterdam/Brussels. Retrieved from https://ec.europa.eu/maritimeaffairs/sites/maritimeaffairs/files/docs/body/study-maritime-and-coastal-tourism_en.pdf

24. **EUNETMAR.** (2013). Study on Blue Growth, Maritime Policy and the EU Strategy for the Baltic Sea Region. Retrieved from www.and-international.comhttp://www.eurofish.dk/www.sustainable-projects.eu

25. **European Commission.** (2012). The 2012 Annual Economic Report on the EU Fishing Fleet (STECF-12-10) Scientific , Technical and Economic Edited by. https://doi.org/10.2788/40549

26. **European Commission.** (2015). European Maritime & Fisheries Fund (EMFF) - Sweden. Retrieved from https://ec.europa.eu/fisheries/sites/fisheries/files/docs/body/op-sweden-fact-sheet_en.pdf

27. **European Commission.** (2009). The Economics of Climate Change Adaptation in EU Coastal Areas.

28. **European Commission.** (2018). The 2018 Annual Economic Report on the EU Blue Economy. Retrieved from https://about.usps.com/who-we-are/postal-facts/size-scope.htm

29. **European Commission.** (2013). Study on Blue Growth, Maritime Policy and the EU Strategy for the Baltic Sea Region Final Report Eurofish International Organisation.

IMP EUNETMAR Study on Blue Growth, Maritime Policy and the EU Strategy for the Baltic Sea Region. Retrieved from www.and-international.comhttp://www.eurofish.dk/www.sustainable-projects.eu

30. **FAO.** (2006). Revenue Distribution Through the Seafood Value Chain. Retrieved from http://www.fao.org/3/a-a0564e.pdf

31. **FAO.** (2006). Revenue distribution through the seafood value chain. Retrieved October 3, 2019, from http://www.fao.org/3/a0564e/a0564e05.htm

32. **FAO.** (2013). Commodity Balances - Livestock and Fish Primary Equivalent. Retrieved April 4, 2019, from http://www.fao.org/faostat/en/?#data/BL

33. **FAO.** (2018). FAO yearbook. Fishery and Aquaculture Statistics 2016. Rome. Retrieved from www.fao.org/fishery/static/Yearbook/YB2016_USBcard/index.htm

34. **Fish Tracker Initiative.** (2017). Empty Nets - How Overfishing Risks Leaving Investors Stranded.

35. **Food and Agriculture Organisation.** (2008). Climate Change for Fisheries and Aquaculture Technical Background Document From the Expert Consultation Held on the Importance of Fisheries and Aquaculture To Livelihoods. Europe, (April), 18.

36. **Free, C. M., Thorson, J. T., Pinsky, M. L., Oken, K. L., Wiedenmann, J., & Jensen, O. P.** (2019). Impacts of historical warming on marine fisheries production, 983(March), 979–983. https://doi.org/10.1126/science.aau1758

37. **Freeport of Riga Authority.** (2019). Summary Financial Statements for the year 2018.

38. **Godinot, S., Vandermosten, J., Campogianni, S., Crasselt, A., Danthine, F., Gueudet, A., … Mangset, L. E.** (2017). European Asset Owners: 2°C Alignment and Misalignment of Public Equity Portfolios 2°c. Retrieved from http://d2ouvy59p0dg6k.cloudfront.net/downloads/22_wwf_asset_owners_report_lr.pdf

39. **Govers, G., Van Oost, K., & Wang, Z.** (2014). Scratching the Critical Zone: The Global Footprint of Agricultural Soil Erosion. Procedia Earth and Planetary Science, 10, 313–318. https://doi.org/https://doi.org/10.1016/j.proeps.2014.08.023

40. **Gozlan, R. E., Britton, J. R., Cowx, I., & Copp, G. H.** (2010). Current knowledge on non-native freshwater fish introductions. Journal of Fish Biology, 76(4), 751–786. https://doi.org/10.1111/j.1095-8649.2010.02566.x

41. **Hall, S. J., Deleaporte, A., Phillips, M. J., Beveridge, M., & O'Keefe, M.** (2011). Blue Frontiers: Managing the environmental costs of aquaculture. Penang, Malaysia.

42. **Hansson, M., Andersson, L., & Axe, P.** (2011). Areal Extent and Volume of Anoxia and Hypoxia in the Baltic Sea (Vol. 42).

43. **HELCOM.** (2018). Economic benefits from the protection and use of the Baltic Sea – State of the Baltic Sea – Second HELCOM holistic assessment. Retrieved September 27, 2019, from http://stateofthebalticsea.helcom.fi/humans-and-the-ecosystem/use-of-baltic-marine-waters/#fish-and-shellfish-harvesting

44. **HELCOM.** (2013). Species Information Sheet Gadus morhua. Retrieved from www.helcom.fi

45. **HELCOM.** (2018). State of the Baltic Sea – Second HELCOM holistic assessment 2011-2016. Retrieved from www.helcom.fi/baltic-sea-trends/holistic-assessments/state-of-the-baltic-sea-2018/reports-and-materials/

46. **HELCOM.** (2018). Economic and social analyses in the Baltic Sea region – HELCOM Thematic assessment 2011-2016. Retrieved from http://www.helcom.fi/baltic-sea-trends/holistic-assessments/state-of-the-baltic-sea-2018/reports-and-materials/

47. **Hindlian, A. Lawson, S., Banerjee, S., Duggan, D., Hinds, M. Sept.** (2019). Taking the Heat: Making cities resilient to climate change. Goldman Sachs, Global Markets Institute.

48. **Hinweis, W.** (2018). Integrating Natural Capital in Risk Assessments: A step-by-step guide for banks, 1–30.

49. **Hoegh-Guldberg, O. et al.** (2013). Indispensable Ocean: Aligning Ocean Health and Human Wellbeing. Retrieved from http://documents.worldbank.org/curated/en/111381468155703584/pdf/826510WP0Indis00Box379862B00PUBLIC0.pdf

50. **Hoegh-Guldberg, O. et al.** (2015). Reviving the Ocean Economy: the case for action - 2015. WWF International, Gland, Switzerland., Geneva, 60 pp.

51. **Honey, M., Krantz, D., University, S., & Program, M.** (2007). CESD: Global Trends in Coastal Tourism Global Trends in Coastal Tourism Center on Ecotourism and Sustainable Development A Nonprofit Research Organization. Retrieved from https://www.responsibletravel.org/docs/Global_Trends_in_Coastal_Tourism_by_CESD_Jan_08.pdf

52. **Horbowy, J.** (1989). A multispecies model of fish stocks in the Baltic Sea (Vol. 7).

53. **Horbowy, J.** (2005). The dynamics of Baltic fish stocks based on a multispecies stock production model. Journal of Applied Ichthyology, 21(3), 198–204. https://doi.org/10.1111/j.1439-0426.2005.00596.x

54. **Hummel, M. A., Berry, M. S., & Stacey, M. T.** (2018). Sea Level Rise Impacts on Wastewater Treatment Systems Along the U.S. Coasts. Earth's Future, 6(4), 622–633. https://doi.org/10.1002/2017EF000805

55. **ICES.** (1994). Fish species interactions in the Baltic Sea (Vol. 10).

56. **ICES.** (2005). Report of the Study Group on Multispecies Assessment in the Baltic (SGMAB). Retrieved from www.ices.dk

57. **ICES.** (2018). 1.2 Advice basis. https://doi.org/10.17895/ices.pub.4503

58. **ICES.** (2009). Report of the Baltic Fisheries Assessment Working Group (WGBFAS). Retrieved from www.ices.dk

59. **ICES.** (2019). ICES Advice on fishing opportunities, catch, and effort Baltic Sea ecoregion Cod (Gadus morhua) in subdivisions 24-32, eastern Baltic stock (eastern Baltic Sea). https://doi.org/10.17895/ices.advice.4747

60. **ICES.** (2019). ICES Advice on fishing opportunities, catch, and effort Baltic Sea ecoregion Cod (Gadus morhua) in subdivisions 22-24, western Baltic stock (western Baltic Sea). https://doi.org/10.17895/ices.advice.4746

61. **ICES.** (2018). Baltic Sea Ecoregion – Ecosystem overview, (December 2018), 1–25.

62. **IPCC.** (2014). Climate Change 2014: Synthesis Report; Chapter Observed Changes and their Causes. Ipcc. https://doi.org/10.1046/j.1365-2559.2002.1340a.x

63. **IPCC.** (2018). Global warming of 1.5°C: An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change,. Retrieved from http://www.ipcc.ch/pdf/special-reports/sr15/sr15_draft.pdf

64. **IPCC.** (2019). Special Report on the Oceans and Cryosphere in a Changing Climate

65. **Lindegren, M., Mö Llmann, C., Nielsen, A., Brander, K., Mackenzie, B. R., & Stenseth, N. C.** (2010). Ecological forecasting under climate change: the case of Baltic cod. The Royal Society, 277, 2121–2130. https://doi.org/10.1098/rspb.2010.0353

66. **Luijendijk, A., Hagenaars, G., Ranasinghe, R., Baart, F., Donchyts, G., & Aarninkhof, S.** (2018). The State of the World's Beaches. Scientific Reports, 8(1), 6641. https://doi.org/10.1038/s41598-018-24630-6

67. **MacKenzie, B. R., Eero, M., & Ojaveer, H.** (2011). Could seals prevent cod recovery in the Baltic Sea? PLoS ONE, 6(5). https://doi.org/10.1371/journal.pone.0018998

68. **MacKenzie, B., & Köster, F.** (2004). Fish production and climate: Sprat in the Baltic Sea -. DTU Orbit, 85(3), 784–794. Retrieved from https://orbit.dtu.dk/en/publications/fish-production-and-climate-sprat-in-the-baltic-sea(65ef9264-3849-4633-ae3d-1f7279bd30c7).html

69. **Martinez, J. L.** (2009). Environmental pollution by antibiotics and by antibiotic resistance determinants. Environmental Pollution, 157(11), 2893–2902. https://doi.org/https://doi.org/10.1016/j.envpol.2009.05.051

70. **Mary, S.** (2017). A deep-dive into the Ocean.

71. **Matczak, M.** (2018). QUO VADIS Exploring the future of shipping in the Baltic Sea, (July).

72. **McCarron, B.** (2017). Empty Nets - How overfishing risks leaving investors stranded.

73. **Meier, H. E. M., Kjellström, E., & Graham, L. P.** (2006). Estimating uncertainties of projected Baltic Sea salinity in the late 21st century. Geophysical Research Letters, 33(15). https://doi.org/10.1029/2006GL026488

74. **Morillo, R., & Spalding, M.** (2017). A Sustainable Blue Economy.

75. **Naylor, R. L., Goldburg, R. J., Primavera, J. H., Kautsky, N., Beveridge, M. C. M., Clay, J., … Troell, M.** (2000). Effect of aquaculture on world fish supplies. Nature, 405(6790), 1017–1024. https://doi.org/10.1038/35016500

76. **Network for Greening the Financial System.** (n.d.) https://www.ngfs.net/en

77. **Nicholls, R. J.** (2004). Coastal flooding and wetland loss in the 21st century: Changes under the SRES climate and socio-economic scenarios. Global Environmental Change, 14(1), 69–86. https://doi.org/10.1016/j.gloenvcha.2003.10.007

78. **Nicholls, R. J., Wong, P. P., Burkett, V., Codignotto, J., Hay, J., McLean, R., … Arblaster, J.** (2007). Coastal systems and low-lying areas.

79. **Niehörster, F., & Murnane, R. J.** (2018). Ocean Risk and the Insurance Industry Ocean Risk and the Insurance Industry, (May), 40.

80. **Ninan, Sharma, Ananthan, & Ojha.** (2005). Intellectual Property Rights in the Fisheries Sector. Journal of Intellectual Property Rights, 10, 52–58. Retrieved from https://www.researchgate.net/publication/228432363_Intellectual_Property_Rights_in_the_Fisheries_Sector

81. **NOAA.** (2018). Global Climate Report - Annual 2018 | State of the Climate | National Centers for Environmental Information (NCEI). Retrieved October 8, 2019, from https://www.ncdc.noaa.gov/sotc/global/201813

82. **OECD.** (2016). The Ocean Economy in 2030, OECD Publishing, Paris,https://doi.org/10.1787/9789264251724-en.

83. **Partington, R.** (2018). Mark Carney warns of climate change threat to the financial system. The Guardian.

84. **Petrášková, E., Vácha, F., Rost, M., Maršálek, M., Rutkayová, J., Beneš, K., … Šulista, M.** (2017). Fish stock losses due to extreme floods - findings from pond-based aquaculture in the Czech Republic. Journal of Flood Risk Management, 11(3), 351–359. https://doi.org/10.1111/jfr3.12332

85. **Policy Research Corporation.** (2016). Country Overview and Assessment - Latvia, 2004, 1–9.

86. **Port of Aarhus.** (2018). Annual report 2017.

87. **Port of Gdansk Authority.** (2017). Summarising the PGA SA's Activities in the Area of Corporate Social Responsibility in 2016.

88. **Port of Helsinki.** (2016). Annual Report 2016.

89. **Ports of Stockholm.** (2017). Ports of Stockholm Annual Report and Sustainability Report.

90. **Potts, J., Wenban-Smith, M., Turley, L., & Lynch, M.** (2018). State of Sustainability Initiatives Review: Standards and the Extractive Economy. Retrieved from https://www.iisd.org/sites/default/files/publications/igf-ssi-review-extractive-economy.pdf

91. **Raven, J., Caldeira, K., Elderfield, H., Hoegh-Guldberg, O., Liss, P., Riebesell, U., … Watson, A.** (2005). Ocean acidification due to increasing. Coral Reefs, 12/05(June), 68. Retrieved from http://eprints.ifm-geomar.de/7878/1/965_Raven_2005_OceanAcidificationDueToIncreasing_Monogr_pubid13120.pdf

92. **Rezaee, S., Pelot, R., & Ghasemi, A.** (2016). The effect of extreme weather conditions on commercial fishing activities and vessel incidents in Atlantic Canada. Ocean and Coastal Management, 130, 115–127. https://doi.org/10.1016/j.ocecoaman.2016.05.011

93. **Rosendal, G. K., Olesen, I., & Tvedt, M. W.** (2013). Evolving legal regimes, market structures and biology affecting access to and protection of aquaculture genetic resources. Aquaculture, 402–403, 97–105. https://doi.org/10.1016/J.AQUACULTURE.2013.03.026

94. **Rozemeijer, M. J. C., Van Den Burg, S. W. K., & Jak, R. G.** (2018). Seabed Mining. Retrieved from https://www.researchgate.net/publication/322750118

95. **Serchuk, F. M., Brown, B., & Wood, P. W.** (n.d.). Atlantic cod (Gadus morhua): assessment and status of the Georges Bank and Gulf of Maine stocks. Retrieved September 5, 2019, from https://www.researchgate.net/figure/Mean-weights-at-age-kg-for-Atlantic-cod_tbl4_285580362

96. **Shvidenko, A.** (2008). Deforestation. In B. B. T.-E. of E. (Second E. Fath (Ed.) (pp. 29–34). Oxford: Elsevier. https://doi.org/https://doi.org/10.1016/B978-0-444-63768-0.00586-2

97. **Spears, C.** (2015, May 22). Is 300 Days Of Sunshine In Colorado A Fact Or Just Good Marketing? CBS Denver. Retrieved from https://denver.cbslocal.com/2015/05/22/300-days-of-sun-not-really-just-good-marketing/

98. **Tacon, A. G. J., Hasan, M. R., & Metian, M.** (2011). Demand and supply of feed ingredients for farmed fish and crustaceans: Trends and prospects. FAO Fisheries and Aquaculture Technical Paper No. 564. Retrieved from http://www.fao.org/docrep/015/ba0002e/ba0002e.pdf

99. **Tallinna Sadam.** (2019). Group Annual Report 2018.

100. **Tandon, B.** (2016). Aquafeed Market by Additives and End User - 2022. Allied Market Research. Retrieved from https://www.alliedmarketresearch.com/aquafeed-market

101. **Tarvainen, H., Tolvanen, H., & Repka, S.** (2015). How can maritime spatial planning contribute to sustainable Blue Growth in the Baltic Sea? Bulletin of the Maritime Institute in Gdansk, 1(30), 86–95. https://doi.org/10.5604/12307424.1178822

102. **The Economist Intelligence Unit.** (2015). The cost of inaction: Recognising the value at risk from climate change. Retrieved from http://webarchive.nationalarchives.gov.uk/+/http:/www.hm-treasury.gov.uk/independent_reviews/stern_

103. **The World Bank.** (2017). The Ocean Economy in Mauritius: Making it happen, making it last, 2(November). https://doi.org/10.1596/28562

104. **Turner, G. M.** (2012). On the cusp of global collapse?: Updated comparison of the Limits to Growth with historical data. Gaia, 21(2), 116–124. https://doi.org/10.14512/gaia.21.2.10

105. **Unctad.** (2016). Review of Maritime Transport 2016. Retrieved from http://unctad.org/rmthttp://unctad.org/transportnews

106. **UNEP.** (2012). Green Economy in a Blue World SYNTHESIS REPORT. Retrieved from www.grida.no

107. **van der Meer, J.** (2016). Coastal flooding. Flood Risk Management: Research and Practice, 3–10. https://doi.org/10.1201/9780203883020.ch1

108. **Vousdoukas, M. I., Mentaschi, L., Voukouvalas, E., Verlaan, M., & Feyen, L.** (2017). Extreme sea levels on the rise along Europe's coasts. Earth's Future, 5(3), 304–323. https://doi.org/10.1002/2016EF000505

109. **WenJun Zhang JianFeng Ou, F. J.** (2011). Global pesticide consumption and pollution: with China as a focus. (F. A. O. of the UN, Ed.). International Academy of Ecology and Environmental Sciences. Retrieved from http://www.iaees.org/publications/journals/piaees/articles/2011-1(2)/Global-pesticide-consumption-pollution.pdf

110. **Wernberg, T., & Straub, S. C.** (2016). Explaining ocean warming: Causes, scale, effects and consequences. Full report. https://doi.org/10.2305/IUCN.CH.2016.08.en

111. **World Bank; United Nations Department of Economic and Social Affairs.** (2017). The Potential of the Blue Economy : Increasing Long-term Benefits of the Sustainable Use of Marine Resources for Small Island Developing States and Coastal Least Developed Countries. World Bank, Washington, DC. © World Bank. https://openknowledge.worldbank.org/handle/10986/26843 License: CC BY 3.0 IGO.

112. **World Bank.** (2018). International tourism, receipts (current USD) | World Bank Data. Retrieved April 11, 2019, from https://data.worldbank.org/indicator/ST.INT.RCPT.CD

113. **World Bank.** (2017). The Sunken Billions Revisited - Progress and Challenges in Global Marine Fisheries. Washington, DC. https://doi.org/doi:10.1596/978-1-4648-0919-4

114. **World Bank Group.** (2017). The Potential of the Blue Economy: Increasing Long-term Benefits of the Sustainable Use of Marine Resources for Small Island Developing States and Coastal Least Developed Countries. Washington DC. Retrieved from https://openknowledge.worldbank.org/bitstream/handle/10986/26843/115545.pdf?sequence=1&isAllowed=y

115. **World Economic Forum.** (2016). The New Plastics Economy Rethinking the future of plastics. World Economic Forum, (January). https://doi.org/10.1103/Physrevb.74.035409

116. **WWF. (2010).** Baltic Ecoregion Programme - Future Trends in the Baltic Sea. https://www.wwf.se/dokument/future-trends-in-the-baltic-sea-wwf-baltic-ecoregion-programme-2010/

117. **WWF. (2015).** Baltic Ecoregion Programme - All hands on deck: Setting course towards a sustainable blue economy. http://wwf.panda.org/?254101

118. **WWF. (2018).** Pioneering global framework for sustainable ocean finance launched at Our Ocean global summit. https://wwf.panda.org/wwf_news/press_releases/?337412%2FPioneering-global-framework-for-sustainable-ocean-finance-launched-at-Our-Ocean-global-summit.

119. **WWF France, AXA Group. (2019).** Into The Wild: Integrating nature into investment strategies. WWF France and AXA recommendations for the members of the G7 Environment meeting in Metz, 5-6 May 2019. https://wwf.panda.org/our_work/finance/?346755/Into-the-Wild-integrating-nature-into-investment-strategies

120. **Zaman, K., Khan, M. M., Ahmad, M., & Rustam, R.** (2012). The relationship between agricultural technology and energy demand in Pakistan. Energy Policy, 44, 268–279. https://doi.org/https://doi.org/10.1016/j.enpol.2012.01.050

APPENDIX

Definition List

100-year events: The storm level that is expected to be exceeded on average only once every 100 years. It is important to note that this is a statistical average, and exceedance events may actually occur more frequently within a specified period.

Blim: Stock size below which the stock is in serious danger of collapse due to reduced recruitment

Blue Economy: All of the sources of financial and non-financial value that humanity derives from marine environments- it includes all economic activities related to oceans, seas and coasts.

Bycatch: An organism that is caught in addition to the target fish. Some by-catches are marketable but most are discarded.

Depreciation: Normal rate of value loss over time due to actual wear from use or for accounting purposes.

Dividends: The share of profits paid to shareholders by a corporation.

Equity: Value of ownership in assets, minus liabilities.

Eutrophication: The excessive enrichment of surface waters with nutrients. While eutrophication can occur naturally, it is normally associated with anthropogenic sources of nutrients, such as fertilizer runoff from agricultural land.

Extreme Sea Level Event: Rare and extreme events of flooding and damages for example from storms. Typically floods and damages from so-called 100-year or 1000-year events are called Extreme Sea Level events.

Feedback loops: Feedback loops are interactions between two or more elements that either produce an amplifying effect (positive feedback loop) or inhibiting effect (balancing feedback loop).

Fishery collapse: Fisheries “collapse” when the economically valuable species in a fishery can no longer be extracted economically, for example because the population is too low to be fished economically.

Fish Landing: Fish landings are defined as the catches of marine fish landed in foreign or domestic ports.

GICs: Global standard classification system for business activities.

Habitat degradation: Habitat degradation means changes (generally anthropogenic) that make a habitat unsuitable or inhospitable for certain species to continue to thrive in.

Holdings: The items in a financial institution’s investment portfolio, such as stocks and bonds.

Integrated Assessment Models (IAMs): Models that integrate socio-economic and environmental factors into a holistic framework to help us understand how human development and societal choices affect each other and the natural world.

Marine: Of or relating to the sea.

Maritime: Connected with the sea, especially in relation to seaborne trade or naval matters.

Multilateral development banks: International banks with the goal of encouraging development, rather than maximizing profits.

NACE: European standard classification system for business activities.

Parameter: Numerical or other measurable factor forming one of a set that defines a system or sets the conditions of its operation.

Recruitment rate: The amount of fish added to the Spawning Stock Biomass each year due to growth and/or migration into the fishing area. For example, the number of fish that grow to become vulnerable to the fishing gear in one year would be the recruitment to the fishable stock that year. This term mostly used in referring to the number of fish from a year class reaching a certain age.

Regime shift: Large, abrupt, persistent changes in the structure and function of an ecological system.

Replacement rate: Used interchangeably with Recruitment rate.

Spawning habitat: Area where eggs are deposited and fertilized, and where at least some juvenile development occurs.

Spawning stock biomass (SSB): Total weight of all sexually mature fish in the stock.

Stranded assets: Assets on corporate balance sheets that rapidly lose their value as a result of forced write-offs.

Systems model: A precise representation of a system’s dynamics used to answer questions via analysis and simulation. The model is often a mathematical representation of a physical, biological or information system.

Tangible assets: Tangible assets are physical and measurable assets that are used in a company’s operations. Assets like property, plant, and equipment, are tangible assets.

Thermohaline circulation: The movement of ocean currents due to differences in temperature and salinity in different regions of water. Temperature and salinity change the density of water, resulting in the water moving accordingly.

Tipping points: The point at which a series of changes or incidents in a system becomes significant enough to cause a larger, more important systemic change.

Trawling: The method of fishing that involves pulling a fishing net through the water behind one or more boats. The net that is used for trawling is called a trawl.

Abbreviation List

BAU: Business as Usual

BE: Blue Economy

GDP: Gross Domestic Product

ESL: Extreme Sea Level

FIs: Financial Institutions

SMEs: Small and Medium Enterprises

SSB: Spawning Stock Biomass

VaR: Value at Risk

List of NACE Codes

We have used the NACE code classification by the DG Maritime Affairs and Fisheries of the European Union, from 'The 2018 Annual Economic Report on the EU Blue Economy'. For more information, and allocation principles for specific NACE sectors, please refer to the source.

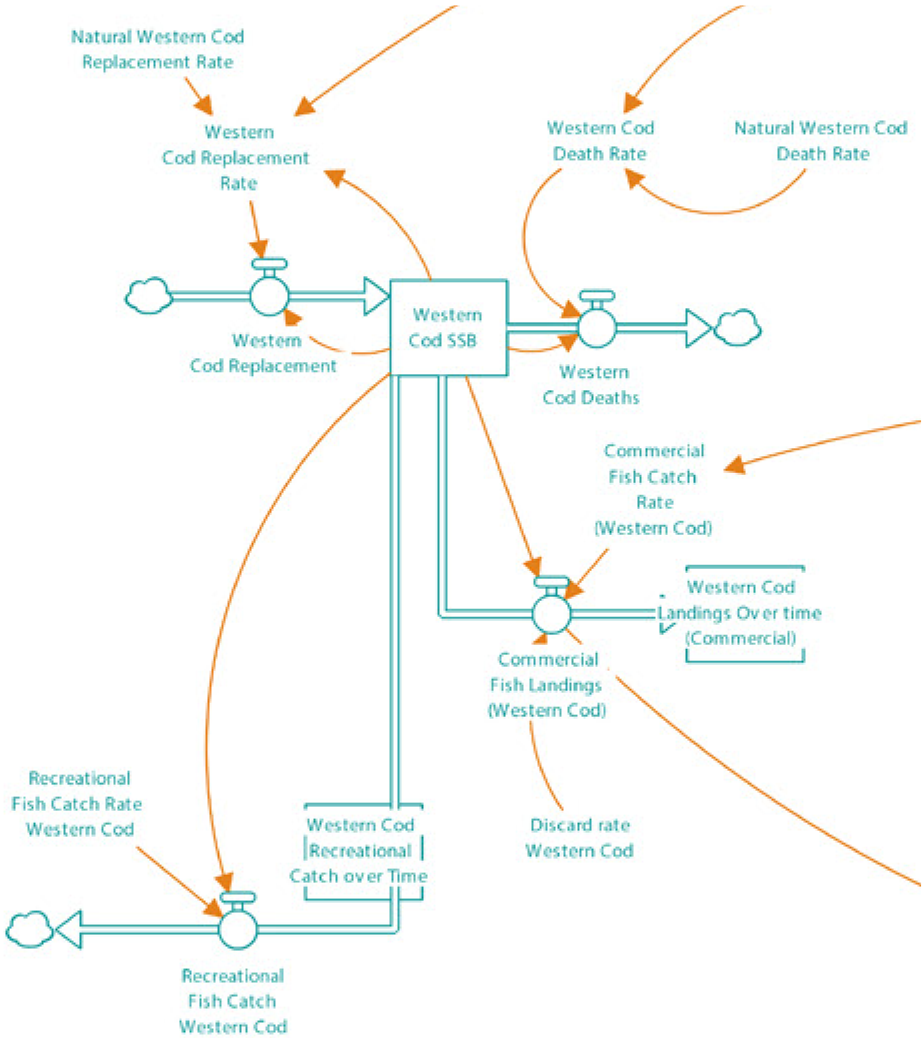
1. **Extraction of Marine Living Resources**
    a. 10.20 Processing and preserving fish, crustaceans and molluscs
    b. 46.38 Wholesale of other food, including fish, crustaceans and molluscs
    c. 47.23 Retail sale of fish, crustaceans and molluscs in specialised stores
2. **Offshore and Oil and Natural Gas**
    a. 06.10 Extraction of crude petroleum
    b. 06.20 Extraction of natural gas
    c. 09.10 Support activities for petroleum and natural gas extraction
3. **Ports, Warehousing, and Construction of Water Projects**
    a. 52.10 Warehousing and storage
    b. 52.22 Service activities incidental to water transportation
    c. 42.91 Construction of water projects
4. **Shipbuilding and Repair**
    a. 30.11 Building of ships and floating structures
    b. 30.12 Building of pleasure and sporting boats
    c. 33.15 Repair and maintenance of ships and boats
5. **Maritime Transport**
    a. 50.10 Sea and coastal passenger water transport
    b. 50.20 Sea and coastal freight water transport
    c. 50.40 Inland freight water transport
    d. 77.34 Renting and leasing of water transport equipment
6. **Coastal Tourism**
    a. 55.10 Hotels and similar accommodation
    b. 55.20 Holiday and other short-stay accommodation
    c. 55.30 Camping grounds, recreational vehicle parks and trailer parks
    d. 55.90 Other accommodation
    e. 47.30 Retail sale of automotive fuel in specialised stores
    f. 49.10 Passenger rail transport, interurban
    g. 49.30 Urban and suburban passenger land transport
    h. 50.10 Sea and coastal passenger water transport
    i. 51.10 Passenger air transport
    j. 47.6 Retail sale of cultural and recreational goods in specialised stores
    k. 47.7 Retail sale of fother goods in specialised stores
    l. I56 Food and beverage service activities

Though not listed in the above report, we have added financial institutions such as banks and insurance companies to the list of sectors that make up and are affected by the Blue Economy. The corresponding NACE codes are:

7. **Financial Institutions**
    a. 64.1 - Monetary intermediation
    b. 64.9 - Other financial service activities, except insurance and pension funding
    c. 65.1 - Insurance

Systems Modeling

We use Stella Architect to build systems models. How this looks and functions is explained briefly here. The following screenshot shows part of our fisheries systems model for illustration:



In the systems models, there are three types of elements:

- **Stocks -** Stocks of materials, populations, revenues over time, etc. These are depicted in the model as boxes. When the model is run over a number of iterations (usually years), data is output for the size of the stock in each year. The size of the stock at year 0 is put into the model as a starting point and over time it decreases or increases based on the size of inflow and outflow.
- **Flows -** Flows are shown as arrows or lines, which generally flow into or out of a stock. These can represent things like deaths or births of a population, growth or loss of value over time, building or decommissioning equipment, etc. When the model is run, the size of the inflow or outflow in a given year is output in data. While parameter values can be hardcoded in flows, generally flows are represented by equations with the values of converters as inputs to the equation.
- **Converters -** Converters are parameters or equations that affect flows directly or alter other parameters. These are shown in the model as text with no icon or box.

Example: Your stock might be a population, with an outflow that represents deaths. A converter could be "Mortality rate", and the outflow (deaths) would be the population multiplied by the mortality rate. The mortality rate could in turn be affected by other converters or parameters such as "Natural mortality rate", "Fatal accident rate", etc. Then the converter for "Mortality rate" would be an equation adding the natural mortality rate and fatal accident mortality rate to get the total mortality rate.

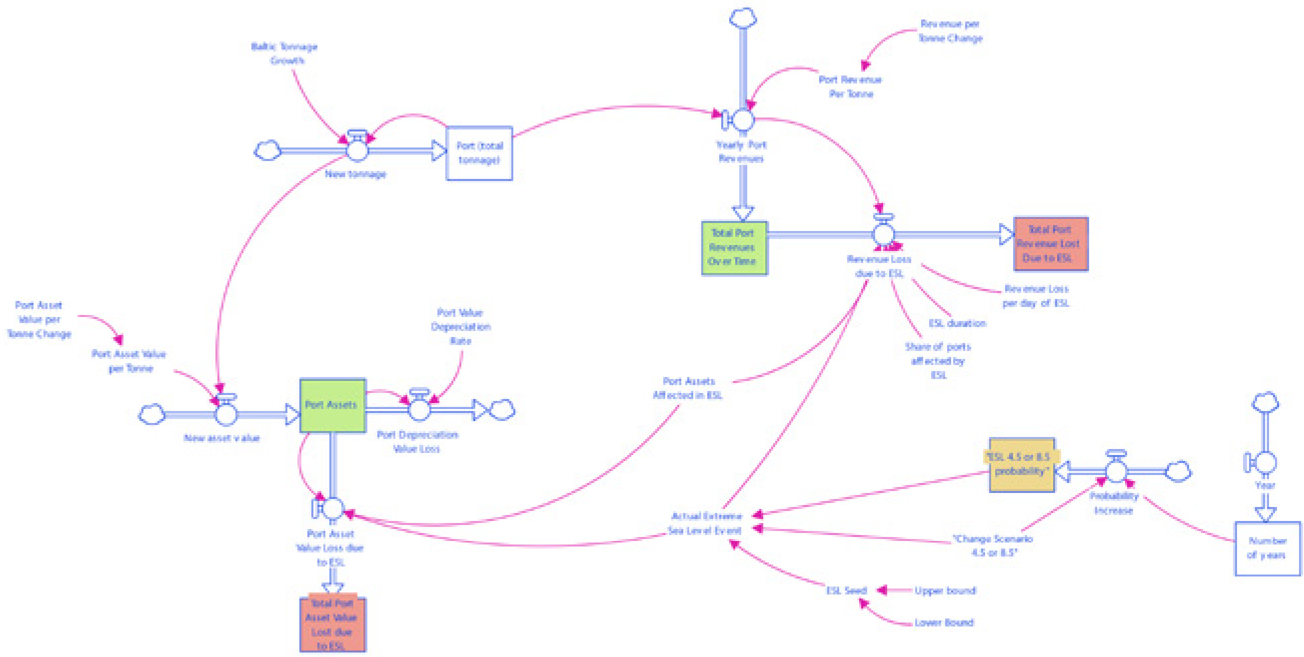
Model Development

In an initial phase of this project, we did a high-level system mapping exercise in conjunction with a literature review of any literature describing risks to the Blue Economy. Any descriptions of causal relationships between elements were stored **in a spreadsheet**, which is **visualized online in Kumu**. Once we had selected case studies to test, this high-level overview was used to check all of the related factors and incorporate as many of the key drivers as possible into the final systems model.

The systems models were built using Stella Architect (one of the most widely-applied systems modeling software programs). The full list of parameters, values, calculations, and references for the model **is provided online** for review or replication.

During the course of the model development, we limited model components primarily to parameters we could find reliable data for. For core elements for which data does not exist (e.g. the implications of future fisheries incentives), we applied a dummy variable to explore the sensitivity and overall implications of a range of values. There are remaining gaps in other critical areas, for example the impact of seafloor disturbance on species, due to a lack of data. These are further described in this appendix.

Baltic Port Assets and Revenues at Risks



Description

The Baltic ports are represented by the total tonnage (throughput of goods in tons) they managed yearly in the Baltic Sea. In 2016, there were 870 Mt of goods moved through the Baltic ports. The growth in terms of tonnage is based on several projections for the freight industry in the Baltic region.

In the system, the (tangible fixed) assets of the ports are associated with the total tonnage managed by these ports. We use the average assets owned by eight Baltic ports (Tallinn, Riga, Helsinki, Malmo, Aarhus, Gdansk, Rostock, Stockholm) located in every Baltic country (except Russia, due to lack of data) and the amounts of tonnage managed by these ports, to infer the average asset value per ton of throughput. Therefore, as tonnage increases due to the economic growth of the freight sector, the amounts of assets (e.g., equipment, infrastructure) and their value increases. In the model, the relationship is linear but it could be made more complex with more research, although data on port assets is limited.

We performed a similar approach for the relationship between tonnage and revenues. We looked at the yearly revenues of these same ports and their tonnage and infer an average value of revenue per ton of goods managed by a port.

Over time the assets and revenues of the Baltic ports increases due to the ongoing growth of the industry.

Baltic ports are susceptible to 100-year Extreme Sea Level (ESL) events that may cause destruction of port infrastructure (and therefore assets) and loss of revenues due to disturbance of port activities (e.g., temporal closure, slower traffic). Due to climate change and other environmental factors related to sea-level change, the current (2016) 100-year event is projected to become more likely in the future. This model represents the impacts from these ESL events on the Baltic ports.

Two climate-change scenarios are modeled - the IPCC RCP4.5 & RCP8.5 scenarios. Under the 4.5 scenario, a 100-year event will occur every 19 years in 2050 and every 4.2 years in 2100 (Vousdoukas et al. 2017). Note that the growth in the likelihood of the event over this century is not linear but closely matches an exponential curve. Therefore, as the model runs, the likelihood of an ESL event rises exponentially. For the 8.5 scenario, a 100-year event will occur every 16.6 years in 2050 and every 0.8 year in 2100. Note that the growth in the likelihood of the event over this century is not linear but for practical reasons, linear from 2016 to 2050 and linear (small change in rate) from 2050 till 2100.

Each time an ESL event occurs, it triggers a loss of assets value (based on a European value for all ports hit by a 100 years event/divided by number of ports for the EU) and the revenues lost due to the events. About 9% of revenues are lost per day for an event of the magnitude of a 100-year ESL, and the event disturbs the ports for a maximum of seven days (Cao & Lam, 2019).

The stocks are lost assets and lost revenues, which represent the accumulated losses from 2016 to 2100.

Further Analytical Comments

Depending on the scenario (4.5 or 8.5), the loss of tangible assets varies substantially, showing that if we continue on the worst climatic path (8.5), we will eventually face much larger risks (in terms of frequency) of economic losses for the Baltic ports.

For example: when the tonnage growth was set at 1.4% - the assets lost for 4.5 was around 4-5B€ over 84 years while under the scenario 8.5, it led to around 30B€ in lost assets.

In terms of Value at Risk, the direct revenue lost due to ESL may not seem significant. When dealing with billions in revenue, the loss of ”only” millions of revenues due to these events makes it hardly visible on a graph. Yet, over 84 years, it does amount to quite a substantial amount of money (in the hundreds of millions, relative to the billions in aggregated revenues over the period of the model).

The freight Baltic ports’ tangible assets at risk of ESL event are quite important. When running the model hundreds of times, a loss of around 5% of the accumulated asset value under scenario 8.5 was frequently observed. In this case, 30B€ were lost when the assets amounted to 700B€. To put it into perspective, an international port cost around 4B€ for its construction (Christodolou et al. 2018). Therefore the total assets loss may amount to the money spent to build 7.5 international ports.

Indications for running different climate scenarios in the Stella Port model

In the Converter “Change Scenario 4.5 or 8.5”, the value of the converter can be changed to 0 for no climate event, leading to a perfect BAU scenario with no chance of asset and revenue loss. If the converter’s value is set to 1, the ESL scenario 4.5 (and the associated event probability) will be the one used by the model. If the converter’s value is set to 2, the ESL scenario 8.5 (and the associated event probability) will be the one used by the model. The 8.5 scenario is worse than the 4.5 in terms of ESL likelihood.

To run all scenarios, a sensitivity analysis can be set to test the values for the converter “Change Scenario 4.5 or 8.5”. The model can be run a 100 times or 1000 times. In practice, the software will run the model for scenario BAU, then scenario 4.5, then scenario 8.5, and therefore if the sensitivity analysis is run 100 times, each scenario will have run 33 times or so.

Mitigation and Adaptation Measures

The revenues and assets of the Baltic ports would also be impacted by the investment required for the implementation of climate adaptation and mitigation measures. For example, a sea wall costs about 3-4 million€ per km and dyke 1-4 million€ per km (Christodoulou et al. 2018). Therefore, the value at risk may be larger for Baltic ports, although some mitigation and adaptation investments may arguably reduce the likelihood of the loss of revenues and assets from an ESL event. While information on the costs of climate adaptation measures is available, we could not find quantitative information on how investment was associated with a decrease of damage, so this is excluded from the current iteration of the model.

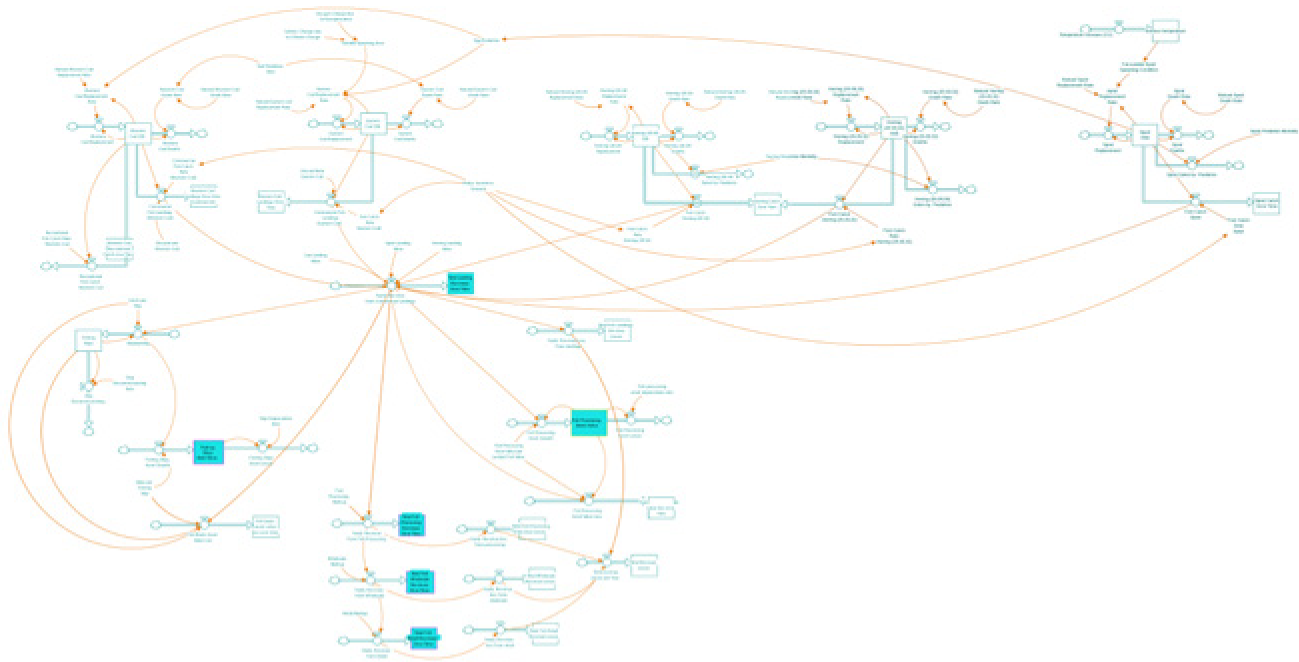
Adding Other Drivers

In addition to the effect of climate adaptation investments and changing value of port assets per ton of goods transported, the model could add several other drivers, such as inflation, projected economic growth for the region, projected regulation of sulphur emission reduction targets. However, the interactions between these different drivers would add complexity leading to higher uncertainties in the results of the model. The addition of other drivers would require careful research but may make the model overall more robust.

This model also does not consider 1000-year events (equivalent to a hurricane like Katrina) - the projected costs would be much (much) higher and the likelihood of occurring is also increasing. Under the 4.5 scenario, present-day 1000-year events will occur every 132 years by 2050, and every 23 years by 2100. Under the 8.5 scenario, an event of this magnitude may occur every 97 years by 2050 and every 4.1 years by 2100 (Vousdoukas et al. 2017).

The impacts of a 1000-year event are hard to forecast due to limited data on the subject and the many uncertainties surrounding these events.

Basic Fish Population and Fishing



Description

For fisheries, we set up a model of the three main fished species in the Baltic Sea: cod, sprat, and herring, which account for around 90% of all of the fish catch in the Baltic Sea (HELCOM, 2019). Since the cod and herring have distinct populations within the Baltic Sea, our model has five different population subsets for Western cod, Eastern cod, herring in subsectors 20-24, herring in subsectors 25-29 & 32, and sprat.

Extensive data is available from ICES on fish populations for the spawning stock biomass (SSB) by year, along with data on catch for each of the fish stocks. There are either two or three flows out of the current SSB, one for the natural fish mortality, one that represents the fishing effort, and one that represents the predation mortality (for the Herring and Sprat stocks). The predation mortality for the two cod populations was integrated to the natural mortality due to data. The predation mortality (about 4.2%) for cod is mainly driven by the seal population (ICES, 2009; Mackenzie et al., 2011)

We start off with the current fishing effort. This is one of the key parameters of the model that can be adjusted to test out different scenarios. The fishing effort, that is, the percent share of a fish population SSB that is caught by fishing ships in one year. The fishing effort for the five Baltic fish populations modelled were based on the average ICES catch data available for the last decade (2008-2018).

To add more dynamism and realism, the change in the fishing effort over time was added to the model. The fishing effort for every fishery was adjusted as a function of the SSB of the fishery concerned and its B-lim. B-lim is a reference point for SSB size. When the SSB is below the

B-lim, there is a high risk of reduced recruitment for this stock (ICES, 2018). In our model, when this occurs, the fishing effort is halved until the population recovers above B-lim. The halving in the fishing effort is a basic feedback that illustrates the limits imposed on fishing efforts due to both fishing effort restrictions (quotas for the fishery's conservation), and due to the increasing fishing difficulty (both economically and physically) with a low-density fish stock. If the given fishery's SSB falls under half of its B-lim, the fishing effort will fall to 0, reflecting a closure of the fishery and the uneconomical nature of the fishing activities for this given fishery. The fishing effort resumes at half of the 10-year average fishing effort when the SSB exceeds half of the B-lim, and completely if the fishery's SSB recovers above B-lim.

Regarding the fishing effort, the ICES accounts for the by-catch of a specific species in the total catch count of this species. For example, herring are often caught as bycatch in sprat fisheries (ICES, 2019). The amount of herring caught in the sprat fisheries is added to the total herring catch for the year. Sprat are also frequently a by-catch of herring fisheries, and therefore these by-catch are accounted for in the sprat fisheries total catch. According to the ICES, there is no bycatch between sprat and herring and cod fisheries, that is, no herring or sprat are caught in cod fisheries and vice-versa. In the model, the bycatch are not explicitly represented as they are included in the data behind the fishing effort rate.

For flows into the SSB, we calculated the SSB replacement rate as a function of the current population using historical data compiled by ICES. When the population size gets down below a certain threshold (B-lim), then the replacement rate is reduced to 75% of its current value. The replacement (also called recruitment) rate may vary yearly due to complex environmental factors, coupled with the fishing efforts. By using historical data over the last decade, it ensures that these variations are taken into account in the model.

Other Drivers of the Baltic Fish Population

Beyond the basic population model parameters, we have included a number of other parameters which represent other drivers of either the replacement rate or the mortality rate. These include salinity, oxygen, temperature change, predation, as well as cod egg predation.

The overall salinity of the Baltic Sea is decreasing, although it is occurring at different rates in different regions of the sea. Climate change is the main driver of this decrease; it increases runoff of freshwater in the Baltic Sea due to increased precipitation in the region, rising temperature, and changes in thermohaline circulation, which reduces the inflow of saline water in the Baltic Sea (Andersen et al., 2015). The Baltic Sea's salinity is estimated to decrease from 8 Practical Salinity Unit (psu) to 6 psu over the 21st century (Meier et al., 2012).

There is also a net decrease in oxygen content in the Gotland Basin, Northern Baltic Proper, and Gdansk Basin (Hansson et al., 2011). Eutrophication, which is driven by regional agricultural activities, is the main contributor to this decrease. The oxygen content of these regions has also to do with complex annual water movements that are difficult to forecast.

Eastern Cod Spawning areas have decreased drastically due to these two drivers over the last five decades. Due to the high degradation of their spawning areas, the spawning effort of the Eastern Cod has decreased between 30 to 50% since 1970. From the three original spawning areas: Eastern Gotland Basin, Gdansk Basin, and Bornholm Basin, only the latter remains a productive spawning area. In the model, we used the rate of spawning area decreased over the last decades (1.24% annual decrease) as a proxy of the recruitment rate for this fish stock (Helcom, 2013). This decreasing rate is driven by complex interrelated factors, such as the ones described above. We have decided to include only the salinity and the oxygen change for simplicity and as they are the main drivers, and share equally their contribution to the spawning area decrease.

The Western cod population has been stable over the last decade, although at a low population density.

Predation on herring (20-24; 25-29) and sprat stocks has been integrated into the model as outflows from their respective SSBs. The predation rates for these three stocks were based on a 10-year average (1994-2004) reported by ICES (2005). The herring and sprat populations are consumed by cod but also other predators, such as seals and sea birds (ICES, 1994; Horbowy, 2005). The literature suggests that there seems to be little effect on change in biomass of herring and sprat stocks on cod SSB, hence no direct predator-prey relationship has been directly added between sprat and herring stocks and the two cod populations (Horbowy, 1989). Except in its first year (not part of the SSB), cod's main predators are seals (Mackenzie et al, 2011; ICES, 2009). Seal predation is integrated in the natural mortality flows of the two cod SSBs, as the seal predation is often included directly in the natural mortality of cod stocks (ICES, 2009).

The rise of the sprat population led to an increase in predation of this species on cod eggs. It is difficult to quantify a change in cod egg mortality due to the sprat population growth (Köster et al., 2003). The model includes this relationship, although due to lack of data, the impact of this relationship on the cod population dynamics was purposely limited. Herring populations have also been praying on cod eggs, especially when the cod populations lays the majority of their eggs in the spring. A relationship therefore may exist between herring and cod recruitment rate although too little data is available to quantify it.

Sprat spawning efforts are positively affected by rising temperature (Lindegren et al., 2009). In the model, the rise of Baltic Sea Surface Temperature (SST) by an average of 0.7 C is coupled to the increase of the recruitment effort of the sprat (MacKenzie et al. 2004). Overall, there is a global regime shift from cod to sprat-dominated ecosystem.

Despite the Eastern cod population being negatively affected by eutrophication, there is no clear relationship between the sprat and herring population health and the surplus of nutrients in the Baltic.

There are other key drivers we wanted to include, but we were unable to find quantitative data for. This includes:

- Damages to habitats and food supply from fishing methods such as trawling - according to ICES (2019), there is no quantitative information available on this.
- More complex interactions between these three fish species and other marine populations (e.g, other predators and prey), beyond what was included.
- Impacts of habitat degradation on spawning of sprat and herring.
- Information on the discrepancy between reported and actual bycatch figures.

These can be added into the model in a qualitative way to explore the dynamics, but for now they are currently excluded.

Revenues from Fish Value Chain

The total value of landed fish is calculated based on the rates (in €/ton) for cod, sprat, and herring and the amounts of fish that are landing yearly after discounting discards from the total catch. To simplify revenues from other parts of the supply chain, we applied a markup for each step in the chain.The value of the landed fish (cod, sprat, and herring) are based on national data collected by FAO (2018). The markups are also based on a FAO analysis (2006) of the distribution of revenues of several fishery value chains.

In the model, the amount of revenue loss due to a potential reduction in total fish landings are calculated based on the total landing value of cod, sprat, and herring in 2018 (about 167M€). The total yearly revenue from landing, processing, wholesale, and retail is calculated and subtracted from the revenue of each sector of the value chain in 2018 to obtain the yearly revenue loss relative to the reference year of 2018. The total revenue losses over the entire simulation (15 years) are computed in the system. The value at risk can therefore also be represented over the simulated period in terms of direct revenue lost from failing fisheries.

Fisheries-related Asset Value

Data is available for fishing boats and assets in the fish processing sector by country, but only a small share of this is related to cod, sprat, and herring fished in the Baltic Sea. Therefore, the share of these total assets is allocated in the model based on the catch of these fisheries over the total fish caught and processed by these assets. If the volume of fish increases, the total asset value also grows in proportion to this. When the volume of fish decreases below the amounts that can be fished or processed using the existing assets and the assets are used at under-capacity, these assets cease to grow and instead slowly decrease over time through depreciation. The share of the total capacity of the assets that go unused due to a decrease in fish landed represent a stranded asset for the fishing and processing industries and result in asset value losses. The depreciation and decommissioning rates (for the ships) constantly accrue regardless of use of the assets.

Policy Scenarios

One additional element we have included in the model is a policy incentive scenario variable. This is a dummy variable that increases or decreases the fishing effort to account for the potential impact of policies that either provide subsidies to fishing equipment or provide incentives to avoid fishing. This dummy variable allows us to explore the range of model outcomes (e.g, growth or decrease in a fishery stock, revenue generation and asset growth) that could be possible if the fishing effort is altered through policy incentive measures.

COLOPHON

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