A Methodology for analysing the impacts of climate change on maritime security

Author information

James Brennan

Department of Politics, Philosophy and Religion, Lancaster University, LA14YL, UK
j.brennan2@lancaster.ac.uk
0000-0003-3458-5214

Basil Germond,

Department of Politics, Philosophy and Religion, Lancaster University, LA14YL, UK
b.germond@lancaster.ac.uk
0000-0002-3895-450X

Author contributions

James Brennan conceived of the study and its design. Material preparation, data collection and analysis were performed by James Brennan. The first draft of the manuscript was written by James Brennan. James Brennan and Basil Germond commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Abstract

This paper presents a methodology for developing a social Cumulative Effects Assessment (CEA) which analyses the impacts of climate change on maritime crime and maritime insecurities. The use of a CEA methodology, including the use of the Effects to Impact Pathway will enable mapping the relationships between certain 'Activities' (e.g. human induced emissions of greenhouse gasses), the 'Pressure' engendered (e.g. warming sea temperatures) and their 'Impacts' (e.g. food shortages) via 'Receptors' (e.g. fishing communities) on specific sectors of society (in this case maritime migration and maritime crime, e.g. illegal fishing). This paper provides a Proof of Concept (PoC) for using such a methodology and shows the applicability of a multidisciplinary approach in understanding causal chains. In this PoC the authors are generating a Non-Geographic Assessment Map that investigates the 'Impacts' that the human induced greenhouse gas emissions have on maritime security. The proposed analytical tool can then be applied in further studies to assess the dependencies and synergies between climate change and the occurrence of maritime insecurity.

Keywords

Cumulative Effects Assessment; Effects to Impacts Pathways; Climate change; Maritime migration; Maritime security; Maritime Crime.

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Consent for publication

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Competing Interests

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1. Introduction: linking climate change and maritime (in)security

Climate change is a unique and novel problem with no precedent. While some of the effects of climate change are currently being felt, most will occur in the future. This makes researching, and predicting, the full scope and impact of these effects difficult. The uniqueness and difficulty of analysing the issue of climate change is compounded especially when looking at its impact on international relations, geopolitics, and security. In these areas of study, assessing and quantifying future impacts becomes harder, as most future predictions about the geopolitical context are speculative, and most analysis of geopolitics happens in real time, in conjunction with the issue or event that is being analysed (Busby, 2008).

A security issue in the area of international relations is something that concerns survival, in other words it is an issue that represents an existential threat to the subject that is under analysis, which within international relations is usually, but not always, the state (Buzan et al., 1998). The nature of security issues then justifies using 'exceptional' measures that are comparable to an existential level threat, traditionally this has implied the use of armed forces (Buzan et al., 1998). Climate Change, in security literature is generally viewed as a 'threat multiplier' as it impacts simultaneously and in conjunction with multiple areas of insecurity and issues of existentialism (Thomas, 2017). Although the effects of climate change are often felt at the level of individuals and societies in extreme cases, especially where governance is already weak or when lacking responsive capacity, it could lead to state failure where the state is unable to function adequately to provide security and safety (Scheffran & Battaglini, 2011).

We are already seeing extraordinary measures to be used in combating the impacts of climate change, such as in 2007 when the UN Security Council held its first discussion linking insecurity and climate change which has been followed by other such discussions in 2011, 2017, and 2018 (United Nations, 2019). Many states around the world have also taken the extraordinary measure of declaring a state of climate emergency in recent years (Harvey, 2020). These measures help to underscore the increasing attention that climate change is garnering and the drive for a greater analysis into understanding the effects climate change can cause and what future impacts these might have. There are some effects of climate change that are already being observed and have robust predictions for the next century (Busby, 2008). The increased understanding climate scientists are providing, gives an outline of what the future natural environment might look like. This provides policymakers and practitioners with a basis on which they can overlay the geo-strategic trends they are observing.

Understanding the ocean and its systems has also recently increased in significance and importance. This includes understanding the impact of climate change on the ocean and vice-versa, which is being termed as the ocean-climate nexus. The United Nations has acknowledged the significance of better understanding the ocean and has declared the 2020's as the "Decade of Ocean Science for Sustainable Development" (UNESCO). The ocean-climate nexus is of importance because of the interlinked challenges of addressing climate change and protecting the ocean. The nexus is seen through the continued calls to use scientific-based decision-making and the decade of ocean science should see continued efforts and undertakings in scientific research to understand the effects of climate change on the ocean (Dobush et al., 2022) (Germond-Duret et al., 2023) (Minas, 2019).

As well as increasing in scientific importance, the securitisation of ocean-space is increasing in global importance (Otto, 2020). Events such as recent disruptions of sea-based supply chains (e.g. the accident blocking the Suez Canal and the shortage of labour in Chinese ports during the Covid-19 pandemic), the AUKUS agreement, the war in Ukraine, and China's continued assertiveness (which has a strong maritime dimension), further highlight the geopolitical importance of the global maritime domain.

In this context, maritime security is becoming more central to both domestic and international agendas. This can be seen by the proliferation of maritime security strategies in the past decade by states (Brazil, China, Japan, United Kingdom, United States, and New Zealand) and regional institutions (African Union and the European Union) (Otto, 2020). From naval power projection to human security and livelihoods, to protecting the natural environment, to economic development, securing the maritime domain is a key challenge and priority at human, societal, national and international levels. In other words, over the past decade, maritime security has become increasingly important and an area of priority for international policymakers (Bueger et al., 2020).

Maritime security is a 'umbrella term' or 'buzzword' that defines what is currently fashionable to focus on in the maritime domain (Bueger, 2015). Maritime security can also be seen as a way of referring to "the security of the maritime domain" (Germond, 2015), linking a number of interconnected themes that are present within the maritime domain such as natural environments or ecosystems, issues such as piracy, illegal fishing, terrorism, or marine pollution, and also the projection of power by states (Bueger et al., 2019). It is important to acknowledge that maritime security means different things to different actors (Siebels, 2019). In this article, the findings are meant to be high-level enough that they can be tailored to specific actors' needs. This should help to ensure findings are useful for a broad range of maritime security actors, as they look to understand the impacts of climate change on the sectors of maritime security.

For this study, we use four sectors of maritime security, combining the four core dimensions of maritime security outlined by Bueger in 2015, which are National Security, Marine Environment, Economic Development, and Human Security (Bueger, 2015) and the security dimensions outlined by Buzan, which are military, political, societal, economic and environmental (Buzan, 1998) (see methodology section below for an explanation of how these four sectors will be tagged against the effects of climate change – as will be seen in the analysis, not all these sectors are independent of each other and some of the issues listed will require responses from multiple sectors of maritime security):

1. **National Security** – This relates to issues that are best delt with at the level of the state. Such issues include the projection of power, the organisation of navies, the defence of territory (both terrestrial and maritime), geopolitical rivalries, interactions with international institutions, and the making of international rules. There are ways in which climate change will impact on this, such as warming seas affecting the efficiency and operability of warships as well as the deployment of personnel (NATO, 2023). Climate change also poses an existential threat to low-lying small island states which could cease to exist with large enough sea-level rise (van Schaik et al., 2018).
2. **Environmental Security** – This relates to issues of environmental degradation, ocean health and marine pollution. Climate change will exacerbate environmental issues within a marine area through the degradation of underwater ecosystems such as coral reefs, it could lead to the migration of fish and increase harmful agal blooms (IPCC, 2019b). As marine ecosystems are vital to human societies providing an array of benefits, understanding the impact of climate change on these ecosystems is important to understanding how these ecosystems will continue to provide these benefits (Wernberg et al., 2023), such as tourism which is a major source of income for some Small Island Developing States and for others it is seen as a route to greater better living standards and economic growth so understanding how the natural environment will be impacted by climate change and the effects this will have on tourism (Pedapalli et al., 2022).
3. **Economic Security** - This relates to sea lanes of communication, global supply chains, maritime resources such as fisheries, aquaculture, energy, and marine tourism (Stone, 2009). Climate change will impact this maritime security sector via fish migration/distribution of fish stock. Increased wave hights and extreme weather events could make sea lanes of communication and global supply chains more vulnerable to disruption, and maritime tourism could take a hit as climate change increases environmental degradation. With 80 percent of the world's petroleum transiting through choke points in or around the Indo-Pacific, the Bab al-Mandab Strait, the Strait of Hormuz, and the Strait of Malacca (Stable Seas, 2021), understanding how climate change impacts on destabilising issues such as armed groups working as pirates or terrorists is crucial.
4. **Human Security** – This relates to issues which cause insecurity for communities and individuals (Stone, 2009). Climate change can impact human security directly through the impacts of extreme weather events, or indirectly through impacts on coastal agriculture and change in the distribution of fish stocks. With Asia and Oceania consuming the highest (24.6 kg) and second highest (23.2 kg) amount of aquatic food per capita, per year (FAO, 2022), the impact of climate change on aquatic and coastal food production and security needs to be understood as best as possible.

Against this backdrop there is still a lack of coherent narrative and analysis that links the effects of climate change to their impacts on maritime security (Germond & Mazaris, 2019). Scheffran and Battaglini have described how the effects of climate change can trigger "a cycle of environmental degradation, economic decline, social unrest and political instability" and how these will have flow on effects that impact global security as they "destabilize regions and expand the geographical extent of crisis, overstretching global and regional governance structures" (Scheffran & Battaglini, 2011). Germond and Mazaris have described how climate change effects natural systems (such as warming sea temperatures causing changes in fish stocks distribution) then impact on human systems (e.g., food insecurity and poverty), which can in turn incentivize maritime crime (such as illegal fishing or piracy), thus contributing to a cycle of insecurity at, or from, the sea (Germond and Mazaris, 2019). As the findings from this study will show, the sectors of maritime security most impacted by the effects of climate change are indeed human security and economic security that are negatively impacted through effects on coastal agriculture, human health, fisheries, and climate-induced mobility.

This highlights that the links and dependencies between climate change and maritime security are multifaceted and impact on societies, especially on vulnerable populations. Therefore, an innovative framework for analysis is needed to assess these links and dependencies; a tool that has proved its validity in related ontological contexts (Mazaris & Germond, 2018).

Thus, this article provides such an assessment tool mapping the whole effect to impact chain, from climate change effects on the ocean to the occurrence of maritime insecurities. This article proposes to base this framework on the underlying methodology of Cumulative Effect Assessments (CEAs). Although CEAs have mainly been applied to assess human impacts on ecosystems, it is possible to apply similar methods to study the links between climate change and maritime security. To do so, the authors suggest using an Effect to Impact Pathway (EIP) methodology, as developed by Judd et al. (2015), to adapt the CEA methodology for analysing natural impacts on social systems.

This article then goes on to undertake a Proof-of-Concept (PoC) to demonstrate the functionality of using CEA and EIP methodologies to assess the dependencies and synergies between climate change and the occurrence of maritime insecurity. This PoC will be created using high quality and robust scientific data from an Intergovernmental Panel on Climate Change (IPCC) report. It will generate a Non-Geographic Assessment Map (NGAM) made up of Effect to Impact Pathways (EIPs), that comprehensively investigates the impacts that human induced greenhouse gas emissions have on maritime security. While these findings make for a good starting point for discussions on policy interventions, as will be discussed later, this pilot study is binary in terms of analysis for it is primarily focused on identifying if an impact is present or not. And while we comment on the frequency of impacts found, this does not necessarily translate equally into the intensity of the threat or harm that might be caused by an impact.

2. Analytical Framework and Methodology

Some scientific reports have aimed to understand and outline the natural science behind the issue, such as the reports from the IPCC. Other reports that have tried to link the effects of climate change and their impacts on security have been mainly qualitative, high-level, and in some instances these reports end up focusing on issues of sustainability. This PoC aims to deliver a more evidence-based approach linking the scientific data behind the effects of climate change to the physical impacts of climate change and how these pathways contribute to the changing nature of maritime (in)security.

2.1. Cumulative Effect Assessment and its application to societal contexts

Climate change is now acknowledged as a threat with such magnitude that it can impact social stability, drive people and communities towards criminal behaviour and cause events that trigger violent and armed conflict. Climate change, the maritime domain, environments and societies are all linked together through a multitude of complex links and pathways, CEAs allow for the identification of multiple impact pathways that are occurring at the same time and allow for the visual representation of their complexities and interactions which is why CEAs are such a good concept to base a framework on (Mazaris & Germond, 2018).

CEAs are a sub-section of Environmental Impact Assessments (Roudgarmi, 2018), and are a method that assess the links and dependencies between the effects of human activity and the impacts these have on the natural environment (Crain et al., 2008) (Halpern et al., 2008). It is mostly used in marine science to analyse and evaluate expected cumulative causal factors of human activities (Gissi et al., 2020). The underlying concept of CEAs is that the impacts of activities and pressures are not independent of each other but interact with each other in ways which may be additive, multiplicative, synergistic, or mitigative (Judd et al., 2015; Roudgarmi, 2018).

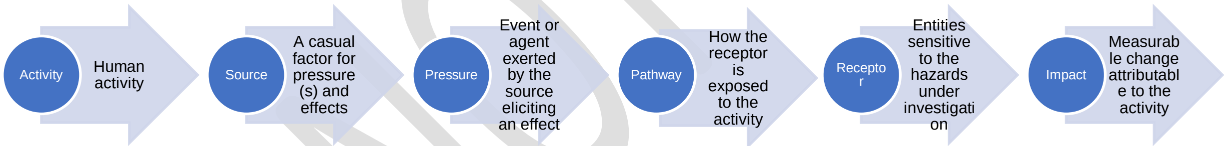
In 2013, Halpern and Fujita gave an overview of how CEAs can be created by understanding an activity and its impacts and generating gridded, geographic maps for each individual activity, which show the intensity of the impact for each pixel/grid (Halpern & Fujita, 2013). These maps are then laid one on top of another and summed to get a total value of the impacts for each pixel/grid (Halpern & Fujita, 2013). Essentially a CEA is the identification and analysis of the total effects of multiple pressures within a certain geographical area and the impacts they cause (Judd et al., 2015).

However, using CEAs as a way of analysing social/societal impacts is rare. Indeed, it is a challenging process because of the complex pathways activities take to impact on societies and individuals, and the difference in interpretation of how different impacts will affect different individuals (Roudgarmi, 2018). However, CEAs as a process for the systematic analysis and evaluation of the impacts of environmental change provide a good assessment basis for the analysis of the impacts caused by climate change on society. This is because CEAs provide an operational framework for mapping activities and sources, and the pressures they create that produce cumulative effects on both natural systems and human systems before they impact on states, sectors of the society, and individuals.

2.2. Effect to Impact Pathway

A way to conduct a societal CEA is to use the EIP method which was initially developed by Judd, Backhaus, and Goodsir (2015) as a way to identify and represent the "Source – Pressure – Pathway – Receptor linkages" (Judd et al., 2015). The authors have visualised the EIP and the linkages it contains in Figure 1. This shows how to use EIPs as a way of determining the cause, effect, and impact relationship and then how to map EIPs to sectors of society rather than to the natural environment, as CEAs were originally designed to do. Indeed, CEAs can be applied to non-physical locations and can instead create NGAMs for the sectors (or sub-sectors) being studied, in this case maritime security. For example, Loxton, Schirmer and Kanowski (2013) explored how social dimensions are integrated within CEAs, discussing how CEAs are usually bound by a geographical area, but going on to talk about how in their model a 'receiving environment' does not need to be a physical area and arguing it could be a "socially defined system, consisting of multiple nested interacting sub-groups, in which activities, actions and exogenous factors were experienced" (Loxton et al., 2013). They also noted that the experience of one impact tends to exacerbate other impacts, especially around perception of injustice (Loxton et al., 2013). Using this approach, a map can be created by delineating boundaries of the sectors/societies for which the impacts of certain activities are wanting to be understood (in this case maritime security).

Figure 1: A visual representation of Judd, Backhaus, and Goodsir's Effects to Impact pathway

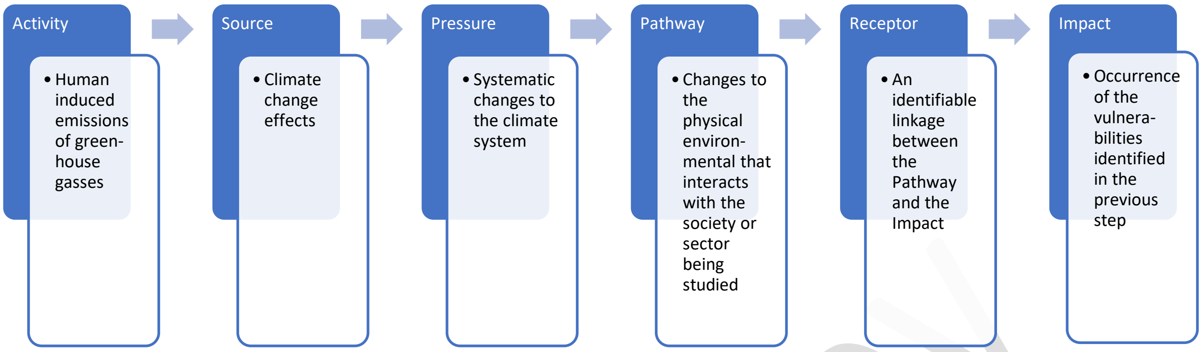


Source: Authors, based on Judd, Backhaus and Goodsir (2015)

Once the boundaries of the sectors/societies are set, research into determining all the EIPs acting within the boundaries can be done. This then creates a NGAM which comprehensively exposes the effects that activities and sources have on the impact.

For this study, the 'Activity' stage would be set as human induced emissions of greenhouse gasses (GHGs). The 'Source' is defined as a "causal factor for pressure(s) and effects" (Judd et al., 2015). In this case this would be climate change effects. Then, the key component of the EIP chain that requires research and an understanding of the relationships at play is the 'Pressure' to 'Receptor' steps, as these are where the most variability will come through with multiple pressures affecting the same impact via the receptors. The 'Pressure' is defined as "an event or agent exerted by the source to elicit an effect" (Judd et al., 2015). In the case of climate change, the Pressure would be systematic changes to the climate system. The 'Pathway' is defined as how the 'Receptor' is exposed to the 'Activity' (Judd et al., 2015); in this case this would be the changes to the physical environmental that interacts with the society/sector being studied. The 'Receptor' is defined as "entities which are sensitive to the hazards under investigation" (Judd et al., 2015). In this case, this would be an identifiable linkage between the 'Pathway' and the 'Impact' usually pinpointed to a specific vulnerability for maritime security. The 'Impact' is defined as a "measurable […] change attributable […] to a human activity" (Judd et al., 2015). In this case, this would be the impact of the 'Receptor' on maritime security, which is the occurrence of the vulnerabilities identified in the previous step. Additionally, in this study, the 'Impact' is the specific vector or threat and/or harm which will ultimately lead directly, or indirectly in such a way that a ‘threat multiplier’ would, to issues of insecurity and existentialism.

Figure 2: A visual representation of variables used in this PoC



Source: Authors

This framework recognizes the securitisation of both climate change and the maritime domain and using this framework allows for the identification of specific paths through which climate change impacts on maritime (in)security and thus contributes to defining the boundaries of what constitutes a (maritime) security threat. This study takes the lens of security from the state level but breaking down the EIPs by the four different aspects of maritime security (c.f. above) allow for the identification of issues as they impact on different referent objects. For instance, the economic security sector allows for the identification of security issues that impact the economic stability of a state such as vulnerable shipping lanes leading to disruptions in the supply of goods or energy which can in turn impact the survival of a state or can compound security issues in a way that multiplies an existing threat in to becoming a question of existentialism for a state.

2.3. Scope of the Proof of Concept

This PoC aims to show the applicability of NGAMs and test the methodology. This is done by building a database of EIPs focused on tracking the effects of climate change to the impacts they have on maritime security.

For this PoC the scope of study will be limited. We use data found in the 2019 IPCC’s *Special Report on the Ocean and Cryosphere in a Changing Climate* (SROCC) for the parts of singular EIPs where scientific data is needed. The data taken from the SROCC will be tagged as being ‘very high confidence’ or ‘very likely’ to occur under the emissions pathway ‘RCP 2.6’. The parts of the EIPs well covered by data from the SROCC are the Source, Pressure and Pathway sections. Where the SROCC inferred the Receptor this is used and, if available, the Impact is used. For parts of the EIPs where scientific data is incomplete, the authors’ assumptions, based on the logical connections to the beginning of the associated EIP, will be used (c.f. ‘Assumptions’ section below). The completed EIPs will then be tagged against one of the maritime security sectors (c.f. ‘Tagging Against Maritime Security Sectors’ section below).

2.3.1. Scientific Validity

To help deal with the issues of predicting a future consisting of novel challenges, this PoC will use scientifically robust data. This data will come from the 2019 SROCC, a report from the IPCC. IPCC assessments are widely regarded as the gold standard for scientific understanding of climate change (IPCC, 2019a). The IPCC does not conduct its own research but identifies the strength of scientific agreement in different areas and indicates where further research is needed. This provides assurance that the data is robust and accurate.

As already stated, to be used in this PoC data must be tagged as very high confidence’ or ‘very likely’ to occur under the emissions pathway ‘RCP 2.6’. This is to try to ensure the data that is used will be as certain and probable of occurring as possible. In some instance the SROCC states that certain effects or impacts were already being observed and these were included. Within the SROCC where no emission pathway was stated for the data outlined it is assumed that these effects will occur with their stated confidence and likelihood.

While it is still uncertain as to the extent that the effects of climate change will occur, having scientifically confident projections about what will likely happen, is a good way of starting the conversation on maritime security. In the future as the data becomes more certain the EIP database and NGAM can be updated. It is also important to stress that some theoretical assumptions about the links and dependencies as exposed in existing literature have not materialised in the data. This might not be because of their inexistence but because of the limited scope of this PoC. Further studies might help confirming or infirming this.

2.3.2. Assumptions

In most cases the authors needed to use assumptions for the 'Receptor' and 'Impact' sections of the EIP. This is because most of the data in the SROCC only covers the first three sections of the EIP. This is due to the SROCC being a mainly scientific report and it not being created to focus on maritime security, as viewed through the lens of international relations.

In some instances the 'Receptor' was stated in the SROCC, but where it was not , and assumption was made about what was the obvious and logical next step in the EIP and its interaction with maritime security. For instance, if the Pathway was 'Increased coastal erosion' then a logical assumption for this Receptor would be 'Damaged coastal infrastructure'.

In the SROCC the 'Impact' was stated fairly regularly, but in these cases it was mostly represented by a vague statement captured in the EIP as 'Increased exposure and vulnerability for coastal communities'. But where the Impact was not stated the assumption was made that the Impact should be the next obvious step in the EIP and it should aim to represent an obvious link to maritime security. Thus giving a reason for the inclusion of the specific EIP within the PoC.

2.3.3. Feedback loops

Within natural systems there are feedback loops that occur. Where these have been identified they are included in the EIP dataset. Where a feedback loop creates an additional EIP, the previous component of the EIP before the component from which the feedback loop flows on from is filled out with 'Feedback loop'. In the current dataset the 'Feedback loops' occur when a Pressure exacerbates or causes another Pressure. In this case the Pressure causing the 'Feedback loop' is 'Increased sea level rise' so this becomes a Source and the Activity becomes 'Feedback loop'.

Given that climate change is a threat multiplier this could plausibly happen at most stages of the EIP chain and Germond and Mazaris (2019) argue that it is not just environmental effects that can have feedback loops on different parts of the environmental system. But also the impacts on humans caused by environmental decline can cause a feedback loop because of the actions of humans in response to this impact (Germond & Mazaris, 2019). An NGAM with a wider scope of data would help to identify where feedback loops are most prevalent.

2.3.4. Tagging Against Maritime Security Sectors

The mapping of the effects of climate change on sectors of society, not just geographic areas, using EIPs is useful. This is because it gives the ability to attribute the impacts to parts of society that will feel these impacts most. This means that the unit of analysis for EIPs needs to be at sub-state level, even if the findings are displayed and mitigation is implemented at the state level.

The four sectors that will be used to tag the EIPs against have been outlined in the introduction: national security, environmental security, economic security, and human security. Because of the need to make assumptions for most EIPs on either their 'Receptor' or 'Impact' there should always be an obvious logical maritime security sector to tag these against.

The tagging against maritime security sectors will only be done against those where the EIP has a direct link to that sector. For example, where there is an EIP with an 'Impact' of 'Decreased coastal agriculture' this has a direct link to 'Human security' (via food security issues) and 'Economic security' (via reduced farming income), but it only has an indirect link to the 'National Security' sector (as it would take a lot of coastal farming to be disrupted to pose a threat to a nation, or for coastal agriculture to be a major part of the nation's food supply to cause this to create a national food security issue[1]). It will thus only be tagged against 'Human security' and 'Economic security', not 'National Security'.

[1] The author notes that there are exceptions to this especially low-lying Small Island Developing States where subsistence farming is critical to existence and all most all land would be considered as coastal land.

3. Findings

This section discusses the analysis of the full EIP dataset found in Annex 8. Annex 1 shows a high-level NGAM, displayed as a Sankey Chart[2] which maps the flow of the EIPs from 'Activity' to 'Impact' and their interactions with each other.

The full dataset while narrow in scope can be used for a basic analysis of the linkages within the EIP's (best visualised in Annex 1). In presenting the findings this article starts by understanding the frequencies of occurrence at each component of the EIP. This will give policy makers and practitioners a guide to understanding where it is best to invest their time and effort.

This section starts below by analysing the most common 'Pathway', 'Receptor', and 'Impact'. Then the analysis turns to the maritime security sectors to identify the most frequent chains and any commonalities between major linkages of different maritime security sectors.

3.1. Pathways

As shown in table 1 the most frequent 'Pathway' is 'Increased salinization of coastal waterways'. This then leads to 12 occurrences of the 'Receptor' 'Reduction in freshwater'. The rest of this 'Receptor's' occurrences being made up of 'Increased salinization of groundwater' which is the third most common Pathway (equal with 'Increased land loss'). Thus, these two Pathways show that a big issue to be addressed is lack of 'freshwater'.

The 'Reduction in marine biomass' is the second most common 'Pathway' but has a wider array of 'Receptors' that it impacts on, so this is a good area for further investigation and potential intervention as it will address a wide array of impacts.

Table 1: Occurrence of Pathways in EIP database

Pathway	No. of	Percentage
Increased salinization of coastal waterways	18	21.95%
Reduction in marine biomass	16	19.51%
Increased salinization of groundwater	12	14.63%
Increased land loss	12	14.63%
Increased coastal erosion	6	7.32%
Increased coastal flooding	6	7.32%
Increased salinization of soil	5	6.10%
Decline in coral reefs	2	2.44%
Reduction of nutrient flows	2	2.44%
Increase in waterborne diseases	2	2.44%
Higher extreme sea levels during extreme weather events	1	1.22%
Grand Total	**82**	**100.00%**

3.2. Receptors

Table 2 shows that the most frequent 'Receptor' is 'Reduction in fresh water'. This then leads to 10 occurrences of the 'Impact' 'Decrease in coastal agriculture'. The other 15 occurrences of this 'Impact' are made up by the 'Receptor' 'Decrease in environmental health' which is the second most frequent receptor.

'Damaged coastal infrastructure' is the third most frequent 'Receptor' and accounts for all of the occurrences of 'increased exposure and vulnerability for coastal communities'. This then would make a great intervention area for actors wishing to increase the resilience of coastal communities.

Table 2: Occurrence of Receptors in EIP database

Receptor	No. of	Percentage
Reduction in fresh water	16	19.51%

[2] Sanky Charts have been used by Gissi et al. (2020) to represent the frequency and combination of human stressors and climate change effects and the level these were studied at.

Decrease in environmental health	15	18.29%
Damaged coastal infrastructure	12	14.63%
Reduction in potable water	10	12.20%
Decrease in seagrasses	6	7.32%
Decrease in habitable land	6	7.32%
Decrease in Kelps	6	7.32%
Change in composition and diversity of fisheries	4	4.88%
Decrease in corals	2	2.44%
Decrease in food security	2	2.44%
Reduction in marine biomass	2	2.44%
Increases in damage from extreme weather events	1	1.22%
Grand Total	**82**	**100.00%**

3.3. Impacts

‘Decrease in coastal agriculture’ was the most common Impact occurring in 25 EIPs (or 30.49% of the time). This Impact is the largest contributor affecting both ‘Economic Security’ (54.35%) and ‘Human Security’ (40.98%). This makes it a useful intervention area to investigate when looking for Impacts that provide the opportunity to address insecurities across multiple sectors of maritime security.

‘Decrease in human health’ occurred in 13 instances (15.85%) and ‘Increased exposure and vulnerability for coastal communities’ occurred in 12 instances (14.85%). ‘Decline in coastal ecosystems’ occurred in 10 instances (12.2%).

Table 3: Occurrence of Impacts in EIP database

Impacts	No. of	Percentage
Decreased coastal agriculture	25	30.49%
Increased exposure and vulnerability for coastal communities	13	15.85%
Decrease in human health	12	14.63%
Decline in coastal ecosystems	10	12.20%
Increase in climate induced mobility	6	7.32%
Reduced fisheries catches	6	7.32%
Reduced food security	4	4.88%
Reduction in economic opportunities from aquaculture	4	4.88%
Decrease in coastal tourism	2	2.44%
Grand Total	**82**	**100.00%**

3.4. Impacted Maritime Security Sectors

Table 4 shows the sectors of maritime security and the number of EIPs they are tagged against. This shows that ‘Human Security’ is the most tagged sector occurring 59 times and ‘Economic Security’ is the second most tagged with 46 occurrences.

Table 4: Occurrences of maritime security sectors

	Environmental Security		**Economic Security**		**National Security**		**Human Security**	
	no. of	% of total tags	no. of	% of total tags	no. of	% of total tags	no. of	% of total tags
EIPs	16	11.43	46	32.86	19	13.57	59	42.14

3.4.1. Human Security

A visual representation of an NGAM that affects ‘Human Security’ can be found in Annex 2.

‘Decreased coastal agriculture’ was the most frequent ‘Impact’ for ‘Human Security’ at 42.37% (see Table 5). This impact could, by the absence of subsistence farming, encourage local coastal communities and populations to either engage in other activities through which to secure their access to food, either turning to maritime crimes, such as IUU fishing or physically moving to areas where agriculture or food is still in abundance which brings with it many of its own issues such as the vulnerability of migrating communities to trafficking and illegal migratory routes and conflict with existing communities for resources in areas in which they might settle (Germond & Mazaris, 2019) (Bueger & Edmunds, 2020) (Balsari et al., 2020).

To identify areas for intervention for policymakers and development actors, we shall look at the two receptors that affect this Impact the most: ‘Decrease in environmental health’ and ‘Reduction in fresh water’. This would see efforts going into supporting the resilience of community’s natural environments (and would be supported through interventions undertaken through the environmental security sub-sector of maritime security), as well as protecting and improving coastal communities’ access to fresh and clean water. Interventions taken at improving and securing these two receptors would align with the most commonly occurring pathway for ‘Human Security’ which is ‘Increase in salinization of coastal waterways’. In looking at how practical interventions could be made we see how intervening earlier in the EIP chain reduces the impact of climate change in multiple ways.

Table 5: Impacts to Human Security as a percentage

Impact	Human Security
Decreased coastal agriculture	42.37%
Decrease in human health	20.34%
Decline in coastal ecosystems	10.17%
Reduced fisheries catches	10.17%
Increase in climate induced mobility	10.17%
Reduced food security	6.78%
Grand Total	**100.00%**

3.4.2. National Security

A visual representation of an NGAM that affects ‘National Security’ can be found in Annex 3.

The way that Climate change will have an effect on ‘National Security’ was found in the data through two impacts: ‘Increased exposure and vulnerability for coastal communities’ (68.42%); and ‘Increase in climate induced mobility’ (31.58%). Both impacts could be limited by ensuring sustainable and resilient development for coastal communities which act to reduce the only two receptors for ‘National Security’: ‘Damaged coastal infrastructure’ and ‘Decrease in habitable land’. To reduce the impact of these two receptors, interventions aimed at securing ‘National Security’ would look at shoring up infrastructure and land against ‘Increased sea level rise’ which is both a ‘Source’ and a ‘Pressure’ and accounts for 84% of the EIPs that affect ‘National Security’.

Table 6: Impacts to National Security as a percentage

Impact	National Security
Increased exposure and vulnerability for coastal communities	68.42%
Increase in climate induced mobility	31.58%
Grand Total	**100.00%**

3.4.3. Economic Security

A visual representation of an NGAM that affects ‘Economic Security’ can be found in Annex 4.

The most frequent impact of climate change on the ‘Economic Security’ sector of maritime security is ‘Decreased coastal agriculture’ at 54.35%. This impact was contributed to by two ‘Receptors’: ‘Decrease in environmental health’ and ‘Reduction in fresh water’ Which, as with ‘National Security’, are affected most frequently by the ‘Pressure’ ‘Increased sea level rise’, making it an obvious intervention area through supporting environmental and water resilience and safety in the face of sea level rise. Yet, being able to intervene at the ‘Pathway’ stage to reduce ‘Increase land loss’ against sea level rise in conjunction with environmental and water resilience would also be a good intervention area as it will reduce the impacts of: ‘Decreased coastal agriculture’ and ‘Increase in climate induced mobility’, which are the most common ‘Pathways’ to impacts on environmental security.

Table 7: Impacts to Economic Security as a percentage

Impact	Economic Security
Decreased coastal agriculture	54.35%
Reduced fisheries catches	13.04%
Increase in climate induced mobility	13.04%
Reduction in economic opportunities from aquaculture	8.70%
Decrease in coastal tourism	4.35%
Decrease in human health	4.35%
Increased exposure and vulnerability for coastal communities	2.17%
Grand Total	**100.00%**

3.4.4. Environmental Security

A visual representation of an NGAM that affects ‘Environmental Security’ can be found in Annex 5.

‘Environmental Security’ had two impacts from climate change through this NGAM: ‘Decline in coastal ecosystems’ (62.50%) and ‘Reduced fisheries catches’ (37.50%). A good intervention area for this would be to act upon the ‘Reduction in marine biomass’ with (37.50%) of all the EIPs flowing through it. Interventions in this area could consist in setting up marine protected areas/reserves, which allow for the replenishment of marine biomass or for interventions against IUU fishing which may in turn become a national security issue due to the nature of IUU monitoring and protection as well as some states activity of using grey zone tactics and maritime fishing militias.

Table 8: Impacts to Environmental Security as a percentage

Impact	Environmental Security
Decline in coastal ecosystems	62.50%
Reduced fisheries catches	37.50%
Grand Total	**100.00%**

4. Discussion

Using an EIP method has shown how the effects of climate change will impact sectors of maritime security and how the causal chains can be drawn out and simplified. This makes it possible to identify the most impacted sectors of maritime security and identify the best areas for intervention. It also allows for a greater and more wholesome understanding of the security impacts of climate change especially in the maritime domain which supports the continued calls for research and understanding of climate security and maritime domain awareness.

4.1. Impacts on maritime security

Our findings show that maritime security sectors are impacted by the effects of climate change via the Impact they have on the four sectors of maritime security. The negative impacts on Human, National, Economic, and Environmental Security all point towards increasing food and water insecurity leading to the vulnerability of coastal populations. Since these are proven factors explaining the occurrence of conflict, maritime crimes, IUU fishing practices, and fisheries conflicts, our findings help pointing towards areas of intervention that could help to prevent or ease these factors and thus maritime insecurity.

This PoC has shown that Human security is the most impacted sector of maritime security. This is a key finding, since human security is an important part of keeping people and communities from engaging in criminal activities including blue crimes (Germond & Mazaris, 2019) which then flow on to impact other areas of maritime security.

In exposing the entire pathway from ‘Activity’ to ‘Impact’, EIPs can help provide insight into where maritime security starts and ends, by being able to track the impacts on maritime security back to their ‘Source’. This effort will contribute to enhance the definition of maritime security and its conceptual boundaries through increasing the knowledge of its “four distinguishing characteristics”: interconnectedness, liminality, transnational, and cross-jurisdictional (Bueger & Edmunds, 2017).

Indeed, the issues of liminality and interconnectedness add to the complexity of maritime security (Bueger et al., 2019) and its operationalization as a concept. Liminality is about understanding how far away from the ocean an 'Activity' or 'Source' can be and still be considered as a generator of maritime (in)security. For example, the 'Source' 'Melting glaciers' can be considered as a threat to maritime security, although 'it' is located far away from the maritime domain. So the question is where to draw the line of what constitutes maritime security and how to ensure wholistic and comprehensive interventions to address the issues identified in relation a 'Source'. For its part, interconnectedness is about understanding the linkages between the different sectors of maritime security (Bueger et al., 2019). Our findings show that such linkages are most prominent in the fact 'decreased coastal agriculture', 'reduced fisheries catches', and 'increase in climate induced mobility' all impact on three out of the four sectors of maritime security. Cross-jurisdictional and transnational characteristics such as a community relocating from one district within a country to another, or foreign fishers fishing within another country's territorial waters or exclusive economic zones will require policy intervention to address 'climate induced mobility' and issues relating to fisheries management.

In our findings, liminality and interconnectedness are shown through the NGMA. Its use of EIPs enables the tracking of an 'Activity' all the way through to its 'Impact' and identifying the number of EIPs impacting on multiple sectors of maritime security. We can then highlight some of the issues that other academics have identified with maritime security such as liminality and interconnectedness of all of the different aspects of maritime security and the co-benefits that can be achieved when picking appropriate interventions.

4.2. Areas for policy interventions

Resilience and sustainable development are key aims in responding to climate change and even more so for coastal communities. This NGAM has shown the interconnectedness of the pathways of climate change's impacts on maritime security underscoring the need for responses and interventions that are wholistic and able to reduce the impact of many effects. This is highlighted by the fact that within this NGAM 'decreased coastal agriculture' is the most frequent 'Impact' for three out of the four maritime security sectors. Indeed, this means that it is a good area for intervention by ensuring that coastal agriculture and farming is adapting in a way that is climate resilient by delivering access to clean water and access to adequate land to undertake coastal agriculture in its current form, both for economic gain and subsistence.

Furthermore, because of the interconnectedness of maritime security, other priority areas to investigate for policy interventions are the impacts 'reduced fisheries catches' and 'increase in climate induced mobility' both of which are also prominent across three sectors of maritime security. Indeed, interventions looking at 'reduced fisheries catches', as mentioned above, are important for addressing the occurrence of maritime crime, as this constitutes a crucial 'Impact' on human security, and this pathway is prone to feedback loops whereby more maritime crime engenders more pressures on the marine environment and coastal communities, which in turn further incentivize maritime crime (Mazaris & Germond, 2018). Other impacts that are good areas for interventions based purely on frequency are 'increased exposure and vulnerability for coastal communities', 'decrease in human health', and 'decline in coastal ecosystems'.

However, there is the question of whether or not the 'Impact' is the best area for intervention, as it would seem logical to act against the 'Activity' as close to the start of the EIP chain as possible, therefore limiting its 'Impact'. So it would be more efficient to consider intervention areas closer to the 'Activity' and 'Source'. This then makes the most frequent 'Pathway' of 'Increases in salinization of coastal waterways' a good area for intervention area when targeting 'Human Security' because of the frequency and the further Impacts this Pathway has.

4.3. Limitations and agenda for research

There are limitations to this PoC mainly because of the scope of the data collection. To address this, the authors propose undertaking in future a larger study, while still using scientifically robust data. With a larger dataset there could be a more fulsome analysis of more interactions along more pathways. This would allow for better focused and more detailed suggestions on areas of intervention. This would enable confirming or infirming the existence of some theoretical links between climate change and maritime security identified in existing literature but that this PoC's data has not highlighted. This could also help providing more precise findings regarding the final link, i.e., how the impacts on the four sectors of maritime security eventually contribute to furthering maritime crime.

A future project with a wider scope of data would better identify where feedback loops are most prevalent. This would also help to better target interventions to reduce the effects of feedback loops and subsequently lower the multiplying effects of the impacts of climate change.

Future NGAMs could also provide deeper analysis by applying certain weightings to individual EIPs in order to evaluate more precisely the impact of individual EIPs. This could be done by calculating the economic value or using vulnerability indexes for the maritime security sectors. This allows for better targeting of policy interventions as not all impacts will be of the same magnitude.

Even without developing a wider project the findings from this article could be used to support the understanding of the impacts that are being experienced and what impacts are top of mind for practitioners or communities. This could be done by using the delphi method[3] to use these initial findings as the focus of a workshop with policymakers and practitioners to further develop the full range of impacts that 'Activities' have. Doing this would also allow for a bottom-up approach to be used with this methodology.

As this methodological approach is not restricted to investigating the impacts of climate change, in future it can be applied to other research areas to understand the impacts of multiple and varied activities on sectors or sub-sectors of society this could be done on issue that are already being recognised as having interactions with climate change, such as biodiversity loss, or the continuing impacts of COVID-19.

5. Conclusion

In this paper the authors have built an NGAM and demonstrated its utility in helping to understand the impacts the effects of climate change will have on maritime security. The underlying methodology for this NGAM is based on the CEA methodology and uses EIP chains to detail the steps an 'Activity' must go through to exert its Impact on society. Using EIPs has allowed for the identification of areas for intervention within the cause and effect' chains that are detailed within the NGAM. This is because such a methodology has allowed for the analysis of the interactions between the different EIPs.

Having proven its utility, this PoC can, even with its limited set of data, support discussions on intervention areas. However as previously argued, to further develop this methodology further studies with a wider scope for data collection should be undertaken, which will allow for a greater analysis and allow for a more fulsome view of the impacts and the interactions between different EIP chains. This methodology can also be used to create an NGAM for other cause to effect issues. These other NGAMs can be used either as a standalone assessment or can be combined with other NGAM's to create detailed picture of all the impacts affecting areas of society.

This PoC, when analysing the impacts of climate change on maritime security, has identified the Human Security aspect of maritime security will be the most affected and the Impact of 'decreased coastal agriculture' is the most frequent impact. However, as the authors place emphasis on intervening as early in the EIP as possible, the area best for analysis of policy interventions would be the Pathways leading on from the Pressure of 'increased sea level rise'.

In sum, this PoC has demonstrated that the CEA/EIP method succeeds in providing data-driven confirmation of several key links and dependencies between climate change and maritime security highlighted in the literature. Furthermore, it has enabled identifying precise areas for policy interventions taking place all along the EIP chain. This enables devising original and targeted responses that are not evident if policymakers only concentrate on the 'Source' (e.g., sea level rise, ocean acidification, etc.) or the final impact on maritime (in)security (i.e., maritime crimes). Instead, we have shown that intervening upstream at the level of, for example coastal agriculture, might help break the EIP chain.

[3] The Delphi method is a repetitive and interactive process of consulting with a group of experts to gather their opinions usually through a series of questionnaires (Landeta, J. (2006). Current validity of the Delphi method in social sciences. *Technological Forecasting and Social Change*, *73*(5), 467-482. https://doi.org/https://doi.org/10.1016/j.techfore.2005.09.002

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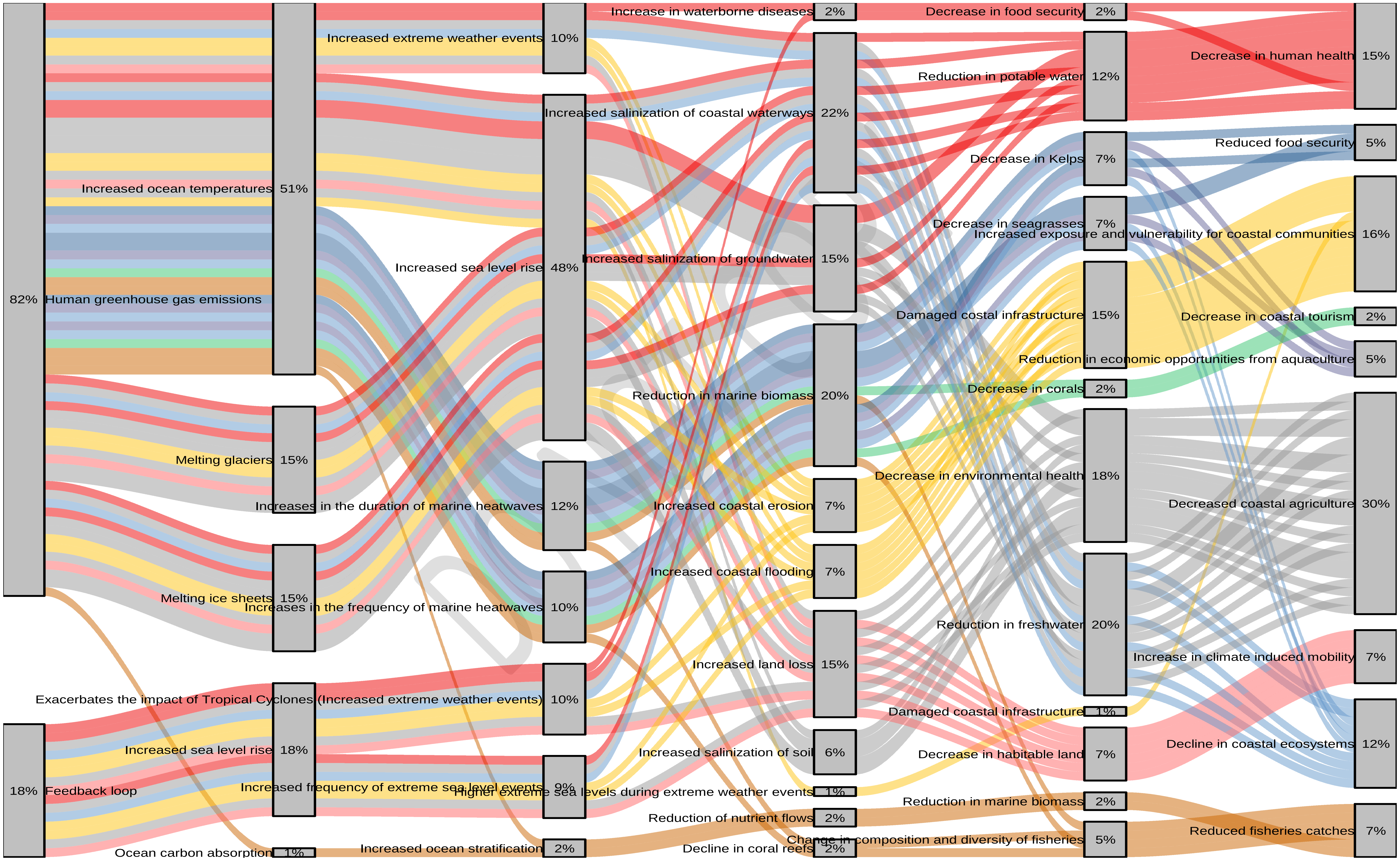
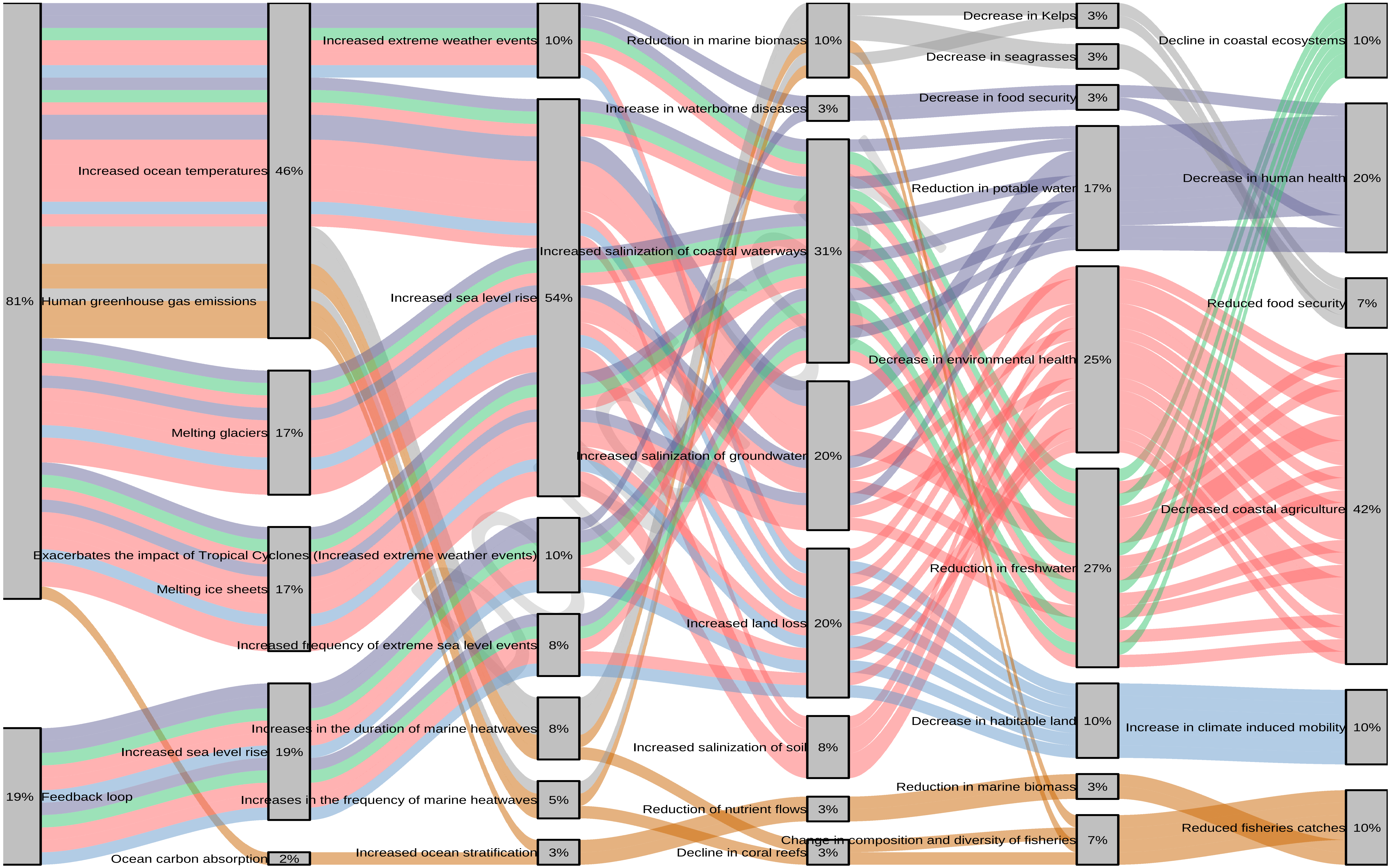
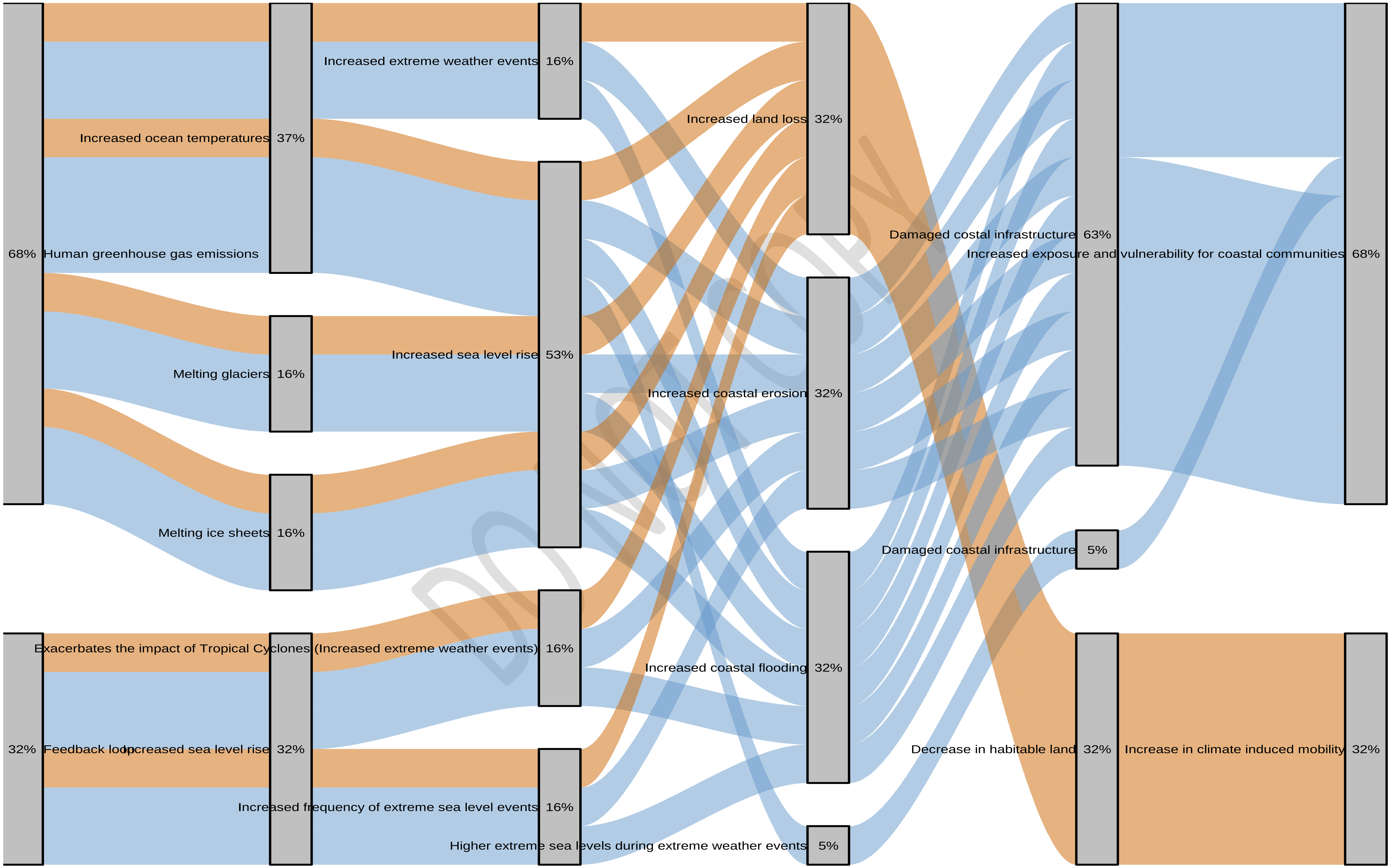
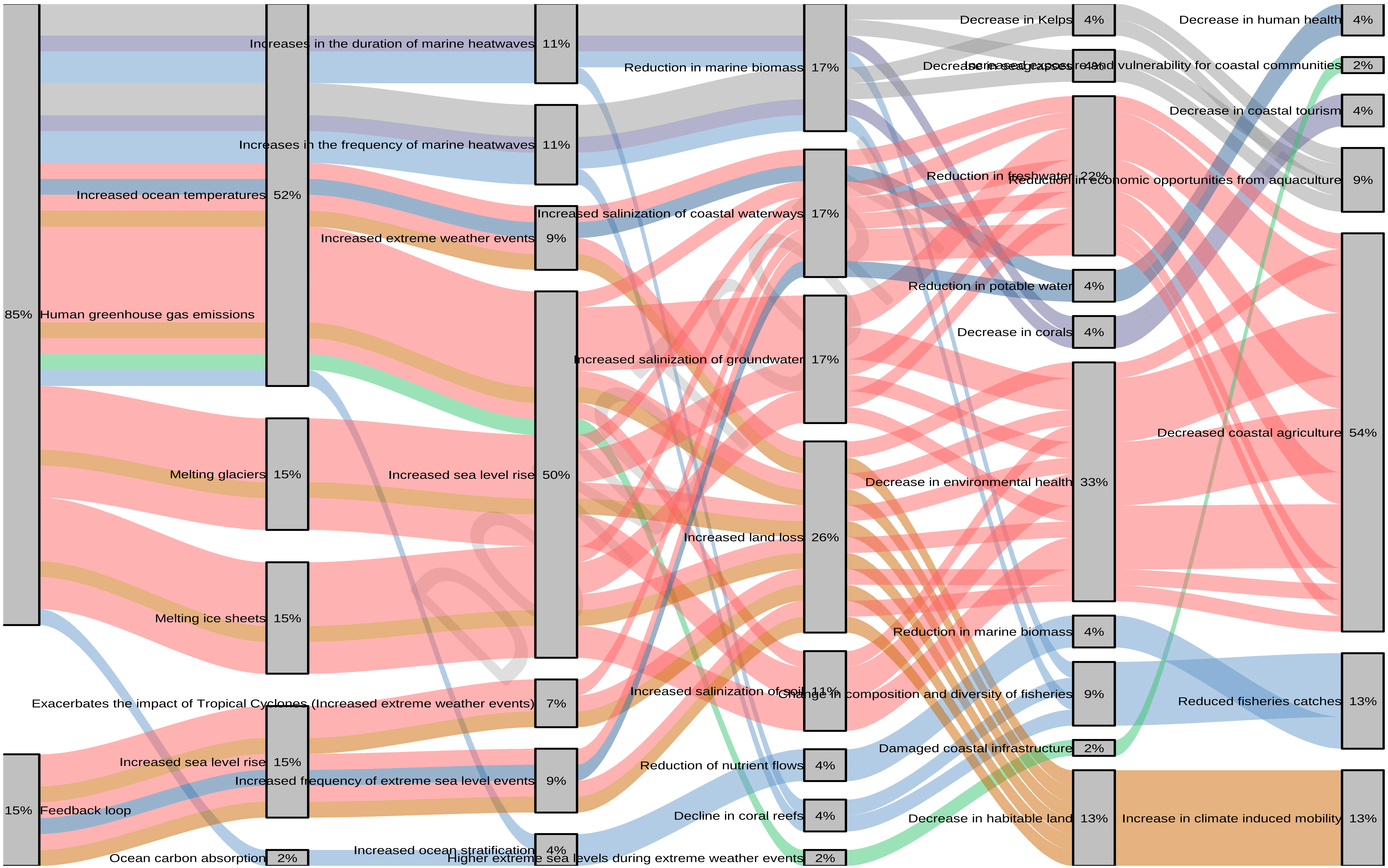
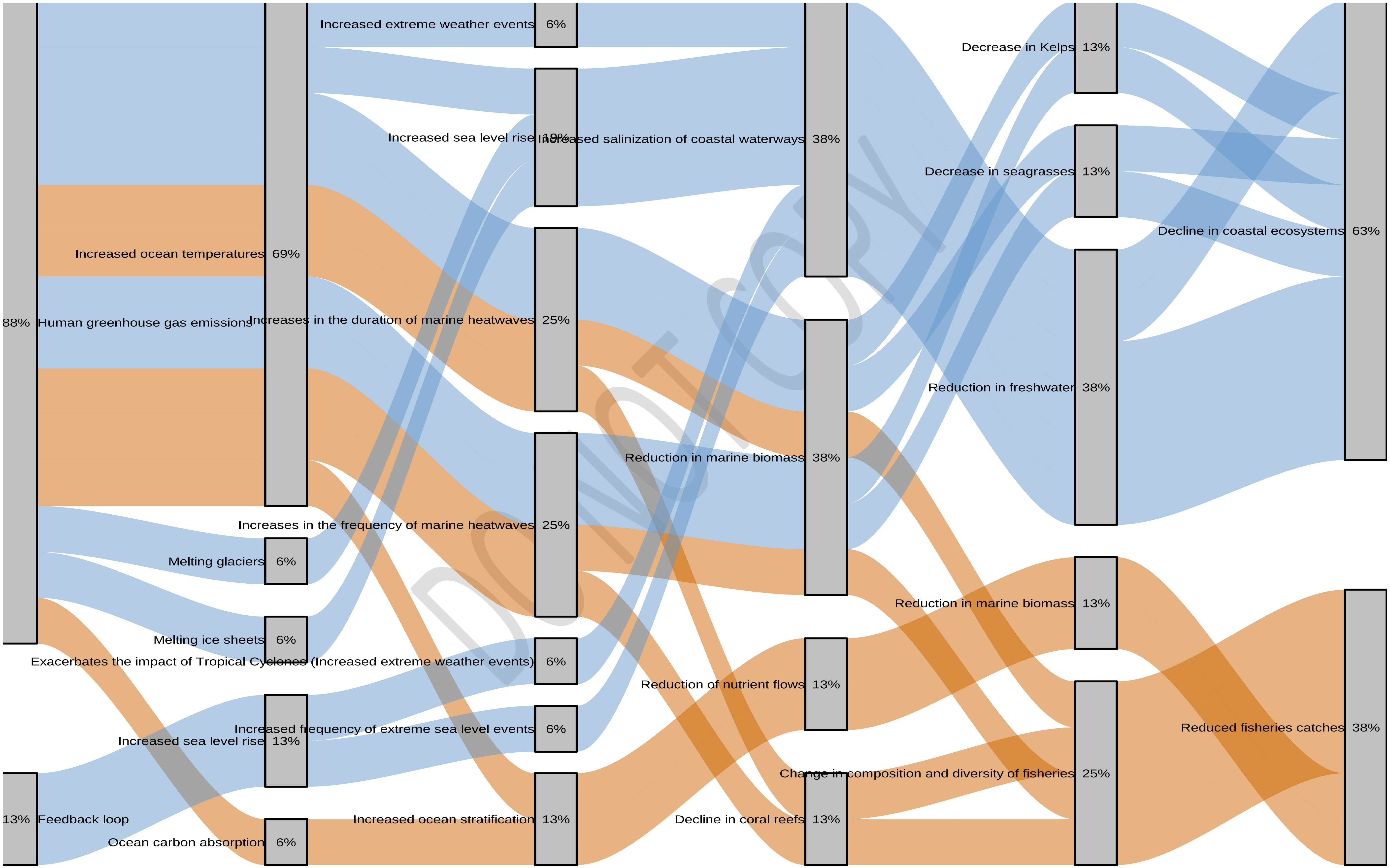
Annex 1 – High-level NGMA mapping Human GHG emissions to Maritime Security Sectors




81% Human greenhouse gas emissions
19% Feedback loop
Increased ocean temperatures 46%
Melting glaciers 17%
Melting ice sheets 17%
Increased sea level rise 19%
Ocean carbon absorption 2%
Increased extreme weather events 10%
Increased sea level rise 54%
Exacerbates the impact of Tropical Cyclones (Increased extreme weather events) 10%
Increased frequency of extreme sea level events 8%
Increases in the duration of marine heatwaves 8%
Increases in the frequency of marine heatwaves 5%
Increased ocean stratification 3%
Reduction in marine biomass 10%
Increase in waterborne diseases 3%
Increased salinization of coastal waterways 31%
Increased salinization of groundwater 20%
Increased land loss 20%
Increased salinization of soil 8%
Reduction of nutrient flows 3%
Decline in coral reefs 3%
Decrease in Kelps 3%
Decrease in seagrasses 3%
Decrease in food security 3%
Reduction in potable water 17%
Decrease in environmental health 25%
Reduction in freshwater 27%
Decrease in habitable land 10%
Reduction in marine biomass 3%
Change in composition and diversity of fisheries 7%
Decline in coastal ecosystems 10%
Decrease in human health 20%
Reduced food security 7%
Decreased coastal agriculture 42%
Increase in climate induced mobility 10%
Reduced fisheries catches 10%


68% Human greenhouse gas emissions
32% Feedback loop
Increased ocean temperatures 37%
Melting glaciers 16%
Melting ice sheets 16%
Exacerbates the impact of Tropical Cyclones
Increased sea level rise 32%
Increased extreme weather events 16%
Increased sea level rise 53%
(Increased extreme weather events) 16%
Increased frequency of extreme sea level events 16%
Increased land loss 32%
Increased coastal erosion 32%
Increased coastal flooding 32%
Higher extreme sea levels during extreme weather events 5%
Damaged costal infrastructure 63%
Damaged coastal infrastructure 5%
Decrease in habitable land 32%
Increased exposure and vulnerability for coastal communities 68%
Increase in climate induced mobility 32%


85% Human greenhouse gas emissions
15% Feedback loop
Increased ocean temperatures 52%
Melting glaciers 15%
Melting ice sheets 15%
Increased sea level rise 15%
Ocean carbon absorption 2%
Increases in the duration of marine heatwaves 11%
Increases in the frequency of marine heatwaves 11%
Increased extreme weather events 9%
Increased sea level rise 50%
Exacerbates the impact of Tropical Cyclones (Increased extreme weather events) 7%
Increased frequency of extreme sea level events 9%
Increased ocean stratification 4%
Reduction in marine biomass 17%
Increased salinization of coastal waterways 17%
Increased salinization of groundwater 17%
Increased land loss 26%
Increased salinization of soil 11%
Reduction of nutrient flows 4%
Decline in coral reefs 4%
Higher extreme sea levels during extreme weather events 2%
Decrease in Kelps 4%
Decrease in seagrasses 4%
Reduction in freshwater 22%
Reduction in potable water 4%
Decrease in corals 4%
Decrease in environmental health 33%
Reduction in marine biomass 4%
Change in composition and diversity of fisheries 9%
Damaged coastal infrastructure 2%
Decrease in habitable land 13%
Decrease in human health 4%
Increased exposure and vulnerability for coastal communities 2%
Decrease in coastal tourism 4%
Reduction in economic opportunities from aquaculture 9%
Decreased coastal agriculture 54%
Reduced fisheries catches 13%
Increase in climate induced mobility 13%


88% Human greenhouse gas emissions
13% Feedback loop
Increased ocean temperatures 69%
Melting glaciers 6%
Melting ice sheets 6%
Increased sea level rise 13%
Ocean carbon absorption 6%
Increased extreme weather events 6%
Increased sea level rise 19%
Increases in the duration of marine heatwaves 25%
Increases in the frequency of marine heatwaves 25%
Exacerbates the impact of Tropical Cyclones (Increased extreme weather events) 6%
Increased frequency of extreme sea level events 6%
Increased ocean stratification 13%
Increased salinization of coastal waterways 38%
Reduction in marine biomass 38%
Reduction of nutrient flows 13%
Decline in coral reefs 13%
Decrease in Kelps 13%
Decrease in seagrasses 13%
Reduction in freshwater 38%
Reduction in marine biomass 13%
Change in composition and diversity of fisheries 25%
Decline in coastal ecosystems 63%
Reduced fisheries catches 38%

Annex 6 - The full EIP Database

Effect to Impact Pathway						Maritime Security sector			
Activity	**Source**	**Pressure**	**Pathway**	**Receptor**	**Impact**	**Environmental Security**	**Economic Security**	**National Security**	**Human Security**
Human greenhouse gas emissions	Increased ocean temperatures	Increased extreme weather events	Increased coastal erosion	Damaged coastal infrastructure	Increased exposure and vulnerability for coastal communities			1	
Human greenhouse gas emissions	Increased ocean temperatures	Increased extreme weather events	Increased coastal flooding	Damaged coastal infrastructure	Increased exposure and vulnerability for coastal communities			1	
Human greenhouse gas emissions	Increased ocean temperatures	Increased extreme weather events	Increased land loss	Decrease in environmental health	Decreased coastal agriculture		1		1
Human greenhouse gas emissions	Increased ocean temperatures	Increased extreme weather events	Increased land loss	Decrease in habitable land	Increase in climate induced mobility		1	1	1
Human greenhouse gas emissions	Increased ocean temperatures	Increased extreme weather events	Increased salinization of coastal waterways	Reduction in freshwater	Decline in coastal ecosystems	1			1
Human greenhouse gas emissions	Increased ocean temperatures	Increased extreme weather events	Increased salinization of coastal waterways	Reduction in freshwater	Decreased coastal agriculture		1		1
Human greenhouse gas emissions	Increased ocean temperatures	Increased extreme weather events	Increased salinization of coastal waterways	Reduction in potable water	Decrease in human health		1		1
Human greenhouse gas emissions	Increased ocean temperatures	Increased extreme weather events	Increase in waterborne diseases	Decrease in food security	Decrease in human health				1
Human greenhouse gas emissions	Increased ocean temperatures	Increased ocean stratification	Reduction of nutrient flows	Reduction in marine biomass	Reduced fisheries catches	1	1		1
Human greenhouse gas emissions	Increased ocean temperatures	Increased sea level rise	Higher extreme sea levels during extreme weather events	Damaged coastal infrastructure	Increased exposure and vulnerability for coastal communities		1	1	
Human greenhouse gas emissions	Increased ocean temperatures	Increased sea level rise	Increased coastal erosion	Damaged coastal infrastructure	Increased exposure and vulnerability for coastal communities			1	
Human greenhouse gas emissions	Increased ocean temperatures	Increased sea level rise	Increased coastal flooding	Damaged coastal infrastructure	Increased exposure and vulnerability for coastal communities			1	
Human greenhouse gas emissions	Increased ocean temperatures	Increased sea level rise	Increased land loss	Decrease in environmental health	Decreased coastal agriculture		1		1
Human greenhouse gas emissions	Increased ocean temperatures	Increased sea level rise	Increased land loss	Decrease in habitable land	Increase in climate induced mobility		1	1	1
Human greenhouse gas emissions	Increased ocean temperatures	Increased sea level rise	Increased salinization of coastal waterways	Reduction in freshwater	Decline in coastal ecosystems	1			1
Human greenhouse gas emissions	Increased ocean temperatures	Increased sea level rise	Increased salinization of coastal waterways	Reduction in freshwater	Decreased coastal agriculture		1		1
Human greenhouse gas emissions	Increased ocean temperatures	Increased sea level rise	Increased salinization of coastal waterways	Reduction in potable water	Decrease in human health				1
Human greenhouse gas emissions	Increased ocean temperatures	Increased sea level rise	Increased salinization of groundwater	Decrease in environmental health	Decreased coastal agriculture		1		1
Human greenhouse gas emissions	Increased ocean temperatures	Increased sea level rise	Increased salinization of groundwater	Decrease in environmental health	Decreased coastal agriculture		1		1
Human greenhouse gas emissions	Increased ocean temperatures	Increased sea level rise	Increased salinization of groundwater	Reduction in freshwater	Decreased coastal agriculture		1		1
Human greenhouse gas emissions	Increased ocean temperatures	Increased sea level rise	Increased salinization of groundwater	Reduction in freshwater	Decreased coastal agriculture		1		1
Human greenhouse gas emissions	Increased ocean temperatures	Increased sea level rise	Increased salinization of groundwater	Reduction in potable water	Decrease in human health				1
Human greenhouse gas emissions	Increased ocean temperatures	Increased sea level rise	Increased salinization of groundwater	Reduction in potable water	Decrease in human health				1
Human greenhouse gas emissions	Increased ocean temperatures	Increased sea level rise	Increased salinization of soil	Decrease in environmental health	Decreased coastal agriculture		1		1

Human greenhouse gas emissions	Increased ocean temperatures	Increases in the duration of marine heatwaves	Decline in coral reefs	Change in composition and diversity of fisheries	Reduced fisheries catches	1	1		1
Human greenhouse gas emissions	Increased ocean temperatures	Increases in the duration of marine heatwaves	Reduction in marine biomass	Change in composition and diversity of fisheries	Reduced fisheries catches	1	1		1
Human greenhouse gas emissions	Increased ocean temperatures	Increases in the duration of marine heatwaves	Reduction in marine biomass	Decrease in corals	Decrease in coastal tourism		1		
Human greenhouse gas emissions	Increased ocean temperatures	Increases in the duration of marine heatwaves	Reduction in marine biomass	Decrease in Kelps	Decline in coastal ecosystems	1			
Human greenhouse gas emissions	Increased ocean temperatures	Increases in the duration of marine heatwaves	Reduction in marine biomass	Decrease in Kelps	Reduced food security				1
Human greenhouse gas emissions	Increased ocean temperatures	Increases in the duration of marine heatwaves	Reduction in marine biomass	Decrease in Kelps	Reduction in economic opportunities from aquaculture		1		
Human greenhouse gas emissions	Increased ocean temperatures	Increases in the duration of marine heatwaves	Reduction in marine biomass	Decrease in seagrasses	Decline in coastal ecosystems	1			
Human greenhouse gas emissions	Increased ocean temperatures	Increases in the duration of marine heatwaves	Reduction in marine biomass	Decrease in seagrasses	Reduced food security				1
Human greenhouse gas emissions	Increased ocean temperatures	Increases in the duration of marine heatwaves	Reduction in marine biomass	Decrease in seagrasses	Reduced food security				1
Human greenhouse gas emissions	Increased ocean temperatures	Increases in the duration of marine heatwaves	Reduction in marine biomass	Decrease in seagrasses	Reduction in economic opportunities from aquaculture		1		
Human greenhouse gas emissions	Increased ocean temperatures	Increases in the frequency of marine heatwaves	Decline in coral reefs	Change in composition and diversity of fisheries	Reduced fisheries catches	1	1		1
Human greenhouse gas emissions	Increased ocean temperatures	Increases in the frequency of marine heatwaves	Reduction in marine biomass	Change in composition and diversity of fisheries	Reduced fisheries catches	1	1		1
Human greenhouse gas emissions	Increased ocean temperatures	Increases in the frequency of marine heatwaves	Reduction in marine biomass	Decrease in corals	Decrease in coastal tourism		1		
Human greenhouse gas emissions	Increased ocean temperatures	Increases in the frequency of marine heatwaves	Reduction in marine biomass	Decrease in Kelps	Decline in coastal ecosystems	1			
Human greenhouse gas emissions	Increased ocean temperatures	Increases in the frequency of marine heatwaves	Reduction in marine biomass	Decrease in Kelps	Reduced food security				1
Human greenhouse gas emissions	Increased ocean temperatures	Increases in the frequency of marine heatwaves	Reduction in marine biomass	Decrease in Kelps	Reduction in economic opportunities from aquaculture		1		
Human greenhouse gas emissions	Increased ocean temperatures	Increases in the frequency of marine heatwaves	Reduction in marine biomass	Decrease in seagrasses	Decline in coastal ecosystems	1			
Human greenhouse gas emissions	Increased ocean temperatures	Increases in the frequency of marine heatwaves	Reduction in marine biomass	Decrease in seagrasses	Reduction in economic opportunities from aquaculture		1		
Human greenhouse gas emissions	Melting glaciers	Increased sea level rise	Increased coastal erosion	Damaged coastal infrastructure	Increased exposure and vulnerability for coastal communities			1	
Human greenhouse gas emissions	Melting glaciers	Increased sea level rise	Increased coastal flooding	Damaged coastal infrastructure	Increased exposure and vulnerability for coastal communities			1	
Human greenhouse gas emissions	Melting glaciers	Increased sea level rise	Increased land loss	Decrease in environmental health	Decreased coastal agriculture		1		1
Human greenhouse gas emissions	Melting glaciers	Increased sea level rise	Increased land loss	Decrease in habitable land	Increase in climate induced mobility		1	1	1
Human greenhouse gas emissions	Melting glaciers	Increased sea level rise	Increased salinization of coastal waterways	Reduction in freshwater	Decline in coastal ecosystems	1			1
Human greenhouse gas emissions	Melting glaciers	Increased sea level rise	Increased salinization of coastal waterways	Reduction in freshwater	Decreased coastal agriculture		1		1
Human greenhouse gas emissions	Melting glaciers	Increased sea level rise	Increased salinization of coastal waterways	Reduction in potable water	Decrease in human health				1
Human greenhouse gas emissions	Melting glaciers	Increased sea level rise	Increased salinization of groundwater	Decrease in environmental health	Decreased coastal agriculture		1		1
Human greenhouse gas emissions	Melting glaciers	Increased sea level rise	Increased salinization of groundwater	Reduction in freshwater	Decreased coastal agriculture		1		1
Human greenhouse gas emissions	Melting glaciers	Increased sea level rise	Increased salinization of groundwater	Reduction in potable water	Decrease in human health				1

Human greenhouse gas emissions	Melting glaciers	Increased sea level rise	Increased salinization of soil	Decrease in environmental health	Decreased coastal agriculture		1		1
Human greenhouse gas emissions	Melting glaciers	Increased sea level rise	Increased salinization of soil	Decrease in environmental health	Decreased coastal agriculture		1		1
Human greenhouse gas emissions	Melting ice sheets	Increased sea level rise	Increased coastal erosion	Damaged coastal infrastructure	Increased exposure and vulnerability for coastal communities			1	
Human greenhouse gas emissions	Melting ice sheets	Increased sea level rise	Increased coastal flooding	Damaged coastal infrastructure	Increased exposure and vulnerability for coastal communities			1	
Human greenhouse gas emissions	Melting ice sheets	Increased sea level rise	Increased land loss	Decrease in environmental health	Decreased coastal agriculture		1		1
Human greenhouse gas emissions	Melting ice sheets	Increased sea level rise	Increased land loss	Decrease in habitable land	Increase in climate induced mobility		1	1	1
Human greenhouse gas emissions	Melting ice sheets	Increased sea level rise	Increased salinization of coastal waterways	Reduction in freshwater	Decline in coastal ecosystems	1			1
Human greenhouse gas emissions	Melting ice sheets	Increased sea level rise	Increased salinization of coastal waterways	Reduction in freshwater	Decreased coastal agriculture		1		1
Human greenhouse gas emissions	Melting ice sheets	Increased sea level rise	Increased salinization of coastal waterways	Reduction in potable water	Decrease in human health				1
Human greenhouse gas emissions	Melting ice sheets	Increased sea level rise	Increased salinization of groundwater	Decrease in environmental health	Decreased coastal agriculture		1		1
Human greenhouse gas emissions	Melting ice sheets	Increased sea level rise	Increased salinization of groundwater	Reduction in freshwater	Decreased coastal agriculture		1		1
Human greenhouse gas emissions	Melting ice sheets	Increased sea level rise	Increased salinization of groundwater	Reduction in potable water	Decrease in human health				1
Human greenhouse gas emissions	Melting ice sheets	Increased sea level rise	Increased salinization of soil	Decrease in environmental health	Decreased coastal agriculture		1		1
Human greenhouse gas emissions	Melting ice sheets	Increased sea level rise	Increased salinization of soil	Decrease in environmental health	Decreased coastal agriculture		1		1
Human greenhouse gas emissions	Ocean carbon absorption	Increased ocean stratification	Reduction of nutrient flows	Reduction in marine biomass	Reduced fisheries catches	1	1		1
Feedback loop	Increased sea level rise	Exacerbates the impact of Tropical Cyclones (Increased extreme weather events)	Increase in waterborne diseases	Decrease in food security	Decrease in human health				1
Feedback loop	Increased sea level rise	Exacerbates the impact of Tropical Cyclones (Increased extreme weather events)	Increased coastal erosion	Damaged coastal infrastructure	Increased exposure and vulnerability for coastal communities			1	
Feedback loop	Increased sea level rise	Exacerbates the impact of Tropical Cyclones (Increased extreme weather events)	Increased coastal flooding	Damaged coastal infrastructure	Increased exposure and vulnerability for coastal communities			1	
Feedback loop	Increased sea level rise	Exacerbates the impact of Tropical Cyclones (Increased extreme weather events)	Increased land loss	Decrease in environmental health	Decreased coastal agriculture		1		1
Feedback loop	Increased sea level rise	Exacerbates the impact of Tropical Cyclones (Increased extreme weather events)	Increased land loss	Decrease in habitable land	Increase in climate induced mobility		1	1	1
Feedback loop	Increased sea level rise	Exacerbates the impact of Tropical Cyclones (Increased extreme weather events)	Increased salinization of coastal waterways	Reduction in freshwater	Decline in coastal ecosystems	1			1
Feedback loop	Increased sea level rise	Exacerbates the impact of Tropical Cyclones (Increased extreme weather events)	Increased salinization of coastal waterways	Reduction in freshwater	Decreased coastal agriculture		1		1
Feedback loop	Increased sea level rise	Exacerbates the impact of Tropical Cyclones (Increased extreme weather events)	Increased salinization of coastal waterways	Reduction in potable water	Decrease in human health				1
Feedback loop	Increased sea level rise	Increased frequency of extreme sea level events	Increased coastal erosion	Damaged coastal infrastructure	Increased exposure and vulnerability for coastal communities			1	
Feedback loop	Increased sea level rise	Increased frequency of extreme sea level events	Increased coastal flooding	Damaged coastal infrastructure	Increased exposure and vulnerability for coastal communities			1	
Feedback loop	Increased sea level rise	Increased frequency of extreme sea level events	Increased land loss	Decrease in environmental health	Decreased coastal agriculture		1		1

Feedback loop	Increased sea level rise	Increased frequency of extreme sea level events	Increased land loss	Decrease in habitable land	Increase in climate induced mobility		1	1	1
Feedback loop	Increased sea level rise	Increased frequency of extreme sea level events	Increased salinization of coastal waterways	Reduction in freshwater	Decline in coastal ecosystems	1			1
Feedback loop	Increased sea level rise	Increased frequency of extreme sea level events	Increased salinization of coastal waterways	Reduction in freshwater	Decreased coastal agriculture		1		1
Feedback loop	Increased sea level rise	Increased frequency of extreme sea level events	Increased salinization of coastal waterways	Reduction in potable water	Decrease in human health		1		1