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Geographical Information Management and Applications

Threats to coastal biodiversity

Cumulative human impacts on Earth's coastal habitats

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Abstract

The coastal zone is the region of Earth where land and sea processes interact. Coastal zones attract large human populations, provide important socio-economic value, and contain a rich biodiversity and a great variety of habitats. Due to the presence of high amounts of population and agriculture the habitats in the coastal zone are under threat. Anthropogenic threats caused by sea level rise, light pollution, nutrients pollution, organic pollution, and inorganic pollution have an impact on coastal habitats in the marine and the terrestrial zone. Research often focuses on either the marine zone or the terrestrial zone, by doing so the interaction between these two zones and the cumulative impacts are highly underestimated. This thesis produces an integrated map of the anthropogenic impacts on coastal marine and terrestrial habitats. To create this integrated map several threats, impacts, and habitat vulnerabilities have been modelled. The resulting global coastal cumulative anthropogenic impact map visualises the impacts that humanity has on its valuable coastal zone. Several biogeographic regions of Earth are under several intense anthropogenic threats. Calculated cumulative impacts from these threats are greatest at coastal zones with widespread agriculture, in combination with the consumption of high quantities of fertilizer and pesticides, high local sea level rise, and high population densities. The biogeographic regions where these factors are all present are Tropical Eastern Pacific Realm, the Temperate Northern Atlantic Realm, and the Western Indo-Pacific Realm. The visualisation of these cumulative impacts will raise awareness to the high impact that the coastal habitats in these regions have to endure.

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Chapter 1: Introduction

This chapter introduces the topic of the research (1.1), presents the existing literature (1.2.1) and literature gap (1.2.2). Based on the literature gap the topic is justified (1.3). Finally, the further outline of the thesis is presented (1.4).

1.1 Research topic

Coastal zones are the regions of Earth where land and sea processes interact. Coastal zones attract large human populations, provide important socio-economic value, and contain a rich biodiversity and a great variety of habitats (Duarte Santos, 2014). Although the absolute boundary is debatable, coastal habitats can be divided into coastal marine habitats and coastal terrestrial habitats. Coastal marine habitats are those habitats that are located close to shore and are submerged, partially submerged or periodically submerged in water (Duarte Santos, 2014). The definition of 'close to shore' is debatable, but generally a marine depth of up to 60 meters is considered as the 'coastal marine zone' (Duarte Santos, 2014; Halpern, et al., 2015).

Coastal marine habitats provide various beneficial services such as nutrient cycling, detoxification of pollutants, food production, raw materials and habitats, regulation of storm-induced disturbances, as well as recreational and entertainment activities (Constanza, et al., 1997). Coastal marine habitats include estuaries, sea grass beds, salt marshes, tidal flats, mangroves, and coral reefs (Lu, et al., 2018). These habitats contain high levels of biomass, coral reefs alone even contain one third of the world's known marine fish species (Moberg & Folke, 1999). Many coastal habitats have unique abiotic components such as the mixing of salt and fresh water, and tidal forces creating unique flora and fauna (Duarte Santos, 2014).

Coastal terrestrial habitats include coastal dunes, beaches, deltas, barrier islands, strand-plains, and coastal cliffs (Raha, Banarjee, Das, & Mitra, 2013; Davis, 2018). Cliffs are the only erosional landforms, i.e. landforms that are formed by erosional forces such as waves and currents. The other before mentioned coastal terrestrial habitats are formed through sedimentation (Davis, 2018). To be able to distinguish in a clear matter between the terrestrial and marine habitats of 'the coast' the term coastal terrestrial habitats is used although the inland area of land from the shoreline is often called the 'coastal zone' in literature.

The services that maritime transport and ports, tourism, fisheries and the availability of freshwater provide makes it that coastal habitats are densely populated areas (Duarte Santos, 2014). This concentration of human population places a stress on coastal habitats. These stresses include a variety of factors such as pollution, invasive species, nutrient inputs and sedimentation (Feist & Levin, 2016). The main threat that these stresses pose to coastal marine habitats is a change in function of these systems. All before mentioned threats cause a decrease in biodiversity; pollution can cause animal mortality, invasive species can cause native species mortality, nutrient inputs from mainly agriculture causes eutrophication resulting in hypoxia and animal mortality, and sedimentation causes coral mortality which eventually leads to animal mortality (Rocha, Peterson, & Biggs, 2015).

Key ecosystem processes such as carbon and nutrient cycling are deteriorated due to a loss of biodiversity (Davies, et al., 2011). The (near) extinction of certain organisms due to anthropogenic influences can cause a serious decline in ecosystem functioning, thus threatening an array of ecosystem services (Gupta, 2014). The ecosystem services provided by coastal habitats include the before mentioned nutrient and carbon cycling, but also natural coastline protection, climate regulation, water purification, and cultural services such as aesthetic and recreational value (Monaco & Prouzet, 2014). Losing these ecosystem services will increase the vulnerability of the world we live in, posing a threat to human society (*ibid*).

1.2 Scientific literature

The main articles that I will use for my thesis are the articles by Halpern *et al* (2015) and Geldmann *et al* (2014). These articles contain research on temporal cumulative threats to marine- (Halpern, et al., 2015) and terrestrial (Geldmann, Joppa, & Burgess, 2014) habitats. The data that is provided to me is the same as was used by these articles. These articles are the guideline for further research to scientific literature. Rocha, Peterson & Biggs (2015) have composed a very clear list of drivers that influence regime shifts at both marine, coastal and terrestrial habitats. This article will act as a guide to investigate several threats to these habitats. The book by Monaco & Prouzet (2014) contains a large amount of research on the vulnerability of coastal habitats. It describes numerous threats in detail and gives several definitions in the field of ecology, a field that is relatively new to me. The book *Encyclopedia of Biodiversity* by Levin (2013) is a 7 volume set that contains a vast amount of articles on ecology. Many chapters from this Encyclopaedia will be cited for my research.

1.2.1 Existing literature

A broad base of literature exists on what threats drive change in marine and terrestrial ecosystem services. Coastal marine habitats are threatened by several drivers such as; artisanal fishing (Jennings & Polunin, 1996; Adam, Anderson, & Shakeel, 1997; Halpern, et al., 2015; Rocha, Peterson, & Biggs, 2015), inorganic pollution (Halpern, et al., 2015; Rocha, Peterson, & Biggs, 2015; Pringle & Triska, 2000), invasive species, night lights, oil rigs, organic pollution (Walker, Hopkin, Sibly, & Peakall, 2006; Halpern, et al., 2015), nutrients pollution (Chen & Krol, 2004; Halpern, et al., 2015; Rocha, Peterson, & Biggs, 2015; Puccinelli, Noyon, & McQuaid, 2016), and direct human impacts (Halpern, et al., 2015; Rocha, Peterson, & Biggs, 2015; Feist & Levin, 2016). These drivers especially affect coastal marine habitats but also impact other marine habitats (Halpern, et al., 2015).

Some of these drivers are not limited to threatening coastal marine habitats and have their origin at terrestrial sources, think about agricultural runoff (nutrient-, inorganic- and organic pollution) and light pollution. Coastal terrestrial habitats face similar threats to coastal marine habitats such as direct human impacts, invasive species and night lights. Halpern, et al. (2015) have, in their research, mapped 19 anthropogenic marine stressors and their change in impact between 2008 and 2013. The resulting map can be seen at figure 1.1.

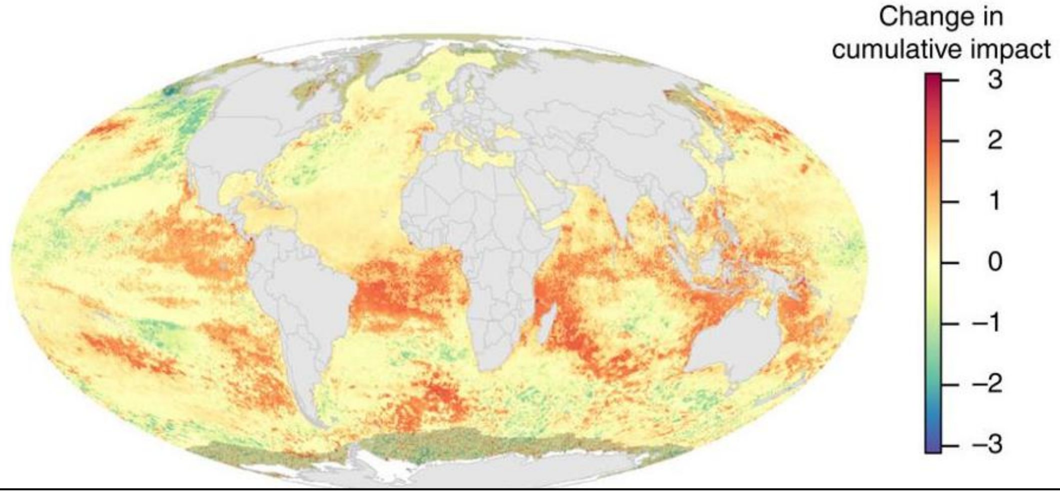


Figure 1.1: *Change in cumulative human impacts to marine* habitats *between 2008 and 2013.* (Halpern, et al., 2015)

Terrestrial habitats are greatly affected by anthropogenic drivers such as land use (Sanderson, et al., 2002; Mittermeier, et al., 2003; Ellis & Ramankutty, 2008; Alkemade, et al., 2009; Geldmann, Joppa, & Burgess, 2014), human population (*ibid*) and night lights (Geldmann, Joppa, & Burgess, 2014). The before mentioned terrestrial drivers are used by Geldmann, Joppa, & Burgess (2014) to draw a global temporal map of threats to terrestrial habitat biodiversity (see figure 1.2). Geldmann, Joppa & Burgess used data from 2010 and 1990 for their cumulative temporale impact change map. Additional threats to the one they used are present, but global data coverage is not always available for threats such as pollution, invasive species, infrastructure and diseases (*ibid*).

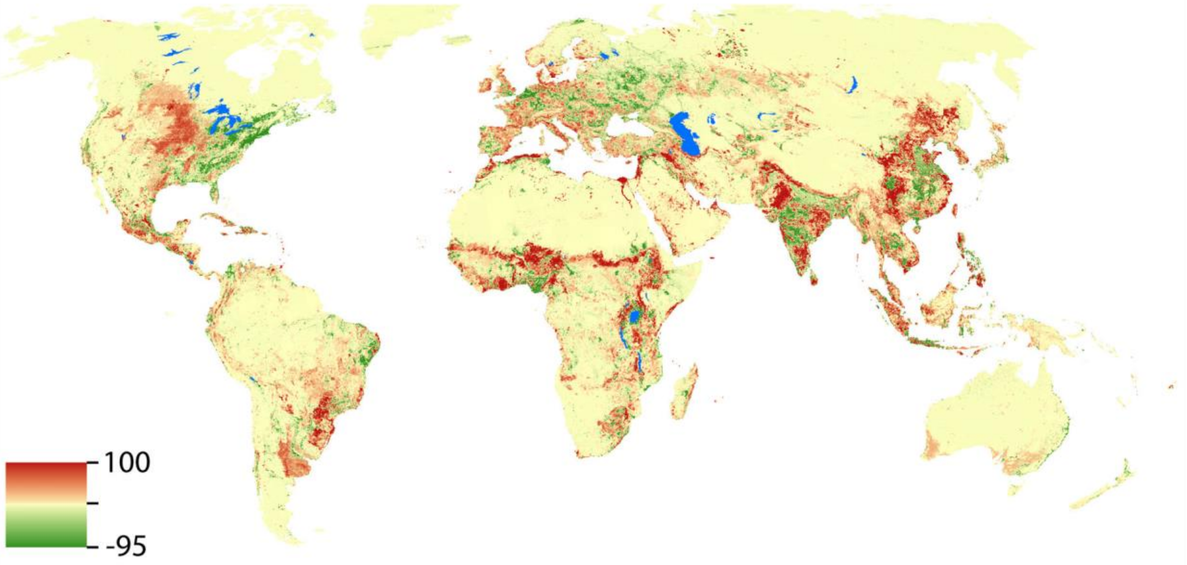


Figure 1.2: *Global distribution of the temporal human pressure index between 1990 and 2010*. (Geldmann, Joppa, & Burgess, 2014)

1.2.2 Literature gap

Research is limited by the data that is available to the researchers performing it. Halpern (2015) and Geldmann (2014) have been forced to reject several datasets due to its lack of global coverage. The absence of data strongly limits research and is probably the reason that a global integrated map is missing, a map that integrates both terrestrial and marine threats to the biodiversity of habitats on a global scale. An integrated map could provide insight to the interaction of marine and terrestrial drivers. This is importand because threaths to marine habitats are not always marine drivers, they are often land-based drivers that affect marine habitats (Halpern, et al., 2015).

1.3 Justification

Coastal habitats are located at the intersection of marine and terrestrial life. The coastal zone has characteristics of both marine- as well as terrestrial habitats. This makes coastal habitats an appropriate research area to perform research to anthropogenic threats to biodiversity (Lu, et al., 2018). A global map of threats to biodiversity in coastal habitats would provide insight to the far stretching effects of human actions to both marine and terrestrial habitats. This map could assist in conservation efforts and help to locate harmful threats to biodiversity, since conservation efforts at marine and terrestrial habitats often differ (Monaco & Prouzet, 2014).

Several studies only, or mainly, focus on the impact of anthropogenic threats on marine habitats (Ban & Alder, 2008; Halpern, et al., 2008; Allan, et al., 2013; Halpern, et al., 2015), or only focus on the impact of anthropogenic threats to terrestrial habitats (Sanderson, et al., 2002; Geldmann, Joppa, & Burgess, 2014), but these habitats cannot be seen separately. These researches are all valuable and cutting edge, being the first ones to even research a cumulative pressure on the land or ocean. But by only looking at terrestrial- or marine habitats you miss the bigger picture. Visualizing the pollution at a coral reef without visualizing the source of this pollution still leaves a lot of questions. This is why this research aims to integrate a selection of pressures on both coastal terrestrial- and marine habitats.

The coastal is zone is often overlooked (Lu, et al., 2018), by analysing the impact on the marine or terrestrial zone separately several stressors are unaccounted for. The coastal zone is under threat by both marine and terrestrial threats, which makes it especially vulnerable (Monaco & Prouzet, 2014). This vulnerability is a threat to the livelihood of millions of people who live in this coastal zone (CIESIN-SEDAC, 2015).

1.4 Outline thesis

The rest of this thesis will continue by informing the reader about the literature that has been consulted for this thesis at Chapter 2. This chapter will present the theory for this thesis where the most important definitions, habitats and threats will be discussed. Following this chapter the methodology of this thesis will be presented at Chapter 3. This chapter will discuss what the research area is, what the units of analysis are, and what variables are used. The data management section will discuss how the variables are modelled, and the following sections will discuss how the vulnerability indexes of the habitats are calculated, how the results and analysis will be presented, and finally the research questions are presented. In Chapter 4 the results will be presented, the single stressor impact score are presented, as well as the cumulative impact scores for several units of analysis. The last section of Chapter 4 will present correlation scores, a multiple regression analysis and a cluster analysis. Chapter 5 will discuss the results as presented in Chapter 4. This will be done at several biogeographic levels. Chapter 6 will conclude the research questions and will discuss the significance of the result, and finally further research is suggested. Chapter 7 aims to reflect on the presented results and will draw attention to the limitations of this thesis. Chapter 8 contains the scientific references used for this thesis, and Chapter 9 contains the Appendix. The Appendix contains detailed data management and outputs.

Chapter 2: Theory

This chapter discusses the key definitions used in this thesis (2.1). Next the Marine Ecoregions of the World will be discussed as section 2.2. The Conceptual model which presents several threats, habitats, and vulnerability indexes is presented at section 2.3. Next the existing literature on coastal marine habitats (2.4), coastal terrestrial habitats (2.5) is discussed. And finally the threats to coastal marine habitats (2.6) and the threats to coastal terrestrial habitats (2.7) are discussed.

2.1 Key definitions

This section discusses several definitions and terms that are important for understanding this thesis.

2.1.1 Ecoregions, habitat type, habitat groups, habitat, ecosystems, landcover classes

In scientific literature there is a use of various terminologies to describe different phenomena that often have similar names and even overlap in what they describe. The terminologies that are used for this thesis are listed below.

- The WWF has developed a biogeographic classification system that is called the *Marine Ecoregions of the World* (MEOW) (Spalding, et al., 2007). Marine Ecoregions are regions closely linked to already existing regional classification systems, based on biogeographic properties of that area (see 2.2 for a detailed description). It is the first system with clearly defined boundaries, which makes it ideal to use as units of analysis for this thesis. The world is divided into 12 Realms, which each are divided into several Provinces, Provinces that can consist of one or more Ecoregions. Note that this classification is done based on marine biogeographic classification, not based on terrestrial biogeographic classification. The WWF has developed a *Terrestrial Ecoregions of the World* as well (Olson, et al., 2001) which will not be used for this thesis.
- *Habitat groups* are groups of habitats, these groups are used by the IUCN (Janssen, et al., 2016) to group together certain habitats with similar properties, in this case terrestrial habitats. The habitat groups used by the IUCN are; Freshwater habitats, Mires and Bogs, Grassland habitats, Shrub habitats, Forest habitats, Sparsely vegetated habitats, and Coastal habitats. I will only go into detail of certain coastal habitats because this is the main scope of this thesis (see: 2.4-5).
- *Habitat*, a habitat is a term used by the IUCN (Janssen, et al., 2016) as well. In this thesis when referring to a habitat an individual habitat within the beforementioned habitat groups is meant, such as coastal dunes, but marine habitats as used by Halpern, et al. (2015), such as salt marshes, as well. The habitats that Halpern, et al. (*ibid*) define that fall within the research area can be found at section 2.4. Marine habitats are generally defined as habitats that are present in the world's oceans and seas (Gubbay, et al., 2016), but also habitats that are periodically part of the marine, being intertidal habitats. The IUCN report for example report on salt marshes in their terrestrial habitats report (Janssen, et al., 2016), but Halpern, et al. (2015) analyse salt marshes as part of the cumulative impacts on marine habitats.
- *Ecosystem*, the term as described by Virginia and Wall (2013) "*An ecosystem encompasses all the organisms of a given area and their relationship with one another and the physical abiotic environment. The ecosystem contains the linkages and dynamic interactions between life and the environment, many of which are essential to society*" (p. 90, Virginia & Wall, 2013). The ecosystem doesn't have a scale and can encompass a single habitat as well as an

entire continent. For this thesis the term ecosystem will only be used in combination with the terminology described in section 2.1.5, the Ecosystem processes - functioning, and - services.

- *Landcover classes* are the classes used by the FAO in their Global Landcover dataset. These classes are at a lower biogeographic level than habitat groups (the FAO uses 22 land cover classes) but at a higher biogeographic level than habitats. The FAO defines land cover as “the observed biophysical cover on the earth’s surface” (Di Gregorio & Jansen, 2000). In a strict sense this comes down to vegetation and man-made features, the landcover classes also include bare rock and soil, and water, although these landcovers are neither man-made or vegetation (*ibid*).

2.1.2 Biodiversity

The term biodiversity encompasses the broad spectrum of biotic scales, from genetic variation within species to biome distribution on the planet (Wilson E. , 1992; Hooper, et al., 2005). Biodiversity can be described as the number of entities (genotypes, species, or ecosystems), their distribution, the difference in their functional traits, and their interactions (Hooper, et al., 2005). The separate characteristics of biodiversity are often used interchangeably with the term biodiversity itself, where the term is often redefined on each occasion according to the context and purpose of the author. For this thesis I define biodiversity as “an attribute of an area that refers to the variety within and among living organisms, biotic communities, and biotic processes, whether naturally occurring or modified by humans” (DeLong, 1996). Biodiversity can be measured as genetic diversity, the number of different types of species, assemblages of species, biotic communities, and biotic processes, and the amount, or abundance, and structure of these. Biodiversity does not have a set spatial scale, ranging from microsites to the entire coastal research area (*ibid*).

2.1.3 Threats to biodiversity

Anthropogenic threats to biodiversity are defined as the actions that cause the alteration of the composition of biodiversity (Hooper, et al., 2005) due to human interventions. Anthropogenic threats to biodiversity include species extraction, the introduction of invasive species, human disturbances, pollution originating from anthropogenic sources, habitat fragmentation, and human caused climate change. Anthropogenic threats do not include natural hazards such as volcanic eruptions, earthquakes, natural coastal erosion, but also don’t include natural invasive species, and naturally occurring epidemics (Hooper, et al., 2005).

2.1.4 Biodiversity vulnerability

Vulnerability is the likelihood or imminence of biodiversity loss to current or impending threatening processes (Wilson, et al., 2005). This includes ecosystems that have already lost their functions because they have been exposed to high levels of threat in the past, making them less vulnerable in the present, but were unable to recover or return to their initial state. Vulnerability can also be described as: “The vulnerability to a threat is the degree to which a system is susceptible to, and unable to cope with a type of change” (Gupta, 2014). The vulnerability of biodiversity can be very different to one threat as opposed to another (Halpern, et al., 2015).

Vulnerability has three main dimensions (Wilson, et al., 2005; Gauthier, Foulon, Jupille, & Thompson, 2013): exposure, intensity, and impact. The first dimension of vulnerability is exposure, or risk. Exposure can be measured as either the probability of a threat affecting an area over a specified time or the expected time until an area is affected. In other words, what is the probability that a threat will occur over a specified time, or what is the time until a threat will occur (Wilson, et al., 2005).

The second dimension is the intensity of these threats (Gauthier, Foulon, Jupille, & Thompson, 2013; Wilson, et al., 2005). Intensity is measured in order of magnitude, frequency, and duration (Harwood, 2000). The measurements include, but don't limit to, cubic meters of timber or fish extracted, or the density of invasive species. To compare intensities relative to each other, they can be measured categorically (Wilson, et al., 2005).

The third dimension is the impact (Gauthier, Foulon, Jupille, & Thompson, 2013; Wilson, et al., 2005). The impact refers to the effects of a threatening process on particular features. The impact of a threat could alter the distribution, abundance, or likelihood of persistence of biodiversity (Wilson, et al., 2005). An impact can be negative, neutral, or positive. Low-intensity selective logging could create opportunities for understory shrub (positive), but high-intensity non-selective logging could destroy several species and habitats (negative) (*ibid*).

2.1.5 Ecosystem processes - functioning, and -services

The impact that a threatening process can have on particular features can encompass a disruption in ecosystem processes and functioning, and ecosystem services (Quljas & Balvanera, 2013; Wilson, et al., 2005; Halpern, et al., 2015). Small changes can cause a chain reaction because species within an ecosystem are generally so closely related to each other that an alteration in the biodiversity of an ecosystem can cause a positive feedback loop, further decreasing biodiversity (Gaston, 1996). This is also due to the fact that certain species have a certain 'role' within the ecosystem called 'functional traits'. If this functional trait is altered, the threat to biodiversity increases (Wilson J. , 1999).

Ecosystem processes are the energy transfer interactions among abiotic and biotic components in terrestrial and aquatic habitats (Chapin, et al., 2000). For example the ecosystem process "movement of pollen" is under threat due to organic pollution (Quljas & Balvanera, 2013). Pesticides can have a devastating effect on insects that are responsible for the fertilization of plants. If the ecosystem process of pollination is affected, the ecosystem service of agricultural food will be affected as well (*ibid*).

An ecosystem service is a component or process that contributes to human well-being when consumed or experienced. Ecosystem services consist of three types according to Haines-Young (Haines-Young & Potschin, 2013); provisioning (tangible, finite resources such as food, fuel and other biotic and abiotic resources), regulating (climate, disease, pollination, fertility, and erosion), and cultural (sense of place or identity, and recreation).

2.2 Classification of marine Ecoregions

For this thesis I follow the classification of the marine Ecoregions of the world (MEOW), a biogeographic classification of the world's coasts and shelves (Spalding, et al., 2007). The Ecoregions are developed to increase the ability to assess the state of habitats on Earth. The classification defines 252 Ecoregions, 62 Provinces and 12 Realms. For this thesis the Realms will be used as the units of analysis (see: 3.1.2), but the Provinces and Ecoregions are used to distinguish the most and least impacted areas as well. The Ecoregions, Provinces and Realms are delineated by biogeographic patterns such as the presence of kelp or the presence of coral, biogeochemical patterns such as nutrient levels and water temperature, climate zones and degree of endemism. The definition of what defines a marine Realm is given (Spalding, et al., 2007);

" Very large regions of coastal, benthic, or pelagic ocean across which biotas are internally

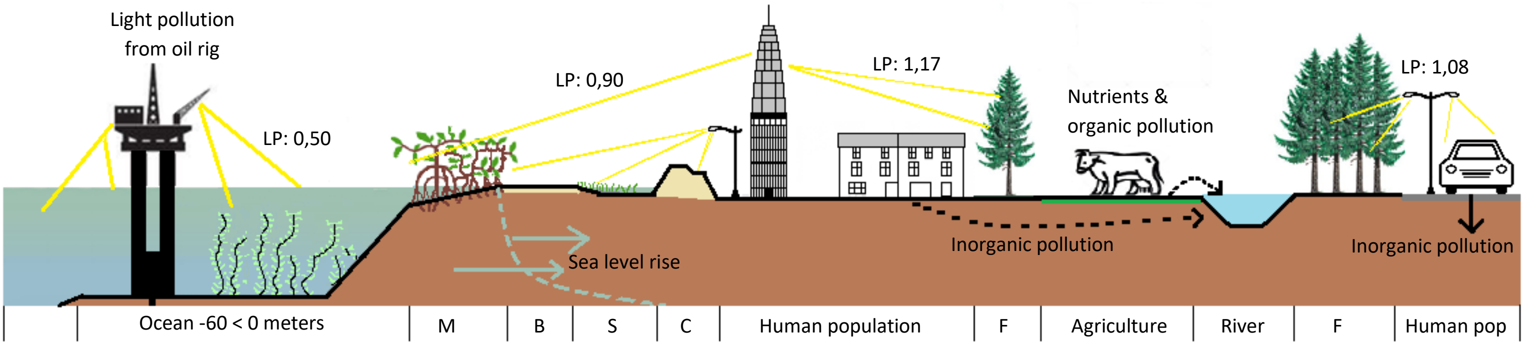
coherent at higher taxonomic levels, as a result of a shared and unique evolutionary history. Realms have high levels of endemism, including unique taxa at generic and family levels in some groups. Driving factors behind the development of such unique biotas include water temperature, historical and broadscale isolation, and the proximity of the benthos (Spalding, et al., 2007).*"*

Realms are divided in climatic zones being temperate, tropical, or polar. Within these climatic zones the Realms are divided based on their location around one of the five Oceans. The temperate Realms that have been defined are; Temperate Northern Atlantic, Temperate Northern Pacific, Temperate South America, Temperate Southern Africa, and Temperate Australasia. The Realms that are located at the tropical zone are; Central Indo-Pacific, Eastern Indo-Pacific, Western Indo-Pacific, Tropical Eastern Pacific, and Tropical Atlantic. The polar Realms that have been defined are the Arctic and the Southern Ocean.

2.3 Conceptual model

This paragraph discusses how the coastal marine (see 2.4) and terrestrial (see 2.5) habitats are threatened by marine threats (see 2.6) and terrestrial threats (2.7). How the threats affect the habitats is visualized at figure 2.1 in a conceptual model. Each of the five threats is visualised, but only a limited amount of habitats. The vulnerability indexes are derived from Halpern, et al. (2015) (see table 3.2) and calculated for this thesis (see 3.4).

Figure 2.1: Conceptual visualization of threats to marine and terrestrial habitats



M: Mangroves **B:** Beach **S:** Salt marshes **C:** Coastal dunes **F:** Forest **LP:** Light Pollution

The visualization shows a kelp forest between the depths of -60 and 0 meters. In the model the kelp forest is threatened by light pollution, light pollution from an oil rig generally has a high intensity and the kelp has a vulnerability index of 0,50 to light pollution. A bit more to the right we see lights from a city reaching a mangroves forest, mangroves have a vulnerability index to light pollution of 0,90. This means that kelp forests are more vulnerable to light pollution than mangroves are to light pollution. The light also hits the beach (index of 2,0), a salt marsh (index of 1,8), coastal dunes (index of 1,36) and an open evergreen forest (index of 1,17). The light pollution from the highway reaches a different forest, a closed evergreen forest that has vulnerability index to light pollution of 1,08.

The inorganic pollution that human population presence creates will eventually most likely end up in rivers. From this river it is transported to the oceans where mangroves have a vulnerability index of 0,5 to inorganic pollution and kelp forests have a vulnerability index of 0,0 to inorganic pollution. On land inorganic pollution has an impact too, the open evergreen forest has a vulnerability index of 0,89 to inorganic pollution. The nutrients pollution and organic pollution from agriculture follow the same path as inorganic pollution. They have an impact on the habitat where the pollution is present and eventually are transported by rivers into the oceans.

The model visualises sea level rise as well. A rising sea level permeates the land and causes salt water intrusion at several different habitats. Beaches for example have a vulnerability index of 2,1 to sea level rise.

These vulnerability indexes only depict how vulnerable a certain ecosystem is to a threat. It does not directly tells the impact of this threat on a habitat. The intensity of the threat multiplied by the vulnerability index of the habitats to that threat determines the impact of the threat on the ecosystem.

2.4 Coastal marine habitats

Within the research area a great amount of different habitats is present. Several of these habitats are defined as coastal marine habitats. The coastal marine habitats that are used in the creation of the integrated cumulative anthropogenic impact map are seagrass beds, shellfish reefs, coral reefs, rocky reefs, kelp forests, shallow soft bottom habitats, and the intertidal habitats: rocky intertidal, beach, mud flats, salt marsh and mangroves (Halpern, et al., 2015). This paragraph seeks to inform the reader about what the habitat types are that are included and what their value is.

2.4.1 Wetlands

Wetlands play major roles in the landscape by providing unique habitats for flora and faunas. Wetlands are important as water-quality enhancing habitats, flood mitigation systems, carbon sinks and global climate mitigating systems. The importance of the protection of our wetlands has come under global attention and knowledge on the recreation of lost wetlands is increasing. Wetlands are particularly fragile and are a clear indicator of pollution and the dismantling of ecosystem services if they disappear (Bedford, Leopold, & Gibbs, 2013).

Wetlands have many distinguished features, the most notable being the presence of standing water for some or a permanent period of time, unique soil conditions, and organisms adapted to or tolerant of saturated soils. Wetlands can hold fresh water, brackish water or salt water and include salt marshes, mangroves, swamps, peatlands and a number of other watery lands with even more different names to them (*ibid*).

2.4.2 Salt marshes

Salt marshes are intertidal grasslands associated with a very high flora and fauna productivity (McOwen, et al., 2017). These areas are mainly dominated by grass because of the ability of these grasses to withstand the high water salinity and floods it has to endure. Salt marshes can be found along protected shorelines outside of the polar zones and tropical regions. The destructive forces of ice prevent the salt marshes from flourishing and the ability of the competitive mangroves are superior at gathering sunlight and nutrients (Silliman, 2014). In the temperate zones salt marshes are limited by freshwater plants because of these plants' superior nutrient gathering abilities. Salt marshes cannot exist along openly exposed shorelines because of the erosional forces of the sea. This limits the location of salt marshes to salty, shallow and sheltered waters of bays, estuaries and lagoons in the temperate regions of our planet. The biological value of salt marshes is extremely high (McOwen, et al., 2017). The abundance of local plants and animals, although with a low diversity, is amazing and rivals and sometimes even exceeds that of coral reefs and tropical rain forests (Silliman, 2014).

2.4.3 Estuaries

Estuaries are partially enclosed coastal bodies of brackish water. The point where a river connects with a sea is where an estuary forms. The size and type of the estuary is dependent on the volume of the fresh water inflow from the river and the local intensity of the tide. An estuary stretches as far up river as there is salt intrusion from the ocean or up to the tidal limit. This definition includes fjords, lagoons, river mouths and tidal creeks (Franckx, 2007).

Estuaries are composed of relatively heterogeneous biologically diverse subsystems, being water column, mud and sand flats, bivalve reefs and beds, seagrass meadows and connected salt marshes. Estuaries are very productive natural systems offering a great amount of ecosystem services including nursery grounds for organisms and recreational zones for humans (Dame, 2008).

The ocean is the ultimate sink for pollutants (see: 2.6.3-5) (Walker, Hopkin, Sibly, & Peakall, 2006). Because the ocean has such a vast volume, the pollutants are not concentrated (highly diluted), but estuaries are the location where high amounts of pollutants enter the ocean. These pollutants were transported from the hinterland, into the river, ultimately ending up in the estuaries. This makes estuaries that are connected to industrialized regions or mining regions heavily polluted (*ibid*).

2.4.4 Tidal flats

A tidal flat is the area of land that is located between the high- and the low tide. Shallow seas such as the Wadden Sea, a sea that stretches from the North coast of the Netherlands to the West coast of Denmark, are located at sheltered areas where rivers have dropped sediment at the ocean floor to raise it to its current level. This results in far stretched near-horizontal mudflats that falls dry during low tide. Tidal flats contain a specific habitat of fauna and intertidal animals. Diversity in tidal flat habitats is low, but biomass and production can be very high. The animals that live at tidal flats usually protect themselves with shelves or are buried in the sediment (Baretta-Bekker, Duursma, & Kuipers, 1998).

2.4.5 Mangroves

Mangrove forests are woodlands found alongside shorelines with remarkable ecological importance. Mangrove forests occur mostly in the tropical and subtropical regions of our planet. An increase in latitude correlates with a decrease in mangrove presence. Mangroves are able to withstand stronger shoreline erosive forces than grass thanks to their strong roots. The presence of mangroves strengthens the soil beneath and the shoreline as a whole allowing other plants to occupy the soil beneath the mangroves (Hogarth, 2013). Mangrove forests include several salinity enduring plants that grow at a direct shoreline (salt water) and more inland at intertidal waters. Their distribution, zonation and association is influenced by several parameters like climate, salinity, tidal range, soil type and wave energy. Mangroves are specialized forests that are inhabited by several different levels of animals. Although mangroves provide shoreline protection against tsunamis, floods and erosion mangroves are extremely fragile and can suddenly disappear (Gosh, 2011).

2.4.6 Seagrass beds

Seagrasses are restricted to marine waters and live in completely submerged waters up to a depth of 50 meters in the clearest waters. Seagrasses can't grow at deeper waters since they require sunlight to absorb CO_2. With this seagrasses are responsible for 15% of the net uptake of CO_2 by oceanic biota. Seagrass can develop vast meadows that provide habitat to endangered and economically important marine animals and provide habitat to a highly diverse ecosystem. Seagrass meadows act as a stabilizer for sediments in the ocean, decreasing ocean sedimentation (Duarte, 2013). Seagrass beds are mainly located at the temperate zone, 6 of the 9 main seagrass species occur only within the temperate climatic zone. The other 3 species occur either at subarctic or subtropical waters (*ibid*).

Catastrophic seagrass decline has been reported for many seagrass species. Diseases that spread among the seagrasses can decimate entire populations. These losses often result from direct human-induced disturbances such as mechanical damages from boating, dredging and trawling. Seagrasses are also under pressure due to nutrient inputs causing eutrophication and due to diffuse sources associated with climate change (Marba & Cebrain, 1996).

2.4.7 Coral reefs

Coral reefs are a collection of the skeletal remains of corals and animals over a timespan of millions of years. These reefs have formed structures of up to 1.2kms thick and more than 2500kms long. Coral reefs support a high diversity and high biomass of marine life and yet they form at one of the least fertile waters of the Earth. Coral reefs flourish on a stable substrate, sunlit depths (above 50m), normal oceanic salinities, an average sea temperature of at least 18°C, high oxygen concentrations, high water clarity and often low nutrient concentrations (Sheppard, Davy, & Pilling, 2009). Because of these conditions corals are restricted to the tropical region. At less favourable conditions some coral species can exist but they hold a lower biodiversity.

Coral bleaching is usually caused by sea surface temperature increases, but can also be caused by low sea temperature, sedimentation, extreme salinities or light levels, and bacterial infection. A major threat to coral habitats is increased nutrient input. Higher levels of nutrients favour species that eat (such as starfish) or cover (algae) corals, both having devastating effects on corals. Other threats to coral reefs include dynamite fishing, overfishing and invasive species (Knowlton & Jackson, 2013).

2.4.8 Kelp forests

Giant kelp is a foundational species that provides a habitat and energy to complex food webs at subtidal zones (Byrnes, et al., 2011). Kelp forests are recognized as one of the most productive and dynamic habitats. Kelp forests occur at temperate and polar zones and can grow up to around 60 meters in length. Kelp tends to grow up to a depth of around 50 meters and grows up to the sea surface to catch sunlight (Mann, 1973). Kelp forests provide habitat to a wide arrange of invertebrates, fish and mammals that use it for food and shelter. A crucial mammal for kelp forests is the sea otter, sea otters eat red sea urchins. If red sea urchins are unchallenged they can completely destroy a kelp forest (NOAA, 2018).

2.4.9 Shellfish reefs

Shellfish reefs are one of the most unknown coastal marine habitats on Earth. This is largely due to the near extinction of oyster reefs (90%) for about a century (Christianen, et al., 2018). Mussels are not always better off, being virtually extinct at the North Sea (*ibid*). Together shellfish reefs have lost 85% of their size and their associated ecological functions (Kent, Gray, Last, & Sanderson, 2016). Shellfish reefs provide habitat to large amounts of species, have a role as a carbon sink, provide flood protection and have been an important source for fisheries. Also, shellfish reefs have the ability to provide an important structure for soft-shelf ocean floors such as the North Sea (Christianen, et al., 2018).

2.5 Coastal terrestrial habitats

The coastal zone is an ill-defined inland zone from the coastline (Matthews, 2003). Coastal terrestrial habitats include coastal dunes, beaches, deltas, barrier islands, strand-plains, and coastal cliffs (Raha, Banarjee, Das, & Mitra, 2013; Davis, 2018). The specific coastal habitats are discussed below, but every habitat group as used by the IUCN Red List of Habitats (Janssen, et al., 2016) is present within the research area of this thesis. These habitat groups will be concisely discussed below. It is important to note that the IUCN report only concerns habitats in the EU 28 and surrounding countries (EU 28+). When looking at a global scale different classifications could be made, but since the IUCN report is instrumental for determining the terrestrial habitat vulnerabilities to anthropogenic stressors, their habitat groups are used for this thesis. The freshwater habitat group consists of habitats including moving and standing waters with submerged, emergent and marginal vegetation, also with saline and brackish habitats inland. The Mires and Bogs habitat group consists of habitats with treeless wetlands on accumulating peat. The Grasslands habitat group describes a diverse and often very species rich range of grassland habitats. The Forest habitat group consists of broadleaved, coniferous and mixed forest habitats. Many of them constituting the potential natural vegetation of their biogeographic zone. Heathland and scrub habitats are dominated by woody sub-shrubs or shrubs and are temporary stages in succession from grasslands to forests. They are maintained by grazing, extraction or burning. Sparsely vegetated habitats include cliffs, screes, volcanic deposits, moraines and snow fields, as well as weed communities. The coastal habitats include salt-marshes, sand and shingle beaches, sand dunes, coastal heath, scrub and woodland (Janssen, et al., 2016).

2.5.1 Deltas

Deltas are important depositional landforms where river mouths flow into an ocean, sea or lake. Sediments accumulated by a river determine delta formation. Rivers that flow into large lakes or inland seas tend to have extensive delta size due to the absence of strong tidal and wave forces. The Netherlands with the Rhine river delta and Bangladesh with the Ganges-Brahmaputra river delta are countries that consist almost entire of one large river delta. Besides the Ganges-Brahmaputra river delta Asia is home to several mega delta such as the Yangtze, Mekong and Irrawaddy river deltas (Box & Fujiwara, 2013).

The biggest part of the transported sediment will become submerged and washed away by the ocean in time. Where there is more space for the sediment to settle, more sediment will remain part of the subaqueous part of the delta and may become subaerial in time. The subaerial part of a delta is the delta plain, which is a seaward extension built by the river sediment. Depending on delta type and climate, the delta may have fluvial channels, tidal flats, wetlands, bays, lakes, beaches and dunes. The subaerial delta is divided in the upper and the lower delta plain. Freshwater fluvial processes dominate the upper delta plain and tidal brackish-to-saline environments dominate the lower delta plain (Roberts, Weimer, & Slatt, 2012). River deltas are important locations for migratory birds and have historically been home to large mammals before extensive human intervention (Campbell, 2012). Biodiversity of the lower delta plain is mainly described at *Estuaries, Tidal flats* and *salt marshes* (2.1.1-3). Biodiversity of upper delta plains differs from the lower delta plain with the presence of freshwater loving flora and fauna (Franckx, 2007).

2.5.2 Coastal dunes

Coastal dunes, occupying transitional zones between terrestrial and marine habitats, are one of the most dynamic and irregular landscapes on Earth (van der Meulen & Udo de Haes, 1996).

Coastal dunes vary in size from hummocky incipient dunes to massive dune complexes more than 50 meters tall. The size and location of coastal dunes are influenced by wind regimes and the frequency of disturbances like overwash (Barrineau, et al., 2015). Vegetation of coastal dunes is generally depended on nutrient availability, as well as morphodynamic conditions influenced by sedimentation and erosion. The vertical zonation of vegetation is related to the depth of the water table (*ibid*). Coastal dunes host specialized flora and fauna that are often endemic to the coast (van der Meulen & Udo de Haes, 1996).

2.5.3 Beaches

Sandy beaches dominate the ocean shorelines of all temperate and tropical continental coasts. Beaches are sandy (or gravel) areas at the intersection of the sea and the shoreline, roughly located within the intertidal area. Beaches form at areas where the sediment is coarse sand or coarser. Beaches also form at locations with finer sediment, given that the wave height is insufficient to erode the sediment (Short, 2008). The morphology and dynamics of a beach can be defined in terms of three interacting factors: tides, waves and particle size (McLachlan & Defeo, 2013). During a storm the wave height and energy increases, thus being able to erode more and bigger sediment from the beach. Beaches tend to have no vegetation unless some hardy pioneer plants that are able to withstand frequent storm and tidal inundation and salt spray (Barrineau, et al., 2015). The three defining factors (tides, waves and particle size) have high predictive power to estimate the species richness of a beach. Tropical beaches support more species than temperate beaches and longer beaches support a greater abundance of species than short (*ibid*). Beaches are widely valued for their aesthetic and recreational value, but also have great value for several species such as sea turtles and seals as a breeding location (Patel, et al., 2016). Beaches are threatened by the coastal squeeze, becoming trapped between the marine side and expanding development along the shoreline (Barrineau, et al., 2015).

2.5.4 Barrier islands

Barrier islands are one of the most dynamic environments on Earth. Small strips of sand islands in the sea affected by sea level, sediment supply and accommodation space. They are the dominant coastline type along the Atlantic and Gulf coast of the United States (Hayes, 2005). Barrier islands form a barrier alongside shorelines, creating sheltered bays or marshes between the island and the shoreline. Forming along shorelines with low tidal range and moderate to high wave energy, barrier islands are a natural coastline protection (*ibid*).

2.5.5 Strand-plains

Just like barrier islands, strand-plains are formed almost entirely by marine processes. They differ from barrier islands in their lack of a lagoon or marsh separating them from the mainland. Strand-plains have no tidal channel inlets that infiltrate salt water into the ecosystem (McCubbin, 1982). Strand-plains are dynamic environments that often lack vegetation that is able to constrain its movement. Due to their dynamic character strand-plains are often foretasted to alter their movement, causing a strong change in its ecosystem. Vegetation at strand-plains must be able to tolerate rapid sand accumulation, flooding, salt spray, sandblast, wind and water erosion, drought and low nutrient levels (Strat, 2013).

2.6 Threats to coastal marine habitats

For this thesis several threats to coastal marine habitats are used to calculate a cumulative impact score. The stressors that are used are 'sea level rise', 'light pollution', 'nutrients pollution', 'organic pollution' and 'inorganic pollution'. The stressors that couldn't be used for this thesis (see 7.1) are 'direct human impacts', 'oil rigs', 'invasive species' and 'artisanal fishing'. This section informs the reader about all of these nine stressors.

2.6.1 Sea level rise

Coastal marine habitats are, together with *direct human impacts* (see: 2.5.6), most vulnerable to *sea level rise* (Halpern, et al., 2015). Sea level rise can be devastating to every single coastal marine ecosystem. Sea level rise raises the ocean, submerging habitats more than they once were. This partly cuts off the supply of sunlight to seagrass beds, coral reefs (Perry, et al., 2018) and kelp forests. It also means that habitats that were partly submerged will become entirely submerged or submerged for a longer period of time during tidal periods, mangroves for example (Albert, et al., 2017). All of these changes will degrade the ecosystem services these habitats provide, mainly due to the rate of the sea level rise in opposition to the capability these habitats have to change. Sea level rise does, however, pose new opportunities to these habitats because of the changing shoreline. If the dynamic shorelines will be given the freedom it needs then this threat could offer chances for coastal habitats (Albert, et al., 2017).

Sea level rise originates from a net surplus of meltwater from land- and ocean based glaciers. Generally an increase of local air and water temperature causes an increase in the melting rate of glaciers. Ocean based glaciers increase their speed towards the ocean and their thickness decreases as well (Allison, Colgan, King, & Paul, 2015). Land based glaciers melt under increased temperatures and their meltwater is transported to the ocean by rivers (*ibid*)**.** The global sea level will rise when insufficient snowfall is able to add on top of these glaciers, snowfall that normally contributes to the growth of the glacier.

2.6.2 Light pollution

Light pollution at marine habitats has effect on biological systems in a myriad of ways. Natural, celestial, light is used by many sea creatures for navigation. The disruption of natural levels of light can cause disorientation and can alter the composition of invertebrates communities and daily routine. Known examples of disruptions in the environment by light pollution also include seabirds colliding with offshore platforms and the disruption of zooplankton feeding cycles (Depledge, Godard-Codding, & Bowen, 2010; Davies, Duffy, Bennie, & Gaston, 2016). The best known example of light pollution at coastal habitats must be the disorientation of turtle hatchlings and adults. Here the adults misinterpret the safety of a beach due to light pollution at beaches, and turtle hatchling misinterpret the artificial light for the ocean (Depledge, Godard-Codding, & Bowen, 2010; Davies, Duffy, Bennie, & Gaston, 2016).

Light pollution is mainly a concern for coastal habitats because the source of the light pollution is land based. Off-shore oil rigs also cause light pollution, but at a lower quantity than land based light pollution (Depledge, Godard-Codding, & Bowen, 2010). Densely populated coastal areas create great amounts of unnatural light, disturbing coastal marine habitats.

2.6.3 Nutrients pollution

The input of excessive nutrients into aquatic habitats is a strong catalyst for eutrophication. Eutrophication is the enrichment of the environment with nutrients and the undesirable effects that these inputs have on its environment. Aquatic habitats are naturally limited by nutrient enrichment (mainly nitrogen and phosphorus), when these limits cease to exist the natural processes change (de Jonge & Elliott, 2008). Bacterial remineralization of large amounts of organic matter depletes the water of oxygen (Puccinelli, Noyon, & McQuaid, 2016). When water is depleted of oxygen dead zones are formed, these zones have significant amounts of decreased biodiversity. Studies have highlighted the indirect effects of eutrophication on the productivity of benthic primary producers. With eutrophication phytoplankton increase productivity, which causes the attenuation of light penetration in the water column (*ibid*).

Urban and agricultural runoff has been linked to anthropogenic nutrient build up in coastal waters. Agriculture is pointed out as the biggest driver of eutrophication worldwide (Puccinelli, Noyon, & McQuaid, 2016). The nutrients that enter coastal habitats vary widely but nitrogen and phosphorus are the most problematic. These nutrients are used for agriculture (fertilizers) to stimulate growth of crops, but not all nutrients are absorbed by the crops. Large amounts of these nutrients enter the groundwater system or are washed away by rainfall in order to enter local streams or lakes. These streams eventually carry the nutrients into the oceans (de Jonge & Elliott, 2008). Observed eutrophication at the Great Barrier Reef corresponded with higher levels of nitrogen and phosphorus while the amount of nutrients found at the Great Barrier Reef was very low. This suggests a high vulnerability of coral reefs to eutrophication (Chen & Krol, 2004).

2.6.4 Organic pollution

Organic pollutants are chemical compounds that have a C-H bond that are harmful to the environment. The biggest source of organic pollutants is pesticides used for agriculture (Halpern, et al., 2008), but many industrial processes generate organic pollution as well (World Ocean Review, 2010).

The fate of organic pollution is determined by uptake and excretion. When a substance has entered the system of an organism the substance can affect certain sites of the organism. Certain sites of the metabolism of the organism may detoxify the substance, or the chemical may act upon the organism. The locations where the chemical acts upon the organism will lead to toxic manifestations that could affect the entire organism. Some organisms falsely ‘recognize’ pollutants and store them in their tissues. Here the pollutant neither acts upon the organism, and neither does the organism act upon the pollutant. The storage of these pollutants can however act upon the predator that consumes the organism. The last attribute of an organism that determines the fate of organic pollutants is the site of excretion. A substance can be excreted as the original substance, but is largely excreted as a different substance (Walker, Hopkin, Sibly, & Peakall, 2006).

Persistent organic pollutants (POPs) are organic pollutants that resist degradation and include pesticides and industrial chemicals. POPs can withstand the sands of time and have the ability to store in animal fatty tissues and accumulate in food chain organisms at the top of their food chain (World Ocean Review, 2010). Accumulation of POPs can cause cancer, genetic defects and weaken the immune system of organisms (Friberg, et al., 2011).

2.6.5 Inorganic pollution

Inorganic compounds are chemical compounds that lack C-H bonds. Inorganic pollutants are inorganic compounds that are harmful to the environment. Inorganic pollution includes but does not limit to heavy metals, pesticides, chlorine and perchlorate (Jin & Fallgren, 2014).

Four factors determine the fate of inorganic pollutants in contaminated habitats (Walker, Hopkin, Sibly, & Peakall, 2006). First, localization determines where the pollutant is; the whole planet, a single ecosystem, or even a single cell. Second, persistence determines the degradability of pollutants, although most metals are non-degradable, some invertebrates have shown to be able to detoxify certain metals (*ibid*). Among the most persistent inorganic pollutants are radioactive substances. Third, bioconcentration and bioaccumulation factors determine how harmful an inorganic pollutant is to certain animals. An animal with a high bioconcentration factor to lead will efficiently accumulate lead to its body and will be poisoned quicker. The bioaccumulation of particular substances determines how easily a substance is accumulated and how quick this substance will be excreted by the body afterwards. Fourth, bioavailability determines the solubility of a substance. Generally the solubility of a metal is negatively correlated with the pH of the liquid (*ibid*).

Under the influence of hypoxia or anoxia in water bodies organic pollutants such as nitrogen and phosphate can alter and become inorganic pollutants (Puccinelli, Noyon, & McQuaid, 2016) this adds to the undesirability of eutrophication. Pollutants with higher solubility are increasingly destructive for coastal habitats. These pollutants are easily transported by water and reach oceans in higher concentrations than pollutants that have lower solubility. The greatest source of non-point inorganic pollution is assumed to origin from urban runoff (Halpern, et al., Supporting Online Material for; A Global Map of Human Impact on Marine Ecosystems, 2008).

2.6.6 Direct human impacts

Direct human impacts on coastal habitats are direct changes in the natural environment by the human species. These changes include damming and other water development, deforestation, forest fragmentation, habitat conversion to agriculture (especially in deltas), and wetland drainage (Ehrlich, Kremen, & Ehrlich, 2013). These impacts are currently among the biggest threats to coastal marine habitats (Halpern, et al., 2015) as they destroy non-human habitats thus reducing them in size and often fragmenting them. This results in an increase of vulnerability of all organisms that live in these habitats.

2.6.7 Oil rigs

The presence of oil rigs have a predominantly negative impact on coastal habitats. Oil rigs are placed on the benthos, destroying the local habitat. The mined oil needs to be transported to adjacent land through pipes and other benthic structures. The placement of these pipes requires the digging of canals through wetlands and other coastal habitats. In addition to the placement of these structures, these structures need maintenance. This means an array of negative environmental impacts related to transport and the construction of dams and canals. Oil production in the Louisiana wetlands for example have accounted for 80% of the total wetlands losses in the United States (Priest & Theriot, 2016). In addition, the mining of oil at sea cause seismic noise pollution, disorienting whales and other marine animals (Griffin, 2018). And finally there is the risk of an oil spill while drilling for oil. The pollutants that enter the ocean and the food web during an oil spill can have extensive and continuous negative effects on marine and terrestrial habitats (Yan, et al., 2016).

2.6.8 Invasive species

An invasive species is one that arrives (often with human assistance) in a habitat it had not previously occupied, then establishes a population and spreads autonomously (Simberloff, 2010). Not all introduced species become invasive species that spread autonomously. Often garden plants or other introduced species can’t persist without human aid.

The introduction of alien marine species occurs mainly by transporting these species in the ballast tanks of ocean vessels. Sea vessels that are not fully loaded with cargo are instable. To increase stability, the ballast tanks are filled with ocean water. This water is discharged when the ships enters the next port when a change in cargo size occurs (Halpern, et al., Supporting Online Material for; A Global Map of Human Impact on Marine Ecosystems, 2008; Ehrlich, Kremen, & Ehrlich, 2013). The content of the discharged ballast water is then able to compete with the local flora and fauna. Ports are the location where the largest amount of alien terrestrial species penetrate local habitats as well (Ehrlich, Kremen, & Ehrlich, 2013).

2.6.9 Artisanal fishing

Artisanal fishing is small-scale fishing using traditional methods. Besides the use of motorized boats and modern materials, many artisanal fishing practices have changed little over the past centuries (Hawkins & Roberts, 2004). Although artisanal fishing is often associated with having a low impact on its environment, several studies have demonstrated significant impacts from artisanal fishing on coral reefs (Adam, Anderson, & Shakeel, 1997). Jennings and Polunin (1996) concluded that removing just 5% of fish biomass could have the ability of significantly altering the structure of coral fish communities. The reason is that fishing preferably targets, and depletes, predatory species, species that have an important role in the fish communities.

Data on the size of artisanal fishing is not available at a global scale. A multivariate analysis by Halpern, et al. (2008) pointed out that a very simple model can explain 79% of the variance. This model contains only two variables, length of coastline and unemployment rate (Halpern, et al., Supporting Online Material for; A Global Map of Human Impact on Marine Ecosystems, 2008).

2.7 Threats to coastal terrestrial habitats

The coastal marine stressors that will be used for this thesis are modelled as coastal terrestrial stressors as well. In addition to the five stressors that will be used (2.7.1-5) several other threats to coastal terrestrial habitats will be discussed as well, these are ‘land use’, ‘human population’ and ‘invasive species’.

2.7.1 Salt water intrusion

Sea level rise does not solely affect marine habitats. Areas that are close to the ocean may experience saltwater intrusion or erosion. Levels of erosion depend on the soil type, incline of the shore, wave height, tide difference and many other factor. For this reason only salt water intrusion will be modelled in this thesis. Salt water intrusion occurs especially when agricultural lands lie below sea-level and are in close proximity to the dyke that protects it from flooding. Often ocean water is connected to groundwater, because ocean water is heavier (due to the salinity) than fresh water it is able to perform pressure on the fresh ground water at the ‘land side’ of the dyke (Bedford, Leopold, & Gibbs, 2013). This salt water intrusion has the ability to decrease habitat productivity and corrupt drinking water (Nguyen, Kamoshita, Dinh, Matsuda, & Kurokura, 2017). The corruption of drinking water is a great concern for cities that have their drinking water source located nearshore, which is always the case for small islands (Gillespie, 2013). Besides the hydraulic connection between the ocean and ground water, the contamination of fresh water is caused by flooding as well. Coastal aquifers with a freshwater recharge on the inland side are normally well protected against saltwater intrusion. The freshwater recharge gives enough pressure to prevent intrusion (Henry, 1964). The likelihood of salt water intrusion can increase due to several events that decrease the freshwater pressure such as land subsidence, land reclamation and drainage, urban and industrial development, gas and deep groundwater extractions, and coastal dune destruction

(Giambastiani, Antonellini, Oude Essink, & Stuurman, 2007).

Salt water intrusion is a complex problem. The rate at which saltwater intrudes a coastal aquifer depends on whether it is a confined or unconfined aquifer, the geological morphology of the local soil, and the hydraulic drive of groundwater flow (Gillespie, 2013).

In large cities in coastal regions such as Dar Es Salaam, Tanzania, pressure on groundwater levels is increasing (Mtoni, et al., 2015). About 75% of the 4 million population depends on groundwater for its drinking water supply. Drillings have observed that up to a distance of 2 kilometres from the shoreline saltwater pollution occurs. This is a major issue for Dar Es Salaam and several other coastal populations. The Netherlands is expected to have future catastrophic problems with saltwater intrusion as well. A large part of the country lies below sea level and continues to sink due to natural and anthropogenic causes (Oude Essink, 2001).

2.7.2 Light pollution

Stable night lights originate from anthropogenic and natural sources. The stable night light product, an online dataset, detects lights from urban settlements, industrial sites, gas flares and wild fires, as well as reflected light from moonlit clouds. Increased night lights are linked to increased economic activity on the ground (Geldmann, Joppa, & Burgess, 2014). The negative effects of night lights on organisms include habitat displacement, modulations in reproductive development, disruption of navigation, activity pattern shifts and disrupts ecosystem service provisioning (Davies, Duffy, Bennie, & Gaston, 2016). Light pollution is said to affect almost every species on Earth (Longcore & Rich, 2004). Species that are nocturnal (active at night) depend on their well-developed sensory senses to gather food. Species that are diurnal (active at daytime) mainly depend on the night for shelter (Longcore & Rich, 2004; Davies, Duffy, Bennie, & Gaston, 2016). Research suggests that non-tropical habitats are less vulnerable to light pollution than tropical habitats thanks to their acquaintance with seasonal variability of daylight (Longcore & Rich, 2004).

2.7.3 Terrestrial nutrients pollution

There is no global stressor data available on the impact of nutrients pollution on terrestrial habitats. There is, however, the knowledge that 50% of the habitable land on Earth is used for agriculture and only 1% is used for built-up area (Roser & Ritchie, 2018), and the knowledge that the majority of the excessive nutrient inputs comes from agriculture (Puccinelli, Noyon, & McQuaid, 2016).

Nitrogen and phosphorus from agriculture enter the environment through manure and fertilizers (Sharpley, 2013). The eutrophication it causes at marine habitats occur widely throughout freshwater sources as well (Carpenter, et al., 1998; Heathwaite, Quinn, & Hewett, 2005). Excessive nitrogen and phosphorus in drinking water can cause numerous health issues to humans and animals as well (Sharpley, 2013).

Nitrogen is highly soluble and easily washes off the agricultural lands to enter local stream and water bodies. The eutrophication it causes is a major contributor to water pollution worldwide (Caruso, O’Sullivan, Faulkner, Sherratt, & Clucas, 2013). Freshwater pollution is not only problematic to biodiversity, but to humans as well since it affects the quality of drinking water (Sharpley, 2013). Nitrogen can bind with the atmosphere as well, and forms NH_3 (ammonia) and NO_x (nitrogen oxides). Agriculture is the largest source of anthropogenic air pollution of NH_3 and causes soil acidification. NO_x is a source of acidification as well as eutrophication (Sharpley, 2013). A small part of the nitrogen enters the soil and makes its way slowly to the groundwater, causing the eutrophication of groundwater.

Phosphorus from agriculture is not as soluble as nitrogen and mainly enters the soil at agricultural locations (*ibid*). The phosphorus enters the groundwater and contributes to the eutrophication of groundwater. The fate of phosphorus and nitrogen is strongly diffused, making it not straightforward to assess. It depends on soil type, climate, topography, hydrology, and land use and management. This creates a widespread and poorly defined impact on water quality (Heathwaite, Quinn, & Hewett, 2005).

2.7.4 Terrestrial organic pollution

There is no global stressor data available on the impact of organic pollution on terrestrial habitats. There is, however, the knowledge that 50% of the habitable land on Earth is used for agriculture and only 1% is used for built-up area (Roser & Ritchie, 2018), and the knowledge that the majority of the excessive organic pollution comes from agriculture (Puccinelli, Noyon, & McQuaid, 2016).

Organic pollution that is transported to the ocean by different water sources (see: 2.6.4) largely originates from extensive agricultural pesticides use, but also from improper sewage and sewage ruptures (Zeng, Zhou, Zhou, & Jia, 2016). Organic pollution in freshwater sources can contribute, like at marine habitats, to eutrophication. Pesticides are the most cost-effective means of pest and weed control, but the repetitive use causes concern about the soil and groundwater quality. How long pesticides reside in the soil depends on the pesticide type (how strongly it binds to the local soil type), but also on environmental conditions such as soil water content, soil type, and pH (Arias-Estévez, et al., 2008).

The ideal pesticide should only affect the targeted organisms, should be biodegradable, and should not leach into the groundwater. Unfortunately this is rarely the case (Johnsen, Jacobsen, Torsvik, & Sorensen, 2001). They affect non-target vegetation and organisms, where they contribute to increased organism death rates and growth limitations (Aktar, Sengupta, & Chowdhury, 2009; Sharpley, 2013). The effect of pesticides on microbial community structure and activity in soil is extremely difficult to grasp. Research (Jacobsen & Hjelmso, 2014) shows that several pesticides have an influence on several microbial biodiversity. Where microbial activity is linked to soil fertility (Gong, Sun, Beudert, & Hahn, 1997). However, the soil is believed to have such a large microbial biodiversity that the influence of pesticides on the overall microbial biodiversity is limited.

2.7.5 Terrestrial inorganic pollution

There is no global stressor data available on the impact of inorganic pollution on terrestrial habitats. There is, however, the knowledge that 50% of the habitable land on Earth is used for agriculture and only 1% is used for built-up area (Roser & Ritchie, 2018), and the knowledge that a great amount of the inorganic pollution comes from urban runoff and industry (Puccinelli, Noyon, & McQuaid, 2016). Agriculture is a source of inorganic pollution as well (*ibid*), but this is mainly caused by organic pesticides that are transformed to inorganic molecules through soil and solubility processes (Nicholson, Smith, Allwoay, Carlton-Smith, & Chambers, 2003). Inorganic pollution, mainly heavy metals, is linked to microbial soil activity (Gong, Sun, Beudert, & Hahn, 1997). Once the inorganic pollutants enter the soil the productivity of the ecosystem is affected and might even collapse. The impact of inorganic pollution is affected by several biotic and abiotic factors such as microbial type, soil type, seasonality, and the interaction with other pollutants.

The largest source of inorganic pollution is urban runoff (Gong, Sun, Beudert, & Hahn, 1997). At urban areas several sources of inorganic pollution exist such as; transportation (Viwkomirski, Sudnik-Vójcikovska, Galera, Vierzbick, & Malavska, 2010), sewage (Gong, Sun, Beudert, & Hahn, 1997), and industry (Biasoli & Ajmone-Marsan, 2007). In their research, Halpern, et al. (2015) solely used urban runoff as an input to model inorganic pollution at river mouths (Halpern, et al., 2008).

The urban environment is a major source of inorganic pollution since built-up areas mainly retain their location. This way the pollution accumulates and the pollution becomes worse over the decades. This is shown in a study researching the dangerous contamination of urban historical parks in comparison with more recently created urban parks. The historical parks had a much higher level of pollution since it has been accumulating over the decades (*ibid*). Since the majority of the urban environment is not a park but buildings and roads, the pollution from transportation usually gets washed off by rainfall, entering the local water system (Gong, Sun, Beudert, & Hahn, 1997). Part of the urban environment is sewage. Sewage, when treated poorly or not treated at all, holds various inorganic pollutants as well (*ibid*).

Industry and mining are sources of several heavy metals as well (Jung & Thornton, 1996; Yousaf, et al., 2016). The intensity of the inorganic pollution at industry is generally higher than at other built-up areas, but the pollution from industry mainly accumulates in the soil, which makes it harder to observe. This makes industry a threat to soil quality as well as water quality, given the fact that inorganic pollution can cause microbial ecosystems to collapse and the fact that this pollution eventually end up in local water systems (see: 2.6.5).

Agriculture accounts for inorganic pollution as well (Nicholson, Smith, Allwoay, Carlton-Smith, & Chambers, 2003). Inorganic fertilizers, sewage sludge, livestock manures, agrochemicals, and atmospheric deposition are all agricultural sources of heavy metals (Zn, Cu, Ni, Pb, Cd, Cr, As, and Hg). Usually these pollutants have a low mobility and low plant uptake, resulting in a slow accumulation of toxic heavy metals. Modern pesticides are mainly organic pesticides, the earlier pesticides were inorganic pollutants which are currently little used (Eldridge, 2008).

2.7.6 Land use

29% of our planet is land, 71% of which is habitable land. Of the habitable land of Earth 50% is used for agriculture, 37% are forests, 11% are shrub lands, 1% is built-up urban land and 1% is Freshwater. Agriculture consists of all cultivated lands such as livestock, crops for livestock, crops, and production forests (Roser & Ritchie, 2018).

Biodiversity loss and landscape patterns have been widely associated at several terrestrial habitats (Malavasi, Bartak, Carranza, Simova, & Acosta, 2018). Landscape ecologists widely agree that the biodiversity of species is affected by two aspects of landscape pattern: composition and configuration (Carranza, Hoyos, Frate, Acosta, & Cabido, 2015). Composition is the type and amount of habitat and configuration is the degree of habitat fragmentation. Loss of habitat and habitat fragmentation often happen simultaneously and are pointed out as two of the most important factors of biodiversity loss (Fahrig, 1998).

A major land use category that degrades habitats on our planet is agriculture (Pringle & Triska, 2000). This is due to the sheer size of the allocation of habitable land for agriculture (Roser & Ritchie, 2018) and also due to the destructive nature of agriculture (Pringle & Triska, 2000; Benke & Cushing, 2005). Agriculture generally requires high amounts of groundwater (Pringle & Triska, 2000), replaces (destruction) and fragments habitats and is a major cause of pollution (nutrients, organic, inorganic) (Benke & Cushing, 2005).

2.7.7 Increase in human population

Increases in human population is linked to a myriad of negative impacts on terrestrial habitats including increased- pollution, habitat destruction, land use and depletion of water sources (Geldmann, Joppa, & Burgess, 2014). Overall, countries with greater increases in coastal population had larger 5-year changes in cumulative impacts. Absolute coastal population size was unrelated to change in cumulative impact. Nevertheless, many places that are largely uninhabited or have relatively low population densities still experienced large increases in impacts. Suggesting that population size may not always drive decreases in ecological conditions (Halpern, et al., 2015). These findings suggest that the increase of a population also has negative effects on uninhabited parts of Earth. It also suggests that the cumulative negative effects on a local ecosystem increases with an increased population density. But, Geldmann, Joppa, and Burgess (2014) suggest that the impact per person decreases with an increase in population density. The fact that population tends to concentrate at coastal regions (Halpern, et al., 2015) suggests that population density increases affects coastal regions more than other regions of Earth.

2.7.8 Invasive species

Invasive species are one of the most important engines of ecosystem modification. Especially for islands alien species can be devastating. There have been several occasions where humans introduced, willingly and unwillingly, species to an island and the entire population of a native species was destroyed. Examples vary from Philippine brown snakes devouring the avifauna of Guam and mosquitoes carrying malaria to Hawaii to exterminate almost the entire native bird population (Ehrlich, Kremen, & Ehrlich, 2013). For continents alien herbaceous plants have had devastating effects as well. Introduced European weeds have replaced Californian grasslands. By displacing native species these habitats will simplify, thus becoming more vulnerable to impacts such as climate change (*ibid*).

Thousands of species have been intentionally introduced because of certain properties that these species possessed (Pimentel, 2013), mainly to grow food and to counter pests. Besides the unintentional side-effects that the intentional invasive species may have, numerous species have been introduced unintentionally as well. These invasive species can cause major economic losses in agriculture, forestry, and other segments of the world economy (*ibid*). Besides enormous economic losses, habitats are affected by alien species as well. Overgrazing by herbivorous invasive species causing soil erosion, predation of indigenous species by carnivorous invasive species, the spread of foreign diseases (Philpott, 2013), overshadowing by invasive plant species, and the superior ability to recover after natural fires causing displacement (Simberloff, 2010) are examples of numerous effects that invasive species can have on habitat biodiversity. The impact of native species on habitats biodiversity is very extensive (Simberloff, 2010; Philpott, 2013; Halpern, et al., 2015), making them extensively studied. These studies have discovered complex interactions between several invasive species that affect biodiversity in ways that are often unnoticed (Simberloff, 2010).

Similar to marine invasive species, ports are the most predictable location where terrestrial invasive species invade habitats (Simberloff, 2010; Pimentel, 2013; Halpern, et al., 2015). Ships transport various types of cargo that can be contaminated with various intentional and unintentional invasive species. From these ports railroads often transport the cargo from the coastal region to the hinterland (Simberloff, 2010). The likelihood that an ecosystem will be affected by invasive species increases with an increase in the number of species that are introduced to the ecosystem (Costello, Springborn, McAusland, & C. & Solow, 2007).

Chapter 3: Methodology

This chapter discusses the methodology of this thesis. The philosophical stance is discussed (3.1), the research design (3.2) discusses the research area, the units of analysis and the sampling procedure. Section 3.3 discussed the data management done for this thesis. The construction of the integrated vulnerability indexes is discussed as section 3.4, the how the results are presented and analysed is discussed at section 3.5 and finally the research questions are presented (see 3.6).

3.1 Philosophical stance

For this thesis certain assumptions are made. The assumptions concern the influence that we have on our environment and how this environment reacts to this influence. How this thesis stands based on these assumptions is discussed here.

Positivism considers the natural world to exist independent of human conception, resulting in measurable objective facts (Guba & Lincoln, 1994). This thesis considers these measurable facts to be quantifiable and that these can be used to construct the cumulative human impact map. The stressors used for this thesis are selected, but this selection is not entirely objective. Humans observe natural phenomenon such as the decline of biodiversity, but the full scale of what biodiversity entails on Earth has not been acquired (Swingland, 2013). In addition, the full scale of natural processes such as adaptation and resilience of habitats is not fully understood yet either (Sanderson, et al., 2002; Hooper, et al., 2005; Swingland, 2013). Finally, there is a possibility that several threats to biodiversity are unknown to humans or are overlooked since humanity does not experience these threats equally as certain habitats do (*ibid*). It is important to be aware of the limitations of the stressors that are used for this thesis. In addition, the interaction that humanity has (threats) with the environment (biodiversity), doesn't change the way the environment reacts to these threats. Objectivism believes that phenomenon exist independent of humanity (Slevitch, 2011), the environment is influenced by humanity and how the environment reacts to this is obedient to certain laws.

3.2 Research design

This section discusses the research design of this thesis. The research area is discussed (see 3.2.1), the units of analysis (see 3.2.2) are presented and the conceptualization of the anthropogenic threats (see 3.2.3) and the following sampling procedure are discussed (see 3.2.4), the sources for the habitat vulnerability indexes are discussed (see 3.2.5) and finally the data sources are presented (see 3.2.6).

3.2.1 Research area

For this research the anthropogenic impacts on the research area will be analysed. This area is limited to a bathymetry of -60 meters from shore and extends on to land up to an altitude of 60 meters as well. Some areas between 0 and 60 meters altitude extend very far land inwards so the distance from shore has to fall within the MEOW dataset, which extends up to 140km land inwards. Additionally, some areas quickly rise to an altitude above 60 meters from shore, so a maximum distance to shore of 40 kilometres is included in the research area as well. With this exact definition of the coastal zone the impact on coastal habitats can be quantified and compared across Earth.

Coastal marine ecosystems are generally limited to a bathymetry of 50 meters, with some exemptions of very clear waters where these can reach up to 60 meters, for this reason this bathymetry is used (Duarte, 2013; Knowlton & Jackson, 2013). The definition of the coastal zone on land differs per scope of a research (Matthews, 2003), because this thesis aims to create a map that visualises the impacts on the marine and terrestrial habitats equally the altitude of 60 meters is used. The marine and terrestrial datasets will be separately modelled either on water or land, this way excluding overlap. The datasets are added together to create an integrated map to quantify the cumulative impacts.

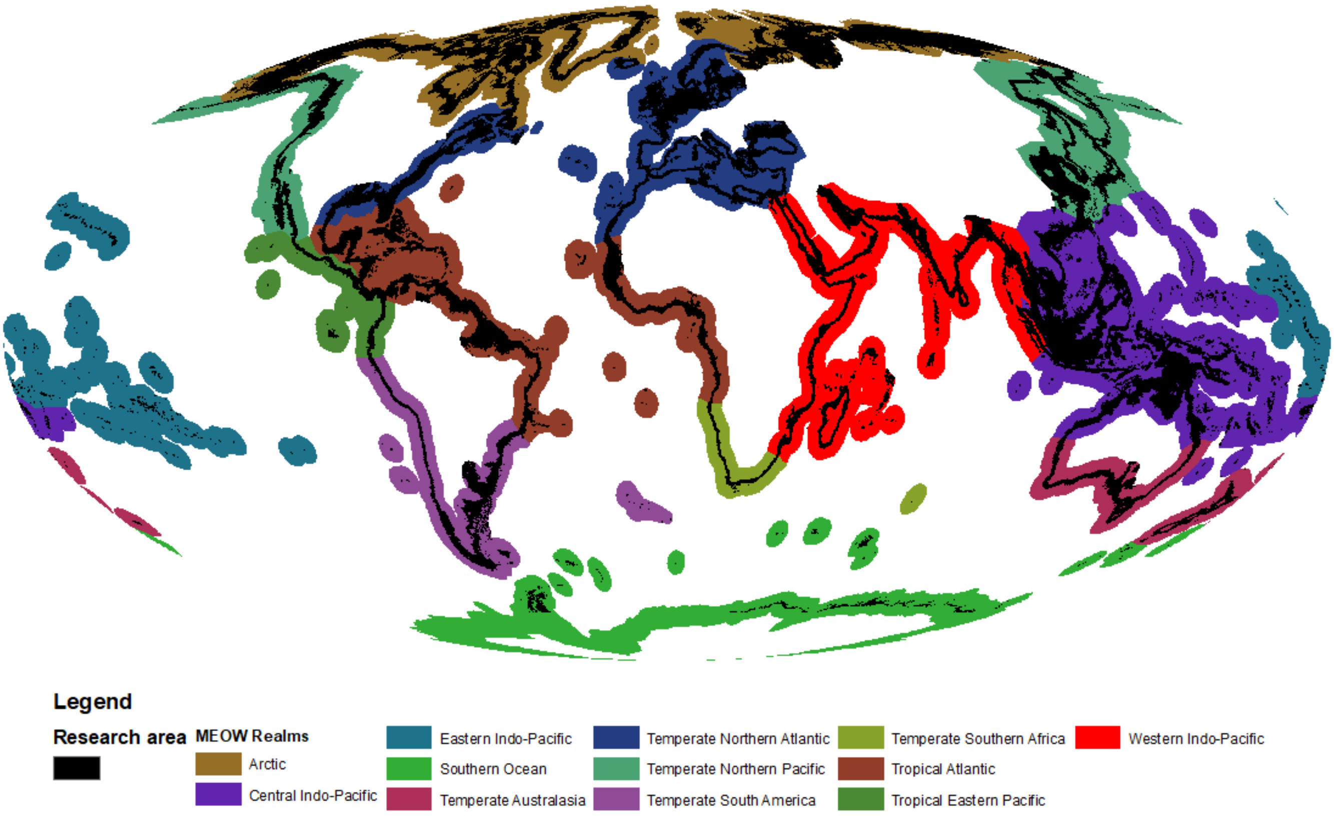
3.2.2 Units of analysis

The units of analysis are the MEOW Realms as defined by Spalding et al. (2007) (see: 2.2). These Realms will be used to quantify the impact of each stressor. The marine Realms are based on climatic geographical zones on Earth, the regions are (in alphabetical order) listed below;

Arctic
Central Indo-Pacific
Eastern Indo-Pacific
Southern Ocean
Temperate Australasia
Temperate Northern Atlantic
Temperate Northern Pacific
Temperate South America
Temperate Southern Africa
Tropical Atlantic
Tropical Eastern Pacific
Western Indo-Pacific

A visualization of the MEOW Realms and the research area can be seen at figure 3.1.

Figure 3.1: The research area within the units of analysis



One level below the Realms are the Provinces, there are 62 Provinces (61 of which contain stressor data). And the lowest level being the Ecoregions, consisting of 232 Ecoregions (213 of which contain stressor data). These Provinces and Ecoregions are all based on (dis)similar biogeographic properties dividing them into smaller regions. For more specific analyses the Provinces and Ecoregions are used as well.

3.2.3 Conceptualization of anthropogenic threats

For this thesis the anthropogenic threats to coastal habitats discussed at paragraph 2.6 and 2.7 are considered. These threats have been cumulatively mapped at previous researches (Geldmann, Joppa, & Burgess, 2014; Halpern & al, 2015; Khamis, Kalliola, & Käyhkö, 2019) but haven't yet been integrated before. In order to be able to integrate the marine and terrestrial anthropogenic threats the variables will need to be made comparable. The marine threats will need a terrestrial counterpart that follows the same method of modelling. In addition the modelled intensity will need vulnerability indexes that follow the same standards as well.

It is assumed that all of the discussed anthropogenic threats have an impact on Earth's coastal habitats, but not all variables can be modelled both on land and water. For this reason the stressors need to be sampled (see 3.2.4).

3.2.4 Sampling procedure

The discussed anthropogenic stressors at paragraphs 2.6 and 2.7 are selected based on several criteria. When these criteria are met the dataset is retained, if not it is rejected.

1. Does the data have global coverage, or can the data alternatively be modelled globally?
2. Can the threat be modelled with the resources of this thesis?
3. Can the impact be modelled the same way at marine and terrestrial habitats?

For global coverage latitudes between 60° North and South are sufficient because on higher latitudes there is very limited human population and permanent ice cover makes impact modelling unreliable (Halpern, et al., 2015). The resources this thesis has are limited, only one student, no financial support, and limited time. This means that complex modelling will not be possible and neither the purchase of datasets. Finally the same threats need to be modelled on both land and sea to be able to compare their impact on land and sea.

3.2.4.1 Variable selection

For this thesis 9 marine threats to coastal habitats are considered. These threats are Sea level rise, Light pollution, nutrients pollution, organic pollution, inorganic pollution, Direct Human Impacts, Oil rigs, Invasive species, and Artisanal fishing (Halpern, et al., 2015). The considered terrestrial threats are land use, human population density, and light pollution (Geldmann, Joppa, & Burgess, 2014). For each stressor the three criteria will be tested.

The selected data will be discussed here, the rejected data is added to section 7.1.

Sea level rise

Local Sea level rise data with global coverage is available from 1993 until present (Church & White, 2011). This data can be used as a marine variable. The same data can be used to model the influence of saltwater intrusion in coastal regions. The dataset will be created from scratch, and will serve as a terrestrial counterpart to the sea level rise data as a marine variable.

Light pollution

A nightlight intensities dataset with global coverage is available (Lloyd, 2016). This data can be used as a terrestrial variable. The dataset does not include the radiance that goes out into the marine zone from settlements close to the shore. This data will need to be modelled to provide a marine light pollution variable.

Nutrients pollution

The nutrients pollution in marine habitats is available, as modelled by Halpern, et al. (2015). This dataset can be used as a variable for marine nutrients pollution. For terrestrial nutrients pollution a dataset needs to be created. This can be done by using statistics on fertilizer use per country in combination with a spatial dataset on the presence of agriculture.

Organic pollution

The organic pollution in marine habitats is available, as modelled by Halpern, et al. (2015). This dataset can be used as a variable for marine organic pollution. For terrestrial organic pollution a dataset needs to be created. This can be done by using statistics on pesticides use per country in combination with a spatial dataset on the presence of agriculture.

Inorganic pollution

The inorganic pollution in marine habitats is available, as modelled by Halpern, et al. (2015). This dataset can be used as a variable for marine inorganic pollution. For terrestrial inorganic pollution a dataset needs to be created. This can be done by using human population density, similar as Geldmann, et al. (2014) have done as well.

3.2.4.2 Acquired marine stressor data

Three modelled threats to coastal marine habitats have been acquired (Halpern & al, 2015). The marine nutrients pollution dataset was modelled from national fertilizer use that has been placed at agricultural locations. From these agriculture locations a distance decay function has been applied to calculate which quantities would end up at which river. From these rivers the transportation of the fertilizers are modelled up to the river mouth. At the marine the pollution would be modelled as a plume from the point of the river mouth with a distance decay function. The same has been done with organic pollution, based on pesticides use. Inorganic pollution has been modelled from human population, polluting the ocean the same way as nutrients pollution and organic pollution do.

3.2.5 Habitat vulnerability sources

Table 3.2 shows the marine habitat vulnerability matrix for this thesis (Halpern, et al., 2015). The matrix distinguishes 11 marine habitats that occur within the research area and gives their relative vulnerability to each of the five marine stressors. The acquired datasets from the previous section have already been multiplied by this matrix, but the modelled ‘sea level rise’ and ‘light pollution’ will still need to be multiplied by these indexes. The locations of these 11 coastal marine

Table 3.2: Marine habitat vulnerability matrix (Halpern, et al., 2015)

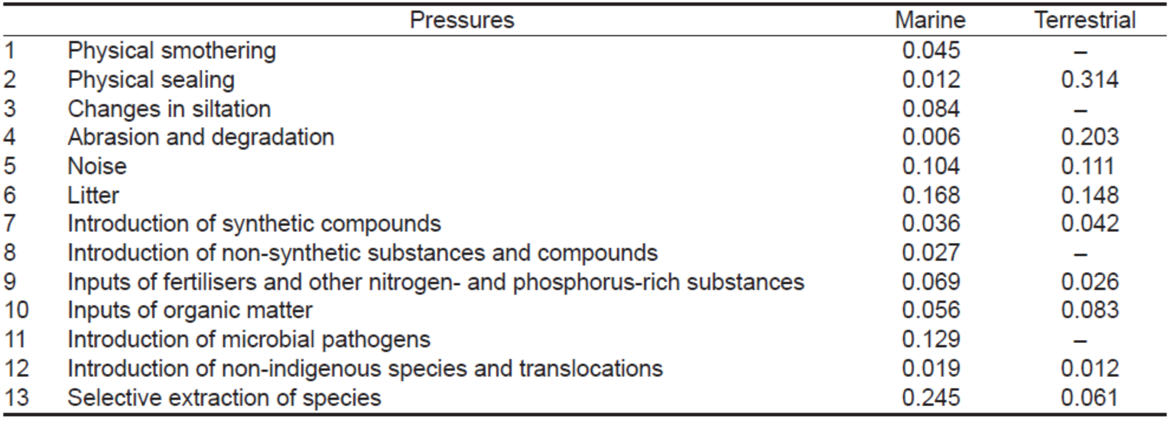
	Sea level rise	**Light pollution**	**Nutrients pollution**	**Org pollution**	**Inorg pollution**
Rocky Intertidal	2.5	1.4	1.6	2.1	2.1
Intertidal Mud	1.9	1.4	1.6	2.8	1.6
Beach	2.1	2	0.4	0.1	0.6
Mangroves	3	0.9	1.8	1.4	0.5
Salt Marsh	3.1	1.8	1.9	1.7	2
Coral	2.4	1	1.8	1.2	0.7
Seagrass	2.6	0.5	2.1	1	0.8
Kelp Forest	1.6	0.5	0.4	1	0
Rocky reef	1.5	0.7	1.6	2.2	2.2
Susp.-Feeder Reef	1.8	1	1.4	2.8	2.7
Shallow soft	2.2	0.5	2	1.2	1.5

habitats are derived from a marine habitat map (Halpern, et al., 2015). From table 3.2 the average of the vulnerability indexes of the intertidal habitats (rocky intertidal, intertidal mud, beach, mangroves, salt marsh) will be used as coastal terrestrial habitats for the creation of the terrestrial habitat map.

The Dutch governmental body of Public Health and the Environment (RIVM) has written a report on the critical nitrogen loads of several habitat groups. These habitat groups are similar to those used by the IUCN. The report by the RIVM is dedicated to the calculation of the critical loads of habitats to several pollutants, but mainly acidic rain and nitrogen depositions. The critical load of a habitat to a pollutant is the amount of that pollutant per hectare per year that can enter the habitat until the function of that habitat deteriorated. The values range from 5 g/hectare/year to 30 g/hectare/year. The lower this value, the more sensitive a habitat group is to nutrients pollution.

Khamis, Kalliola, and Käyhkö (2019) did research on the cumulative human impacts on the 'coastscapes' of Zanzibar. They used the European Union's list of anthropogenic stressors and modified them to fit the local stressors on the coast of Zanzibar. The research modelled the impact of several stressors (see table 3.3) including inputs of fertilisers and other nitrogen- and phosphorus-rich substances, inputs of organic matter, and changes in siltation. These three stressors and the vulnerability index of marine habitats and terrestrial habitats to these stressors can be used for the construction of terrestrial habitat vulnerability indexes.

Table 3.3: The weights generated from the Web-HIPRE tool using SMARTER model for individual types of human pressure on the coastscape of Zanzibar, for the marine and terrestrial environments (Khamis, Kalliola, & Käyhkö, 2019)



	Pressures	Marine	Terrestrial
1	Physical smothering	0.045	–
2	Physical sealing	0.012	0.314
3	Changes in siltation	0.084	–
4	Abrasion and degradation	0.006	0.203
5	Noise	0.104	0.111
6	Litter	0.168	0.148
7	Introduction of synthetic compounds	0.036	0.042
8	Introduction of non-synthetic substances and compounds	0.027	–
9	Inputs of fertilisers and other nitrogen- and phosphorus-rich substances	0.069	0.026
10	Inputs of organic matter	0.056	0.083
11	Introduction of microbial pathogens	0.129	–
12	Introduction of non-indigenous species and translocations	0.019	0.012
13	Selective extraction of species	0.245	0.061

The European Red List of Habitats (Janssen, et al., 2016) contains valuable information on the vulnerabilities of terrestrial habitats to anthropogenic stressors as well. Per habitat group they have researched how many habitats within the habitat group are vulnerable to which threats (anthropogenic and natural). The habitat groups are Freshwater, Mires and bogs, Grasslands, Shrub habitats, Forests, Sparsely vegetated habitats, and Coastal habitats. The results of this report are found in diagram 3.4. Several of these threats can't be used for this thesis, but some can provide useful information on how vulnerable certain habitat groups are to certain threats and how these vulnerabilities compare to other habitat groups.

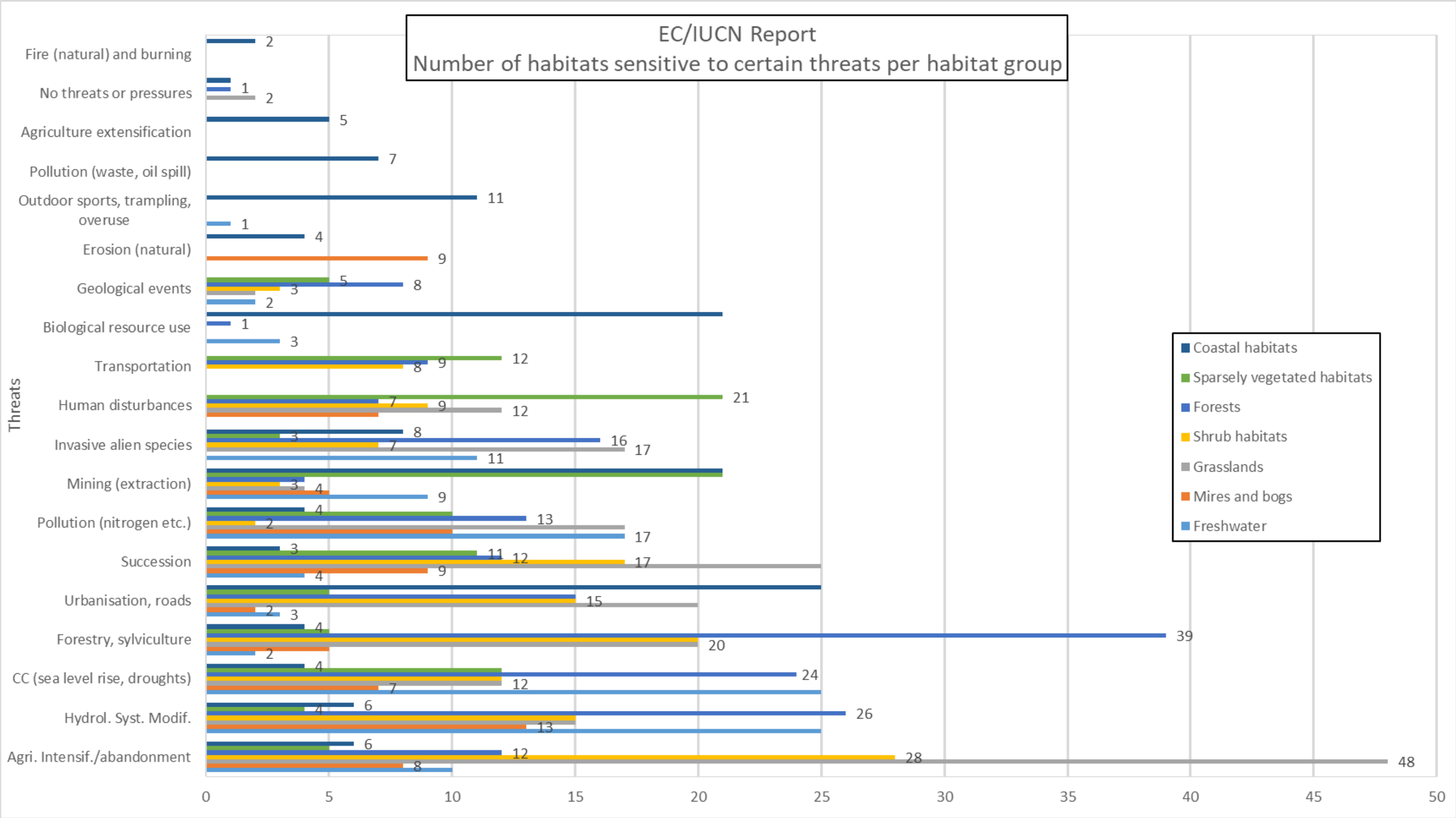


Diagram 3.4, EC/IUCN report on the number of habitats sensitive to certain threats per habitat

3.2.6 Data sources and properties

This thesis makes use of several datasets. Table 3.5 provides a good view of which ones they are, where these are found, what its coverage is, for what model it is used and from when the data stems.

Table 3.5: Data sources used for this thesis, with name, resolution, coverage, source, purpose, and year.

#	Dataset	Spatial resolution	Coverage	Reference	Link	Used for	Year
1	GSHHS World political boundaries	Shapefile	Global	(Wessel & Smith, 2017)	link	All	2010
2	Marine Ecoregions	Shapefile	Global	(Spalding, et al., 2007)	link	Research area, units of analysis	2007
3	Bathymetry & elevation data	1 arc minute		(Smith & Sandwell, 1997)	link	Research area, terrestrial sea level rise	1997
4	Anthromes	5 arc minute	Global	(Ellis, Klein Goldewijk, Siebert, Lightman, & Ramankutty, 2010)	link	Terrestrial- nutrients and organic -pollution, Sea Level Rise,	2000
5	Nightlights	0.5 arcminute	60°S to 75°N	(Lloyd, 2016)	link	Terrestrial & marine lights pollution	2013
6	Human Population Density	5 arc minute	Global	(CIESIN-SEDAC, 2015)	link	Terrestrial- Inorganic pollution & Sea Level Rise	2015
7	Local Sea level rise	1° x 1° grid	65.5°S to 65.5°N	(Church & White, 2011)	link	Terrestrial & marine sea level rise	1993-2015
8	National Fertilizer use	National figures	Global	(FAO, 2015) (TradingEconomics, 2019) (WorldBank, 2019)	link	Terrestrial nutrients pollution	2015
9	National pesticides use	National figures	Global	(FAO, FAOSTAT: Pesticides Use, 2019)	link	Terrestrial organic pollution	2015
10	Marine- nutrients, organic, inorganic -pollution, oil rigs	5 arc minute	Global.	(Halpern, et al., 2015)	link	Marine- nutrients, organic, inorganic -pollution, marine light pollution	2013
11	Marine habitats	5 arc minute	Global	(Halpern, et al., 2015)	link	Sea level rise, Light pollution	2013
12	Terrestrial habitats	10 arc-seconds	Global	(ESA, 2010)	link	Terrestrial threats	2010

3.3 Data management

This thesis aims to create an integrated global cumulative threats to coastal habitats map. It makes use of existing data when possible, and creates the data that isn't available. The datasets that are not created from scratch are the marine- nutrients, organic & inorganic -pollution datasets, the marine sea level rise dataset, and the terrestrial light pollution dataset. This section informs the reader about the data management that is done to make use of the available datasets and about the data management done to create the remainder of the anthropogenic threats. A more precise and technical description of the data management can be found at the Appendix (see 9.1-9).

3.3.1 Research area

The datasets and shapefiles that are used to create and determine the research area are bathymetry & elevation, World Topo, and the Marine Ecoregions Of the World (MEOW) (see table 3.5). First, a Boolean raster from the elevation between -60 and 60 meters is created. Then a Euclidean distance from the shoreline is created, which is reclassified to a Boolean dataset, setting the area within the 40km range to 1 and all other values to NoData. The land part of the 40km buffer is extracted and added to the elevation file. Finally, the dataset is limited to within the MEOW shapefile. For a visualisation of the research area and its units of analysis see figure 3.1**.**

3.3.2 Habitat maps; Marine

The habitat map as modelled by Halpern, et al. (2015) contains 19 habitats.. All 19 habitats are used to create a habitat map. This is to make sure that all habitats that are present within the research area are included and to make sure that all cells within the marine zone of the research area have a vulnerability index. The resulting habitat map has a lot of overlap; rocky intertidal, intertidal mud, beach, salt marsh, and suspension feeder reefs are all located at the same cells for example. To accommodate this, the mean of the (vulnerability index of the) cells that overlap is taken.

Next, the raster files that contain the values with the vulnerability of each habitat to respectively sea level rise and light pollution are managed. They are reprojected to the same XY Coordinate System as all other datasets in this thesis (GCS_WGS_1984), during this transformation they will also receive the same cell size as the research area (0,0083333333 square decimal degrees). Finally a data management is applied to make sure that all cells along the coastline have values, taking the value of the closest cell if data is missing. This is necessary when working with unfamiliar data, there will always be a difference in coastline, cell size, and projection.

3.3.3 Habitat maps; Terrestrial

The terrestrial habitat map is created from the GlobCover landcover classes from the ESA (ESA, 2010). This dataset contains 23 landcover classes, the biggest being the water bodies (oceans etc.). The size of this landcover class is greatly reduced because only the classes on land within the research area are retained. Each of the 23 classes is still present within the research area and for each of these classes a vulnerability to sea level rise, light pollution, nutrients pollution, organic pollution, and inorganic pollution is calculated. What these vulnerability indexes are, and how they are calculated is discussed in detail at section 3.4. Each terrestrial dataset will be multiplied with this terrestrial habitat vulnerability map.

3.3.4 Marine; Nutrients-, inorganic-, and organic pollution

The three stressor datasets from the Halpern (2015) paper only need minor data management. The marine organic-, inorganic-, and nutrients- pollution datasets need to be transformed to the spatial reference as used for the other datasets (GCS_WGS_1984), during this transformation they will also receive the same cell size as the other datasets. Because Halpern, et al. might have used a different shoreline or land dataset the data might have some cells along the coast without data. To accommodate this the data is nibbled onto land. The cells on land will receive the same value as the closest value in the marine datasets. Finally only the values in the marine zone, within the research area, are kept, all other cells will now have NoData values. See Appendix 9.2 for the model.

3.3.5 Sea level rise

The local differences in sea level rise & fall are available as a dataset (see 3.2.2 #8). This dataset is provided as a raster file with 320 bands, each band represents a month. From its first measurement at the beginning of 1993 up to the end of 2019. The average sea level of the first year of the measurement (12 months) is subtracted from the 12 months of 2015, resulting in a local sea level rise (LSLR) dataset between 1993-2015. The resolution of this dataset is coarse (1°), resulting in large missing areas of data near the shoreline. This is negated by nibbling the data onto land with the closest LSLR data, next the cell size is resampled to reduce loss of data. Just like Halpern, et al. (2015) I changed the sea level drop to 0, due to a lack of knowledge on positive or negative effects of a local sea level drop. Next the marine sea level rise is limited to the research area, multiplied by the vulnerabilities of the marine habitats to SLR and finally standardized. A more detailed description can be found at Appendix 9.3.1.

Terrestrial sea level rise data (salt intrusion) needs to be created from scratch. To model the influence of salt water intrusion several researches have been consulted (Barlow & Reichard, 2010; Qi & Qiu, 2011; Rahmawati, Vuillaume, & Purnama, 2013; EEA, 2014). From these researches a maximum distance to the shoreline of 34,16km and a maximum altitude of 313m for the influence of sea level rise on salt intrusion rates have been chosen. The process of calculating these values is described below.

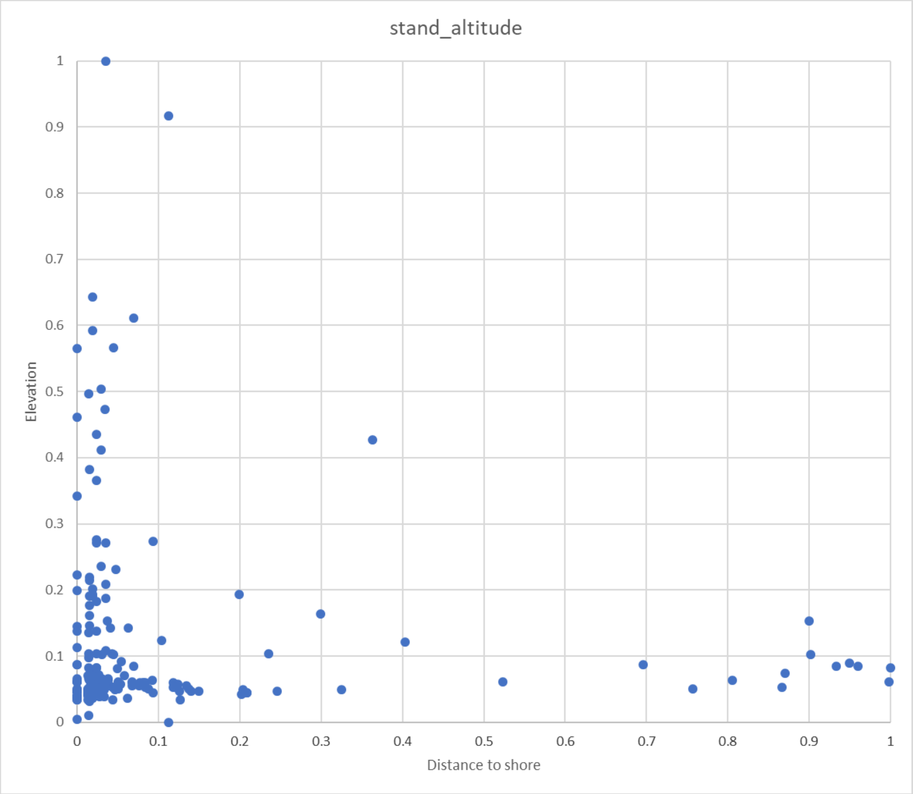
For this research the intrusion of salt water will be modelled based on three research papers and one dataset;

- Salt intrusion in Coastal and Lowland areas of Semarang City (Rahmawati, Vuillaume, & Purnama, 2013)
- Environmental hazard from saltwater intrusion in the Laizhou Gulf, Shandong Province of China (Qi & Qiu, 2011)
- Saltwater intrusion in Southeast Florida (Barlow & Reichard, 2010)
- Waterbase – Groundwater quality in Europe, EEA (EEA, 2014)

The journal papers all had images of their research area in it, these images were georeferenced to their location on Earth. From these georeferenced images points were taken and used in the analysis together with the points from the EEA.

The points where saltwater intrusion has been found are analysed for their location. This is done with a ‘zonal statistics’ where their distance from the shoreline and their elevation is extracted. The resulting graph (figure 3.6) can be found below.

Figure 3.6: Standardized elevation against standardized distance to shoreline for known saltwater intrusion locations



With the exception of one point (located in Greece, with a distance from shore of 18km and an elevation of 183m) we can say that the locations of the salt water intrusion are either elevated or have a long distance from shore, but are not both.

The majority of the points has a distance less than 7 kilometres from shore (180 out of 205 points) and the majority of the points lie below an elevation of 115 meters (188 out of 205 points). The maximum distance from the shore is 49.4km and the highest elevation is 453 meters.

Additional statistics such as average and percentiles shouldn't be analysed because the data points are very limited and far from complete. Only 3 papers and one database have been used for this graph. These data points can only be used for learning basic trends. After compiling these points we know that elevated areas can still experience salt water intrusion, but it seems more common for lower lying points. The same can be said for a distance to shore, close to shore is more common but intrusion up to almost 50km has been recorded. When the values are standardized they can be analysed and compared. When the standardized values are summed then the lower left corner can be extracted. The sum with a value of 0,69 contains the majority of the values and shows a natural break.

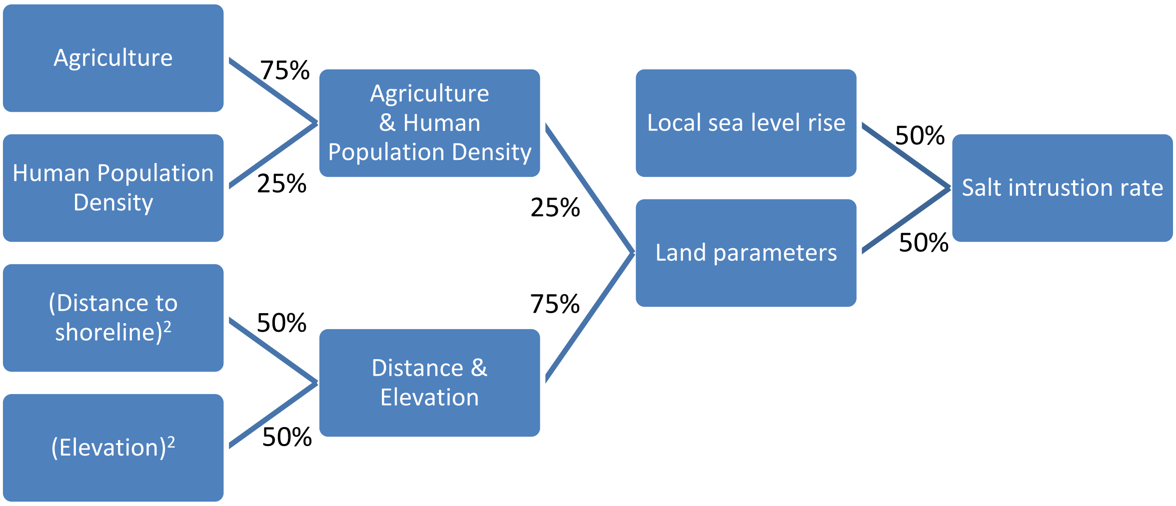
The value 0,69 of the sum of the standardized values, of the distance to shore and elevation, mark an area that contains 190 out of the 205 data points. This knowledge will be used to create a layer that combines the elevation and distance to the shoreline. The maximum distance to shore in the research area of this thesis is far greater than 40 kilometres (450km) and the elevation in the research area is far greater than 453 meters as well (4869m).

The value 0,69 of the standardized dataset of the salt intrusion points corresponds to 34,16km distance and 313m altitude. These values are chosen as the maximum values for the influence of SLR on land to be sure that the estimation is conservative. This is done because the outlying distances and elevations could be caused by factors unbeknownst to this research such as polluting salt mines and other forms of pollution (EEA, 2014).

Additionally, the presence of agriculture (based on their net primary production) and the presence of human population density have been weighted as well. The combination of these factors result in a sensitivity dataset where a cell close to shore, with a low elevation, the presence of agriculture, and a high population density (HPD) are all combined to increase the influence of the LSLR. The opposite of these factor decrease the influence of LSLR on salt water intrusion rates. The different factors are weighted (see figure 3.7); LSLR (50%), Distance to shoreline (18,75%), elevation (18,75%), HPD (3,125%), agriculture (9,375%). These weightings are based on the fact that 70% global water usage is consumed for agriculture, 20% by industry, and 10% for domestic use (worldometers, 2020). The location of industry isn't modelled, but it is more likely to occur at populated areas. Because of the water consumption by these sectors the Agriculture:HPD ratio is set to 3:1. The distance to the shoreline and the elevation of that location seem just as important to their change of salt water intrusion from shore (Barlow & Reichard, 2010; Qi & Qiu, 2011; Halpern, et al., 2015), but together they are much more important than Agriculture & HPD. Based on literature (Barlow & Reichard, 2010; Qi & Qiu, 2011; Bedford, Leopold, & Gibbs, 2013; Halpern, et al., 2015) the Elevation & Distance to Agriculture & HPD ratio is set to 3:1.

The intensity of the modelled salt water intrusion rate is limited to the research area, multiplied with the vulnerability of the landcover class, and finally standardized. A more detailed description can be found at Appendix 9.3.2.

Figure 3.7: Flowchart of the construction of the terrestrial sea level rise stressor



3.3.6 Light pollution

Light pollution data has been acquired from a bulk of raster files that each represent one square decimal degree of Earth. These rasters (about 135x180) have been added together to one file that represents the terrestrial light pollution. Some values did cross the shoreline into the marine, these were removed to prevent overlap.

The terrestrial dataset is used to predict the light pollution on water. By studying the lightpollutionmap.info map I could learn about the behaviour of terrestrial based light pollution on water. This light pollutes the skies up to a distance of 150km from shore. Another important observation is the intensity of the lights coming from oil rigs. These are as intense as heavily populated areas and have to be included in the analysis. Oil rigs are given a value of 60 (63 is the maximum) and are added to the light pollution data. This data is managed with the focal statistics function, for every cell a radius of 100km is taken and the average of this circle is the value for that cell. This results in a dataset that looks similar to the lightpollutionmap.info map and is used as the marine light pollution map. Next the pressure map is multiplied by the habitat vulnerability map. Both the marine and terrestrial datasets are extracted for the research area and are standardized as well. See Appendix 9.4 for a more detailed description.

3.3.7 Nutrients pollution

Marine nutrients pollution is available online from the Halpern (2015) paper. This data is managed identically to the organic and inorganic pollution data. All datasets are reprojected to the XY Coordinate System that the other datasets have as well. It is reprojected from the Mollweide WGS84 to the GCS WGS84 projection, during this projection the same cell size is used as well. Next the data is nibbled on to land to prevent possible empty cells along the shoreline due to the use of different shoreline shapefiles between this thesis and other researches. Finally, only the data on the marine is retained. See Appendix 9.2 for a more detailed description.

Terrestrial nutrients pollution needs to be created from scratch. For this, the Anthromes map is used to determine where agriculture is located, Rice villages, Irrigated villages, Rainfed villages, Pastoral villages, Residential irrigated croplands, Residential rainfed croplands, Populated croplands & Residential rangelands are considered as agricultural. The fertilizer data is retrieved from several sources such as Trading economics (TradingEconomics, 2019), the World Bank (WorldBank, 2019), specific reports from i.a. the FAO (FAO, Fertilizer Use by Crop in the Democratic People's Republic of Korea, 2003; Earth Trends, 2003; Ricepedia, 2001; Cabo Verde, 2012; The World Bank, 2010; FAO, 2008), but mainly from FOAstat. All data is provided in kg/ha and is multiplied by the amount of arable land per country. The size of nutrients pollution per country is divided by the amount of cells that are considered as agricultural (from the Anthromes dataset) that each country contains. The data is finally log-transformed to increase comparability. These calculations result in a value per country that represents a log-transformed kg of fertilizers per agricultural cell per country. This data is multiplied in ArcMap by the presence of agriculture (0 or 1) in each country. The data is then limited to the research area and multiplied with the vulnerability index of the landcover class where the threat occurs and finally standardized. See Appendix 9.5 for a more detailed description.

3.3.8 Organic pollution

Marine organic pollution data is managed identical to the marine nutrients pollution data (see 3.3.7).

Terrestrial organic pollution needs to be created from scratch. For this, the same presence of agriculture is used, just like the terrestrial nutrients pollution. The data on pesticides use is not as freely available as fertilizer use and is mainly retrieved from the FAO. The data is divided by the amount of agricultural cells present in that country and log-transformed and. This data is multiplied by the presence of agriculture (0 or 1). The data is then limited to the research area and multiplied with the vulnerability index of the landcover class where the threat occurs and finally standardized. See Appendix 9.6 for a more detailed description.

3.3.9 Inorganic pollution

Marine inorganic pollution data is managed identical to the marine nutrients pollution data (see 3.3.7).

Following Halper, et al. (2015) and Geldmann, et al. (2014), inorganic pollution is modelled from human population density. Since inorganic pollution mainly comes from the presence of human population in urban areas the terrestrial inorganic pollution can be modelled from HPD. The data is square rooted because Geldmann, et al. (2014) state that an increase in HPD results in a decrease in pollution per individual. The data is then limited to the research area and multiplied with the vulnerability index of the landcover class where the threat occurs and finally standardized. See Appendix 9.7 for a more detailed description.

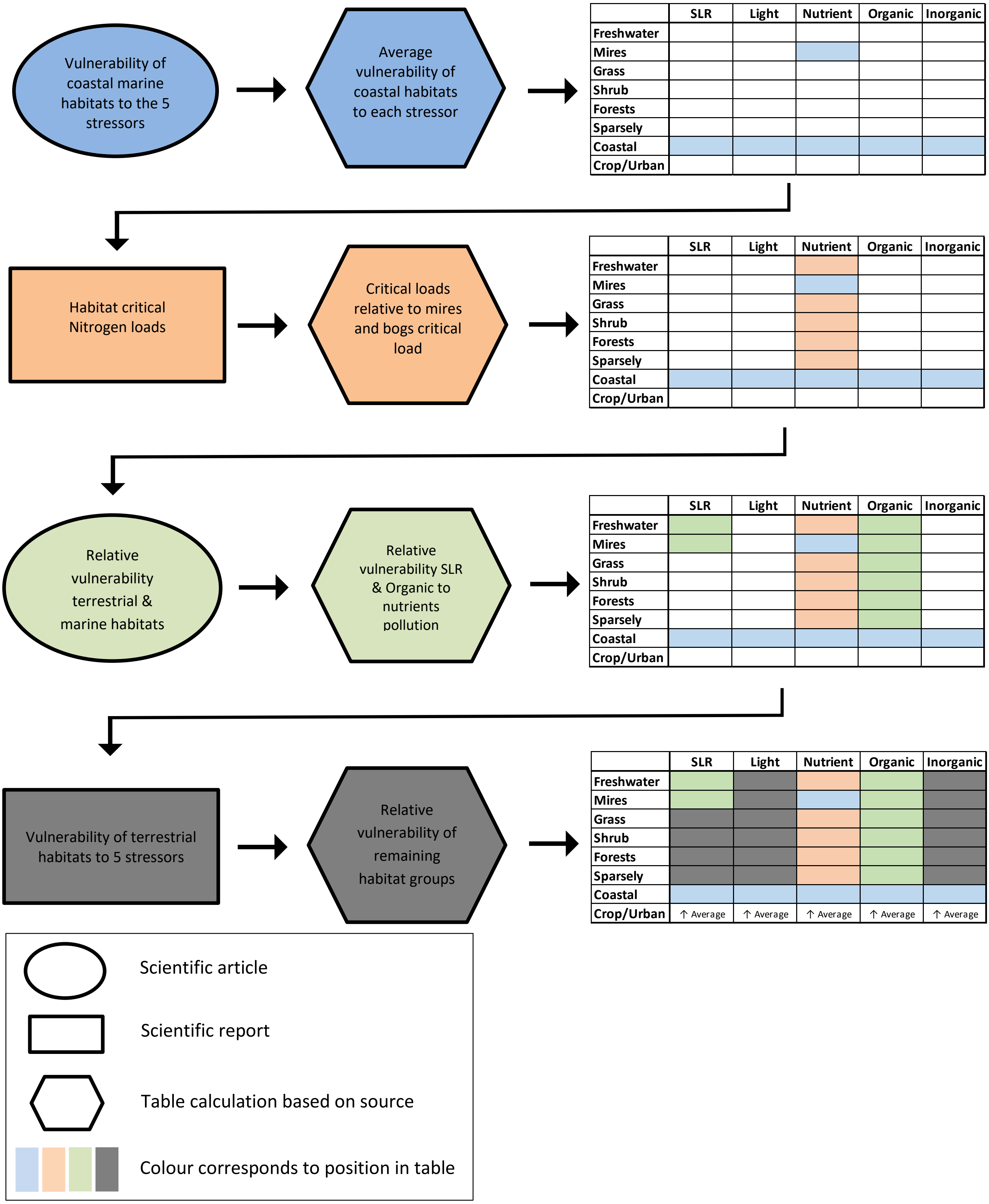
3.4 Constructing integrated vulnerability indexes

Threats to coastal ecosystem biodiversity have different impacts on different habitats. For this thesis several sources are used to construct the terrestrial habitat vulnerability indexes. This index needs to be aligned with the marine vulnerability indexes from table 3.2 (Halpern, et al., 2015). Table 3.2 is constructed with the use of their expert opinion and the expert opinion of other researchers. These indexes will be used as the basis for the terrestrial habitat vulnerability map.

To be able to sufficiently compare the terrestrial and marine data integrated weights are required. This requires a habitat map similar to the one used by Halpern, et al. (2015). Here the vulnerability index of for example a forest to nutrients pollution needs to reflect its vulnerability in comparison to the vulnerability index of a kelp forest to nutrients pollution. These vulnerability indexes are created through literature research of previous cumulative human impact studies (Halpern, et al., 2015; Khamis, Kalliola, & Käyhkö, 2019) as well as a report of the European Commission and IUCN, the European Red List of Habitats (Janssen, et al., 2016). The amount of research that has been done on the relative vulnerability of marine and terrestrial habitats to anthropogenic stressors is very limited and the anthropogenic stressors that are used for their research are rarely the same as those used for this thesis. This is accommodated with the research that is available (2015; CCE, RIVM, 2017; Khamis, Kalliola, & Käyhkö, 2019) in combination with the Red List of Terrestrial Habitats of Europe (Janssen, et al., 2016).

The vulnerability matrix for terrestrial habitats will be similar to table 3.2 and this table will be the foundation as well. From this table five intertidal habitats can be used (see figure 3.8); Rocky Intertidal-, Intertidal Mud-, Beach-, Mangroves-, and Salt Marsh habitats. These habitats are all coastal habitats that could be considered both as marine and terrestrial habitats. The average vulnerability of these five habitats to the five selected stressors is used as values for the vulnerability indexes of coastal habitats.

Figure 3.8: Flowchart of the creation of the terrestrial habitat vulnerability indexes



	SLR	Light	Nutrient	Organic	Inorganic
Freshwater					
Mires			🟦		
Grass					
Shrub					
Forests					
Sparsely					
Coastal	🟦	🟦	🟦	🟦	🟦
Crop/Urban					

	SLR	Light	Nutrient	Organic	Inorganic
Freshwater			🟧		
Mires			🟦		
Grass			🟧		
Shrub			🟧		
Forests			🟧		
Sparsely			🟧		
Coastal	🟦	🟦	🟦	🟦	🟦
Crop/Urban					

	SLR	Light	Nutrient	Organic	Inorganic
Freshwater	🟩		🟧	🟩	
Mires	🟩		🟦	🟩	
Grass			🟧	🟩	
Shrub			🟧	🟩	
Forests			🟧	🟩	
Sparsely			🟧	🟩	
Coastal	🟦	🟦	🟦	🟦	🟦
Crop/Urban					

	SLR	Light	Nutrient	Organic	Inorganic
Freshwater	🟩	⬛	🟧	🟩	⬛
Mires	🟩	⬛	🟦	🟩	⬛
Grass	⬛	⬛	🟧	🟩	⬛
Shrub	⬛	⬛	🟧	🟩	⬛
Forests	⬛	⬛	🟧	🟩	⬛
Sparsely	⬛	⬛	🟧	🟩	⬛
Coastal	🟦	🟦	🟦	🟦	🟦
Crop/Urban	↑ Average	↑ Average	↑ Average	↑ Average	↑ Average

The vulnerability index of Mires and Bogs to nutrients pollution is identical to the vulnerability index of coastal habitats to nutrients pollution. This is done because mires and bogs are similar in their composition to coastal habitats (Janssen, et al., 2016). For the further construction of the vulnerability indexes of the habitats groups to nutrients pollution a report by a Dutch government body (RIVM) is used (CCE, RIVM, 2017) (orange cells figure 3.8). This report lists the critical load of habitat groups to nutrients pollution. These critical loads are used as a relative vulnerability between the habitat groups to nutrients pollution. Next, the vulnerability of terrestrial and marine habitats to nutrients pollution relative to terrestrial and marine habitats to organic pollution is used (Khamis, Kalliola, & Käyhkö, 2019) (green cells figure 3.8).

For the vulnerability indexes of Freshwater, Mires and Bogs, Grasslands, Shrub habitats, Forests, and Sparsely vegetated habitats to sea level rise, light pollution, and inorganic pollution the IUCN report (Janssen, et al., 2016) is used (grey cells figure 3.8). For sea level rise “climate change” as a threat is used, Light pollution is a combination of “urbanisation, roads” and “disturbances”, and for inorganic pollution “Urbanisation, roads” and “Transportation” is used. The amount of habitats within each habitat group that is sensitive to these threats is used to construct a table similar to table 3.2. The constructed values are checked with the theoretic framework (2.4-7) to see if they seem logical. In some cases an index is adjusted, this is the case for the vulnerability of Freshwater inorganic pollution and the vulnerability of Sparsely vegetated habitats to organic pollution. The vulnerability index of the Freshwater habitats group to inorganic pollution would receive a value of 0,15 if based on the IUCN/EC report, an index extremely low compared to the other indexes. Instead a value of 0,50 was chosen, still making this the lowest vulnerability index. The vulnerability of the Sparsely vegetated habitats group to organic pollution would have an index of 3,3 if based on the paper by Khamis, Kalliola, and Käyhkö, instead the same value of the Forest habitats group to organic pollution is taken, which is more in line with the IUCN report (Janssen, et al., 2016) . The constructed table (3.9) can be found below.

Table 3.9: Constructed vulnerability indexes per habitat group

Habitat group	**Sea level rise**	**Light pollution**	**Nut pollution**	**Org pollution**	**Inorg pollution**
Freshwater	2,05	1,55	1,68	1,37	0,50
Mires and bogs	1,78	1,32	1,46	1,18	1,00
Grasslands	1,18	1,55	0,56	1,79	0,74
Shrub habitats	1,64	1,62	0,67	2,15	1,19
Forests	2,44	1,08	0,75	2,39	0,92
Sparsely vegetated habitats	2,00	2,54	1,12	2,39	1,07
Coastal habitats	2,52	1,50	1,46	1,62	1,36
Cropland/Urban	1,95	1,59	1,10	1,84	0,97

In this table the Cropland/Urban habitat group is an average of the 7 other habitat groups. This habitat group is necessary because the GlobCover dataset (ESA, 2010) has several landcover classes that are artificial, these are Urban and Cropland classes (see: Table 3.10). The GlobCover dataset uses 23 different land cover classes that all can be categorized as a mixture of the eight habitat groups from table 3.8. These mixtures can be “80% Grassland, 20% Forest” or “20% Grassland, 40% Shrubs, 40% Mires and Bogs” (see: 3.11), for these landcover classes the vulnerability indexes from table 3.9 are used with the corresponding percentages. The resulting table can be found on this page at table 3.10, the percentages that are used to construct the indexes for table 3.10 can be found on the page after (3.11).

These indexes are added as values to the GlobCover dataset and these values are used to multiply the intensity of the terrestrial anthropogenic stressor with the vulnerability of the local habitat to that stressor. This way the terrestrial stressor variables will represent an impact based on the local habitat vulnerability to that stressor, similar to that of the marine stressors in order to be compared.

Table 3.10: Constructed vulnerability indexes per FAO habitat

Landcover class	**Sea level rise**	**Light pollution**	**Nutrients pollution**	**Organic pollution**	**Inorganic pollution**
Post-flooding or irrigated croplands (or aquatic)	1.95	1.59	1.10	1.84	0.97
Rainfed croplands	1.95	1.59	1.10	1.84	0.97
Mosaic cropland (50-70%) / vegetation (grassland/shrubland/forest) (20-50%)	1.87	1.52	0.93	1.95	0.96
Mosaic vegetation (grassland/shrubland/forest) (50-70%) / cropland (20-50%)	1.83	1.49	0.84	2.00	0.96
Closed to open (>15%) broadleaved evergreen or semi-deciduous forest (>5m)	2.19	1.17	0.71	2.27	0.89
Closed (>40%) broadleaved deciduous forest (>5m)	2.44	1.08	0.75	2.39	0.92
Open (15-40%) broadleaved deciduous forest/woodland (>5m)	2.19	1.17	0.71	2.27	0.89
Closed (>40%) needleleaved evergreen forest (>5m)	2.44	1.08	0.75	2.39	0.92
Open (15-40%) needleleaved deciduous or evergreen forest (>5m)	2.19	1.17	0.71	2.27	0.89
Closed to open (>15%) mixed broadleaved and needleleaved forest (>5m)	2.19	1.17	0.71	2.27	0.89
Mosaic forest or shrubland (50-70%) / grassland (20-50%)	1.70	1.43	0.65	2.08	0.93
Mosaic grassland (50-70%) / forest or shrubland (20-50%)	1.36	1.58	0.61	1.94	0.92
Closed to open (>15%) (broadleaved or needleleaved, evergreen or deciduous) shrubland (<5m)	2.08	1.32	0.72	2.28	1.04
Closed to open (>15%) herbaceous vegetation (grassland, savannas or lichens/mosses)	1.55	1.51	0.63	2.03	0.95
Sparse (<15%) vegetation	2.00	2.54	1.12	2.39	1.07
Closed to open (>15%) broadleaved forest regularly flooded (semi-permanently or temporarily) - Fresh or brackish water	1.86	1.29	0.91	1.85	0.89
Closed (>40%) broadleaved forest or shrubland permanently flooded - Saline or brackish water	1.96	1.34	0.96	1.91	1.04
Closed to open (>15%) grassland or woody vegetation on regularly flooded or waterlogged soil - Fresh, brackish or saline water	1.74	1.34	0.89	1.79	0.87
Artificial surfaces and associated areas (Urban areas >50%)	1.95	1.59	1.10	1.84	0.97
Bare areas	2.00	2.54	1.12	2.39	1.07
Water bodies	2.05	1.55	1.68	1.37	0.50
Permanent snow and ice	2.00	2.54	1.12	2.39	1.07
No data (burnt areas, clouds,…)	1.95	1.59	1.10	1.84	0.97

Table 3.11: Percentages of the habitat classes from table 3.8 used to construct the values of table 3.9.

Landcover class	Composition
Post-flooding or irrigated croplands (or aquatic)	100% Cropland
Rainfed croplands	100% Cropland
Mosaic cropland (50-70%) / vegetation (grassland/shrubland/forest) (20-50%)	60% Cropland, 40%(Grassland/Shrub/Forests)
Mosaic vegetation (grassland/shrubland/forest) (50-70%) / cropland (20-50%)	20% Forests, 20% Grassland, 20% Shrub, 40% Cropland
Closed to open (>15%) broadleaved evergreen or semi-deciduous forest (>5m)	80% Forests, 20% Grassland
Closed (>40%) broadleaved deciduous forest (>5m)	100% Forests
Open (15-40%) broadleaved deciduous forest/woodland (>5m)	80% Forests, 20% Grassland
Closed (>40%) needleleaved evergreen forest (>5m)	100% Forests
Open (15-40%) needleleaved deciduous or evergreen forest (>5m)	80% Forests, 20% Grassland
Closed to open (>15%) mixed broadleaved and needleleaved forest (>5m)	80% Forests, 20% Grassland
Mosaic forest or shrubland (50-70%) / grassland (20-50%)	30% Forests, 30% Shrubs, 40% Grassland
Mosaic grassland (50-70%) / forest or shrubland (20-50%)	60% Grass, 40% Shrubs
Closed to open (>15%) (broadleaved or needleleaved, evergreen or deciduous) shrubland (<5m)	55% Forest 45% Shrubs
Closed to open (>15%) herbaceous vegetation (grassland, savannas or lichens/mosses)	15% Forest, 40% Grass, 45% Shrubs
Sparse (<15%) vegetation	100% Sparse vegetation
Closed to open (>15%) broadleaved forest regularly flooded (semi-permanently or temporarily) - Fresh or brackish water	40% Forests, 30% Grass, 30% Mires and bogs
Closed (>40%) broadleaved forest or shrubland permanently flooded - Saline or brackish water	33%Forest, 33% Shrub, 33% Mires and Bogs
Closed to open (>15%) grassland or woody vegetation on regularly flooded or waterlogged soil - Fresh, brackish or saline water	30% Forest, 40% Grassland, 30% Mires and Bogs
Artificial surfaces and associated areas (Urban areas >50%)	100% Cropland
Bare areas	100% Sparse vegetation
Water bodies	100% Freshwater
Permanent snow and ice	100% Sparse vegetation
No data (burnt areas, clouds,…)	100% Cropland

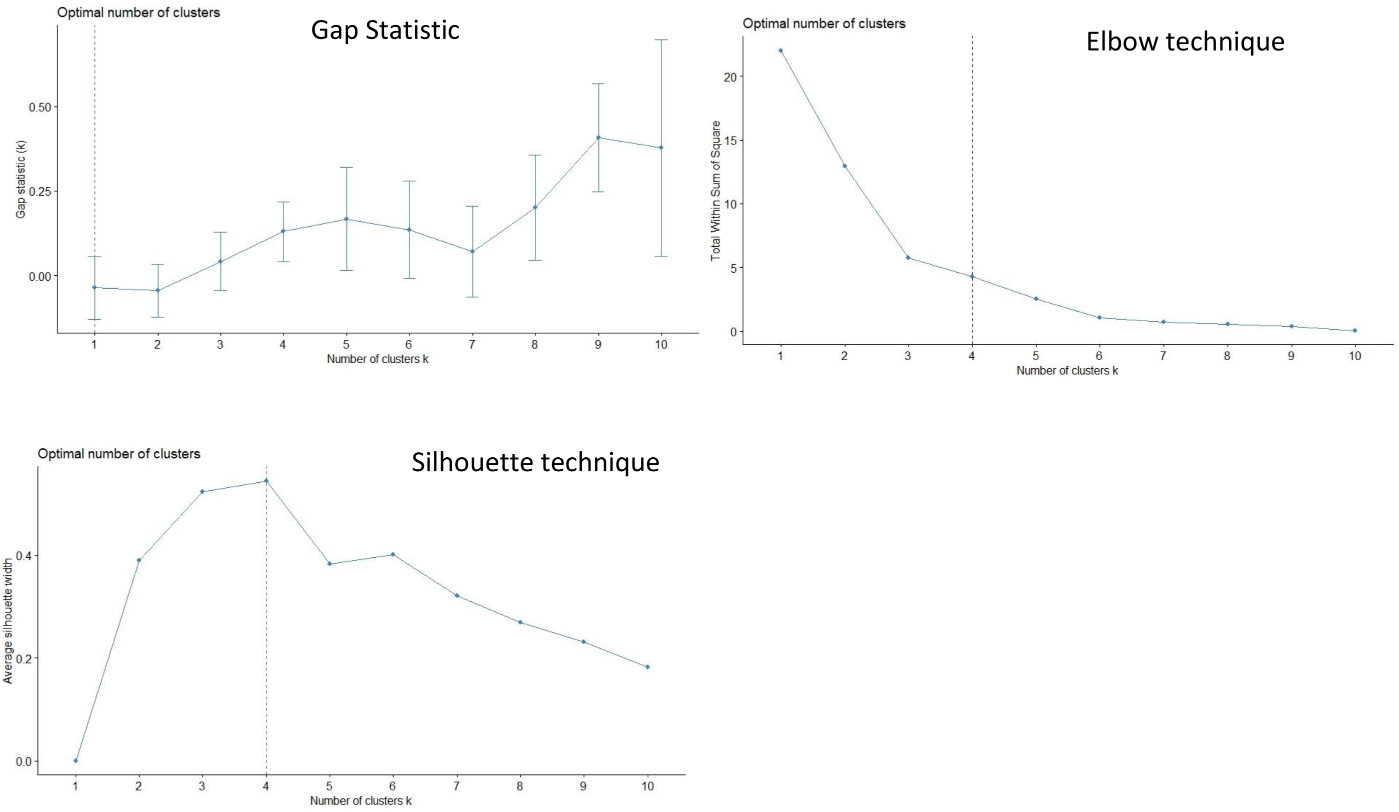
3.5 Results and analysis methods

The individual stressors will be presented in the form of global maps (see 4.1.1). Each stressor is visualised with the terrestrial and marine zone shown in the same map. Next, four zoomed in regions will be visualised (see 4.1.2). These locations are chosen because they show different distinguishable impact scores around Earth and their visualisation is a good example of the different impacts around the globe. These four locations are Florida in the United States, The United Kingdom and Ireland, the Eastern Mediterranean, and the coast of China. The mean individual stressors are visualised in bar charts as well, these are shown per Realm (see 4.1.3), a stacked bar chart visualises the share of each stressor in the cumulative impact score of the Realm next. Histograms will show the spread of data across a Realm for a specific stressor. For these histograms a common spread of data and a less common spread of data is chosen. For the complete output of Histograms per Realm (see 9.11.2) and per stressor (see 9.11.1) see the Appendix. The next section (see 4.2) visualises the cumulative impact score of a region. The most impacted and least impacted Realms, Provinces, and Ecoregions are mapped. The presentation of the results in the form of a map is done in the projected coordinates system Mollweide (Sphere based) because this projection is an equal-area projection, a property that is very useful when comparing areas at different latitudes. Visualisation will be done in ArcGIS.

Section 4.3 makes use of the statistical software GeoDa and R. In GeoDa the R^2 of several variables is calculated, the multiple regression analysis is done, and Multidimensional Scaling is done here as well. Section 4.3 presents the correlation between dependent and independent variables. Marine organic pollution is for example dependent on terrestrial organic pollution because it is a land-based marine stressor. A multiple regression analysis will visualise the average influence of each stressor on the cumulative impact score of the Ecoregions. Section 4.3.3 will present correlations between Realms. The statistical software R is used to compute a Pearson correlation matrix based on the 10 variables. This matrix will present similarity between the Realms based on the stressors. Clustering the Realms together is the next step. This is done by reducing dimensionality of the 10 stressors. A Multidimensional Scaling in GeoDa will reduce the 10 variables to 2 variables. The Euclidean distance method is used to calculate the distance between the variables for the MDS, resulting in the same result if we would use a Principal Component Analysis (PCA). With this 2 dimensional plot a cluster analysis will be done. The clustering method that will be used is k-means clustering. The R code of the correlation matrix computation and k-means clustering analysis can be found at Appendix 9.10.

Before the k-means clustering can be performed, this is done in R, the optimal amount of k-means clusters needs to be determined. To determine what is the best amount of clusters several techniques are used. These are the “Gap Statistic technique”, “Elbow technique”, and “Silhouette technique”. The outputs can be found at figure 3.12 showing that the optimal amount of clusters is 1 for the Gap statistic technique and 4 for the other two techniques. Concluding that 4 is the optimal amount of k-means clusters for this dataset. The k-means clustering with 4 clusters is performed and visualised as well.

Figure 3.12: Optimal amount of k-means clusters



3.6 Research questions

Several research question will serve as the direction for this thesis. After the creation of the cumulative anthropogenic impact map the discussion of the results will allow the research questions to be answered (see: 6.1). The impact scores will be analysed using the units of analysis.

The main research question of this research is: "What regions of Earth are most impacted by anthropogenic stressors, and what regions are least impacted?". This question can measured at several different levels of the units of analysis. These levels will divide the main research question into several sub questions.

- Which Realms are most impacted?
    - Which stressors are responsible for the biggest impact in these Realms?

- Which Realms are least impacted?
    - Which stressors are responsible for the biggest impact in these Realms?

- Which Provinces are most impacted?
    - Which stressors are responsible for the biggest impact in these Provinces?

- Which Provinces are least impacted?
    - Which stressors are responsible for the biggest impact in these Provinces?

- Which Ecoregions are most impacted?
    - Which stressors are responsible for the biggest impact in these Ecoregions?

- Which Ecoregions are least impacted?
    - Which stressors are responsible for the biggest impact in these Ecoregions?

Chapter 4: Results

In this chapter the results of this research are presented. The results comprise of the presentation of 10 stressors for both the marine and terrestrial zone of sea level rise, light pollution, nutrients pollution, organic pollution, and inorganic pollution. These scores are the modelling outputs of the cumulative impact of a set of selected threats to the coastal zone, as these are calculated by multiplying the intensity of the stressor by the vulnerability of the habitat where the stressor occurs. The cumulative impact score is the sum of these 10 stressors, either in the terrestrial or marine zone, resulting in a maximum score of 5. The equation for calculating the impact score at a cell is presented below.

$$\mathrm{Impact}_j \ = Stressor_i \times Vulnerability_j$$

Here the Impact on habitat *j* is calculated by multiplying the intensity of Stressor *i* by the vulnerability of habitat *j* to Stressor *i*. The cumulative impact to one cell is calculated by adding together the standardized (0-1) Impacts on that cell by Stressor *i...n*.

First, the individual stressors are presented (4.1). The modelling outputs are presented in the form of histograms, charts and maps per Realm as well as the four zoomed in regions; Florida, the UK and Ireland, the Eastern Mediterranean, and China.

Next, the modelling outputs of the cumulative impacts are presented (4.2) in the form of histograms, charts and maps. This will mainly be done per Realm but the most impacted and least impacted Provinces and Ecoregions, the lower biogeographic levels of the MEOW, will be presented as well. Finally several statistics are presented based on the single and cumulative impact scores (4.3).

4.1 Single stressors

This paragraph visualises the stressors individually. First each stressor is visualized on a global scale (see 4.1.1), then each stressor is visualised at four zoomed in regions (4.1.3), and then the impact per Realm is visualised with bar charts (4.1.3). Histograms are created as well, these can be found in the Appendix 9.11.1-2, some of these histograms are presented at section 4.1.3 as well. Each stressor is standardized to values between 0-1 with green being low values and red high values.

4.1.1 Global individual stressor maps

Sea level rise (figure 4.1), light pollution (figure 4.2), nutrients pollution (figure 4.3), organic pollution (4.4) and inorganic pollution (4.5) are mapped on a global scale.

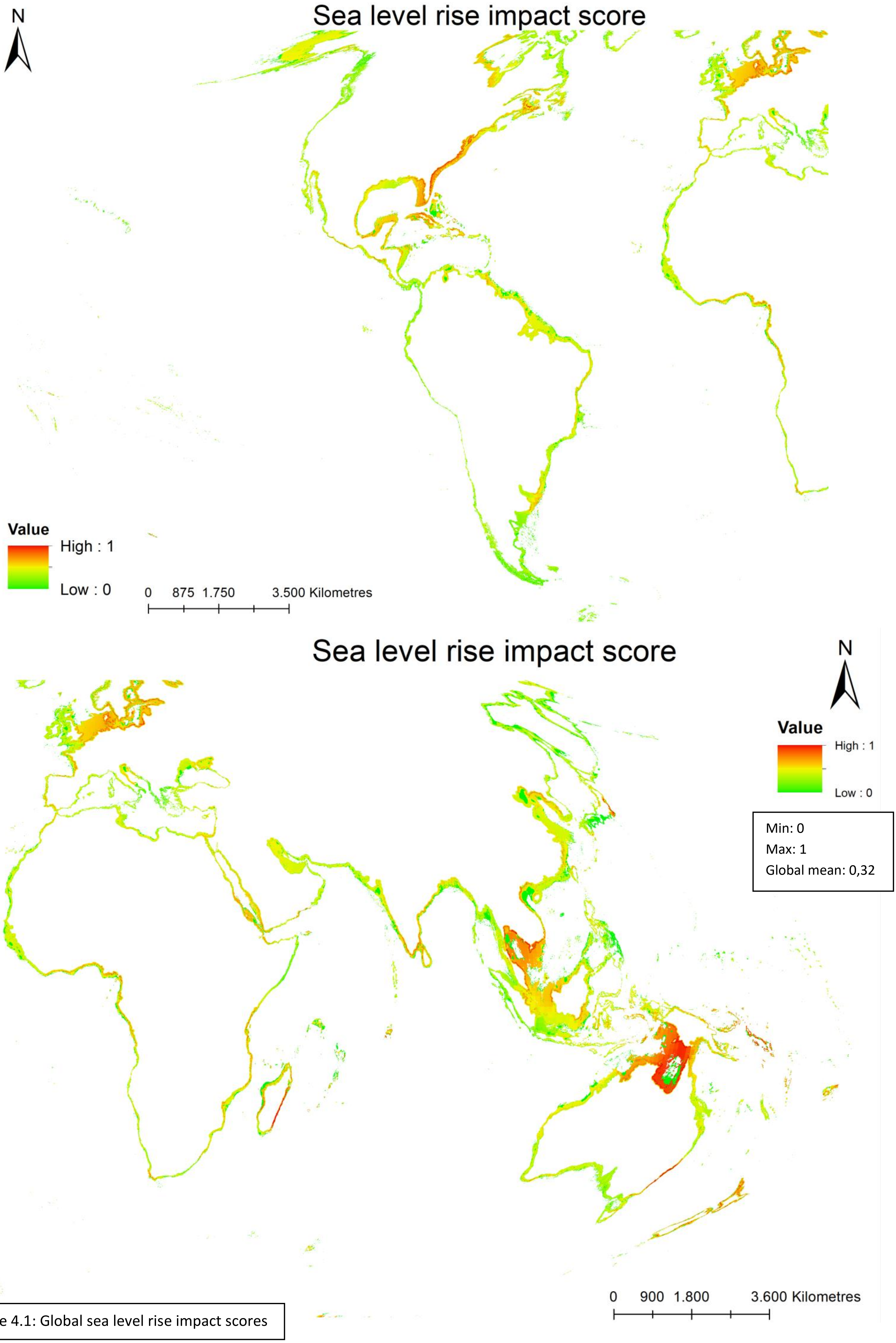


Figure 4.1: Global sea level rise impact scores

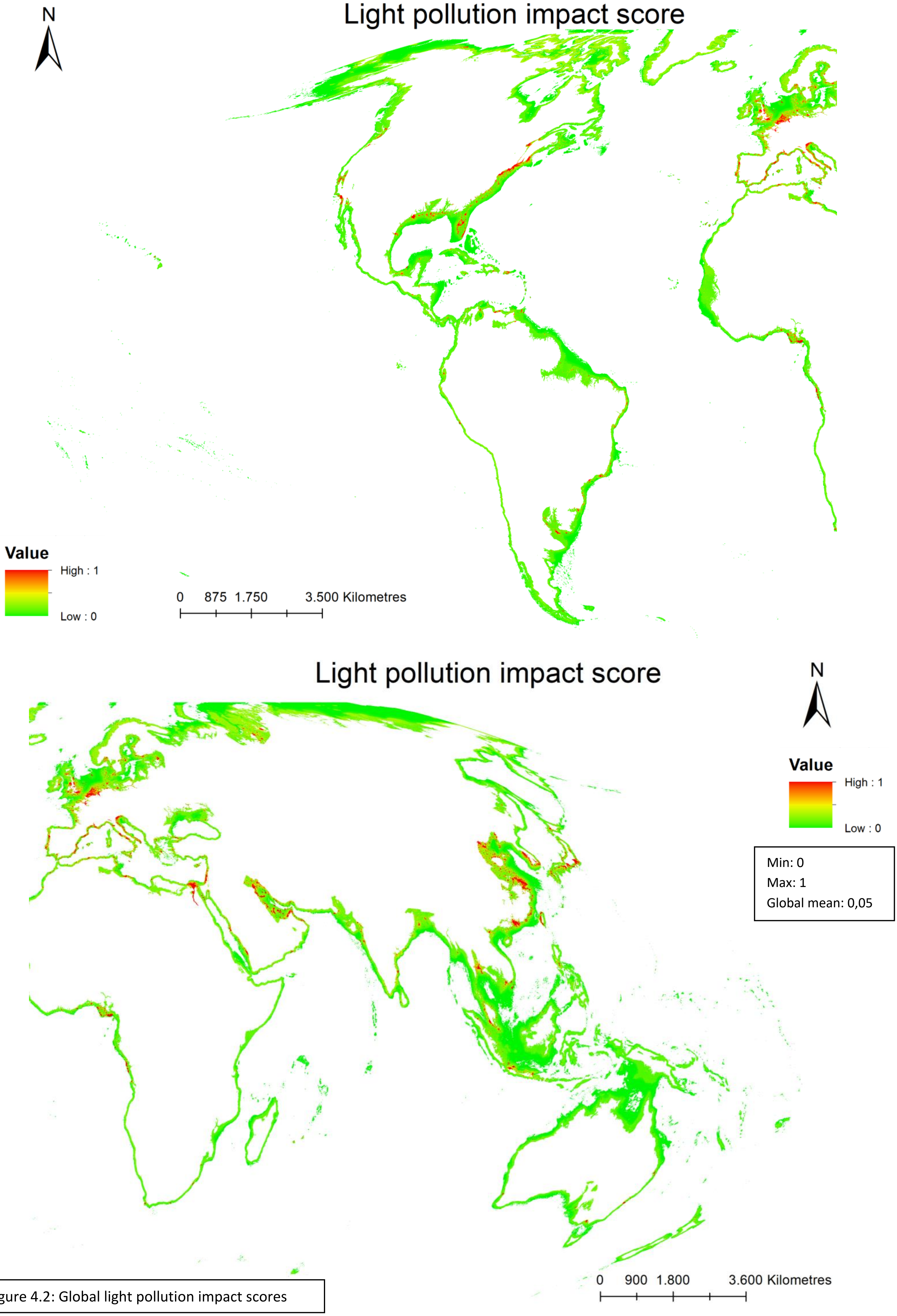


Figure 4.2: Global light pollution impact scores

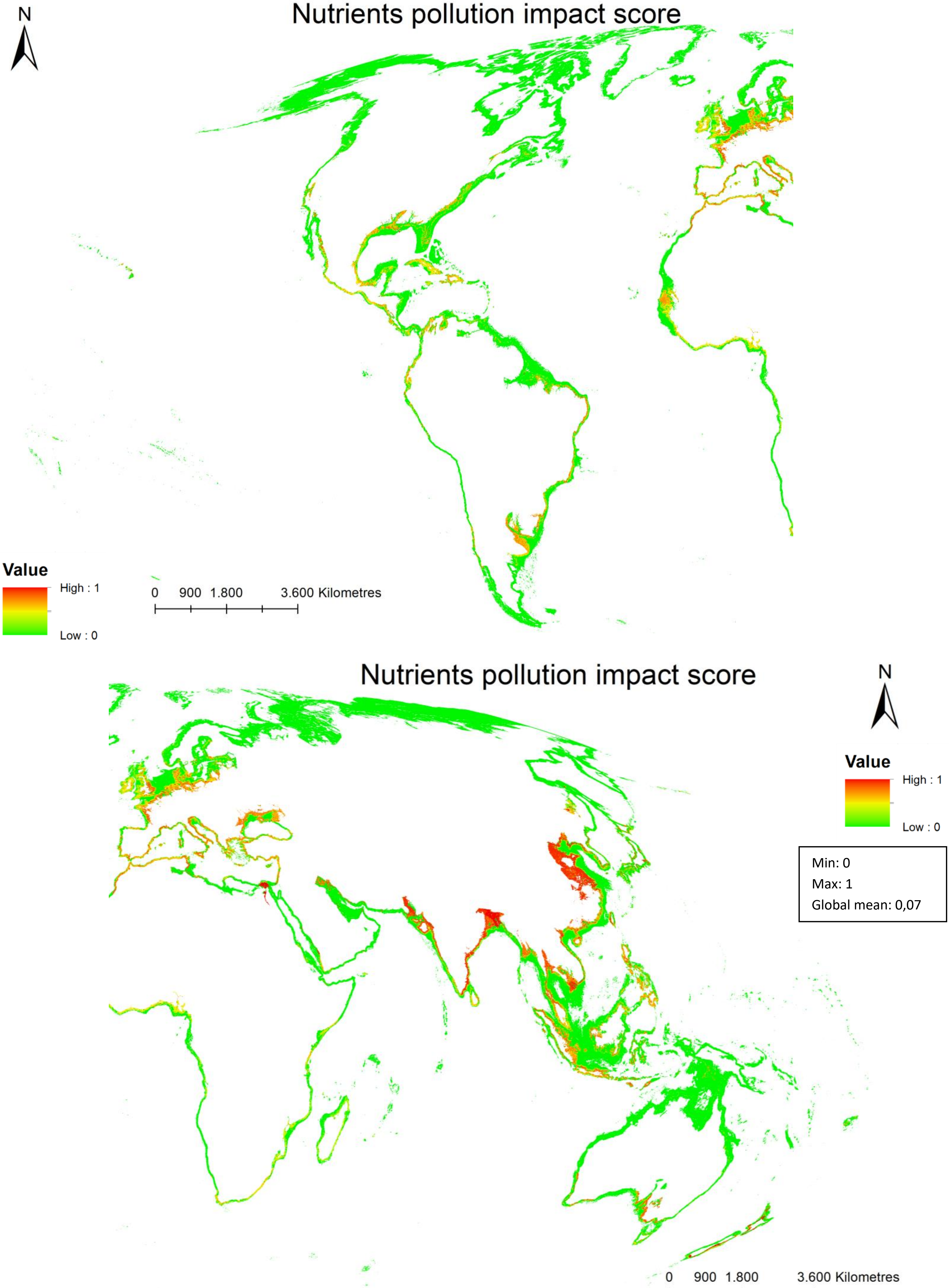
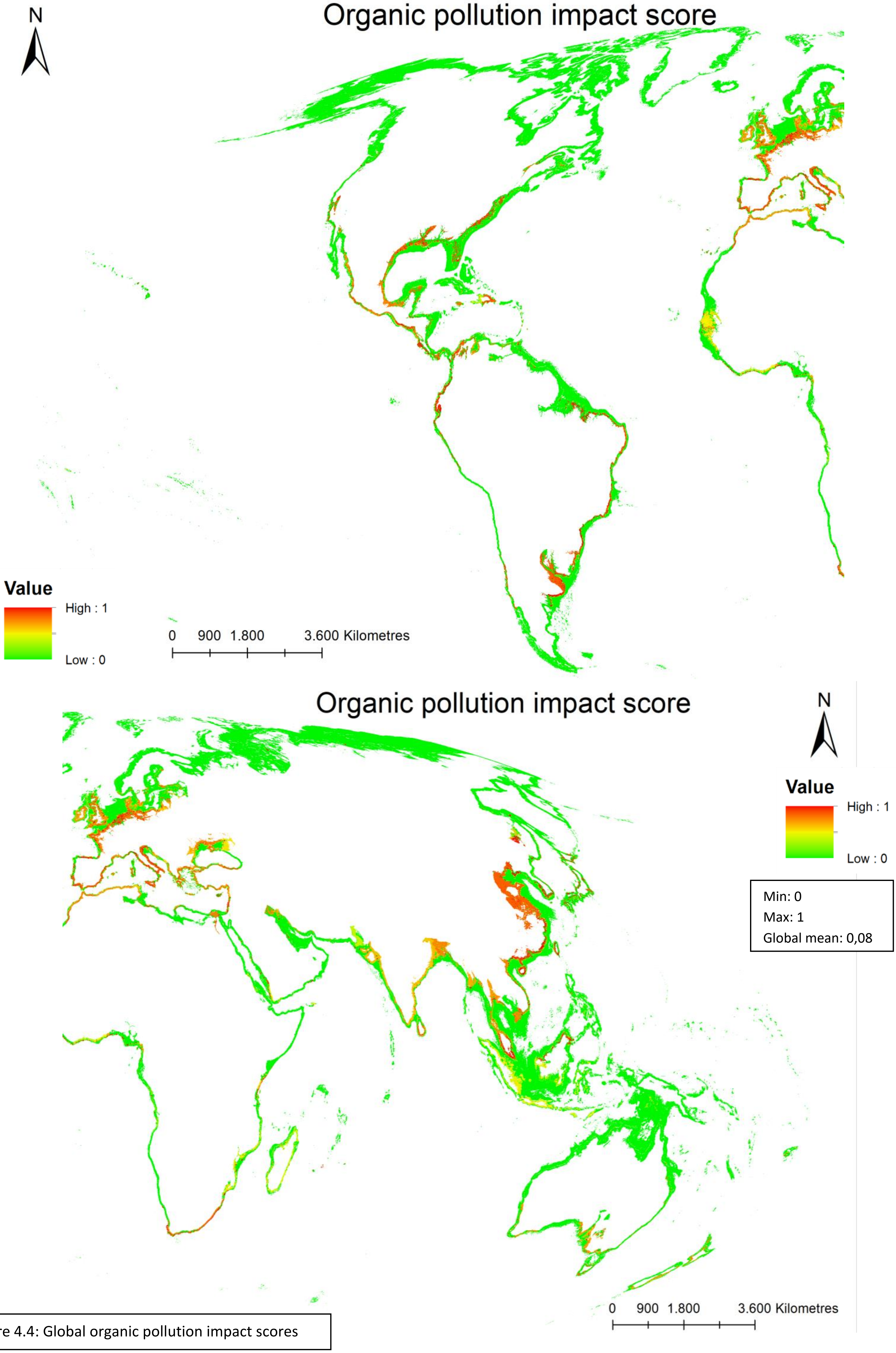


Figure 4.3: Global nutrients pollution impact scores



Min: 0
Max: 1
Global mean: 0,08

Figure 4.4: Global organic pollution impact scores

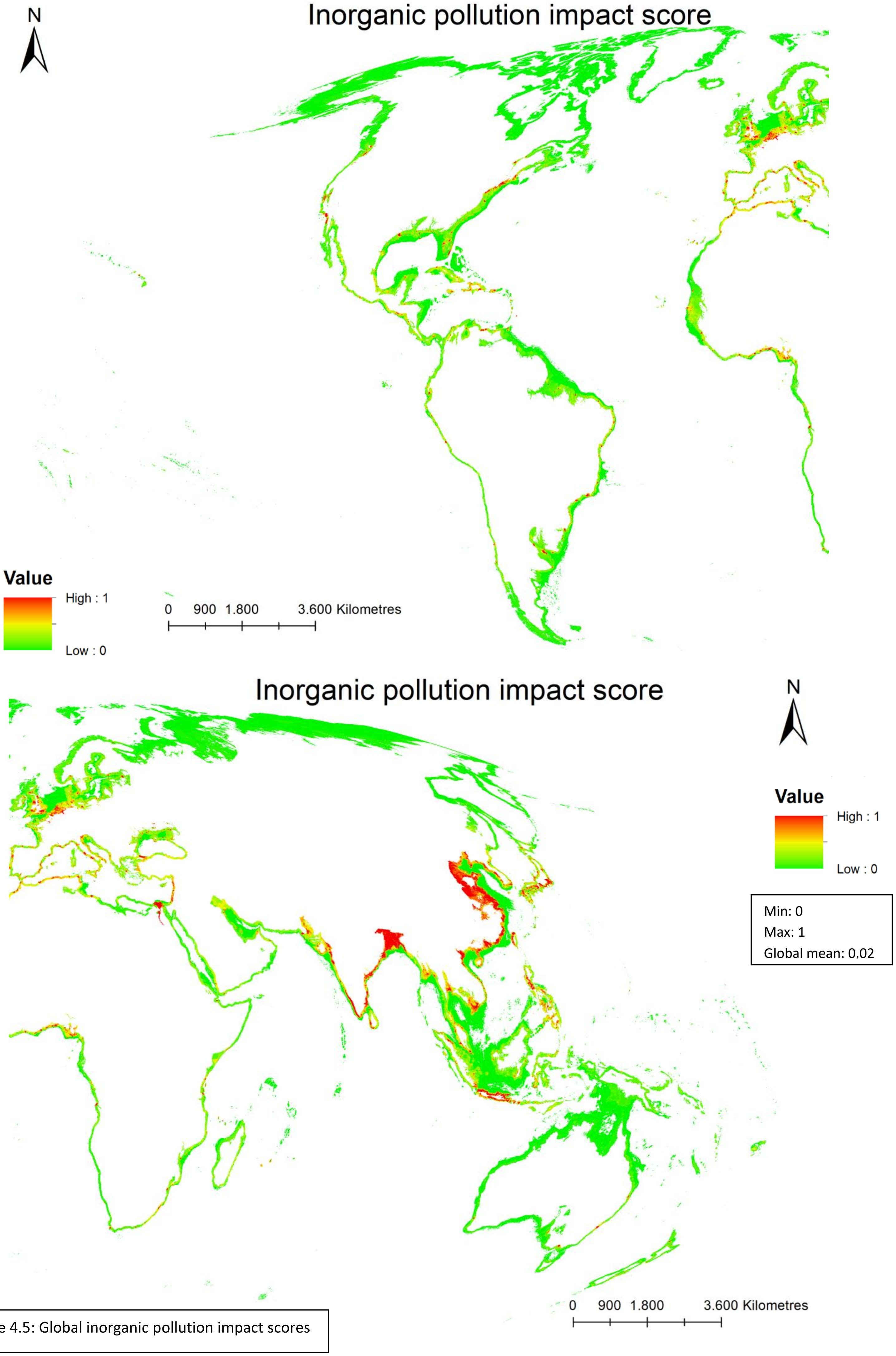
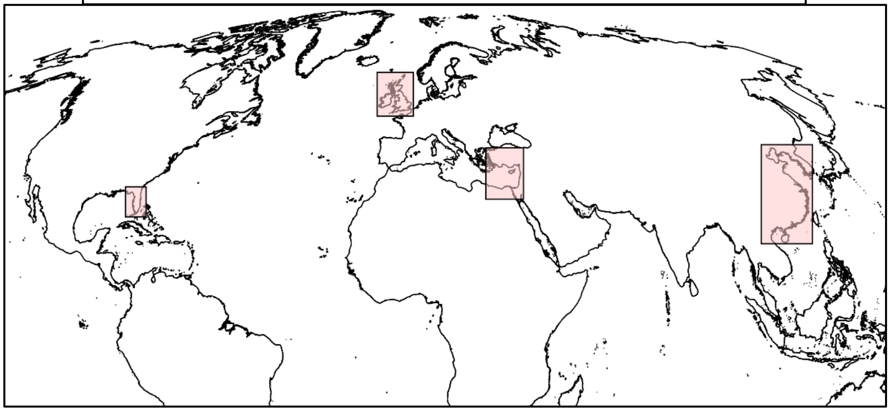


Figure 4.5: Global inorganic pollution impact scores

4.1.2 Local individual stressor maps

To get a good view of the difference in impact scores between several stressors around the globe, four areas have been zoomed in upon. For each area the individual stressors are mapped as well as the cumulative impact score at figure 4.7 (next page). Where these locations are can be seen at figure 4.6.

Figure 4.6: Locations of the zoomed in areas of figure 4.7



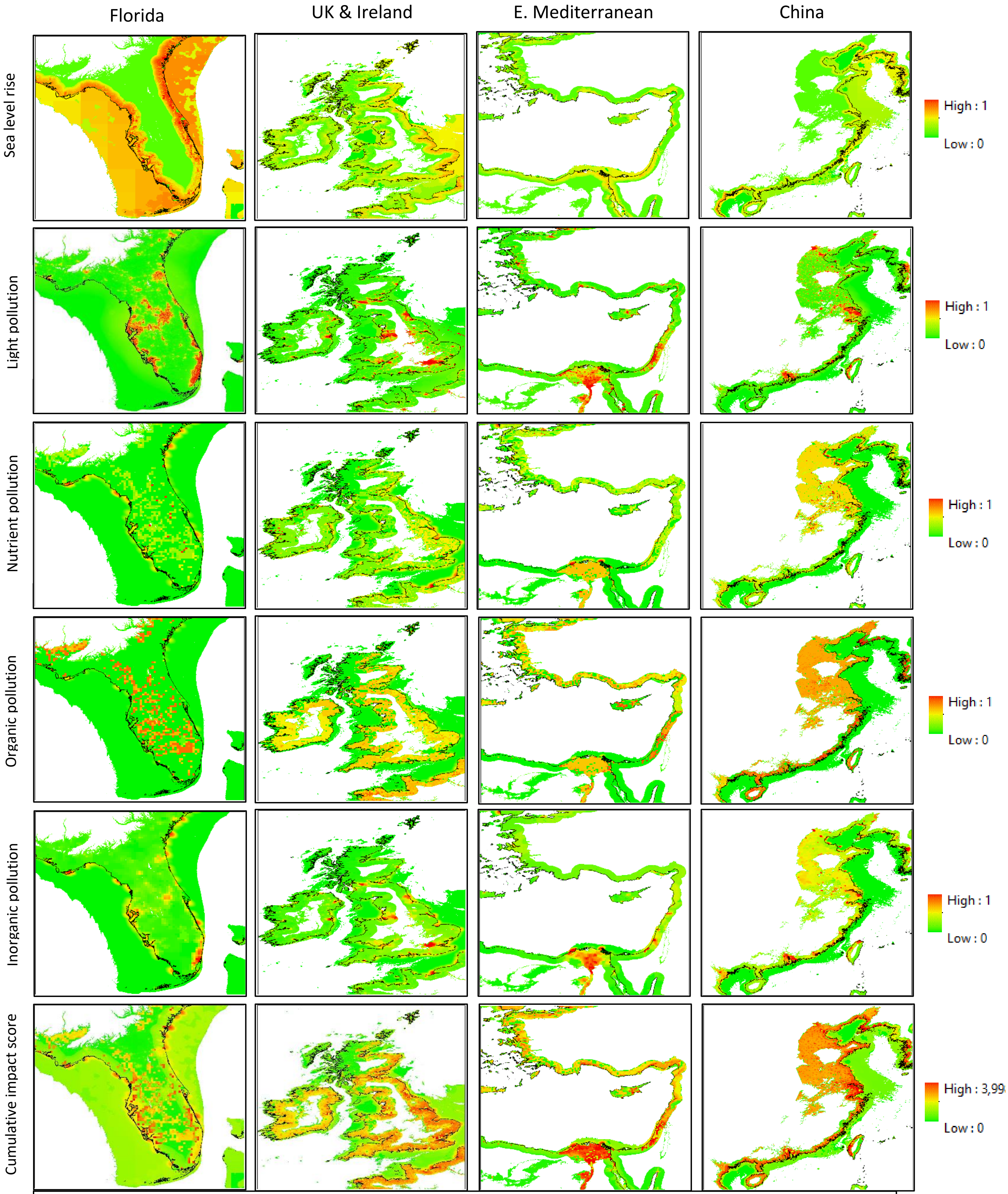


Figure 4.7: Visualisation of the impact score per stressor on Florida, the United Kingdom & Ireland, the Eastern Mediterranean, and China.

4.1.3 Bar charts per Realm

In this section two bar charts are presented. First, figure 4.8 presents each Realm and their mean impact score per stressor visualised as bars. The darker bars with black lining are the terrestrial stressors, the lighter colours the marine stressors with blue being sea level rise, yellow being light pollution, green being nutrients pollution, pink being organic pollution, and grey being inorganic pollution.

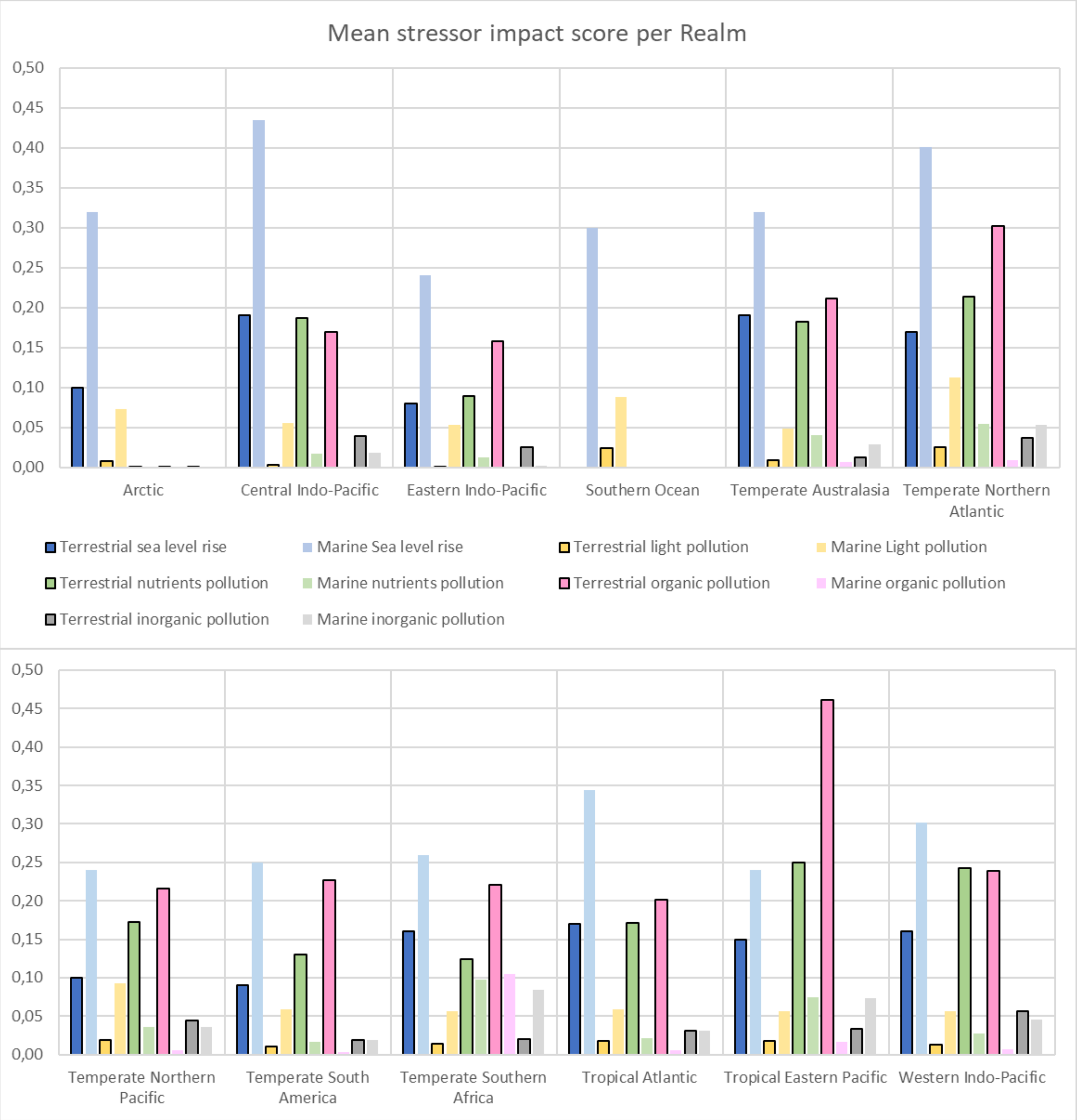


Figure 4.8: The mean impact score of each 10 stressors, divided per Realm

Next each Realm is visualised at figure 4.9 with their cumulative impact score along the Y-axis and the part that each stressor has in this impact score.

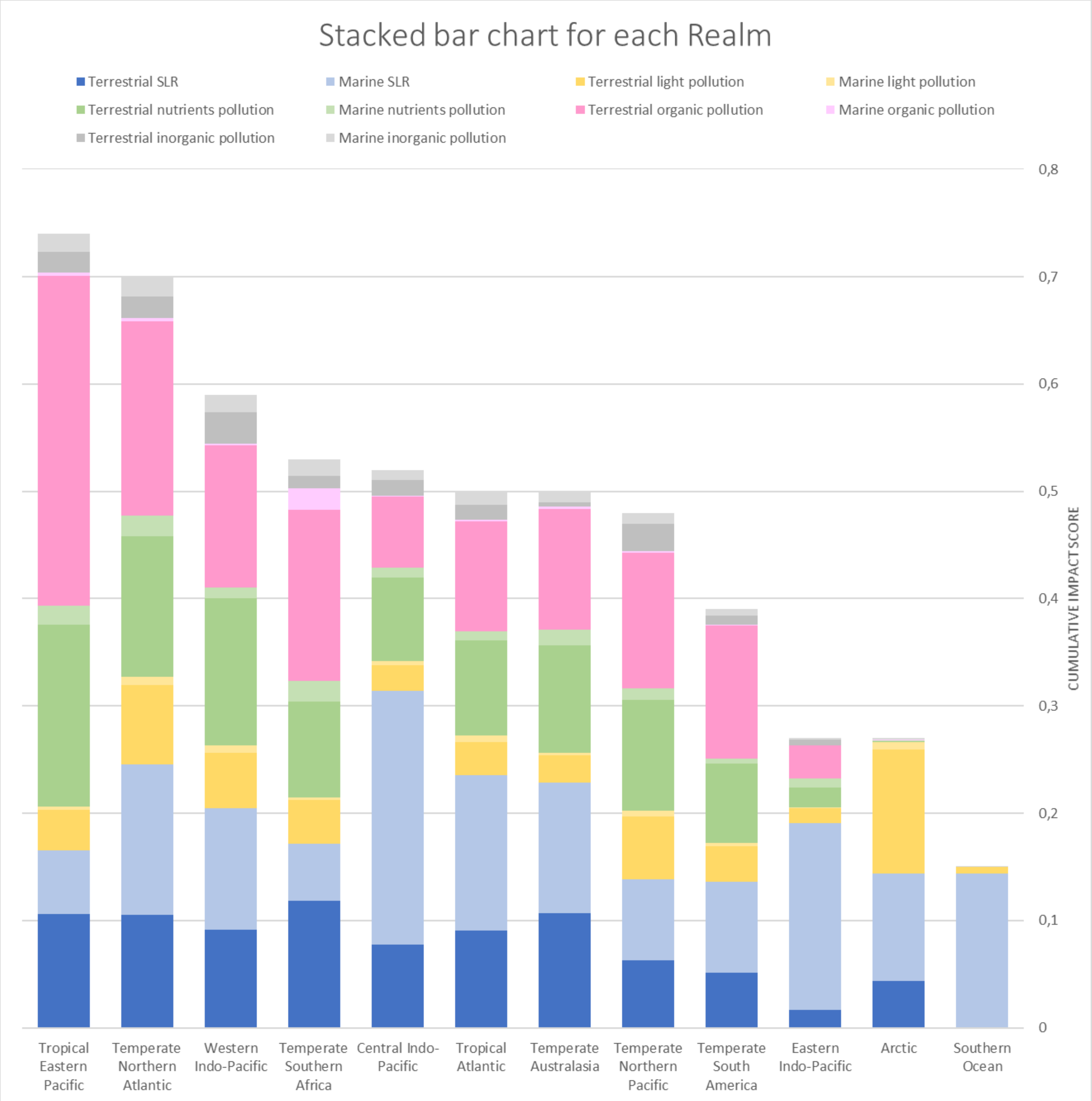


Figure 4.9: Stacked bar charts of the share of each stressor of the cumulative impact per Realm

Complementing the bar charts of figure 4.8 and figure 4.9 are the mean impact scores of each stressor across each Realm. Table 4.10 presents the mean impact score of 10 stressors at 12 Realms.

Table 4.10: Mean impact scores for each stressor across each Realm

	Sea level rise		**Light pollution**		**Nutrients pollution**		**Organic pollution**		**Inorganic pollution**	
Realm	Terrestrial	Marine	Terrestrial	Marine	Terrestrial	Marine	Terrestrial	Marine	Terrestrial	Marine
Arctic	0,100	0,319	0,007	0,073	0,000	0,001	0,000	0,000	0,001	0,001
Central Indo-Pacific	0,190	0,434	0,003	0,056	0,188	0,018	0,170	0,001	0,039	0,018
Eastern Indo-Pacific	0,080	0,240	0,001	0,053	0,089	0,013	0,158	0,000	0,025	0,003
Southern Ocean	0,000	0,300	0,024	0,088	0,000	0,000	0,000	0,000	0,000	0,000
Temperate Australasia	0,190	0,320	0,010	0,049	0,182	0,041	0,212	0,006	0,013	0,028
Temperate Northern Atlantic	0,170	0,401	0,026	0,112	0,214	0,055	0,302	0,009	0,037	0,053
Temperate Northern Pacific	0,100	0,240	0,019	0,093	0,173	0,035	0,215	0,006	0,045	0,036
Temperate South America	0,090	0,250	0,010	0,058	0,130	0,016	0,226	0,004	0,019	0,019
Temperate Southern Africa	0,160	0,260	0,014	0,056	0,124	0,097	0,221	0,104	0,020	0,084
Tropical Atlantic	0,170	0,344	0,017	0,059	0,171	0,021	0,201	0,005	0,031	0,031
Tropical Eastern Pacific	0,150	0,240	0,018	0,056	0,250	0,075	0,462	0,016	0,033	0,073
Western Indo-Pacific	0,160	0,302	0,013	0,056	0,243	0,028	0,238	0,006	0,057	0,045

To visualise how the data is spread within each stressor histograms are created. These histograms per Realm can be found in full at Appendix 9.11.1. Here some of these Histograms will be visualised as well. The chosen Histograms will inform the reader how common spread of data within a stressor looks like and how less common spread of data within a stressor looks like. The Y-axis represents different frequencies for each histogram, by doing this a visual comparison is possible between Realms with a different size (marine and terrestrial). Sometimes the X-axis starts at a value of 0,01 due to the frequency of the 0 values within that Realm. By doing so the spread of data can still be observed.

The spread of data of Sea level rise generally looks similar for each Realm. Figure 4.11 presents the terrestrial and marine sea level rise Histograms for the Temperate Australasia Realm. This Histogram represents a Realm that is averagely impacted by sea level rise compared to the Temperate Northern Atlantic Realm that is more heavily impacted by sea level rise (figure 4.12).

Figure 4.11: Terrestrial and Marine sea level rise impact scores at the Temperate Australasia Realm

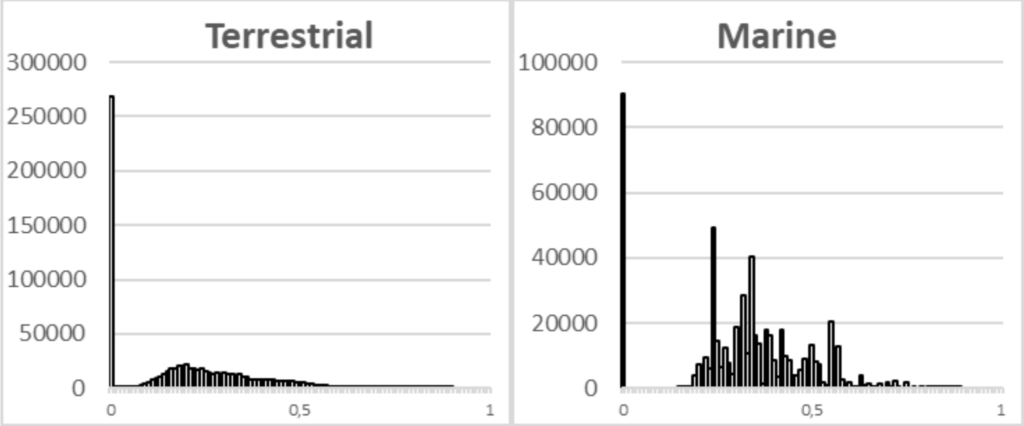
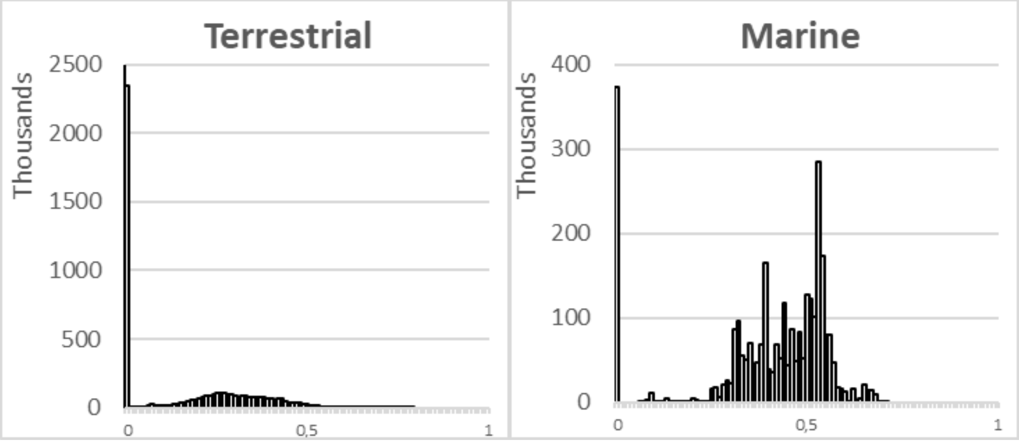
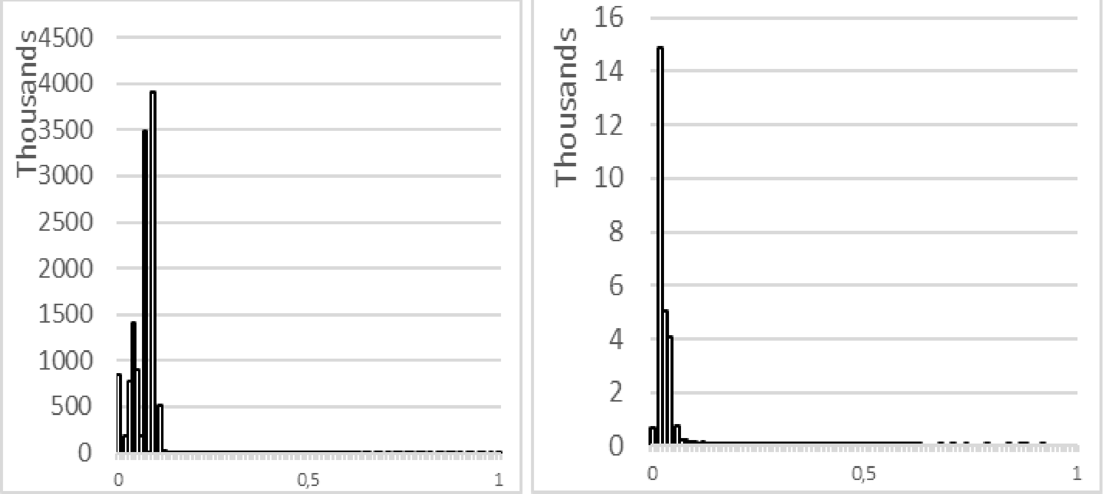


Figure 4.12: Terrestrial and Marine sea level rise impact scores at the Temperate Northern Atlantic Realm



The spread of data of terrestrial light pollution generally looks the same for each Realm, with the exception of the Arctic Realm. Figure 4.13 visualises the terrestrial light pollution at the Arctic Realm on the left and the terrestrial light pollution of the Eastern Indo-Pacific on the right.

Figure 4.13: Terrestrial light pollution impact scores for the Arctic Realm (left) and the Eastern Indo-Pacific Realm (right)



Marine nutrients pollution is visualised at the figure 4.14 and 4.15 histograms. The spread of data for marine nutrients-, organic-, inorganic-, and light- pollution are generally the same. Figure 4.14 visualises the spread of data of the Central Indo-Pacific Realm, associated with an averagely impacted Realm, and figure 4.15 a more heavily impacted Realm, the Temperate Southern Africa.

Figure 4.14: Marine Nutrients pollution impact score at the Central Indo-Pacific Realm

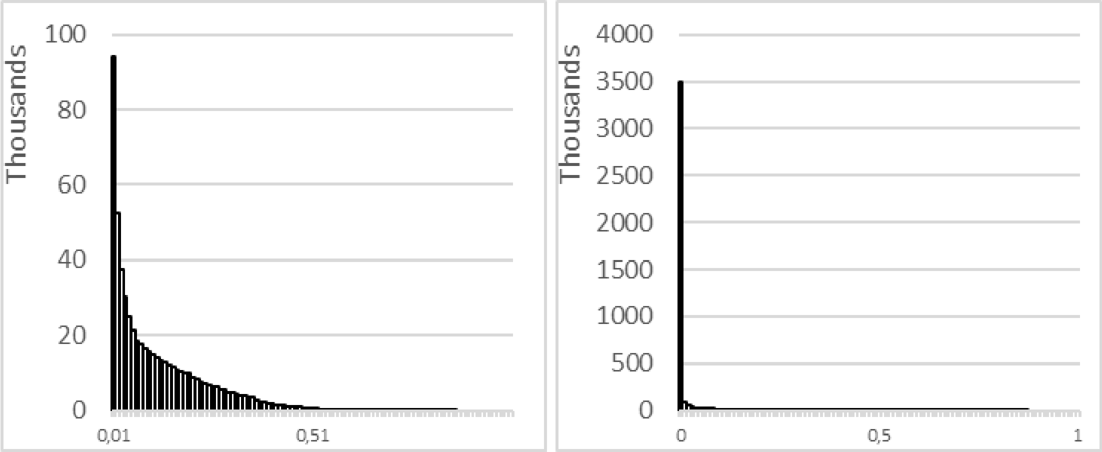
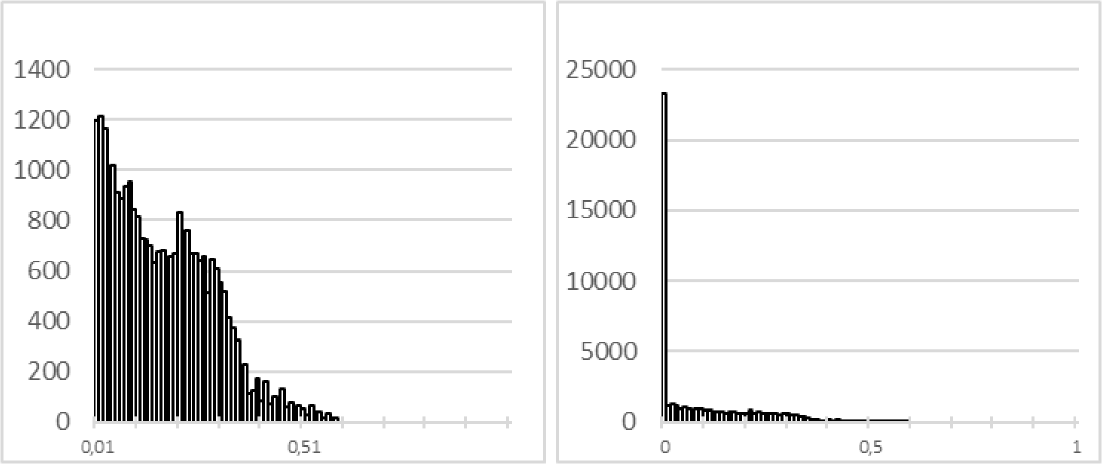
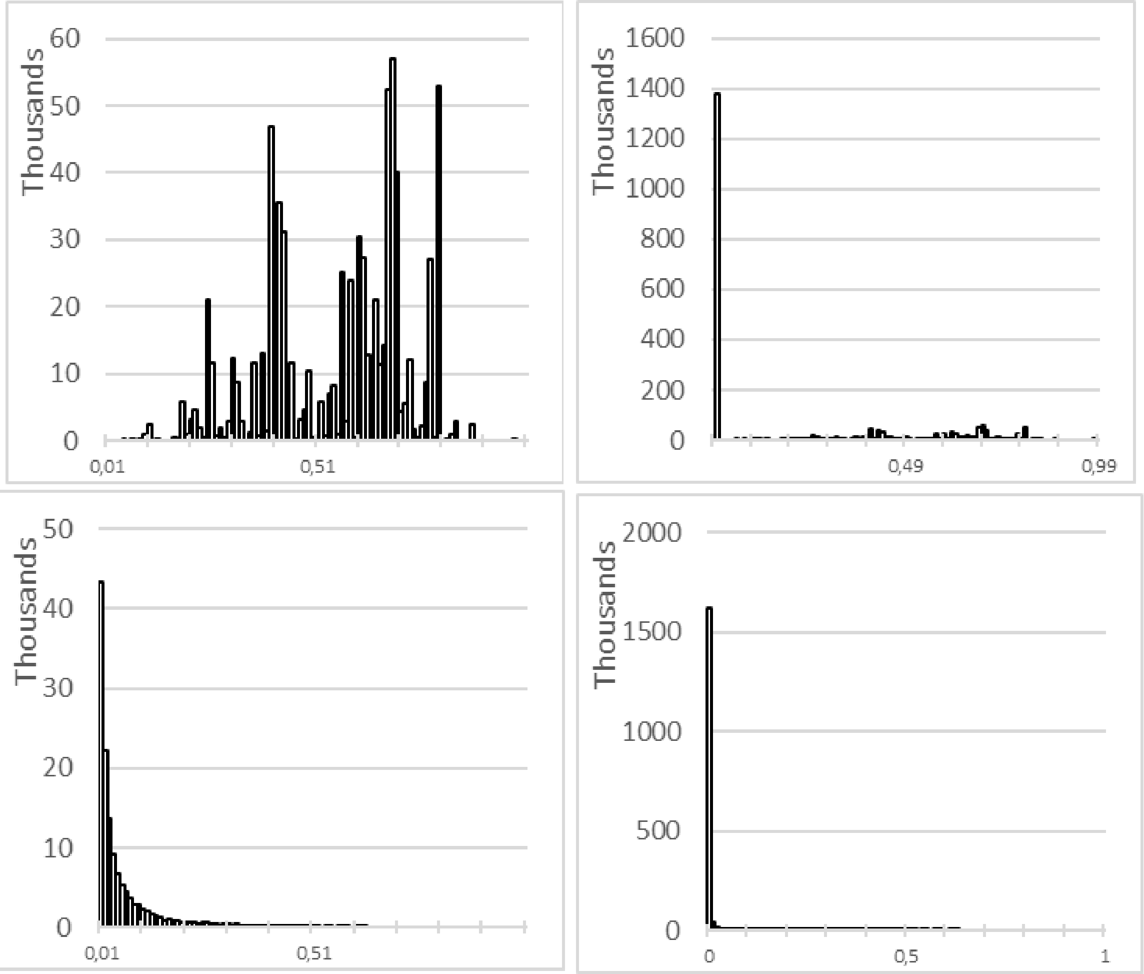


Figure 4.15: Marine Nutrients pollution impact score at the Temperate Southern Africa Realm



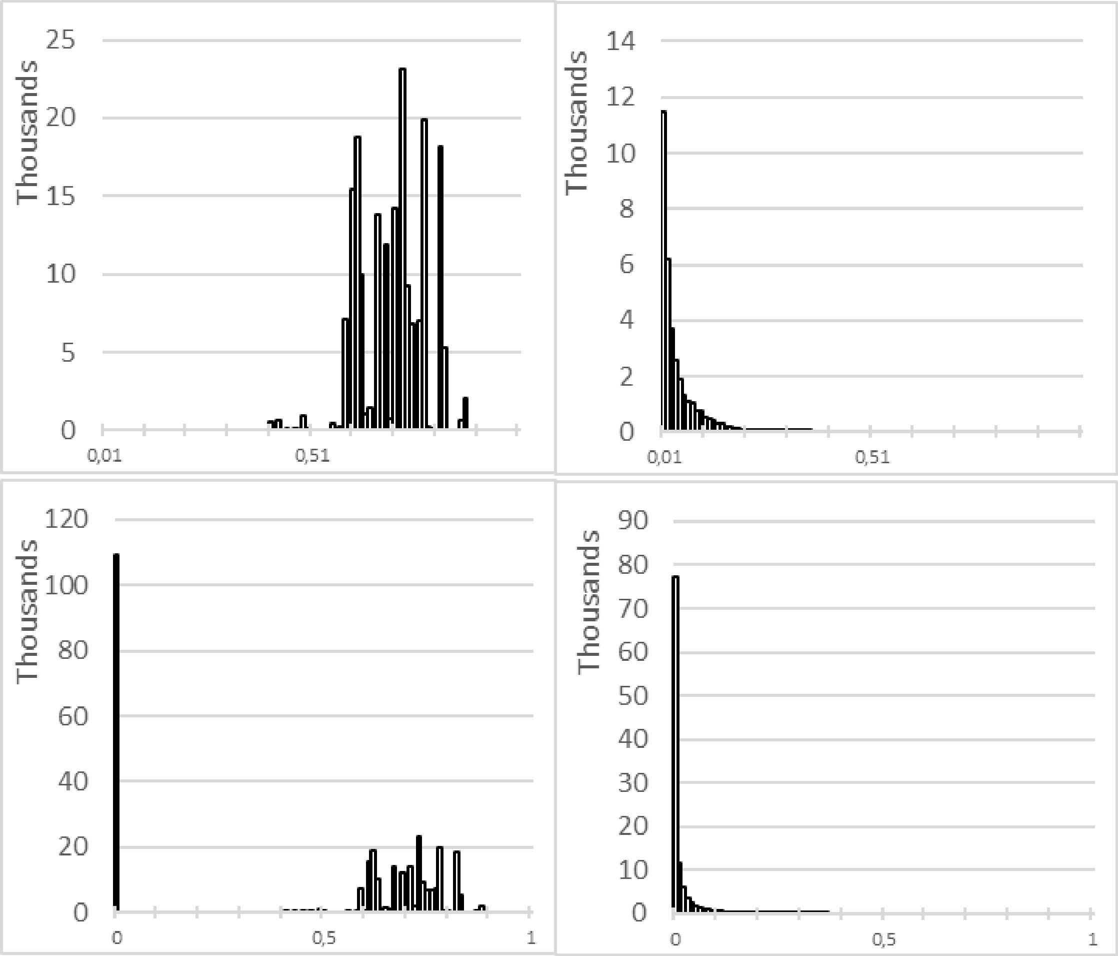
Histograms for terrestrial organic pollution and terrestrial nutrients pollution look very similar. Figure 4.16 presents the histograms of an averagely impacted Realm, the Tropical Atlantic Realm. The top two histograms depict the terrestrial organic pollution, and the bottom two histograms depict the marine organic pollution.

Figure 4.16: Terrestrial (top) and marine (bottom) organic pollution at the Tropical Atlantic Realm



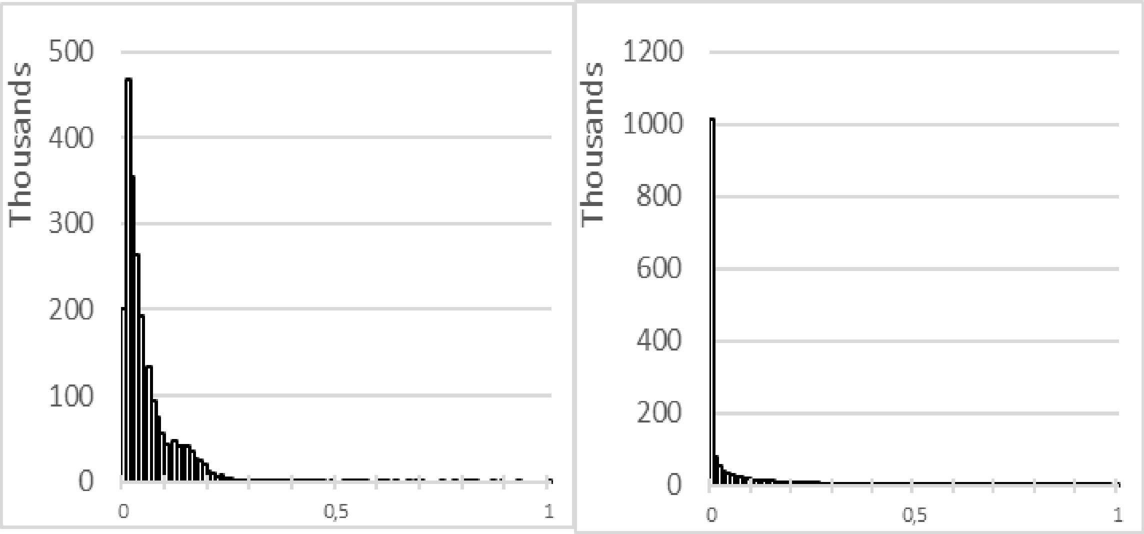
The next histograms (figure 4.17) presents terrestrial (top) and marine (bottom) organic pollution as well. But this time at a more heavily impacted Realm, the Tropical Eastern Pacific. The spread of data is very similar to that of the Tropical Atlantic Realm.

Figure 4.17: Terrestrial (top) and marine (bottom) organic pollution at the Tropical Eastern Pacific Realm



Inorganic pollution has very similar histograms across each Realm. At figure 4.18 the terrestrial inorganic pollution (left) and marine inorganic pollution (right) at the Western Indo-Pacific Realm is presented.

Figure 4.18: Terrestrial (left) and Marine (right) inorganic pollution at the Western Indo-Pacific Realm



4.2 Cumulative impacts

This section presents the cumulative impacts on several regions. Figure 4.19 visualises the global cumulative impact score per Realm, ordered by their mean cumulative impact score. The cumulative impact score is visualised in the form of a global map as well (figure 4.20). The spread of data of the cumulative impact score per Realm can be found at Appendix 9.11.2.

Based on the mean cumulative impact score the most impacted Realms are the Tropical Eastern Pacific (see: figure 4.21) and the Temperate Northern Atlantic (see: figure 4.22-23). The least impacted Realms are the Southern Ocean, Arctic, and Eastern Indo-Pacific Realms. Due to the limited coverage of the Realms around the poles only the Eastern Indo-Pacific Realm is visualised (see: figure 4.24.1-2). The boundaries of the Realms are visualised by a black line, the adjacent Realms are visualised with hashed lines filling the area.

Table 4.19: Cumulative impact anthropogenic scores of the Realms

Realm	**Research Area size, *1000 km^2**	**Min**	**Max**	**Mean**	**Standard Deviation**
Tropical Eastern Pacific	32,75	0	2,57	0,74	0,60
Temperate Northern Atlantic	581,70	0	3,99	0,70	0,55
Western Indo-Pacific	294,75	0	3,10	0,59	0,52
Temperate Southern Africa	18,49	0	2,98	0,53	0,52
Central Indo-Pacific	527,44	0	3,01	0,52	0,44
Tropical Atlantic	295,39	0	3,56	0,50	0,44
Temperate Australasia	103,44	0	2,65	0,50	0,49
Temperate Northern Pacific	392,10	0	3,42	0,48	0,58
Temperate South America	150,61	0	2,84	0,39	0,48
Arctic	321,45	0	2,82	0,27	0,18
Eastern Indo-Pacific	6,91	0	1,89	0,26	0,28
Southern Ocean	3,13	0	0,71	0,15	0,19

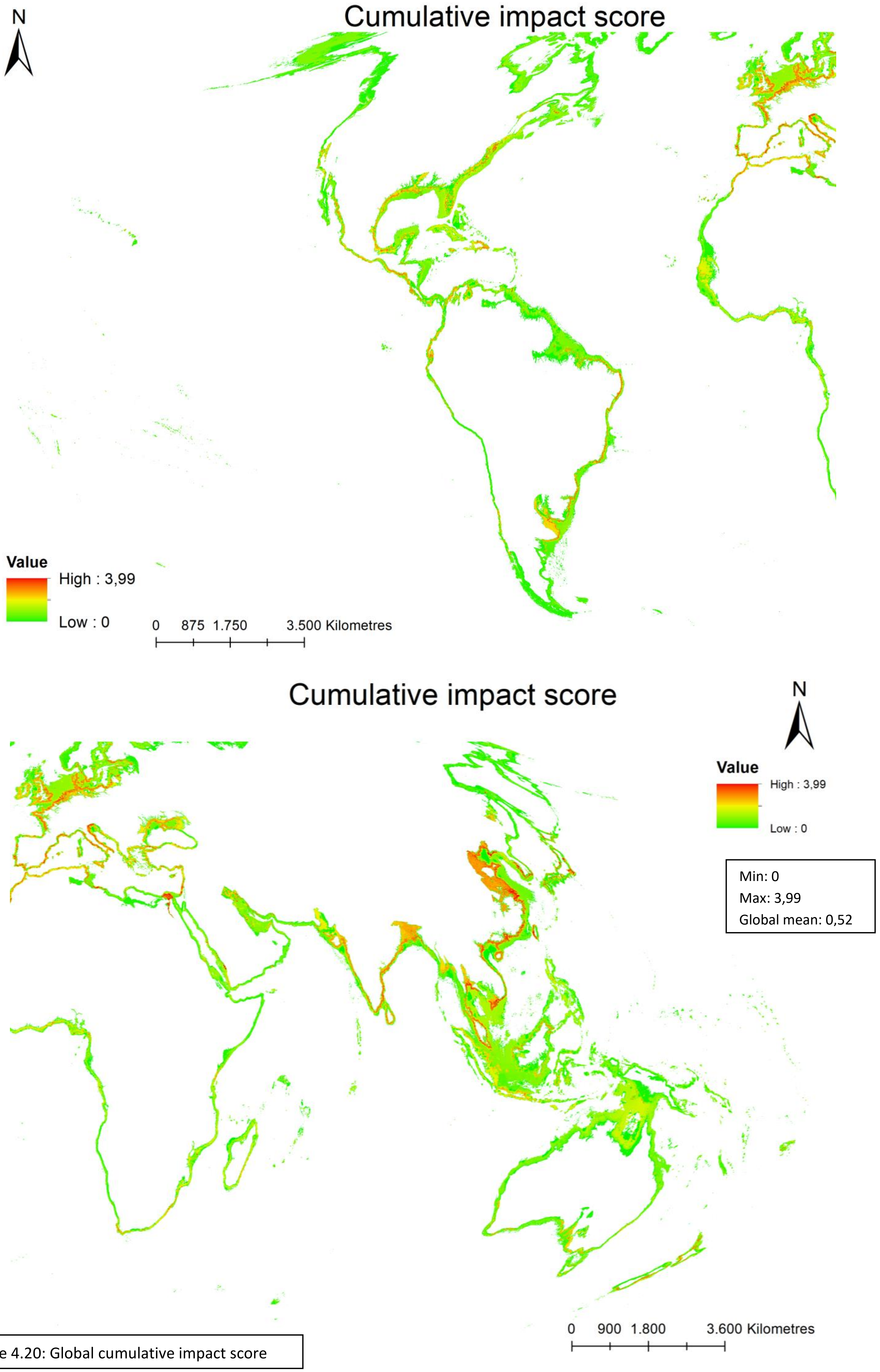


Figure 4.20: Global cumulative impact score

Figure 4.21

Cumulative human impacts on the Tropical Eastern Pacific Realm

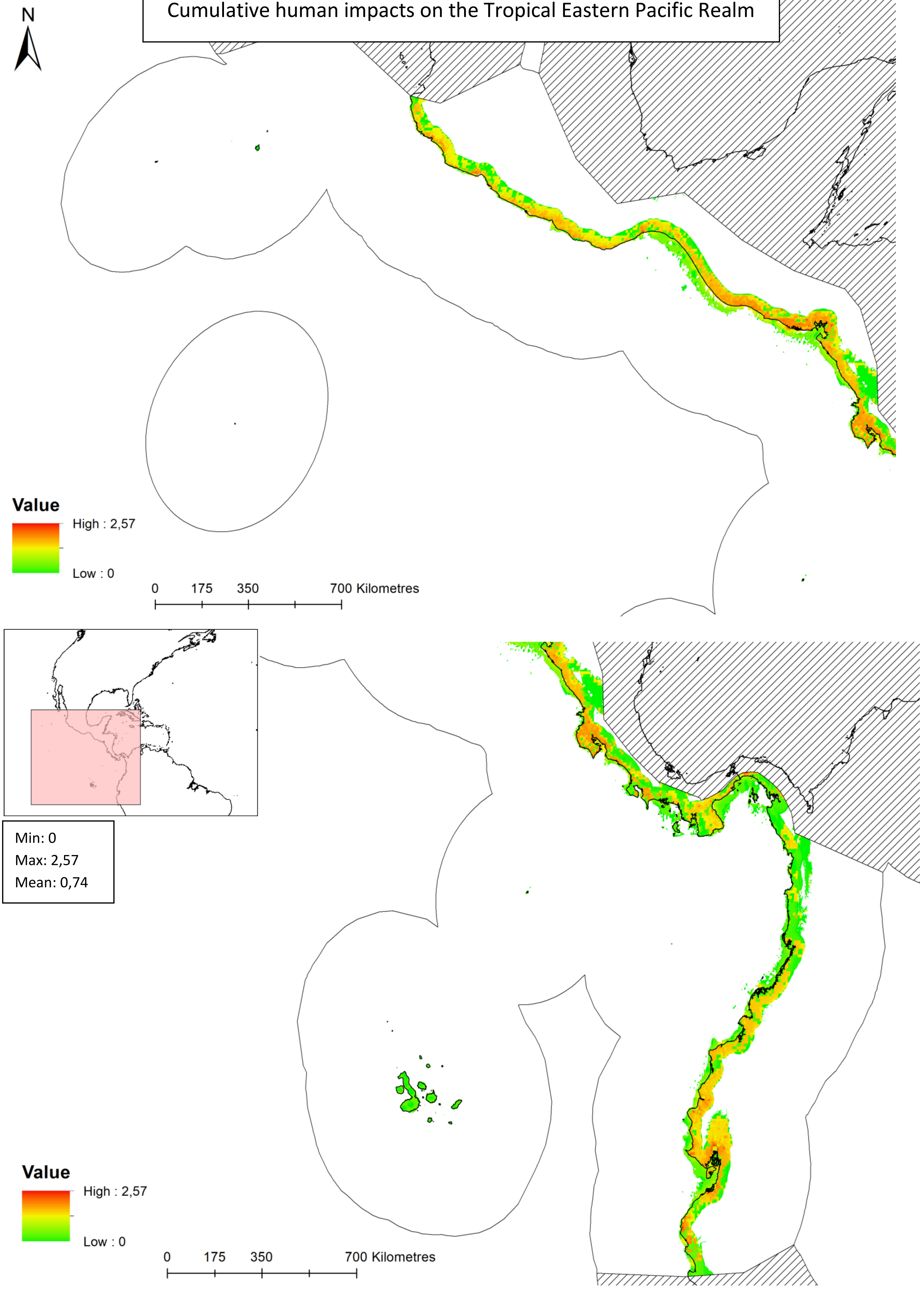


Figure 4.22

Cumulative human impacts on the US and Canada east coast, as part of the Temperate Northern Atlantic Realm

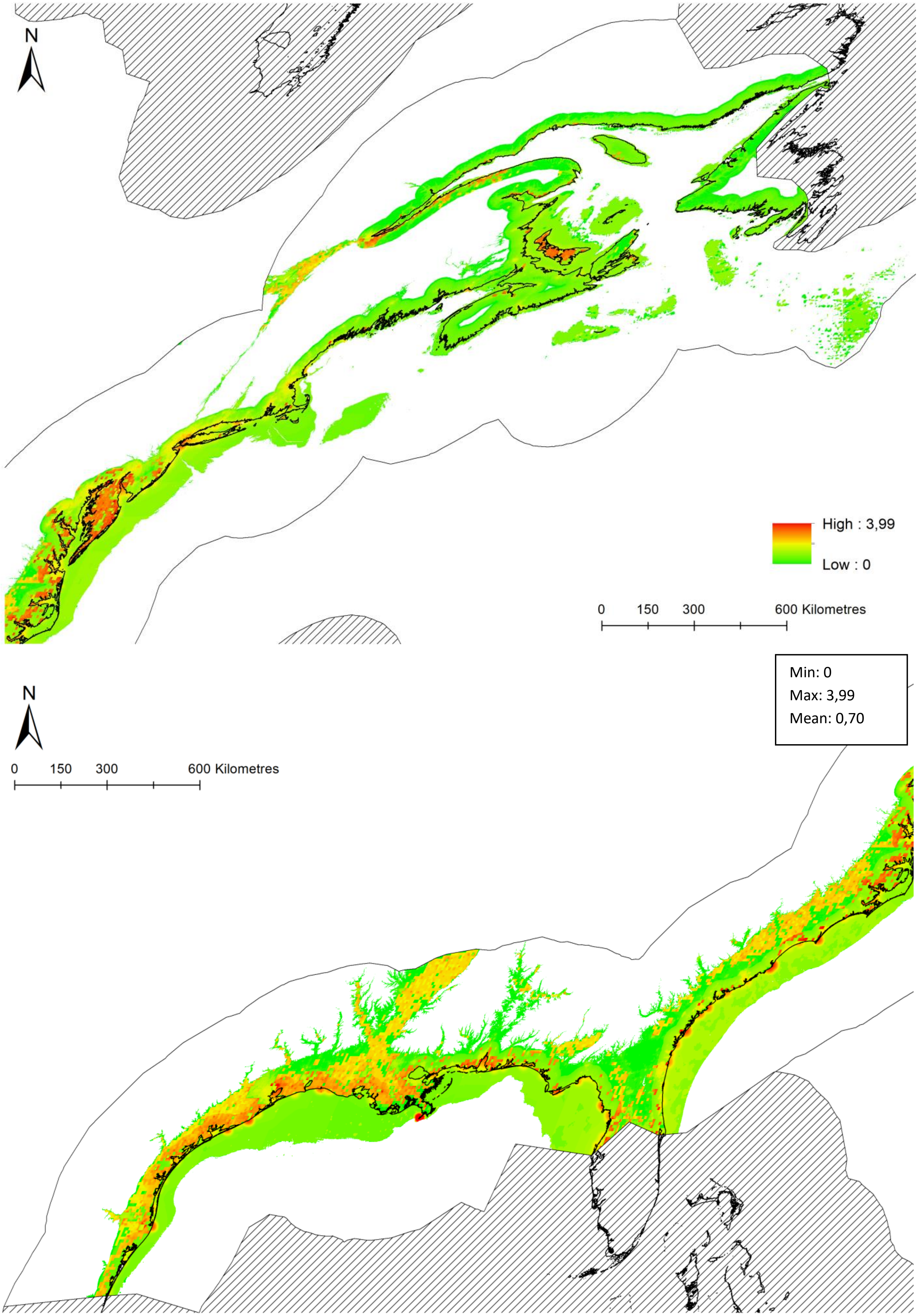
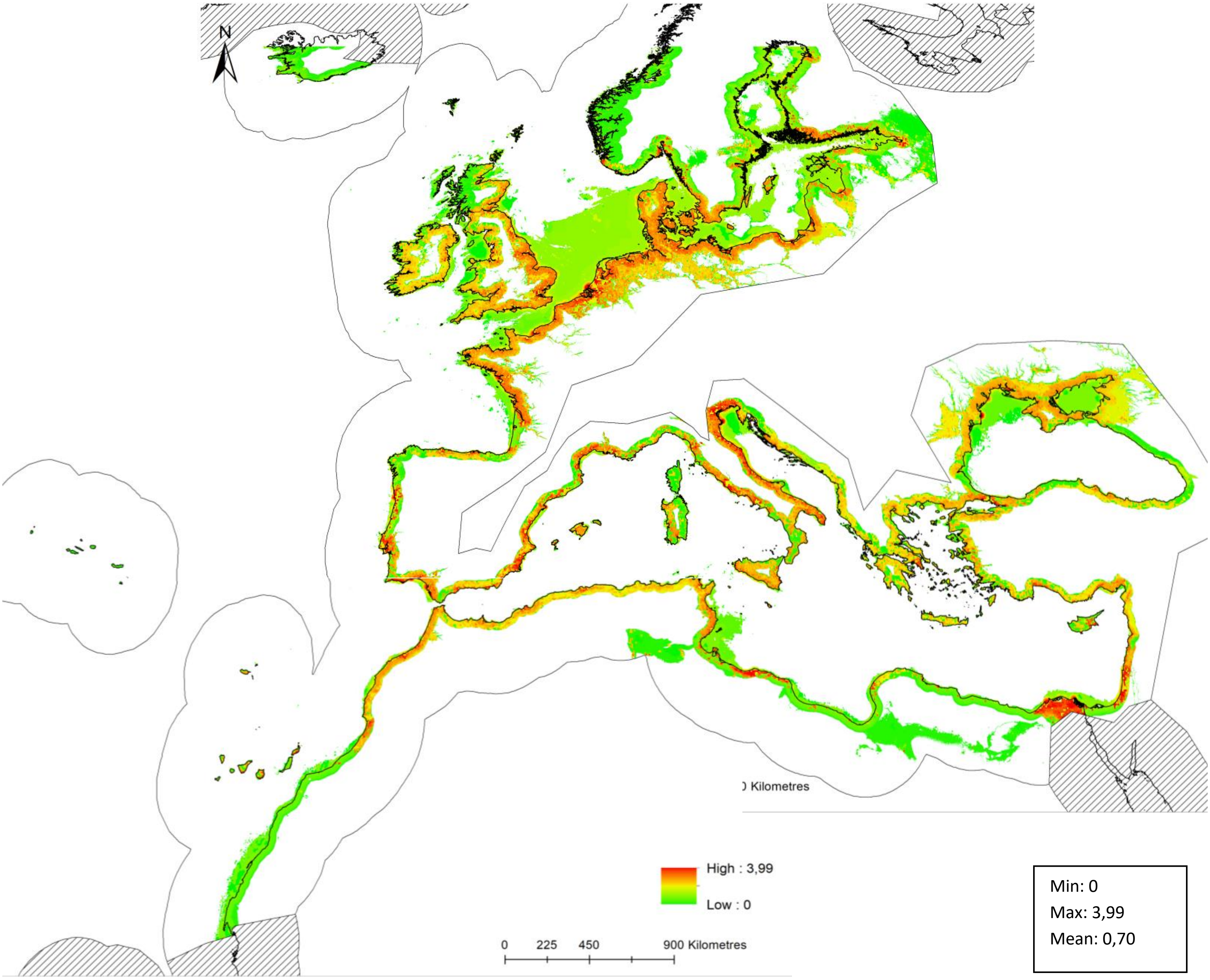


Figure 4.23

Cumulative human impacts on Europe, as part of the Temperate Northern Atlantic Realm



Min: 0
Max: 3,99
Mean: 0,70

Figure 4.24.1

Cumulative human impacts on the Hawaii Ecoregion, as part of the Eastern Indo Pacific Realm

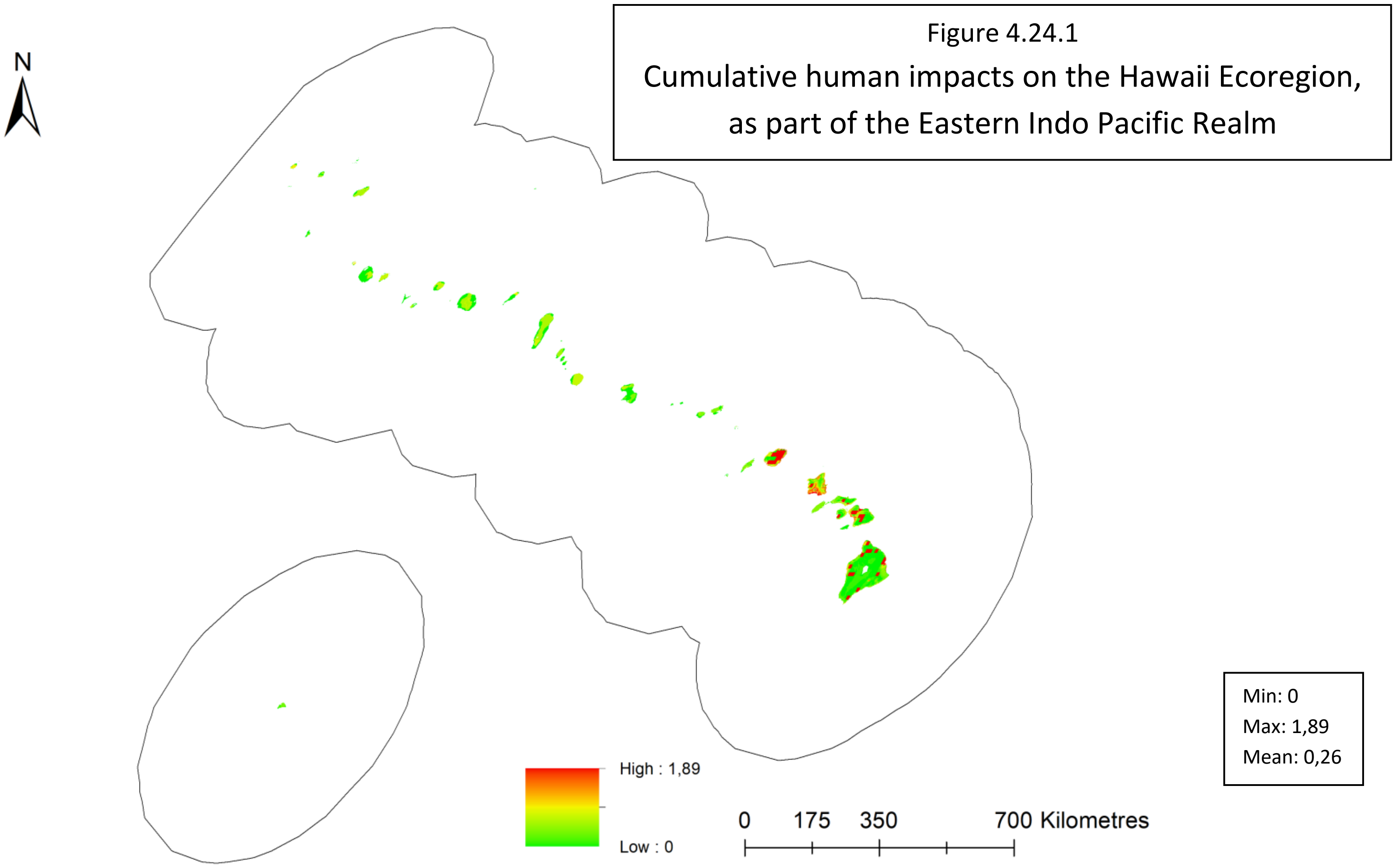


Figure 4.24.2

Cumulative human impacts on the Tuamotus Ecoregion, as part of the Eastern Indo Pacific Realm

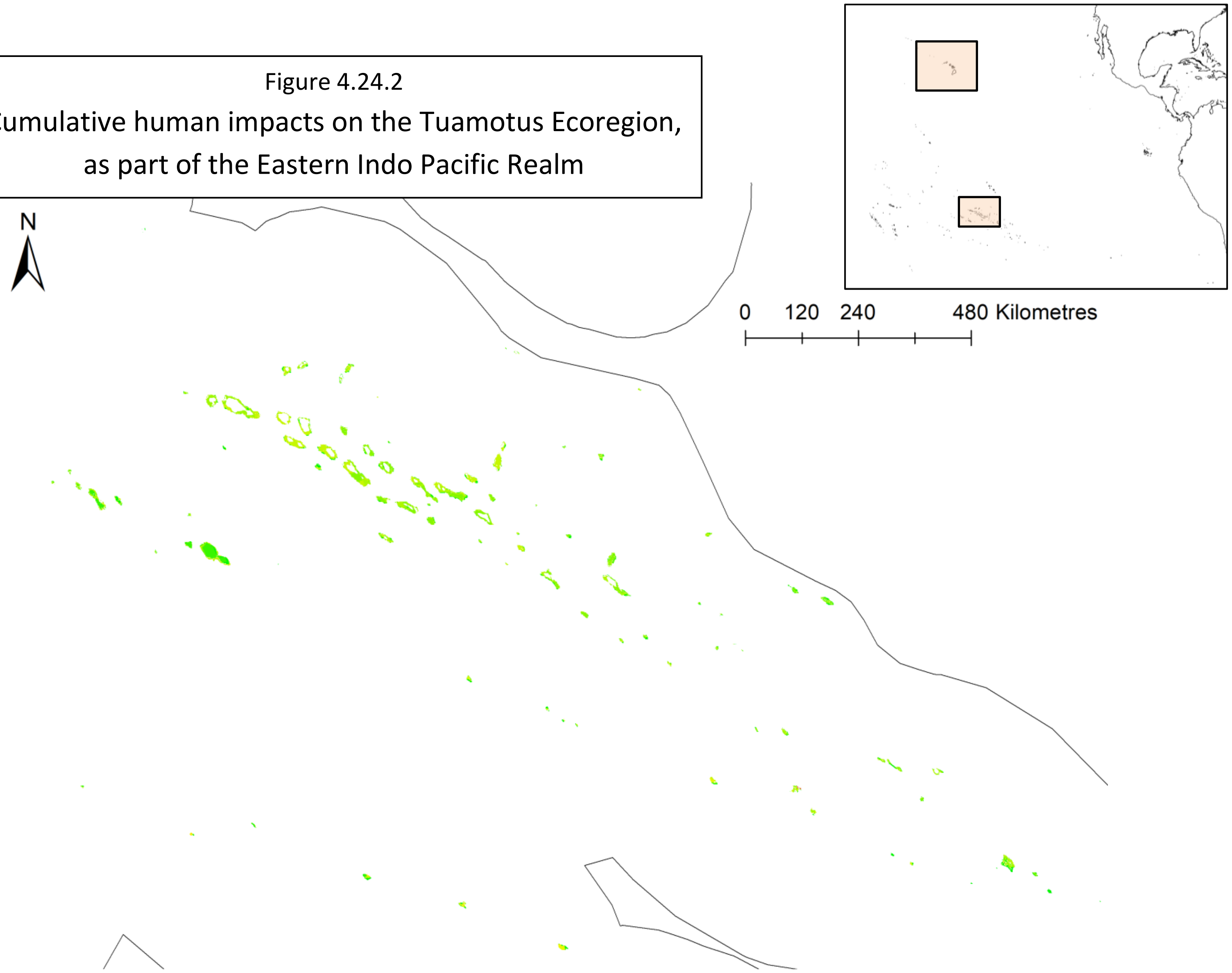


Table 4.25: Most impacted Provinces

Province	**Research Area, *1000 km^2**	**Min**	**Max**	**Mean**	**StDev**
Bay of Bengal	52,96	0,00	2,89	0,92	0,61
Mediterranean Sea	108,49	0,00	2,96	0,81	0,64
Warm Temperate Northwest Pacific	53,95	0,00	3,42	0,78	0,69
Black Sea	43,72	0,00	2,67	0,78	0,54
Lusitanian	34,44	0,00	2,88	0,77	0,63
Agulhas	8,40	0,00	2,98	0,77	0,56
West and South Indian Shelf	48,86	0,00	3,06	0,76	0,57
Tropical East Pacific	31,95	0,00	2,57	0,75	0,60

Table 4.25 presents the most impacted MEOW Provinces. From these Provinces several are part of the Temperate Northern Atlantic Realm (see figures 4.22-23) being the Mediterranean Sea, the Black Sea and the Lusitanian, these Provinces will not be visualised. The Bay of Bengal Province is visualised (figure 4.26), as well as the Warm Temperate Northwest Pacific Province (figure 4.27), the Agulhas Bank Ecoregion (figure 4.29) and Natal Ecoregion (figure 4.28) make up the Agulhas Province, the West and South Indian Shelf is visualised at figure 4.30, and the Tropical East Pacific makes up the entire Tropical Eastern Pacific Realm (figure 4.14).

Figure 4.26

Cumulative human impacts on the Bay of Bengal Province

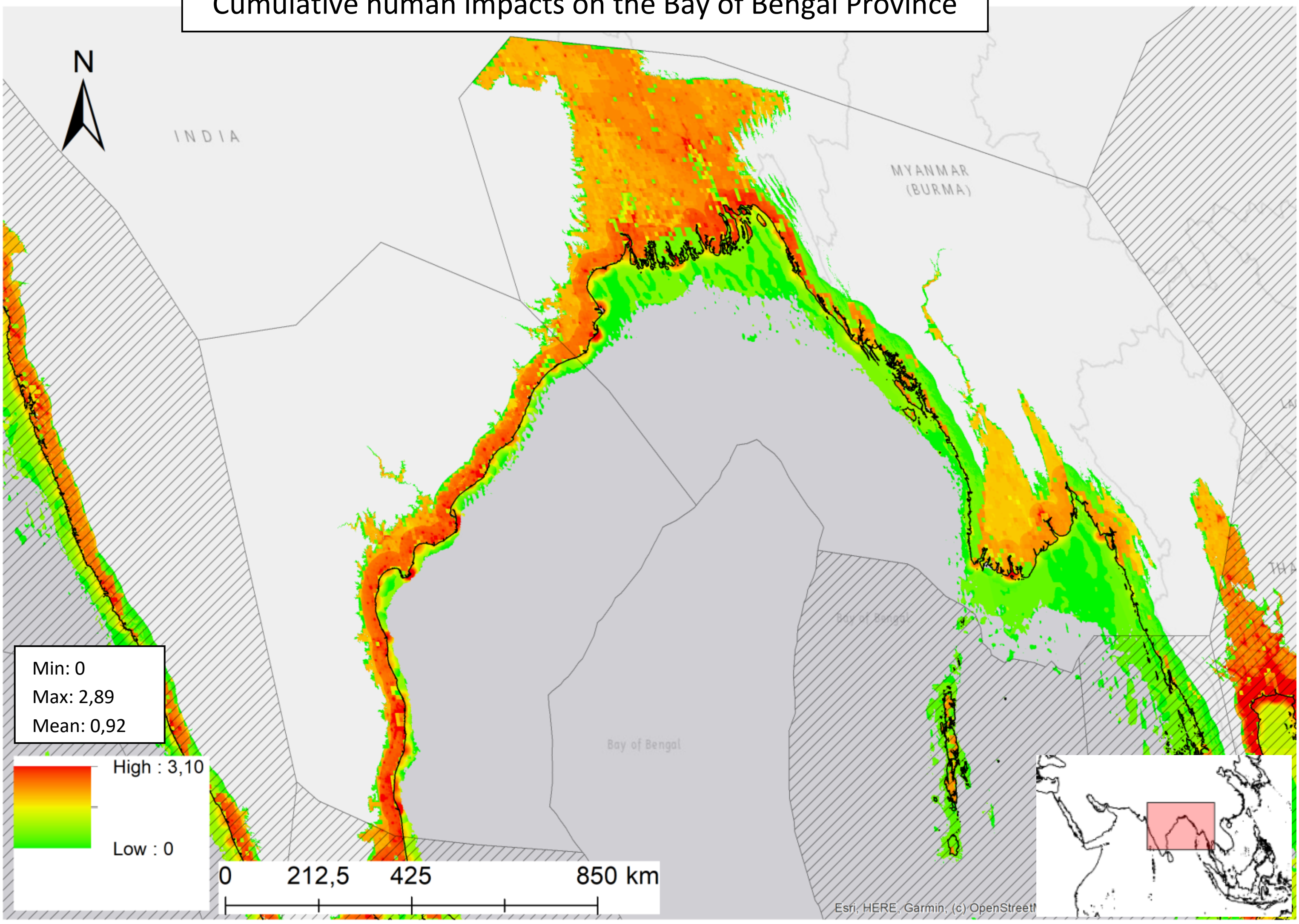
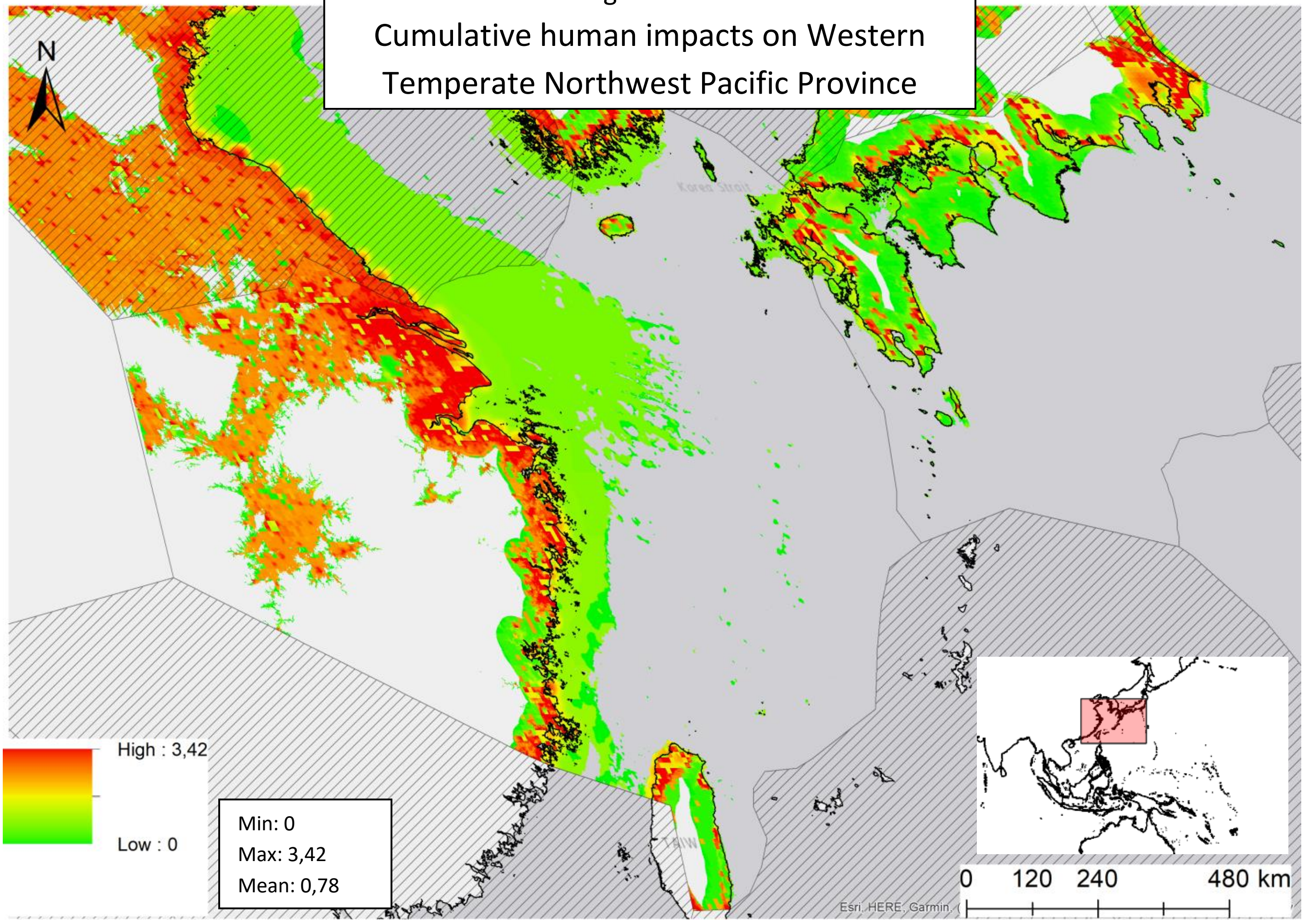


Figure 4.27

Cumulative human impacts on Western Temperate Northwest Pacific Province



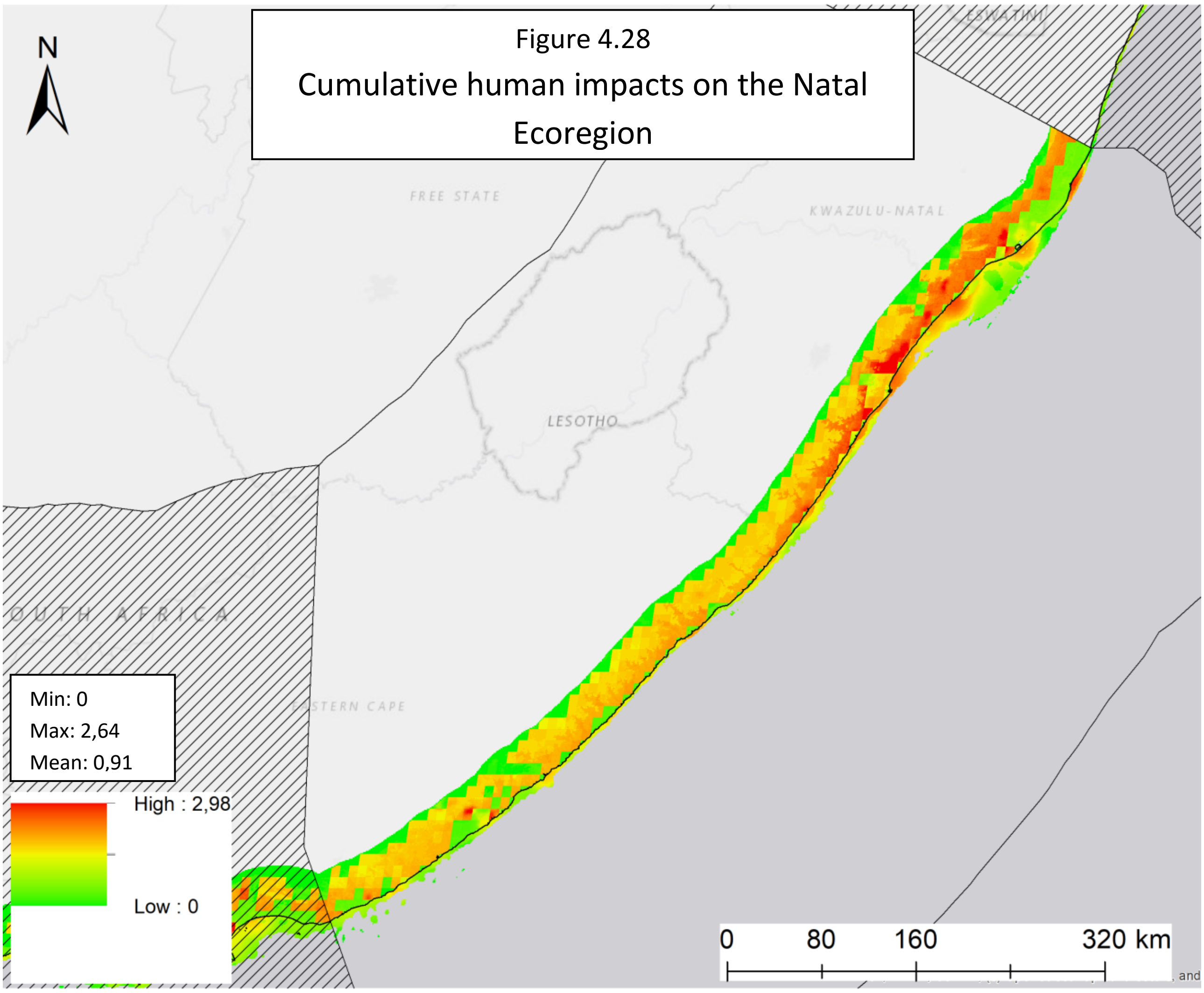


Figure 4.28
Cumulative human impacts on the Natal Ecoregion

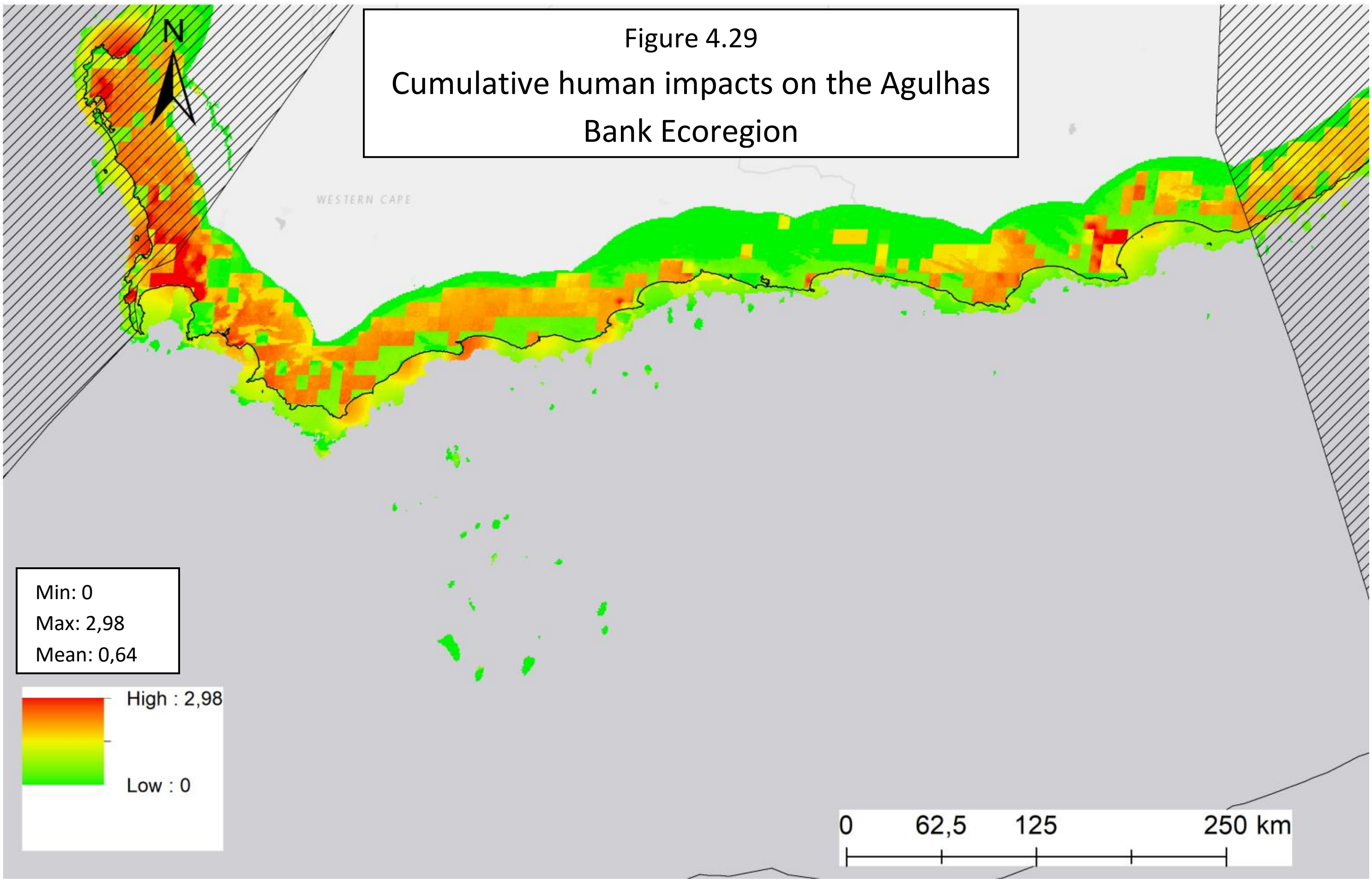
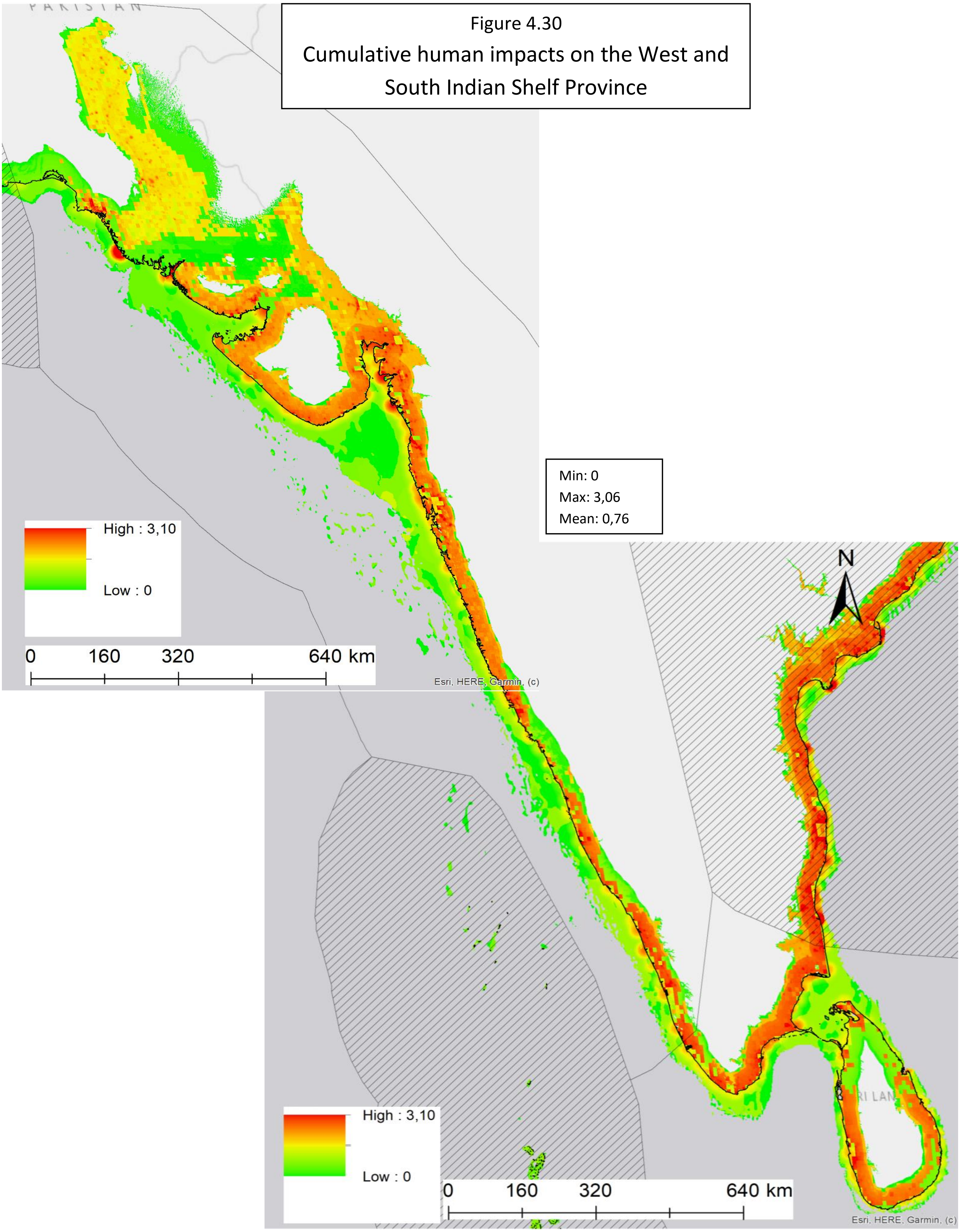


Figure 4.29
Cumulative human impacts on the Agulhas Bank Ecoregion

Figure 4.30

Cumulative human impacts on the West and South Indian Shelf Province



Min: 0
Max: 3,06
Mean: 0,76

1Table 4.30: Least impacted Provinces

Province	Research Area, *1000 km^2	Min	Max	Mean	StDev
Easter Island	0,02	0,00	0,31	0,06	0,08
Juan Fernandez and Desventuradas	0,03	0,00	0,35	0,06	0,12
Marquesas	0,16	0,00	0,68	0,10	0,15
Subantarctic New Zealand	0,26	0,00	0,71	0,13	0,21
St. Helena and Ascension Islands	0,06	0,00	0,42	0,14	0,17

Table 4.31 presents the least impacted Provinces. The least impacted Provinces are all small island (groups) being Easter Island (figure 4.32), Juan Fernandez and Desventuradas (figure 4.33), Marquesas (4.34), Subantarctic New Zealand (4.35), and the St Helena and Ascension Islands Province (4.36).

Figure 4.32
Cumulative human impacts on the Easter Island Province

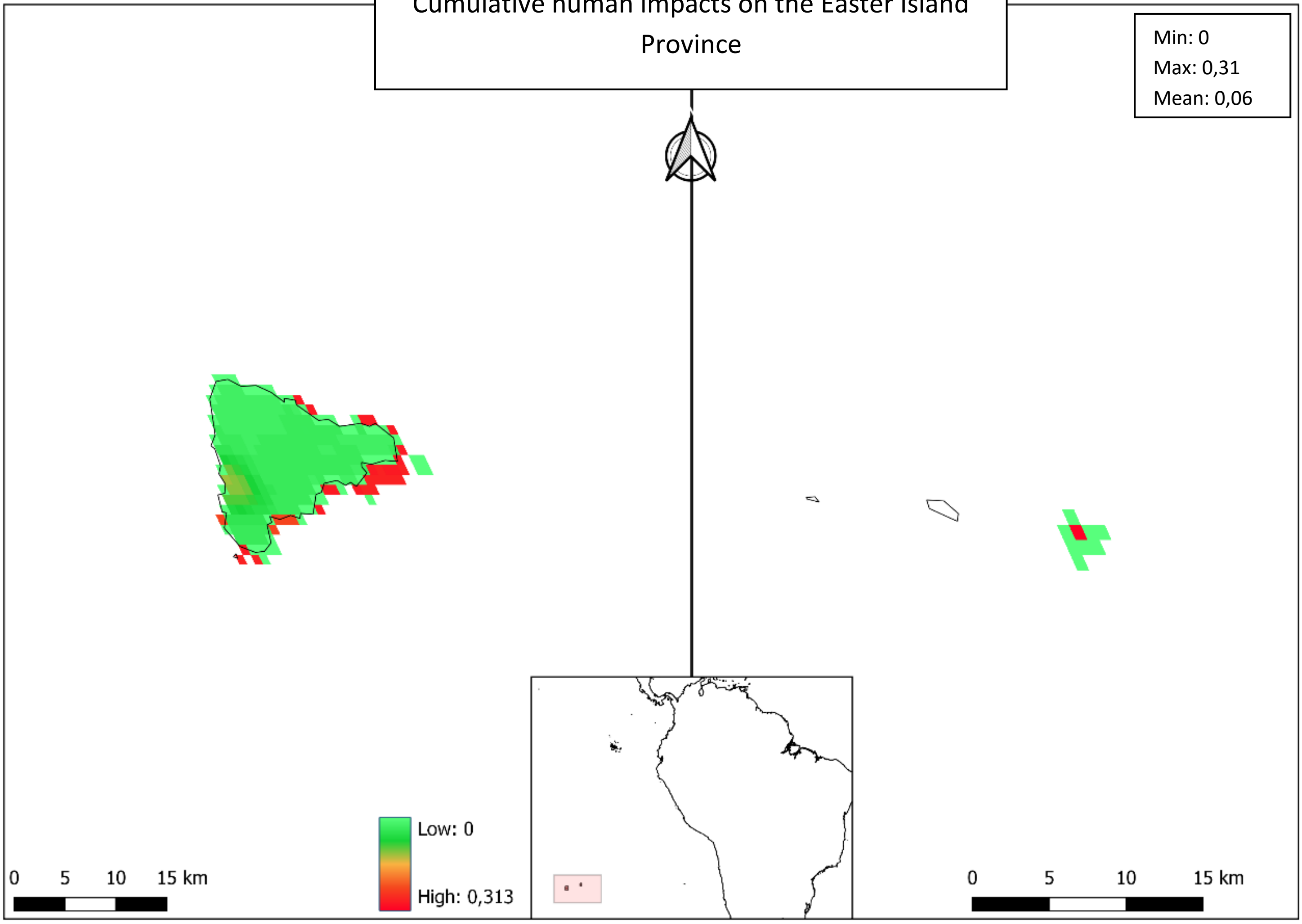
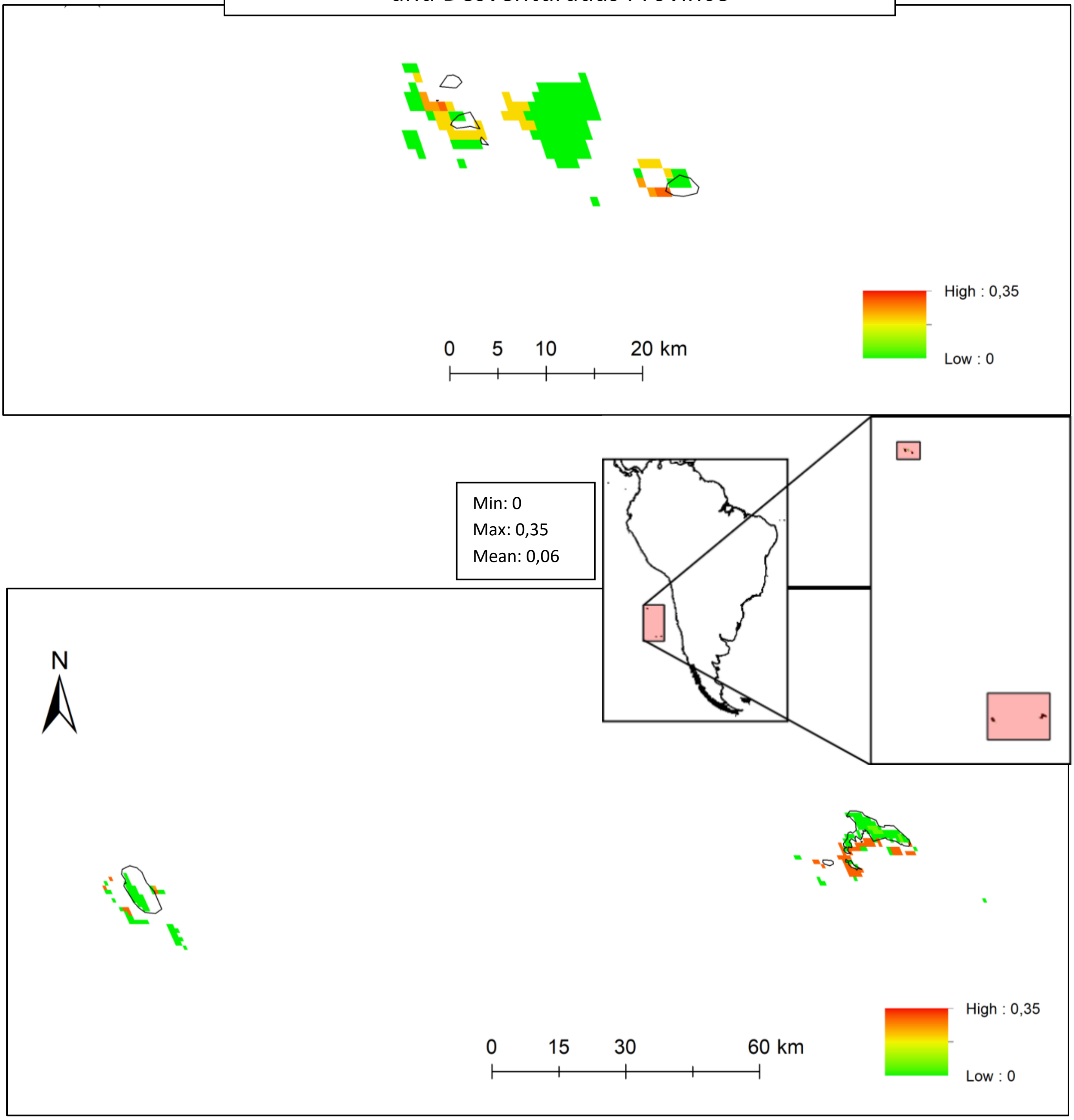


Figure 4.33

Cumulative human impacts on the Juan Fernandez and Desventuradas Province



Min: 0
Max: 0,35
Mean: 0,06

Figure 4.34

Cumulative human impacts on the Marquesas Province

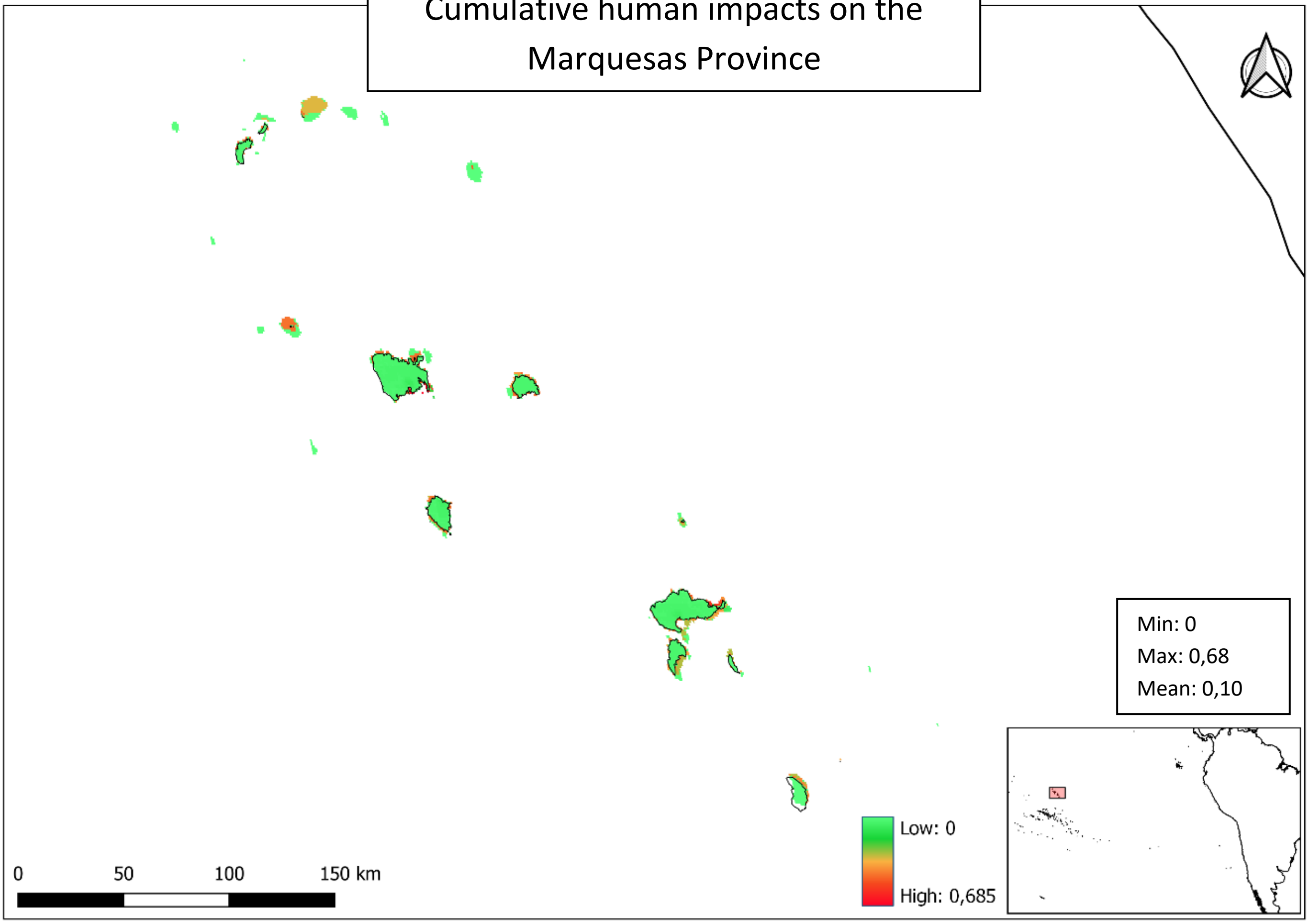


Figure 4.35

Cumulative human impacts on the Subantarctic New Zealand Province

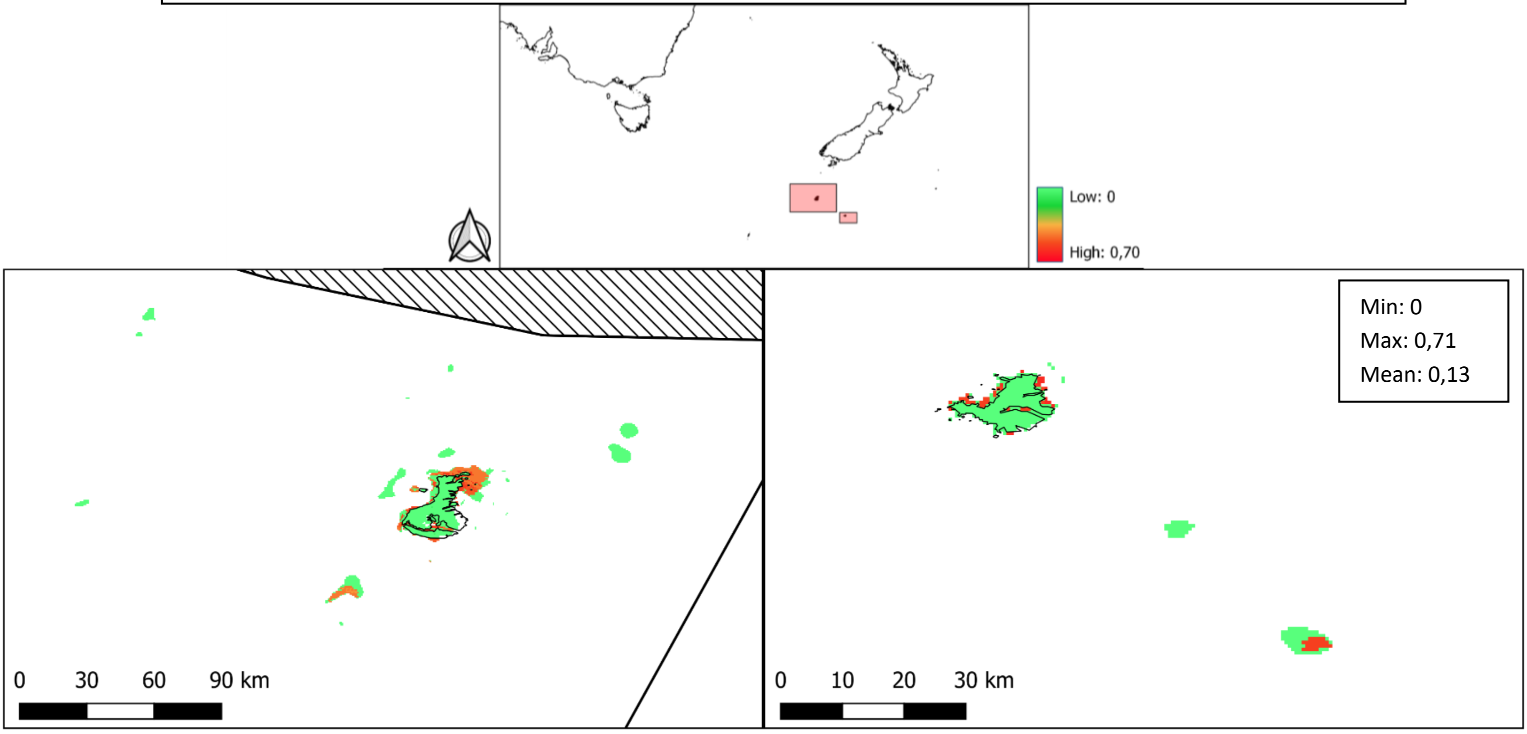


Figure 4.36
Cumulative human impacts on the St. Helena and Ascension Islands Province

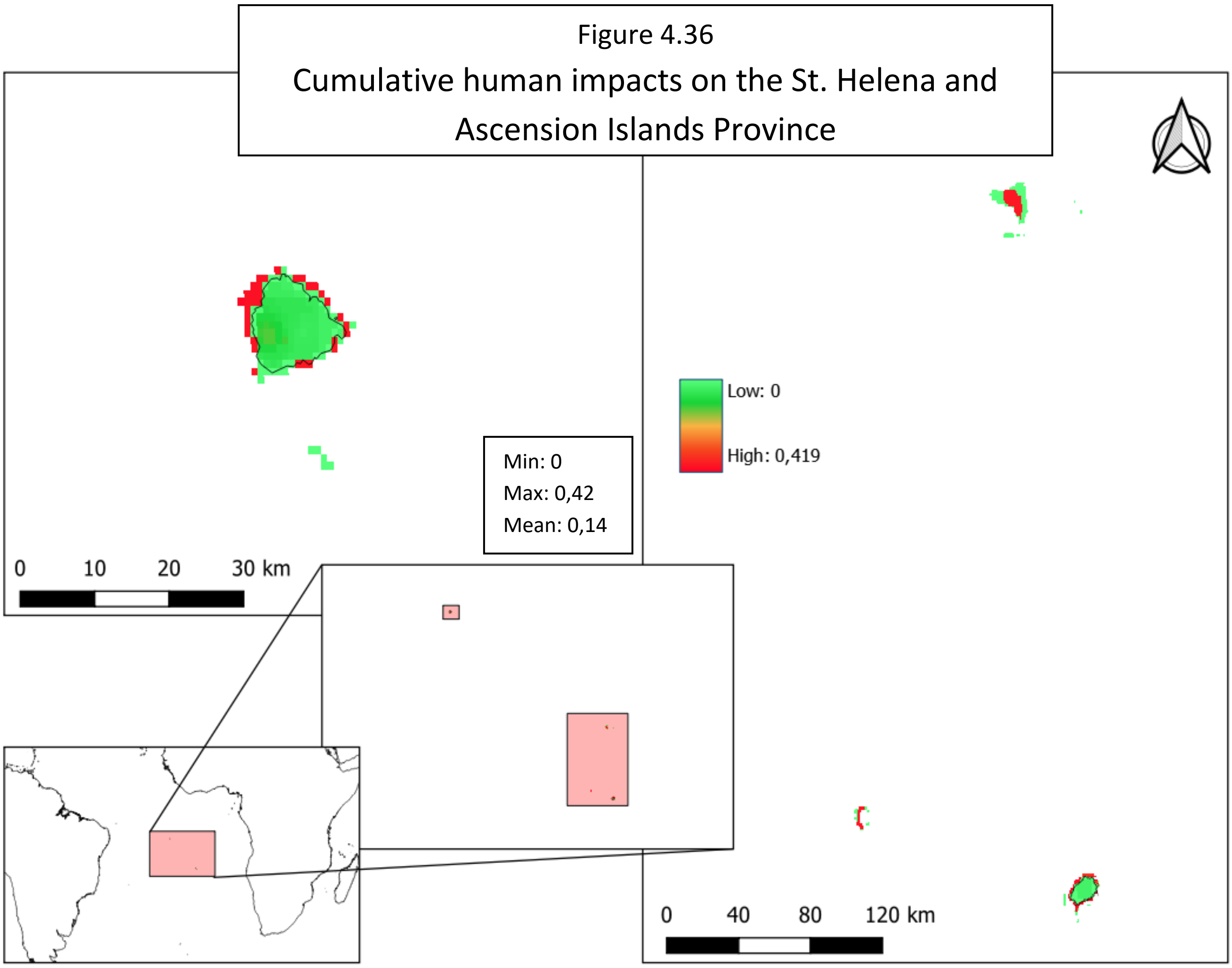


Table 4.37: **Most impacted Ecoregions**					
Ecoregion	**Research Area, *1000 km^2**	**Min**	**Max**	**Mean**	**StDev**
Eastern India	8,97	0,00	2,85	1,15	0,61
Alboran Sea	4,86	0,00	2,90	1,10	0,52
Yellow Sea	76,15	0,00	3,30	1,03	0,66
Adriatic Sea	14,23	0,00	2,84	0,99	0,64
Ionian Sea	8,55	0,00	2,78	0,93	0,59
South European Atlantic Shelf	19,08	0,00	2,88	0,93	0,64
Mexican Tropical Pacific	4,53	0,00	2,50	0,92	0,54
Southern Vietnam	13,86	0,00	2,99	0,92	0,59
Western Mediterranean	25,84	0,00	2,96	0,91	0,64
Natal	4,04	0,00	2,64	0,91	0,51
South India and Sri Lanka	9,86	0,00	2,50	0,89	0,59
Aegean Sea	16,55	0,00	2,81	0,88	0,57
North Sea	91,31	0,00	3,15	0,88	0,54
Northern Bay of Bengal	43,99	0,00	2,89	0,87	0,60
Guayaquil	5,37	0,00	2,57	0,87	0,60

The most impacted Ecoregions, the lowest biogeographic level of the Marine Ecoregions of the World, are listed at table 4.37. From these Ecoregions the majority is either part of the most impacted Realms or Provinces. Eastern India and the Northern Bay of Bengal are part of the Bay of Bengal Province (Figure 4.26), the Alboran Sea, Adriatic Sea, Ionian Sea, Western Mediterranean, and Aegean Sea are all part of the Mediterranean Sea Province, which is part of the Temperate Northern Atlantic (Figure 4.22-23). The South European Atlantic Shelf and the North Sea are both part of the Temperate Northern Atlantic as well (Figure 4.22-23), the Mexican Tropical Shelf and the Guayaquil are part of the Tropical Eastern Pacific Realm (figure 4.21), and the Natal ecoregion is visualised as part at the Agulhas Province (Figure 4.29). The South India and Sri Lanka Ecoregion is part of the West and South Indian Shelf (Figure 4.30). The Ecoregions that haven't been visualised yet are the, Yellow Sea (Figure 4.38) and South Vietnam (Figure 4.39).

Figure 4.38

Cumulative human impacts on the Yellow Sea Ecoregion

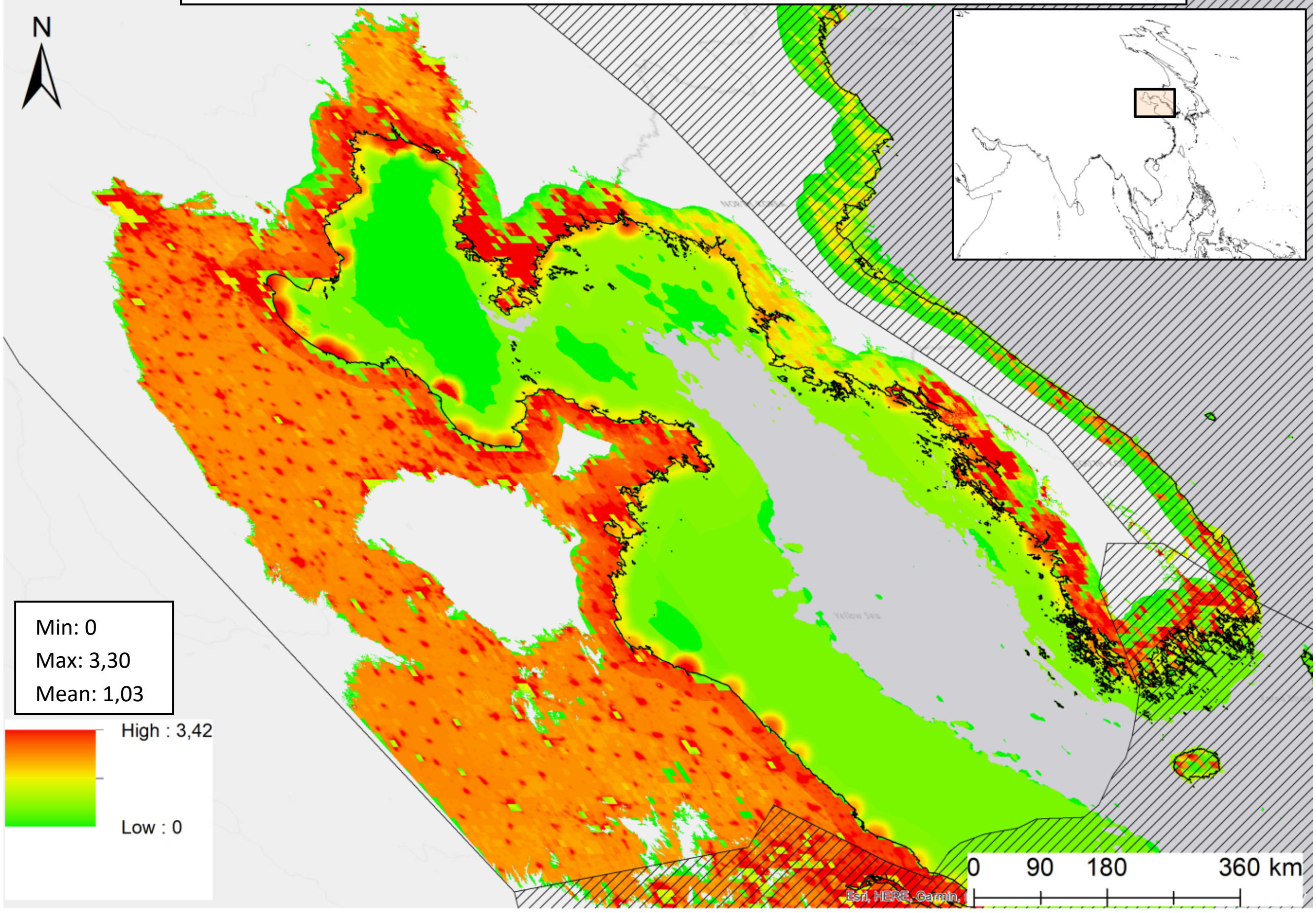


Figure 4.39

Cumulative human impacts on the South Vietnam Ecoregion

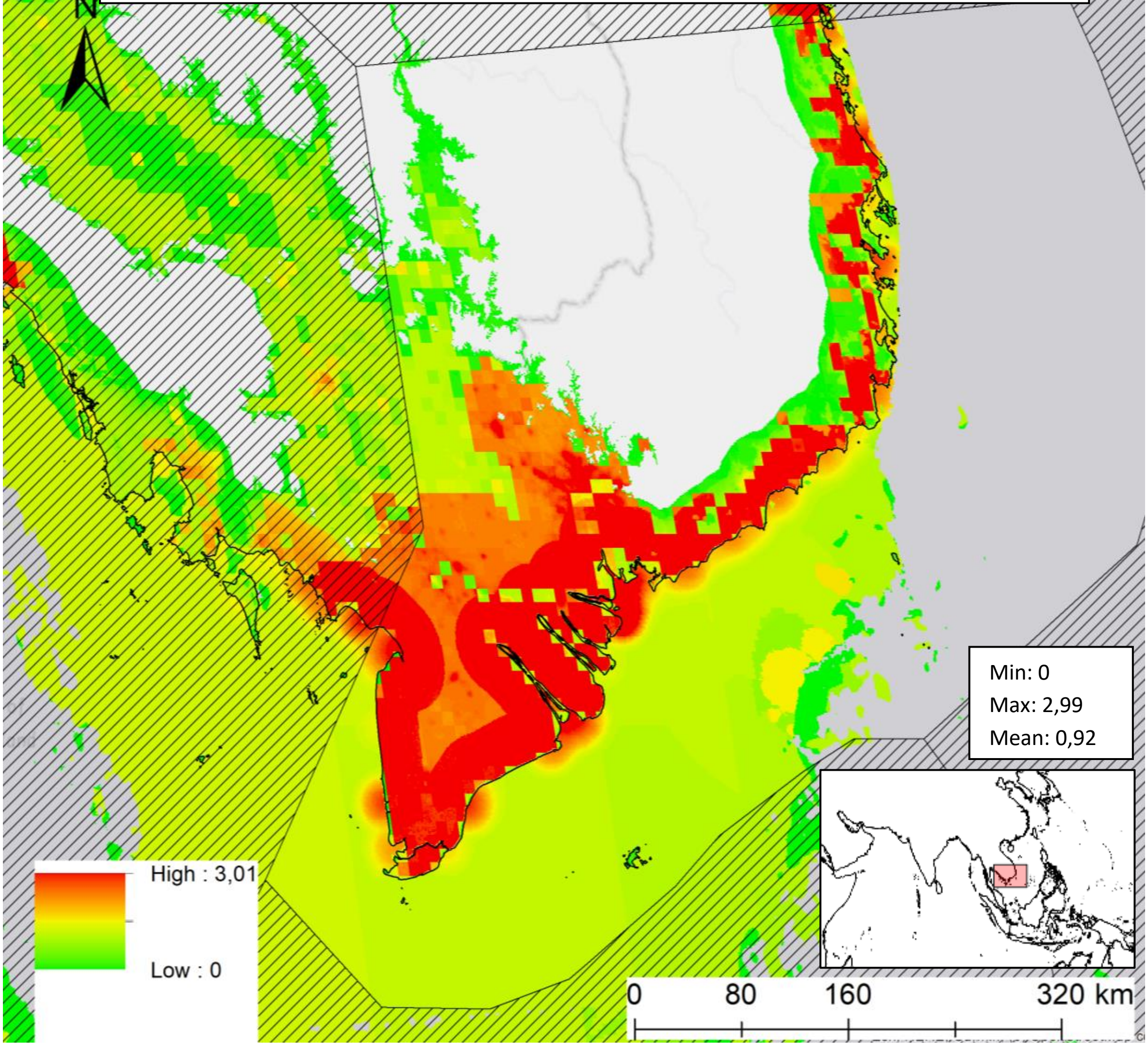


Table 4.40: The least impacted Ecoregions

Ecoregion	Area, *1000km	Min	Max	Mean	StDev
Northern Galapagos Islands	0,00	0,00	0,39	0,03	0,10
Chukchi Sea	0,32	0,00	0,11	0,04	0,01
North and East Barents Sea	1,11	0,00	0,71	0,05	0,05
Prince Edward Islands	0,06	0,00	0,41	0,05	0,08
Easter Island	0,02	0,00	0,31	0,06	0,08
Juan Fernandez and Desventuradas	0,03	0,00	0,35	0,06	0,12
South Sandwich Islands	0,02	0,00	0,48	0,07	0,13
Beaufort-Amundsen-Viscount Melville-Queen Maud	0,10	0,00	0,11	0,07	0,03
Bouvet Island	0,01	0,00	0,50	0,08	0,14
Revillagigedos	0,03	0,00	0,37	0,08	0,12

The least impacted Ecoregions are the- Northern Galapagos Islands (Figure 4.41), Chucki Sea (very limited coverage, not visualised), North and East Barentsz Sea (very limited coverage, not visualised), Prince Edward Islands (Figure 4.42), Easter Island (Figure 4.32), Juan Fernandez and Desventuradas (4.33), South Sandwich Islands (Figure 4.43), Beaufort-Amundsen-Viscount (very limited coverage, not visualised), Bouvet Island (Figure 4.44), and Revillagigedsos (Figure 4.43) - Ecoregions. Easter Island and the Juan Fernandez and Desventuradas eocregions are Provinces with only one Ecoregion, they can be found on the previous page as Provinces. The Chucki Sea, North and East Barentsz Sea and the Beaufort-Amundsen-Viscount all fall largely outside the research area, for this reason these are not visualised.

Figure 4.41

Cumulative human impacts on the Northern Galapagos Ecoregion

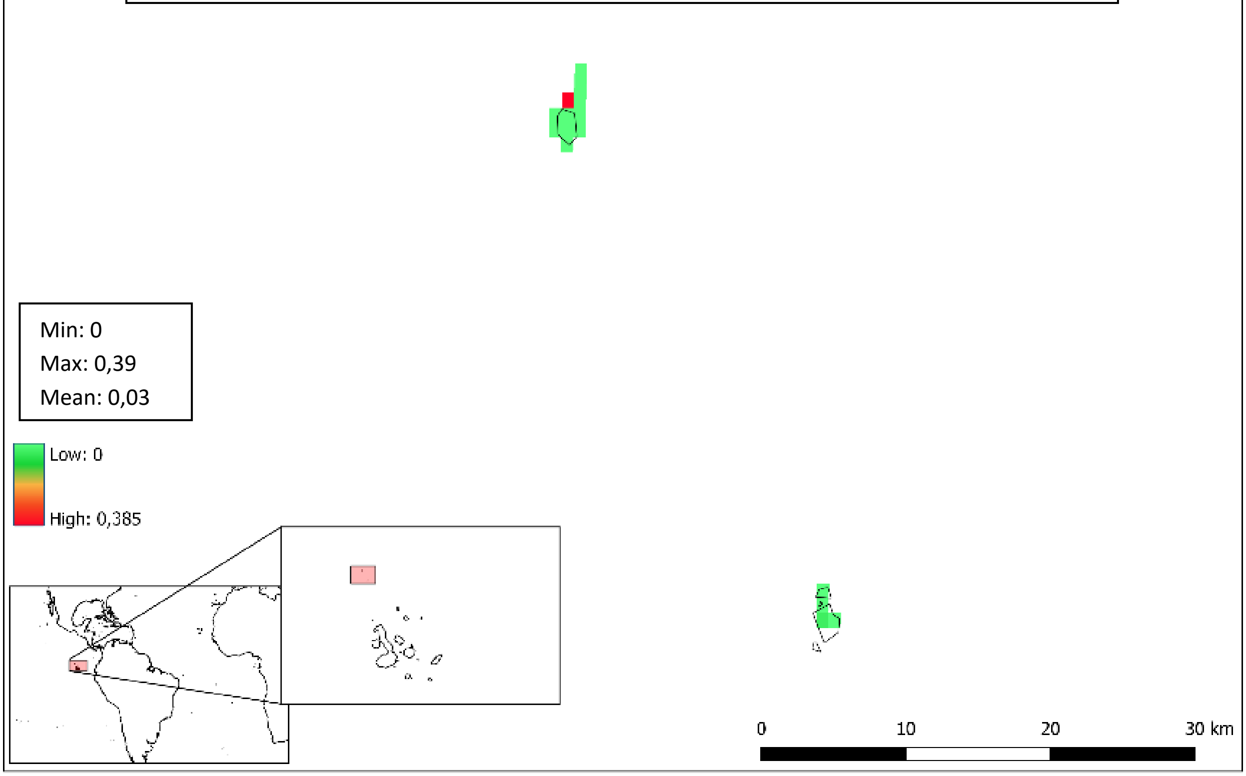


Figure 4.42

Cumulative human impacts on the Prince Edward Islands Ecoregion

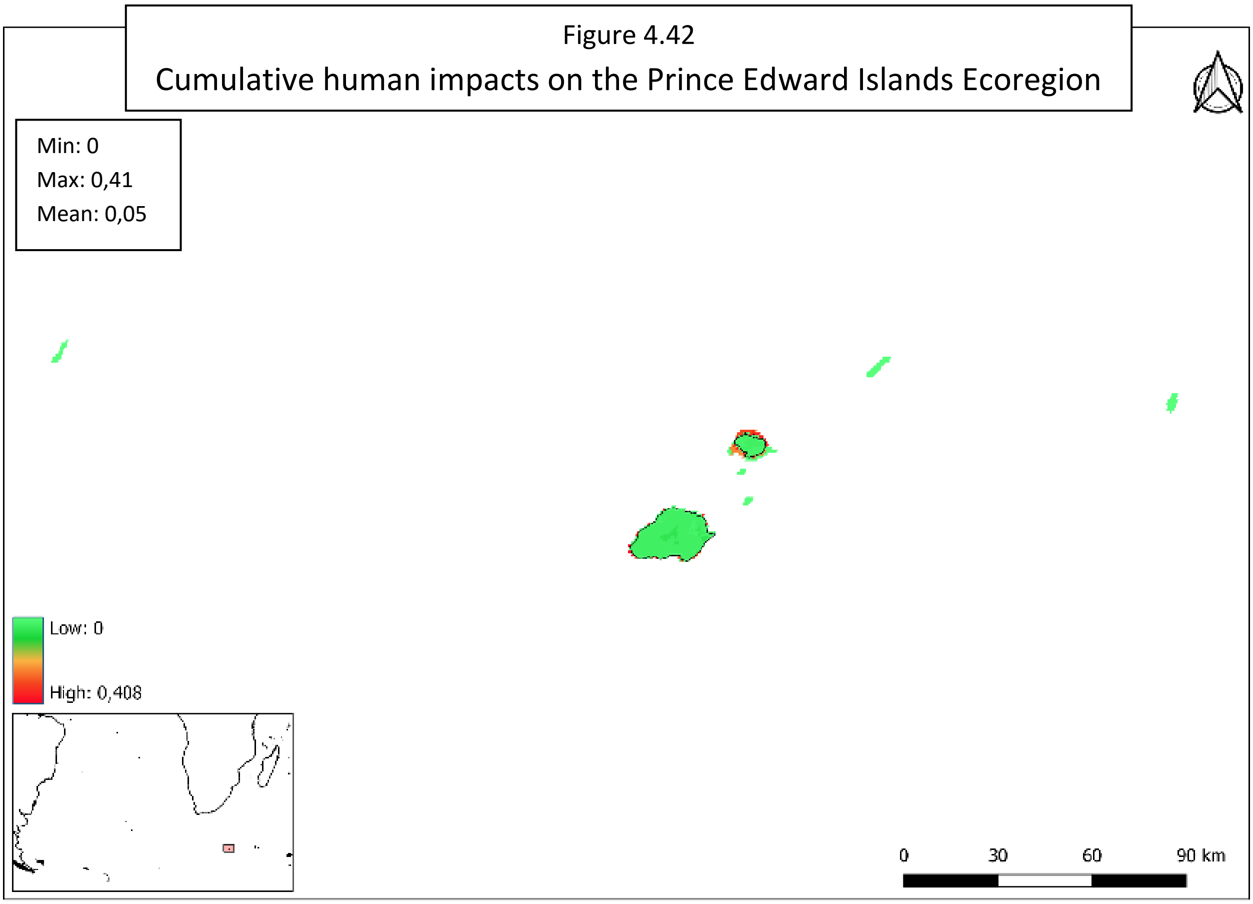


Figure 4.43

Cumulative human impacts on the South Sandwich Islands Ecoregion

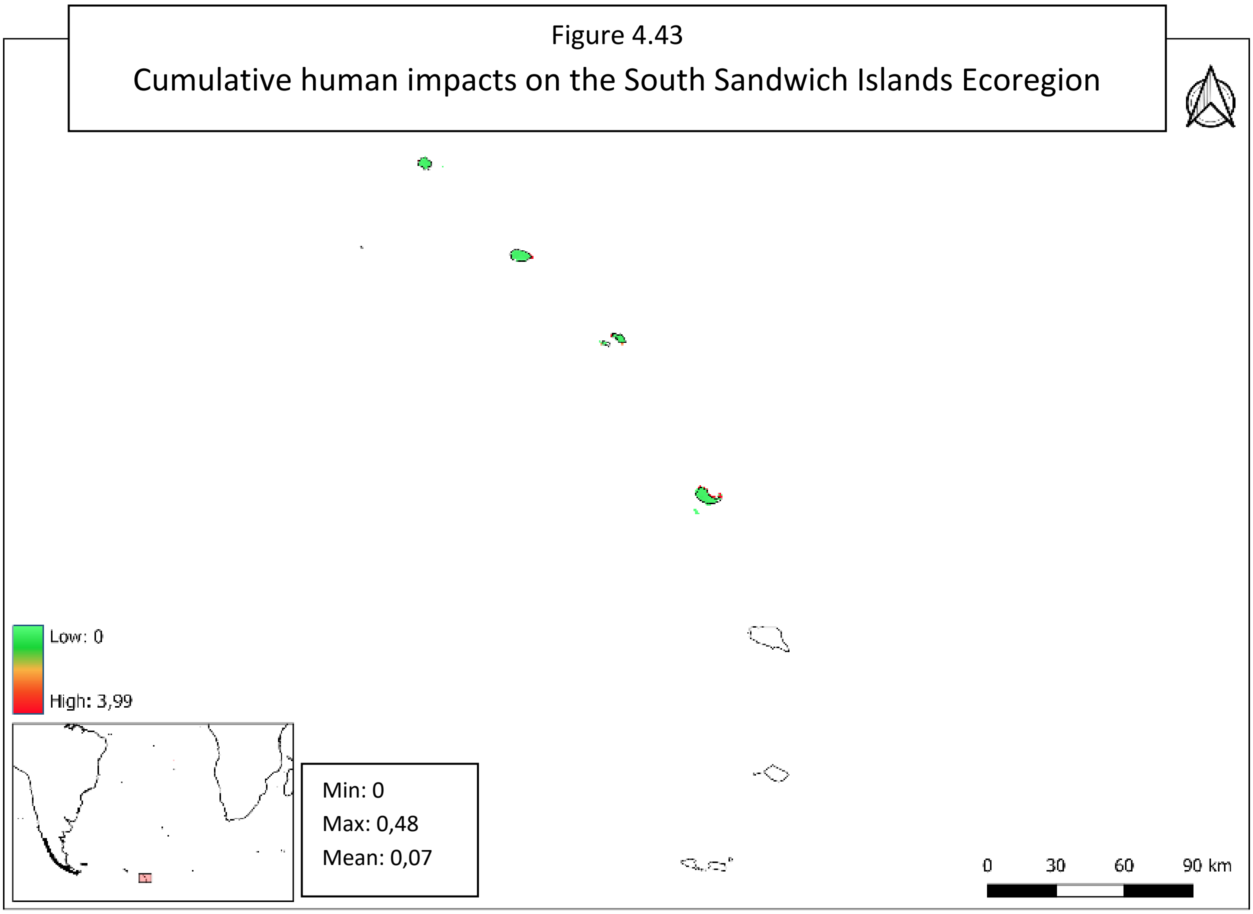


Figure 4.44
Cumulative human impacts on the Bouvet Island Ecoregion

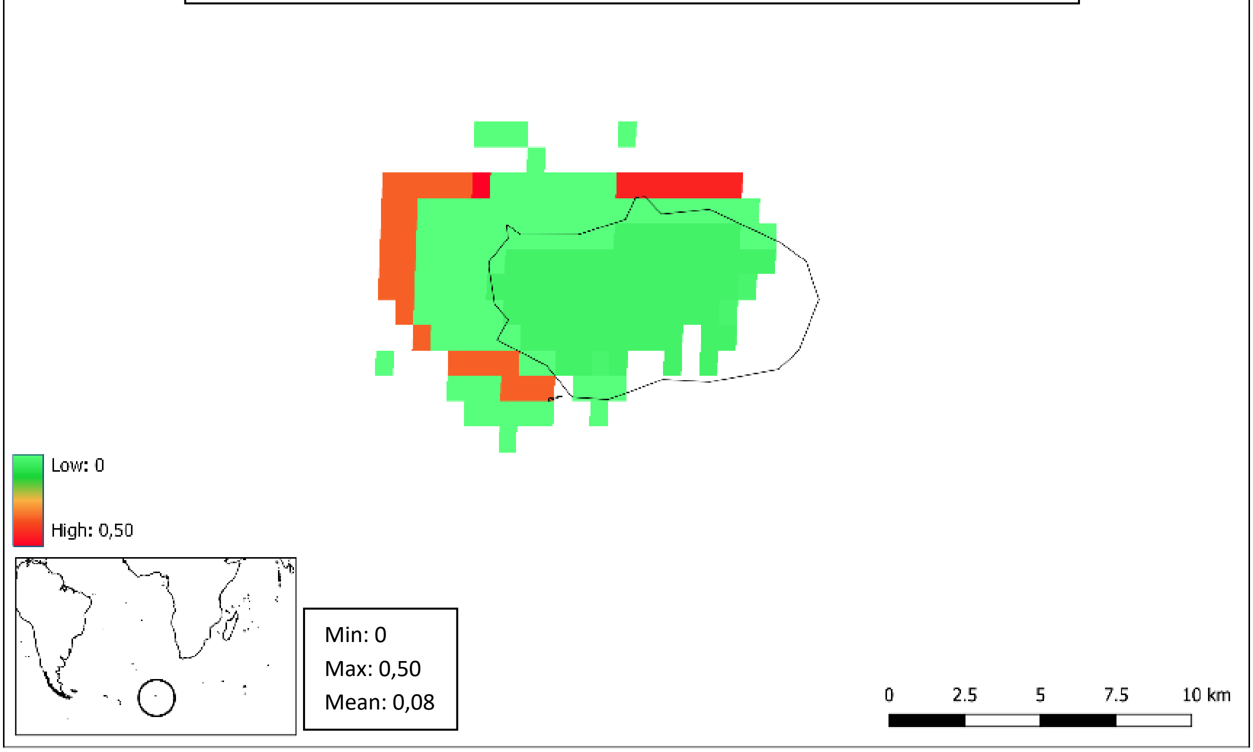
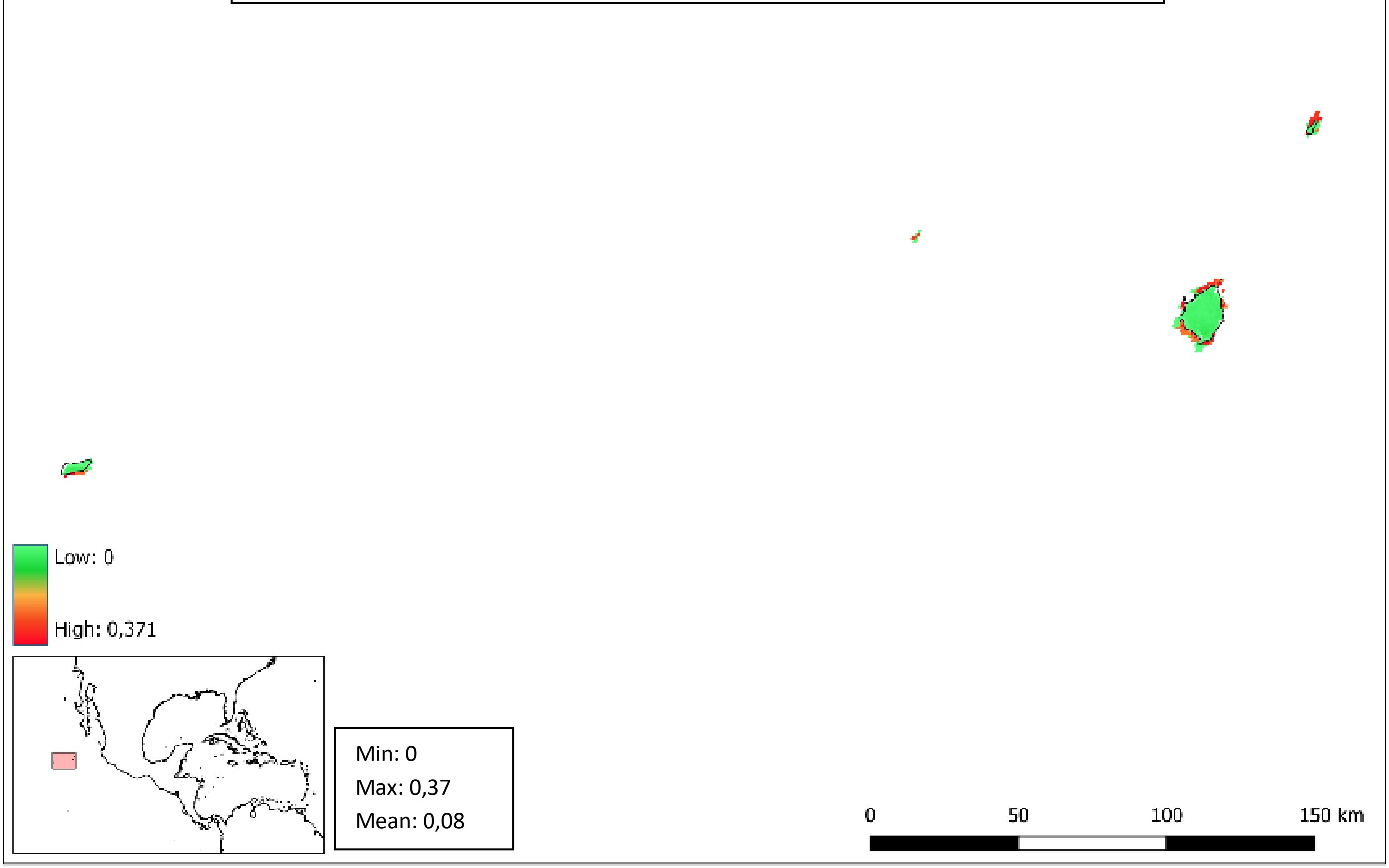


Figure 4.45
Cumulative human impacts on the Revillagigedos Ecoregion



It almost seems that islands are largely spared from anthropogenic stressors, but there are several islands that are quiet heavily impacted. The list below (table 4.46) are Ecoregions that are islands and have a mean cumulative impact score above 0,50.

Table 4.46: Cumulatively the most impacted Ecoregion islands (mean >0,50)

Ecoregion	Min	Max	Mean	Realm
Arafura Sea	0	2,38	0,54	Central Indo-Pacific
Azores Canaries Madeira	0	2,81	0,57	Temperate Northern Atlantic
Celtic Seas	0	2,50	0,75	Temperate Northern Atlantic
Central Kuroshio Current	0	2,74	0,58	Temperate Northern Pacific
Central New Zealand	0	2,38	0,64	Temperate Australasia
Chagos	0	0,77	0,53	Western Indo-Pacific
Lesser Sunda	0	2,01	0,54	Central Indo-Pacific
Northeastern Honshu	0	3,16	0,69	Temperate Northern Pacific
Northeastern New Zealand	0	2,18	0,60	Temperate Australasia
South Kuroshio	0	2,40	0,58	Central Indo-Pacific
Southeast Madagascar	0	1,59	0,78	Western Indo-Pacific
South New Zealand	0	2,24	0,53	Temperate Australasia
Southern Java	0	2,17	0,69	Central Indo-Pacific
Sunda Shelf/Java Sea	0	2,45	0,53	Central Indo-Pacific
Greater Antilles	0	2,43	0,71	Tropical Atlantic

Besides highly impacted islands, the research area also contains Ecoregions on the continent that experience low cumulative impacts. The Ecoregions listed at table 4.47 have a mean cumulative impact score below 0,20 and are located on the continent. These Ecoregions are all remote areas with low human population densities, regions that are hard to access and/or have unfavourable cold climates. These Ecoregions are less affected by the land based drivers that result from human population.

Table 4.47: Cumulatively the least impacted mainland Ecoregions (mean <=0,20)

Ecoregion	Min	Max	Mean	Realm
Central Somali Coast	0	0,79	0,19	Western Indo-Pacific
Channels and Fjords of Southern Chile	0	1,85	0,11	Temperate South America
Chiloense	0	2,13	0,17	Temperate South America
Gulf of Alaska	0	1,57	0,20	Temperate Northern Pacific
Humboldtian	0	2,47	0,18	Temperate South America
North American Pacific Fijordland	0	1,43	0,11	Temperate Northern Pacific
North Patagonian Gulfs	0	2,60	0,18	Temperate South America
Northern Labrador	0	1,22	0,16	Arctic
Oregon, Washington, Vancouver Coast and Shelf	0	2,20	0,20	Temperate Northern Pacific
Patagonian Shelf	0	2,50	0,17	Temperate South America
Sea of Okhotsk	0	2,23	0,17	Temperate Northern Pacific

4.3 Cumulative and individual stressor analysis

In this section additional analysis is done. What part of the research area is affected by how many stressors is presented at section 4.3.1. Several R^2 coefficients are presented at section 4.3.2 to present correlations. And at section 4.3.3 a cluster analysis will inform the reader about the similarity and dissimilarity between Realms.

4.3.1 The quantity of stressors present at cells

Table 4.48 presents the amount of cells of the research area that is affected by what amount of stressors. Each cell represents a cell size of 0,008333 square decimal degrees. This size corresponds to 0,86 km^2 at the equator and 0,43 km^2 at 45 degrees North or South of the equator.

Table 4.48: The amount of cells affected by what number of stressors

Number of stressors present	Count
0	2 088 709
1	3 780 616
2	12 423 719
3	8 500 253
4	4 927 181
5	7 566 161
Sum	39 286 639

Table 4.48 shows how many cells within the research area are affected by what multitude of stressors. These figures show that only 2,7% of the research area is unaffected by any of the 10 stressors, and that 92,5% of the research area is affected by two or more stressors simultaneously.

4.3.2 Predicted variance and regression

The next table present correlation figures of several predictors. The figures are acquired with the statistical software GeoDa. Table 4.49 presents the correlation between a dependent stressor and their independent stressor. For the marine based stressor sea level rise the independent variable is marine sea level rise and the dependent variable terrestrial sea level rise. For the land-based stressors (light, nutrients, organic, and inorganic pollution) the terrestrial stressor is the independent variable and the marine stressor is the dependent variable. An R^2 of 0,653 for example, means that 65,3% of the variance of the dependent variable (in this case terrestrial sea level rise) can be explained by the variance of the independent variable (in this case marine sea level rise). All correlations are positive and significant.

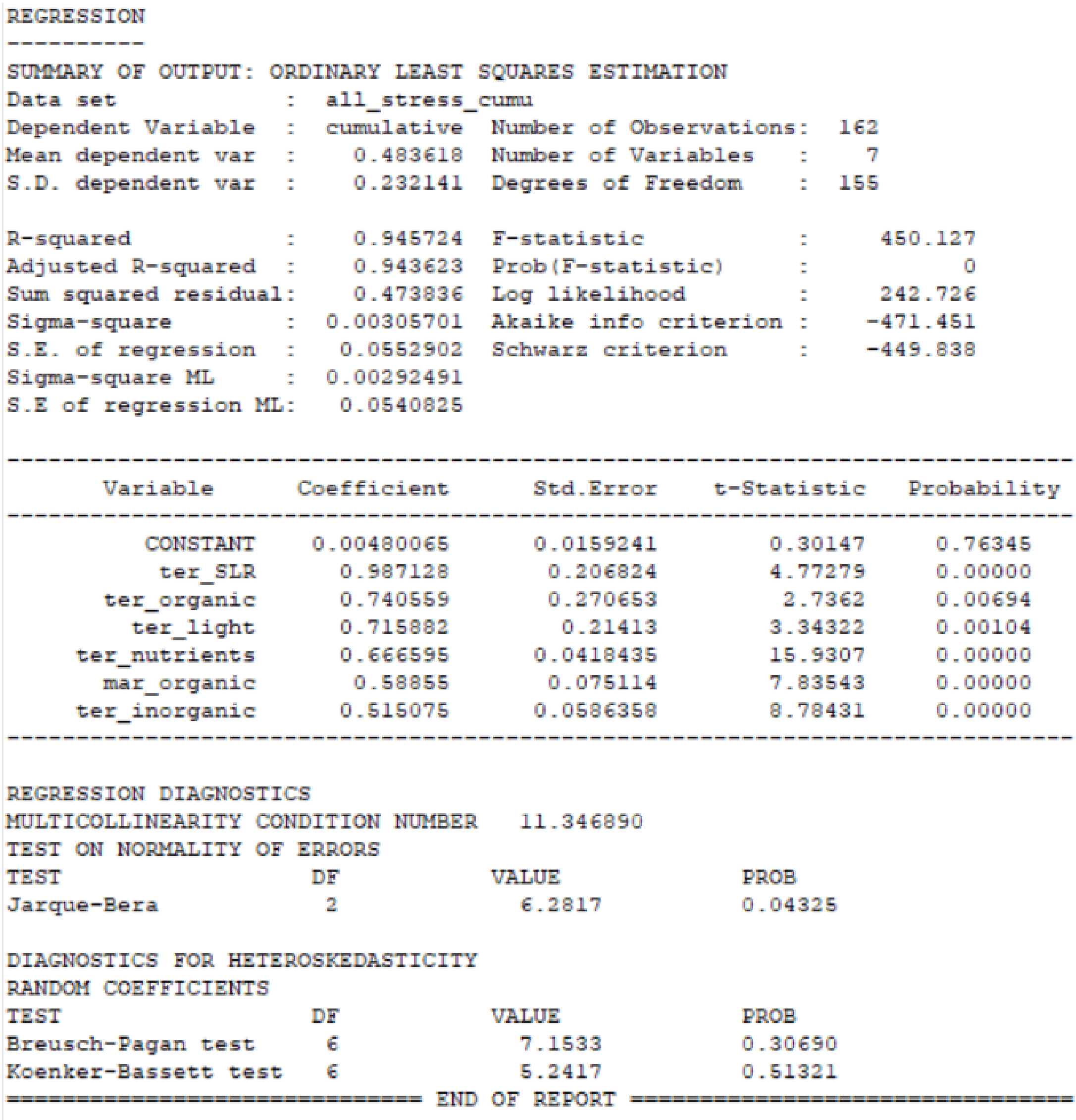
Table 4.49: R^2 of the mean impact score of a dependent stressor against their independent stressor.
* $p<0,001$

Threat	**Terrestrial SLR**	**Marine light**	**Marine Nutrients**	**Marine Organic**	**Marine Inorganic**
R^2	0,653*	0,219*	0,382*	0,095*	0,235*

A multiple regression analysis can tell us which stressors have the biggest influence on the cumulative impact score of an Ecoregion (see figure 4.50). There are 162 Ecoregions where the 6 selected variables are present. These variables have been selected based on their probability. The marine stressors sea level rise, light pollution, nutrients pollution, and inorganic pollution were not significant in predicting the cumulative impact score. Excluding them from the multiple regression analysis makes the model a better fit (the Akaike info criterion decreases when these stressors are excluded).

The adjusted R^2 is 0,94, 94% of the cumulative impact score can be predicted by using the five terrestrial stressors and marine organic pollution. The Coefficient tells us that one unit increase in mean light pollution on average increases the cumulative impact score of an Ecoregion with 0,716. We can say that terrestrial sea level rise has the biggest influence on the cumulative impact score and marine organic pollution the smallest influence on the cumulative impact score across the Ecoregions.

Figure 4.50: Multiple regression analysis

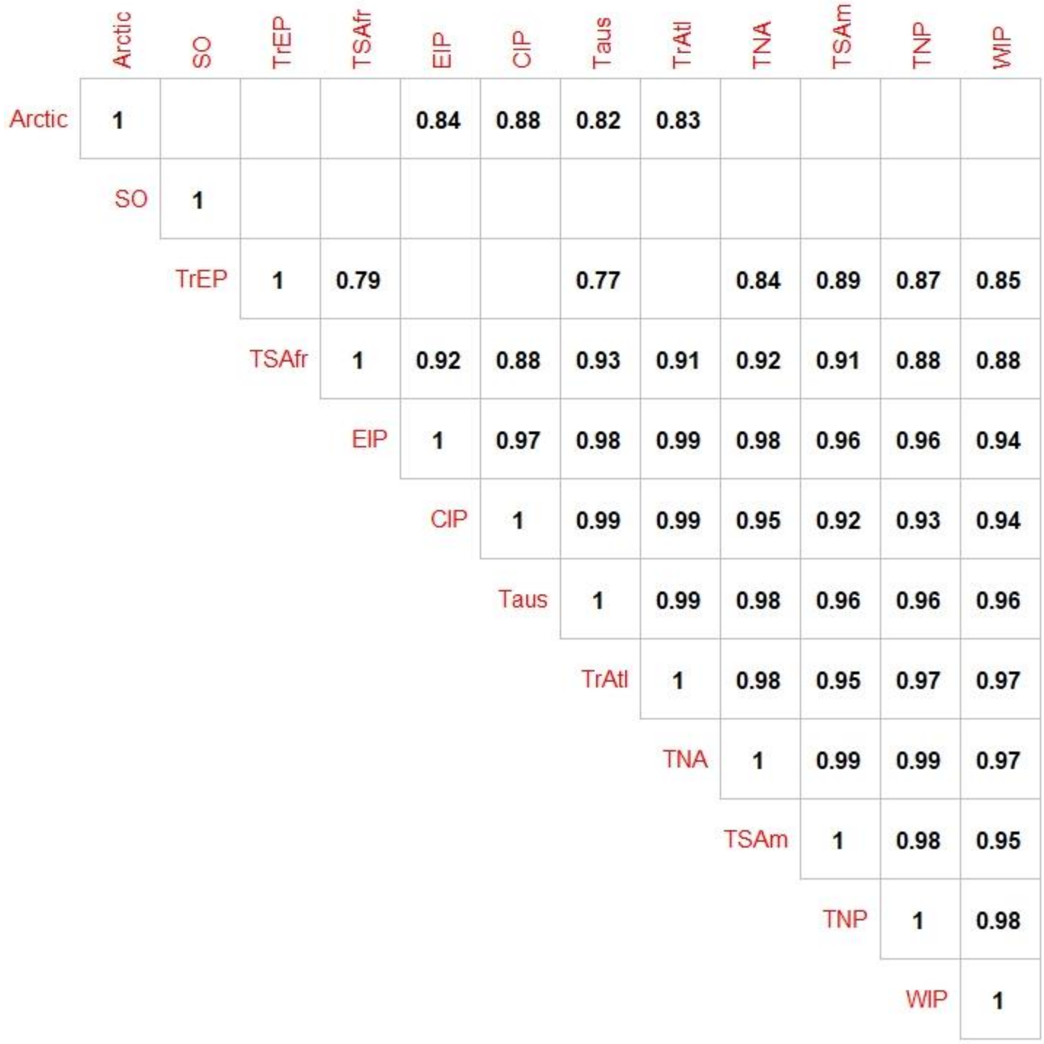


```
REGRESSION
----------
SUMMARY OF OUTPUT: ORDINARY LEAST SQUARES ESTIMATION
Data set            :  all_stress_cumu
Dependent Variable  :  cumulative  Number of Observations:  162
Mean dependent var  :    0.483618  Number of Variables   :    7
S.D. dependent var  :    0.232141  Degrees of Freedom    :  155

R-squared           :    0.945724  F-statistic           :     450.127
Adjusted R-squared  :    0.943623  Prob(F-statistic)     :           0
Sum squared residual:    0.473836  Log likelihood        :     242.726
Sigma-square        :  0.00305701  Akaike info criterion :    -471.451
S.E. of regression  :   0.0552902  Schwarz criterion     :    -449.838
Sigma-square ML     :  0.00292491
S.E of regression ML:   0.0540825

-----------------------------------------------------------------------------
       Variable      Coefficient       Std.Error     t-Statistic   Probability
-----------------------------------------------------------------------------
          CONSTANT    0.00480065       0.0159241        0.30147      0.76345
           ter_SLR      0.987128        0.206824        4.77279      0.00000
       ter_organic      0.740559        0.270653         2.7362      0.00694
         ter_light      0.715882         0.21413        3.34322      0.00104
     ter_nutrients      0.666595       0.0418435        15.9307      0.00000
       mar_organic       0.58855        0.075114        7.83543      0.00000
     ter_inorganic      0.515075       0.0586358        8.78431      0.00000
-----------------------------------------------------------------------------

REGRESSION DIAGNOSTICS
MULTICOLLINEARITY CONDITION NUMBER   11.346890
TEST ON NORMALITY OF ERRORS
TEST                  DF           VALUE              PROB
Jarque-Bera            2             6.2817           0.04325

DIAGNOSTICS FOR HETEROSKEDASTICITY
RANDOM COEFFICIENTS
TEST                  DF           VALUE              PROB
Breusch-Pagan test     6             7.1533           0.30690
Koenker-Bassett test   6             5.2417           0.51321
============================== END OF REPORT ================================
```

4.3.3 Cluster analysis

This section aims to visualise similarity between Realms. The first figure (4.51) presents a correlation matrix based upon the 10 stressors. A correlation between each Realm is calculated with the Pearson Correlation method. Values close to 1 represents a high correlation and values close to 0 represent a low correlation. Correlation values that are not significant (a p-value higher than 0,01) are not shown. The Realms in the figure are sorted based on a hierarchical clustering with Ward.D2 (mean linkage) and Euclidean distance. Mean or average linkage clustering computes all pairwise dissimilarities between the elements in cluster 1 and the elements in cluster 2, and considers the average of these dissimilarities as the distance between two clusters. This clustering gives the same outcome as the clustering at figure 4.52.

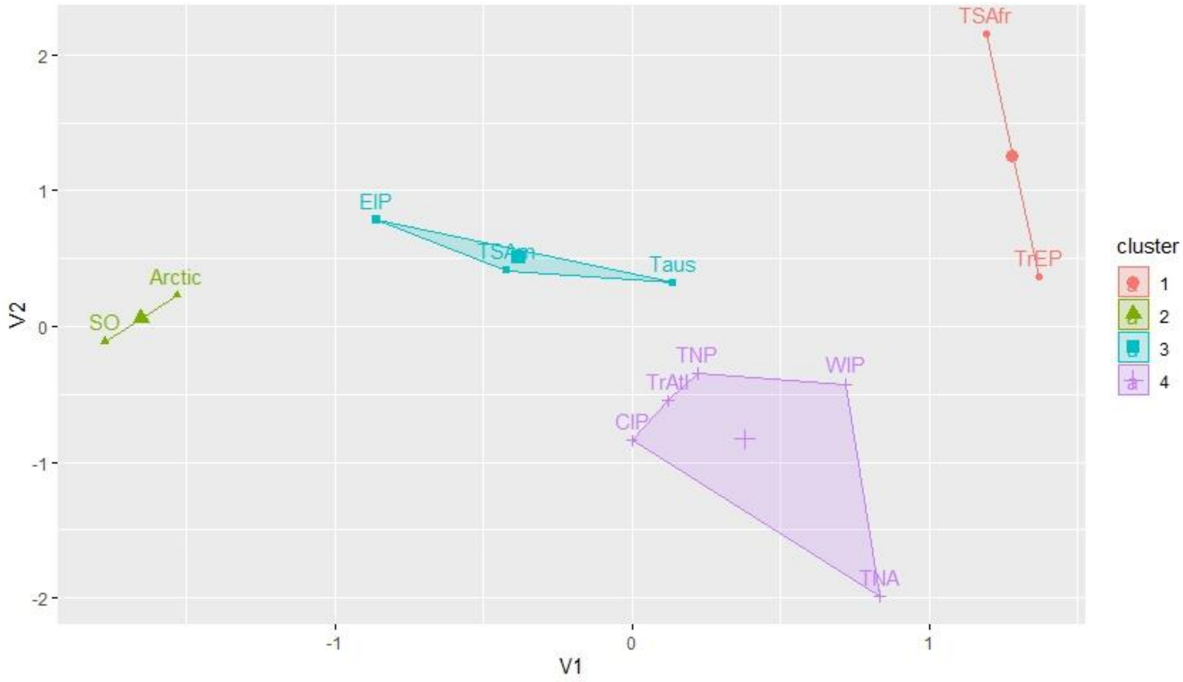
Figure 4.51: Pearson correlation matrix



	Arctic	SO	TrEP	TSAfr	EIP	CIP	Taus	TrAtl	TNA	TSAm	TNP	WIP
Arctic	1				0.84	0.88	0.82	0.83				
SO		1										
TrEP			1	0.79			0.77		0.84	0.89	0.87	0.85
TSAfr				1	0.92	0.88	0.93	0.91	0.92	0.91	0.88	0.88
EIP					1	0.97	0.98	0.99	0.98	0.96	0.96	0.94
CIP						1	0.99	0.99	0.95	0.92	0.93	0.94
Taus							1	0.99	0.98	0.96	0.96	0.96
TrAtl								1	0.98	0.95	0.97	0.97
TNA									1	0.99	0.99	0.97
TSAm										1	0.98	0.95
TNP											1	0.98
WIP												1

Next, the Realms are clustered based on a k-means clustering. This will be done after reducing the dimensionality of the variables with Multidimensional Scaling (MDS), performed with GeoDa. The 10 variables are reduced to two variables that represent the variation within the 10 variables. The two variables retrieved from MDS are imported to R. In R these two variables are analysed to determine the optimal amount of clusters (see figure 3.12). The optimal amount of 4 k-means clusters is used to perform a k-means clustering. The resulting k-means clustering is visualised in figure 4.52.

Figure 4.52: Visualisation of a k-means clustering of MDS variables

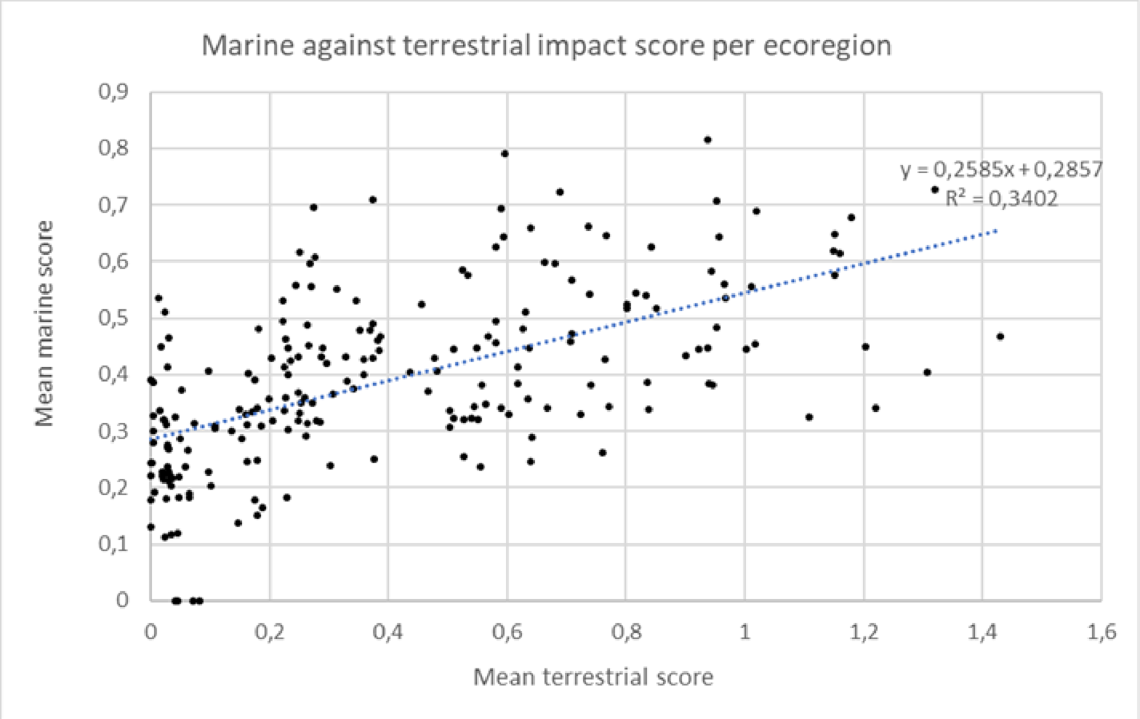


This clustering shows that based on the five terrestrial and five marine stressors several Realms can be clustered together. These clusters are:

Cluster 1 (red): Temperate Southern Africa and Tropical Eastern Pacific.
Cluster 2 (green): Southern Ocean, and Arctic.
Cluster 3 (blue): Eastern Indo-Pacific, Temperate South America, and Temperate Australasia.
Cluster 4 (purple): Temperate Northern Pacific, Tropical Atlantic, Central Indo-Pacific, Temperate Northern Atlantic, and Western Indo-Pacific.

4.3.4 Marine-terrestrial impact score relation per Ecoregion

To visualise a potential relationship between the marine and terrestrial impacts a graph is created (see graph 4.53). The mean marine impact is visualised against the mean terrestrial impact per Ecoregion. The differentiation from the trendline tells us the difference in impact score between the terrestrial and marine stressors per Ecoregion. The size of the difference can be found at Appendix 9.11.5. Points located further away from the trendline are Ecoregions with a different ratio between the marine and the terrestrial impact scores than the trendline predicts. Points above the trendline have a higher mean marine impact score than predicted, points below the trendline have a lower mean marine impact score than predicted by the trendline based on the mean terrestrial impact score. The Ecoregions that differ the most from the trendline are presented at table 4.54.



Graph 4.53: Cumulative marine impact scores against cumulative terrestrial impact scores per Ecoregion. Trendline p <0,001

Table 4.54: Ecoregions where either the cumulative- marine and terrestrial stressor impact scores differ greatly from each other

Ecoregion	Mean terrestrial impact score	Mean marine impact score	Absolute deviation from trendline	Realm
Manning-Hawkesbury	0,60	0,79	0,35	Temperate Australasia
Arafura Sea	0,27	0,70	0,34	Central Indo-Pacific
Namaqua	0,37	0,71	0,33	Temperate Southern Africa
Natal	0,94	0,82	0,29	Temperate Southern Africa
Arnhem Coast to Gulf of Carpentaria	0,25	0,62	0,27	Central Indo-Pacific
Gulf of Tonkin	1,22	0,34	0,26	Central Indo-Pacific
Northeastern Honshu	0,69	0,72	0,26	Temperate Northern Pacific
Carolinian	0,59	0,69	0,25	Temperate Northern Atlantic
Northern Monsoon Current Coast	0,28	0,61	0,25	Western Indo-Pacific
Northern Bay of Bengal	1,11	0,33	0,25	Western Indo-Pacific
Chagos	0,01	0,54	0,25	Western Indo-Pacific
Torres Strait Northern Great Barrier Reef	0,27	0,60	0,24	Central Indo-Pacific

Chapter 5: Discussion of results

In this chapter the results of this research will be discussed. The most important findings have been presented in chapter 4, and a complete list of results can be found at the Appendix (see: 9.11). First each stressor individually and then the cumulative impact scores at the Realm level will be discussed at section 5.1. Section 5.2 discusses the most impacted as well as the least impacted Provinces and section 5.3 discusses the most and least impacted Ecoregions.

5.1 Analysis of impact of anthropogenic threats per Realm

The multiple regression analysis (see figure 4.50) shows that the stressors that have a significant impact on the difference in the cumulative impact score between the Realms are salt water intrusion, terrestrial organic pollution, terrestrial light pollution, terrestrial nutrients pollution, marine organic pollution, and terrestrial inorganic pollution. The beforementioned stressors are in order of the stressor that on average adds the most to the cumulative impact score of a Realm to the stressor that on average adds the least. The combined mean impact score of these 6 stressors can explain the variance of 94,3% of the cumulative mean impact score of the Realms. The excluded stressors (marine sea level rise, marine light pollution, marine nutrients pollution, and marine inorganic pollution) do add to the cumulative impact score of a Realm, but their contribution to the difference between the Realms is not significant. This is due to the fact that marine sea level rise is relatively high across each Realm (it even adds the most to the cumulative impact score of almost every Realm) and it doesn't really have a big difference in impact between the Realm. The other stressors have about the same impact score across each Realm as well. This means that the intensity of these four stressors isn't significant in predicting a difference in cumulative impact score between the Realms.

5.1.1 Sea level rise

Sea level rise has the biggest mean impact score at the research area within every Realm out of all of the stressors, except for the Tropical Eastern Pacific where organic pollution is the stressor with the highest mean impact score (see: Figure 4.10). The high mean sea level rise impact scores can be explained by several factors. Firstly, sea level rise is the only marine-based stressor, it originates from the marine zone and affects the terrestrial zone. Sea level rise affects large areas of the marine zone and consequently has an impact on large areas of the research area. The other four threats are more focussed, either around agriculture or human population, still leaving many areas with a low impact. Sea level rise on the other hand will likely occur at an entire bay or coast (Church & White, 2011). Additionally, lights-, nutrients-, organic-, and inorganic- pollution are land-based stressors that originate from the terrestrial zone (Halpern, et al., 2015). This means that these four pollutants, when in the marine zone, generally are more intense when more proximate to land and have a small or no impact on areas further removed from the coast. This means that locations quiet far off the coast that are still within the research area are unaffected by any of the other stressors (these cells will have a value 0 for these stressors), but are still affected by sea level rise. Figure 4.7 shows this clearly, where the several locations into the Gulf of Mexico, west of Florida, and into the North Sea, east of the UK, are only impacted by sea level rise.

Sea level rise impact scores in the terrestrial zone is strongly correlated, and significantly, to sea level rise in the marine zone (see table 4.49). 65,3% of the variance of the mean terrestrial sea level rise impact within an Ecoregion can be explained by the mean marine sea level rise impact score of that Ecoregion. This makes sense because marine sea level rise is a boundary condition for terrestrial sea level rise, increasing in impact with higher LSLR values. Habitat vulnerability indexes are also quiet similar for marine habitats and terrestrial habitats, making the impact similar between the marine and terrestrial zone similar as well.

The Realm with the highest sea level rise impact score in both the marine and terrestrial zone is the Central Indo-Pacific Realm. This is due to a high local sea level rise (Church & White, 2011) close to shore in combination with big stretches of shallow water at the Gulf of Thailand, South Chinese Sea between Sumatra and Borneo, and the Gulf of Carpentaria between Australia and Papua (Smith & Sandwell, 1997). The local Sea level rise also causes higher terrestrial sea level rise impact scores at the low lying coastal lands of Papua, Sumatra, Borneo, and Vietnam. An example of hazards caused by local sea level rise at Southern Vietnam is a the Mekong River Delta (Erban, 2014). Here increased groundwater extraction in combination with sea level rise causes increased flooding, this results in saltwater intrusion and the projection is future permanent loss of (agricultural) land. Similar observations are done along the Indonesian coast where local sea level rise in combination with land inundation due to natural and anthropogenic causes increase the need for adaptation to salt water intrusion (Fenoglio-Marc, et al., 2012).

5.1.2 Light pollution

Light pollution mainly originates from cities, other settlements, and roads (Davies, Duffy, Bennie, & Gaston, 2016). Although population is high at coastal areas (CIESIN-SEDAC, 2015), the presence of agriculture is still dominant (Ellis & Ramankutty, 2008). This results in a relatively low impact of light pollution in comparison to other stressors. In between large cities the impact scores are relatively low, but in and around cities the higher. In these cities light pollution is so concentrated that the impact is high and cause disturbances to habitats (Davies, Duffy, Bennie, & Gaston, 2016). Cities deprive animals of their natural biorhythm, forcing them to move to darker areas or to adapt their behaviour (Longcore & Rich, 2004) (see: 2.7.2 for more info).

On water, pollution by night lights carries even further than on land (Falchi, et al., 2016). There are no hills or forests to stop lights emitted from the coast or from an oil rig to impact a habitat 30kms away from its source. According to the visualisation on (Lightpollutionmap, 2020) light travels up to 150km from a highly polluted large city until the sky returns to an “excellent dark sky” (Falchi, et al., 2016). Mean marine light pollution impact scores are significantly correlated to mean terrestrial light pollution impact scores (see table 4.49). 21,9% of the variance of mean marine light pollution at Ecoregions can be explained by the mean terrestrial impact score of that Ecoregion. The mean impact scores in the marine zone across the Realms are higher than the mean impact score of the terrestrial zone (see table 4.8). The higher marine impact score can be explained by the fact that light pollution is much more spread out on water than it is on land. On land the impact scores are more concentrated (Lloyd, 2016), leaving larger areas on land with a relatively low impact score whereas the water is affected by the human population directly located at the coast. Since this population is highest at the direct shoreline, the light pollution at the marine zone is affected by the most intensely impacted areas of the terrestrial zone (Davies, Duffy, Bennie, & Gaston, 2016).

The only stressor that has an impact on the Arctic- and the Southern Ocean Realms besides sea level rise is light pollution. This is mainly due to oil rigs in Alaska and Russia, as well as several (oil) cities in Russia (Lloyd, 2016). Besides the presence of these cities and settlements, there is very little population at the Arctic and Southern Ocean Realms (CIESIN-SEDAC, 2015). The high contribution of terrestrial light pollution to the cumulative impact score of the Arctic Realm (see 4.9) is exceptional. When comparing the values of the Arctic Realm at areas with no population to the

Southern Ocean where there isn't any population either we can see the same trend. There is a consistent impact score of around 0,07 at the areas close to the polar circles. Because the Arctic has much more land within its research area than the Southern Ocean, the impact score really adds up for the Arctic Realm. This score can't be explained and the provider of the dataset doesn't mention this possible error (see 7.4). When moving away from the polar circles the light pollution impact score is more in line with expectations, being minimal light pollution at areas with very limited human population and high light pollution at specific locations, mainly at settlements and roads.

The Realms with the highest mean marine lights pollution are the Temperate Northern Atlantic Realm, the Temperate Northern Pacific Realm, and the Southern Ocean Realm. These Realms have a relatively high human population along the coast. With the Southern Ocean having very small masses of land, a small settlement can have a great impact. The Temperate Northern Atlantic Realm contains the very populous coastal areas of the United States east coast as well as Europe (Worldbank, 2019). And the Temperate Northern Pacific contains the northern half of the Chinese coast as well as Japan, and the United States west coast (*ibid*). Especially compared to the African continent, the South American continent and Australasia, the Temperate Northern Atlantic- and Pacific Realms have very high concentrations of lights pollution.

5.1.3 Nutrients pollution

Mean terrestrial nutrients pollution impact scores are higher than mean marine nutrients pollution impact scores across every Realm (see table 4.10), except for the two Polar Realms. Marine nutrients pollution is significantly correlated to terrestrial nutrients pollution (see table 4.49). 38,2% of the variance of the mean marine nutrients pollution impact score of an Ecoregion can be explained by the mean terrestrial nutrients pollution impact score of that Ecoregion. This can be explained by the fact that the terrestrial nutrients pollution at a certain Ecoregion will likely get washed down in the same area into the marine (Biasoli & Ajmone-Marsan, 2007). The correlation is strong because marine habitats are relatively more vulnerable to nutrients pollution than terrestrial habitats are (see table 3.2 and table 3.9). This would make the mean impact on the marine higher than on the terrestrial, but because the pollution gets relatively quickly diluted large areas of the marine remain relatively lightly affected.

Except for the polar Realms, terrestrial nutrients pollution is present in high quantities at every Realm. The Tropical Eastern Pacific (0,25) and the Western Indo-Pacific (0,24) Realms have the highest average nutrients pollution impact score. The Easter Tropical Pacific (figure 4.21) is a relatively small Realm with a high concentration of agriculture (Ellis, Klein Goldewijk, Siebert, Lightman, & Ramankutty, 2010; FAO, 2015; FAO, FAOSTAT: Pesticides Use, 2019). The consumption of fertilizers in the Tropical Eastern Pacific Realm isn't especially high, but agriculture is present along virtually the entire coast of the Realm. The Western Indo-Pacific Realm on the other hand is a different case. India (see figure 4.26 and) is an example of a country with high concentrations of agriculture along all of its coastline (Ellis, Klein Goldewijk, Siebert, Lightman, & Ramankutty, 2010) and having an above average fertilizer consumption per hectare (FAO, 2015), together with Bangladesh and Pakistan these countries make up the majority of the nutrients pollution of the Western Indo-Pacific (*ibid*).

At the polar Realms there is no terrestrial nutrients pollution modelled and near-zero marine nutrients pollution. This is due to there being nearly no cultivated lands present in these Realms (Ellis, Klein Goldewijk, Siebert, Lightman, & Ramankutty, 2010), because the climate at these latitudes barely allow for agriculture (Climate Greenland, 2020). Fertilizer use at several small islands at the Southern Ocean and Eastern Indo-Pacific Realm is often missing or has the value 0 (FAO, 2015).

The Temperate Southern Africa Realm has the highest mean marine nutrients pollution score (see table 4.10). This is due to its average terrestrial nutrients pollution in combination with very steep coasts, quickly exceeding a depth of 60 meters, ending the research area of this thesis. This means that the short part of the ocean that belongs to the research area is heavily polluted, raising the mean impact score. At other locations where the slope of the ocean floor is more gentle the transported pollution from the rivers has space to dilute within the research area, resulting in parts of the research area with 0 pollution further away from the river delta.

Some countries have exceptional fertilizer consumption amounts. Qatar has a fertilizer use of 6314 kg/ha (FAO, 2015), almost five times as much as the second most consuming country New Zealand with 1717 kg/ha, and third in line is Bahrain with 1319 kg/ha. Although Qatar and Bahrain show no marine nutrients pollution at all, the impact of these excessive amounts can be devastating for groundwater quality and whenever rainfall washes down these quantities of nutrients into the ocean (Biasoli & Ajmone-Marsan, 2007). Bahrain and Qatar probably show no marine nutrients pollution due to the absence of rivers in these countries and because rivers are used to model the point source for marine nutrients pollution (Halpern, et al., 2015). New Zealand on the other hand contributes greatly to the mean marine nutrients pollution impact score of the Temperate Australasia Realm.

5.1.4 Organic pollution

The location of impact of organic pollution is the same location as nutrients pollution. For this thesis the variables were both modelled from agriculture, making them easy to compare. In general we can say that terrestrial habitats have a higher vulnerability to organic pollution than to nutrients pollution, and that marine habitats have a lower vulnerability to organic pollution than to nutrients pollution (Khamis, Kalliola, & Käyhkö, 2019). This is reflected in the vulnerability indexes as well (see: figures 3.3, and 3.9). The mean terrestrial organic pollution impact scores are much higher than the mean marine organic pollution impact scores (see table 4.10). This results is a significant, but weak, correlation between these two stressors (see table 4.49). About 9,5% of the variance of the mean marine organic pollution impact score at an Ecoregion can be explained by the mean terrestrial organic pollution impact score at that Ecoregion. This explained variance is relatively low. This can be explained by the combined effect of the diluted pollution when it reaches the marine and the fact that marine habitats are less vulnerable to organic pollution than terrestrial habitats are to organic pollution (*ibid*).

The results (see: table 4.10) show that mean terrestrial organic pollution impact scores are higher than mean terrestrial nutrients pollution impact scores for every Realm except for the Central Indo-Pacific and the Western Indo-Pacific Realms. This is due to the fact that in the Central Indo-Pacific and Western Indo-Pacific Realms fertilizer consumption is relatively high (FAO, 2015). These countries are for example Indonesia which ranks 79th of the world in total pesticides consumption (FAO, FAOSTAT: Pesticides Use, 2019) but 13th of the world in fertilizer consumption (FAO, 2015), India is 11th in the world in pesticides consumption (FAO, FAOSTAT: Pesticides Use, 2019), but 2nd in the world in fertilizer consumption (FAO, 2015), and also Bangladesh, which has the 32nd largest pesticides consumption (FAO, FAOSTAT: Pesticides Use, 2019), but the 14th largest fertilizer consumption (FAO, 2015). The overall global trend of a higher mean terrestrial organic than nutrients pollution impact score is due to the fact that on average terrestrial habitats are more vulnerable to organic pollution than they are to nutrients pollution (Khamis, Kalliola, & Käyhkö, 2019).

As mentioned before, the terrestrial organic pollution at the Tropical Eastern Pacific Realm is extraordinary. It has the highest mean impact score of every variable across every Realm. The only Realm that has a higher mean marine organic pollution impact score than the Tropical Eastern Pacific Realm is the Temperate Southern Africa Realm. This, in combination with average pesticides use, is high for the same reason why nutrients pollution has such a high mean marine nutrients pollution impact score in that Realm.

The countries with the largest pesticides consumption are China, the United States, Brazil, and Argentina (FAO, FAOSTAT: Pesticides Use, 2019). These four countries make up 68% percent of the total pesticides consumption of the world. When divided by hectares of arable land the top 4 is occupied by small island states; Saint Lucia, Cook Islands, Bermuda, and the Maldives. The agriculture on these islands (except for Saint Lucia) is too small or spread out for the Anthromes database to register. This results in these countries not having any agricultural cells on their island to place these high figures, so on the modelled map these countries will have a terrestrial organic impact score 0. As a result the organic pollution impact at these islands is underestimated.

5.1.5 Inorganic pollution

Terrestrial inorganic pollution is modelled from human population density. Marine inorganic pollution impact scores are affected by the population of the whole country (Halpern, et al., 2015) whereas terrestrial inorganic pollution impact scores are only affected by coastal population. The Realm with the highest mean terrestrial inorganic pollution impact score is the Western Indo-Pacific Realm (see table 4.10). The entire coast of India, but also the Ganges and Brahmaputra rivers Delta (the majority of Bangladesh) have very high concentrations of human population (CIESIN-SEDAC, 2015). With this population comes a lot of inorganic pollution from waste, transport, and industry (Gong, Sun, Beudert, & Hahn, 1997). As mentioned before, although human population is relatively high at coastal areas, it is not as numerous as agriculture. The high concentration of human population decreases their inorganic pollution per person (Geldmann, Joppa, & Burgess, 2014) and also moves them away from other locations, leaving other locations with a low impact. Although a higher population density decreases the mean inorganic impact score, the presence of such high densities of population at coastal areas causes a huge pressure on its biodiversity (Gong, Sun, Beudert, & Hahn, 1997; Geldmann, Joppa, & Burgess, 2014). Except for the Polar Realms, every Realm has a mean terrestrial inorganic pollution impact score between 0,01 and 0,06.

Inorganic pollution is the only stressor out of nutrients-, organic-, and inorganic pollution that has higher mean marine impact scores than mean terrestrial impact scores at about half of the Realms. The mean marine inorganic pollution impact score is significantly correlated to the mean terrestrial impact score of the same Ecoregion. 23,5% of the variance of the mean marine impact scores of the Ecoregions can be explained by the mean terrestrial impact score of the same Ecoregion (see table 4.49). The vulnerability of terrestrial habitats to inorganic pollution is on average about the same as the vulnerability of marine habitats to inorganic pollution (see tables 3.2 and 3.10). But the difference in vulnerability between several habitats is relatively big. This results in some habitats being highly impacted relative to other habitats. This is the case for the dominant habitat present in the marine zone (Halpern, et al., 2015), the shallow soft bottom habitat. This coastal marine habitat has a vulnerability of 1,5 to inorganic pollution, raising the mean marine inorganic pollution impact score. This value is higher than the highest vulnerability index of terrestrial habitats, so effectively within the coastal zone marine habitats are more vulnerable to inorganic pollution than terrestrial habitats are. The higher marine impact score can also be explained by the concentrated nature of inorganic pollution from human population. Some areas are highly affected, at cities, and many areas are lightly affected where there is no high population density. The pollution does eventually end up in river mouths after they have been transported by surface or ground-waters where the pollution is spread out. Because all data is standardized the concentrated nature of inorganic pollution, in comparison to nutrients and organic pollution, makes for a relatively low average impact score on the terrestrial zone. The higher marine impact scores can also be partially explained by the nature of the data transformation performed for the terrestrial inorganic pollution model. Fertilizer use and pesticides use were both log-transformed, similar to the research by Halpern, et al. (2015), the human population density on the other hand was square rooted, similar to Geldmann, Joppa & Burgess (2014). The difference in data transformation results in values lying further from each other at the square root transformation than at the log-transformation. This results in a lower average impact score for terrestrial inorganic pollution than would be the case if a log-transformation was applied.

5.1.6 Cumulative impact scores

The average cumulative impact score (table 4.19) per Realm ranges from 0,15 (Southern Ocean) to 0,74 (Tropical Eastern Pacific). For the Tropical Eastern Pacific this means that every cell within the research area has an average impact score of 0,74 out of a maximum possible impact score of 5. The Realms that have relatively low impacts are the Arctic (0,27), Eastern Indo-Pacific (0,26), and the Southern Ocean (0,15). Coverage closer to the poles is limited, although this only slightly affects the modelled cumulative impact score, the limitation is discussed at section 7.4.

The low average impact score of these three Realms can be explained by the small size of the landmasses in the Realms as well as the low population in these areas. The Eastern Indo-Pacific Realm consists completely of small islands. The most populated (CIESIN-SEDAC, 2015), and the island with the highest cumulative impact score is Hawaii (figure 4.24.1). Several other islands include Samoa and Kiribati. Besides Hawaii, the majority of these islands, including Kiribati, have no registered fertilizer and pesticides use, or very low levels as is the case for Samoa with a consumption of 0,5 kg/ha for both fertilizers and pesticides (FAO, 2015; FAO, FAOSTAT: Pesticides Use, 2019). Samoa, one of the more populated countries of the Eastern Indo-Pacific (CIESIN-SEDAC, 2015) has a population of 200 000 with a density of 71 inhabitants/km^2 (Worldbank, 2019), this is reflected in the terrestrial inorganic and light pollution impact score of the main islands of Samoa. The impact score at these islands is higher than many of the other islands in this Realm, but these are still very low compared to for example New Zealand, which only has a population density of 19 inhabitants/km^2 but where the majority of this population lives along the coast (CIESIN-SEDAC, 2015). Additionally, the Eastern Indo-Pacific Realm contains several atolls that are completely below sea level (Smith & Sandwell, 1997). An example are the Tuamotus islets (figure 4.24.2) where the majority of the shallow water has no land nearby, thus being unaffected by modelled land-based threats.

The Southern Ocean Realm has low population densities (Worldbank, 2019) and limited agriculture as well (FAO, 2015; FAO, FAOSTAT: Pesticides Use, 2019). There is no record of fertilizer and pesticides use of for example the Prince Edward Islands and Bouvet Island (*ibid*) and the population density of these islands is 0 permanent inhabitants (Worldbank, 2019).
To accommodate for the absence of data these islands were given the same value as the lowest

fertilizer and pesticides consuming countries. These values are 0,33 kg/ha fertilizer from the Central African Republic (FAO, 2015) and a total of 30kg of pesticides from the Comoros (FAO, FAOSTAT: Pesticides Use, 2019).

The mean sea level rise impact score at the Eastern Indo-Pacific is the biggest contributor to the cumulative impact score as it is at so many other Realms (see: figure 4.9). For the Eastern Indo-Pacific this is especially troublesome because complete countries are threatened to become submerged under water (Ödalen, 2014). First this will be temporary, causing salinization of water sources on the islands, but finally islands with a low elevation will disappear and its inhabitants will need to migrate (Monaco & Prouzet, 2014). This is something that has been happening for the Carteret Atoll since 1980, a group of small islands belonging to Papua-New-Guinea (*ibid*). Several Small Island States that do not belong to a country that has a large main island that is under (less) threat will lose their entire sovereignty (Ödalen, 2014) and will need to migrate to a different sovereign state.

The most impacted Realms are the Tropical Eastern Pacific and the Temperate Northern Atlantic (see: table 4.19 and figures 4.21-23). The size of the human population (Worldbank, 2019) at these Realms and the high saturation of agriculture (Ellis, Klein Goldewijk, Siebert, Lightman, & Ramankutty, 2010) make it that these areas have very high impact scores across all variables. An important note is the influence of the geographical location of the Realms on the mean cumulative impact score. The Realms are divided by biogeographical properties, not based on human population or political boundaries. Several Realms have a heavily impacted part and a lightly impacted part. India (highly impacted) is the same Realm as the east coast of the African continent (lightly impacted), both part of the Western Indo-Pacific, and China is partly part of the Temperate Northern Pacific together with scarcely populated areas such as East-Russia and Alaska, whereas the southern part of China is part of the Central Indo-Pacific Realm with scarcely or less populated areas such as Papua New Guinea and Northern-Australia (CIESIN-SEDAC, 2015). The Temperate Northern Atlantic and Tropical Eastern Pacific contain highly populated areas along virtually its entire coast (*ibid*). The biggest contributor to the mean cumulative impact score of the Tropical Eastern Pacific Realm is terrestrial organic pollution. This can be explained due to Colombia, Mexico, Peru and Guatemala all being in the top-30 of highest pesticide consuming countries in the world (FAO, FAOSTAT: Pesticides Use, 2019). To have this many countries with such a high pesticide consumption within a single biogeographic Realm poses a great threat to the unique biodiversity of any Realm. The high rate of endism within each Realm (Spalding, et al., 2007) makes them unique, this becomes under threat when encountered with high amounts of pesticides (Johnsen, Jacobsen, Torsvik, & Sorensen, 2001). The pesticides affect non-target vegetation and organisms, where they contribute to increased organism death rates and growth limitations (Aktar, Sengupta, & Chowdhury, 2009; Sharpley, 2013).

5.1.7 Similar impact scores across Realms

The Pearson correlation matrix (see figure 4.51) gives a good indication of the similarity between the 12 Realms. Correlation matrixes are used to present correlation between variables. In this case the Realms are used as variables and the stressors are used as observations. The ‘observation’ of marine sea level rise will have different values across the ‘variables’ of the Realms. The Realms that have similar trends in the intensity across the 10 stressors will have a correlation coefficient close to 1. The matrix shows that there is a lot of similarity between the majority of the Realms. This makes sense because the 10 stressors are modelled the same way at each Realm. The Realms that are not significantly similar show up blank, there is no significant correlation between the impact scores in the Southern Ocean Realm and the other Realms, and the Arctic Realm is only significantly correlated to four Realms (the Eastern Indo-Pacific, Central Indo-Pacific, Temperate Australasia, and the Tropical Atlantic). Realms will be correlated if they are similar in the phenomenon that cause the impact scores, being local sea level rise, fertilizer and pesticides consumption, human population (density), and elevation and bathymetry. The Realms at figure 4.51 are sorted based on a hierarchical clustering with Ward.D2 (mean linkage) and Euclidean distance. It shows the same clusters as figure 4.52. Figure 4.52 is not produced with a hierarchical clustering though, it is done with a k-means clustering. This is done after the 10 stressors are reduced to 2 variables that represent the multidimensionality of these 10 variables as two-dimensional variables. The plotted points are divided into four clusters. The k-means and hierarchical clustering both create the same outcome, increasing the reliability of the outcome.

The Realms that can be clustered as similar Realms are, cluster 1: the Temperate Southern Africa, the Temperate South America and the Tropical Eastern Pacific. The second cluster is the Southern Ocean and the Arctic, the third the Eastern Indo-Pacific, Temperate South America, and Temperate Australasia, and the fourth and biggest cluster the Temperate Northern Pacific, Tropical Atlantic, Central Indo-Pacific, and Temperate Northern Atlantic.

The Temperate Southern Africa Realm and the Tropical Eastern Pacific Realm are similar as being small Realms with a marine zone limited in size, a high saturation of agriculture (Ellis, Klein Goldewijk, Siebert, Lightman, & Ramankutty, 2010), and low local sea level rise (Church & White, 2011). The mean impact scores of the Tropical Eastern Pacific are higher than that of the Temperate Southern Africa, but the spread of the intensity across the stressors is similar. Especially the part that the terrestrial organic pollution has in the cumulative impact score of these Realms makes them similar.

The Southern Ocean Realm and Arctic Realm are similar because they are both mainly affected by sea level rise and light pollution. The Arctic has a mean light pollution impact score that is much higher, but the presence of the other stressors is negligible at both Realms.

The Eastern Indo-Pacific Realm is as similar to the Temperate South America Realm and the Temperate Australasia Realm as the Temperate South America and Temperate Australasia are to several Realms of the fourth cluster. The Realms in these two clusters are all relatively similar to each other, but the outliers of each cluster (Eastern Indo-Pacific of the third cluster and the Temperate Northern Atlantic of the fourth) are quiet dissimilar. Still, the Eastern Indo-Pacific, Temperate South America, and Temperate Australasia are similar because of their relatively low mean sea level rise impact scores and their similar nutrients and organic pollution ratio. Note that the share of marine sea level rise in the cumulative impact score of the Eastern Indo-Pacific is very high, but the mean impact score isn’t.

The Temperate Northern Pacific, Tropical Atlantic, Central Indo-Pacific, and Temperate Northern Atlantic are similar because of their relatively high mean sea level rise impact score in combination with an organic and nutrients impact score that are relatively similar. Additionally the inorganic pollution in these Realms is relatively high as well.

5.2 Analysis of impact of anthropogenic threats per Province

As visualized at figures 4.27-30, the most impacted Provinces are the Bay of Bengal, the Mediterranean Sea, the Warm Temperate Northwest Pacific, the Black Sea, and the Lusitanian. With the Bay of Bengal Province being part of the Western Indo-Pacific Realm, the Warm Temperate Northwest Pacific Province being part of the Temperate Northern Pacific Realm, and the other three

Provinces being part of the Temperate Northern Atlantic Realm. These Provinces have high mean impacts scores across virtually every anthropogenic stressor. Sea level rise has an impact on every Province, on the terrestrial and the marine, but especially terrestrial nutrients and organic pollution are very high at these Provinces. The mean impact score of terrestrial organic pollution lies around 0,45 and around 0,35 for nutrients pollution for each Province. The light pollution and inorganic pollution stressors have above average impact scores as well, with mean light pollution around 0,12 and inorganic pollution around 0,10. The visualisation at figures 4.27-30 show that the majority of the research area at these Provinces are impacted by at least one stressor, a feat that undoubtedly has an impact on the biodiversity of these Provinces.

The least impacted Provinces have been visualised at figures 4.31-4.36. These small islands have both a very limited terrestrial area as well as marine area within the research area. The majority of these islands have low population densities (CIESIN-SEDAC, 2015) with Juan Fernandez and Desventuradas at 9 pop/km^2, St Helena and Ascension Islands at 13,5 pop/km^2, Marquesas at 9 pop/km^2, and Subantarctic New Zealand at 0 pop/km^2. The population density at Easter Island (23 pop/km^2 (*ibid*)) is the highest, consequently its inorganic pollution levels are the highest as well. The light pollution levels at these islands is very low as well (Lloyd, 2016). The impact on these islands is possibly underestimated due to the lack of coverage of the Anthromes dataset (Ellis, Klein Goldewijk, Siebert, Lightman, & Ramankutty, 2010) and the lack of fertilizer and pesticides data on these location as well (FAO, 2015; FAO, FAOSTAT: Pesticides Use, 2019). The only stressor that consistently has an impact on these islets is sea level rise. The combination of low local sea level rise, little agriculture and small human populations make these Provinces lightly impacted by anthropogenic threats.

5.3 Analysis of impact of anthropogenic threats per Ecoregion

The most impacted Ecoregions are visualised at figures 4.38-4.40. These Ecoregions are Eastern India, the Alboran Sea, the Adriatic Sea, the Ionian Sea, the South European Atlantic Shelf, the Western Mediterranean, the Yellow Sea, Southern Vietnam, the Mexican Tropical Pacific, and the Natal -Ecoregion. The first six of these ten most impacted Ecoregions are part of the five most impacted Provinces on Earth, the next two Ecoregions are adjacent to any of these most impacted Provinces, the next Ecoregion (the Mexican Tropical Pacific) is part of the most impacted Realm, and the final Ecoregion (the Natal) is responsible for the majority of the mean impact score of the Southern African Realm. These Ecoregions have similar impact scores as the most impacted Provinces, but with mean scores even a bit higher. These Ecoregions show even fewer to no coastal cells that are unimpacted by anthropogenic stressors.

The least impacted Ecoregions (figures 4.42-45); the Northern Galapagos Ecoregion, the Prince Edward Islands Ecoregion, the South Sandwich Islands Ecoregion, the Bouvet Island Ecoregion, and the Revillagedsos Ecoregion are islands that are very remote and experience very few anthropogenic impacts. These islands have mean cumulative impact scores below 0,08, almost solely caused by sea level rise. Just like the least impacted Provinces, the combination of low local sea level rise, little agriculture and small human populations make these Ecoregions lightly impacted by anthropogenic threats.

It almost seems as if islands are largely spared from anthropogenic stressors, but there are several islands that are quiet heavily impacted. Table 4.46 lists several islands with a mean cumulative impact score above 0,50. These islands are, in contrast to the least impacted islands, either part of a bigger country, are larger islands, or are just islands that are interesting for touristic exploitation due to its climate and accessibility. Because of these factors the islands have a higher population density (Monaco & Prouzet, 2014). With this population comes a higher vulnerability to sea level rise, and more light-, nutrients-, organic-, and inorganic pollution as well. The greatest anthropogenic impact on these islands is marine sea level rise and terrestrial sea level rise. The combination of being an island, surrounded by water, having human population (CIESIN-SEDAC, 2015) and agriculture (FAO, 2015) and a relatively high local sea level rise figure (Church & White, 2011) makes these islands particularly vulnerable to salt water intrusion. Additionally, these islands suffer from a presence of agriculture with organic and nutrients pollution as well (FAO, 2015; FAO, FAOSTAT: Pesticides Use, 2019) as, to a lesser degree, lights pollution (Falchi, et al., 2016) and inorganic pollution. An example is the Azores Canaries Madeira Ecoregion (mean cumulative impact score of 0,57). This Ecoregion consists of islands that either are part of Spain or Portugal, these islands all have an international airport, and have high population densities. The Canary islands have a population density of 280 pop/km^2, Madeira a density of 323 pop/km^2, and the Azores have a density of 106 pop/km^2 (Worldbank, 2019).

Besides highly impacted islands, the research area also contains Ecoregions on the continent that experience low cumulative impacts. The Ecoregions listed at table 4.47 have a mean cumulative impact score below 0,20 and are located on the mainland. These Ecoregions are all remote areas with low human population densities (CIESIN-SEDAC, 2015), regions that are hard to access and/or have unfavourable cold climates. These Ecoregions are less affected by the land based drivers that result from human population. For example the Gulf of Alaska Ecoregion (mean cumulative impact score of 0,20) is a large Ecoregion, the entire coastline of the Ecoregion has settlements, but because the Ecoregion is so large the population density of the entire Ecoregion is low (*ibid*). Additionally this Ecoregion doesn't have any agriculture cells located in it either (Ellis, Klein Goldewijk, Siebert, Lightman, & Ramankutty, 2010). The absence of agriculture in Anchorage (located in the Gulf of Alaska Ecoregion and the capital of Alaska) is incorrect (Farm Flavor, 2020), but agriculture is very limited and is mainly clustered around Anchorage.

Figure 4.53 visualises the correlation between the cumulative marine stressors and the cumulative terrestrial stressors at an Ecoregion. The covariance of the mean marine impact score can be explained for 34% by the mean terrestrial impact score, with a p value below 0,001. The variance from the trendline as drawn at figure 4.53 shows the expected mean marine impact score based on the mean terrestrial impact score per Ecoregion. Ecoregions that show a large deviation from this trendline are listed at table 4.54. The variation value is absolute, so either the mean marine impact score is higher or lower than expected. Ecoregions where there was a mean impact score of 0 on either the marine or terrestrial are excluded from this table. The expected trend between mean terrestrial impact scores and mean marine impact scores is that the mean terrestrial impact score is lower than the mean marine impact score at lower mean terrestrial impact scores. At around a mean terrestrial impact score of 0,40 the mean marine impact score is expected to be about the same value. Above a mean terrestrial impact score of 0,40 the mean terrestrial impact score of an Ecoregion is expected to be higher than the mean marine impact score.

An important factor influencing the mean impact score in the marine zone is its slope. When the research area has a high slope then the marine zone of the research area is relatively small. This often results in a mean increase of the impact score in the marine zone. This is due to the fact that marine light-, nutrients-, organic-, and inorganic pollution all decrease with distance from the shore, so if the marine zone is small, the mean impact score tends to be higher. If there is high local sea level rise on the other hand, a large marine zone can still have a relatively high mean impact zone.

Although the Manning-Hawkesbury Ecoregion is home to Australia's largest city Sydney, due to its relatively steep coastline the research area is very narrow at the marine. Due to a high local sea level rise and low presence of agriculture the majority of the mean cumulative impact score is made up of sea level rise. Where sea level rise is fully counted at the marine, it is subdue to a distance decay function on the terrestrial, resulting in a mean marine impact score that is a lot higher than figure 4.53 predicts. The Arafura Sea, the Arnhem Coast to Gulf of Carpentaria, and the Torres Strait Northern Great Barrier Reef, Ecoregions have a higher mean marine impact score for a similar reason. These Ecoregions experience limited terrestrial stressors, but do experience (very) high local sea level rise figures while having a large marine research area. The mean marine impact score is expected to be higher than the mean terrestrial impact score at these values, but the difference is much larger than predicted. These three Ecoregions are all located around the Strait between Australia and Papua.

The Namaqua Ecoregion is located at the Southwest Temperate Southern Africa Realm and has a steep coastline. This results in a narrow marine research area with relatively high mean light-, nutrients-, organic-, and inorganic pollution impact scores. This in combination with limited agriculture on the terrestrial research area of the Ecoregion results in a mean marine impact score that is a lot higher than the mean terrestrial impact score.

The Natal Ecoregion (see: figure 4.28) experiences relatively low local sea level rise (Church & White, 2011), but does have a high coastal population (CIESIN-SEDAC, 2015) and presence of agriculture (Ellis, Klein Goldewijk, Siebert, Lightman, & Ramankutty, 2010). This results in a high mean terrestrial impact score, but due to its steep coastline the mean marine impact of the Natal is still higher than predicted by the trendline.

The Gulf of Tonkin Ecoregion, located at North Vietnam and Southern China, and the Northern Bay of Bengal Ecoregion, running from Bangladesh to Myanmar both have very high mean terrestrial impact scores, resulting from fertilizer and pesticides use (FAO, 2015; FAO, FAOSTAT: Pesticides Use, 2019), in combination with a relatively low local sea level rise (Church & White, 2011). Because the marine zone of these Ecoregions is relatively large, the mean marine impact score is relatively low. The factors result in a terrestrial impact score that is much higher relative to the mean marine impact score than the trendline predicts.

The Northeastern Honshu Ecoregion, just north of Tokyo, has a steep coastline. Although the terrestrial stressors have relatively high values, the small marine research area within this Ecoregion results in a high mean marine sea level rise impact score.

The Carolinian Ecoregion, the area stretching from Northeastern Florida up to the South-Carolina coast, experiences several terrestrial stressors. All terrestrial stressors are present, but due to a high local sea level rise (Church & White, 2011) the mean marine impact score is higher than the mean terrestrial impact score, which deviates from the trendline. This Ecoregion differs from the Manning-Hawkesbury Ecoregion because it does have a large marine research area.

The Northern Monsoon Current Coast Ecoregion is located along the South-Somalia and North-Kenya coastline. This Ecoregion has a relatively large terrestrial research area with low terrestrial impacts (FAO, 2015; Lloyd, 2016; FAO, FAOSTAT: Pesticides Use, 2019). A large river deposits large amounts of land based pollution into the ocean, increasing the mean marine impact score. Additionally the local sea level rise (Church & White, 2011) has a greater influence on the cumulative impact score than the terrestrial stressors, resulting in a mean marine impact score that is relatively much higher than predicted by the trendline.

The Chagos Ecoregion, located just south of the Maldives, holds several atolls that are highly affected by marine sea level rise (Church & White, 2011). The atolls are mainly subaquatic and thus experience virtually no terrestrial impacts. As a results the mean marine impact score is higher dan the mean terrestrial impact score, much higher than predicted by the trendline.

Chapter 6: Conclusion

This chapter will discuss the research questions of this thesis. They will be answered at 6.1 following the discussed results of the previous chapter. The significance of the findings of this thesis will be presented at section 6.2 and finally further research will be suggested 6.3.

6.1 Research questions

This section answers the research questions that are presented at section 3.6

- *Which Realms are most impacted?*

  The most impacted Realms are the Tropical Eastern Pacific Realm, the Temperate Northern Pacific Realm, and the Western Indo-Pacific Realm. The Tropical Eastern Pacific has an average cumulative impact score of 0,74, which is the highest of all Realms. The second most impacted Realm is the Temperate Northern Atlantic, which has an average cumulative impact score of 0,70. The third most impacted Realm is the Western Indo-Pacific with an average cumulative impact score of 0,59.

  After these three most impacted Realms there is a middle group of less impacted Realms. These Realms are the Temperate Southern Africa, the Central Indo-Pacific, the Tropical Atlantic, the Temperate Australasia, and the Temperate Northern Pacific Realms. These Realms all have average cumulative impact scores between 0,53 and 0,48.

  - Which stressors are responsible for the biggest impact in these Realms?

    Not every Realms has the same size, and neither does every Realm have the same marine area in relation to its terrestrial area. Areas with larger marine area and high local sea level rise are greatly affected by marine sea level rise. The Central Indo-Pacific and the Eastern Indo-Pacific have large marine areas relative to their terrestrial area, making sea level rise the major contributor to the average cumulative impact score.

    Except for the two least impacted Realms, organic pollution has the biggest impact score of the Realms after sea level rise. When looking at terrestrial and marine stressors separately, terrestrial organic pollution can even have the biggest contribution to the cumulative impact score out of the 10 threats. Terrestrial organic pollution has the biggest share in the cumulative impact score at the Tropical Eastern Pacific-, the Temperate Northern Atlantic-, the Temperate Southern Africa-, and the Temperate Northern Pacific Realm.

    Terrestrial nutrients pollution has a substantial share in the cumulative impact score of the most impacted Realms as well. It has the biggest share in the average cumulative impact score of its Realm in the Western Indo-Pacific Realm, and has the second biggest share in the average cumulative impact score of the Tropical Eastern Pacific Realm and the Temperate Northern Pacific Realm.

- *Which Realms are least impacted?*

  The least impacted Realms are the Eastern Indo-Pacific, Arctic, and Southern Ocean Realms. The Eastern Indo-Pacific and the Arctic have the second lowest average cumulative impact score with 0,27, the Southern Ocean Realm has the lowest average cumulative impact score with 0,15. The Temperate South America Realm has the fourth lowest average cumulative impact score with 0,39.

  - Which stressors are responsible for the biggest impact in these Realms?

    The Southern Ocean Realm is almost solely impacted by marine sea level rise and in a small amount by terrestrial light pollution. Sea level rise has the biggest share in the average cumulative impact score at the Eastern Indo-Pacific and Arctic Realm as well. The Eastern Indo-Pacific Realm does have a presence of nutrients and organic pollution, the Arctic Realm on the other hand has no registered agriculture and its average cumulative impact score is for a great part due to terrestrial light pollution.

    The Temperate South America Realm has about the same proportions between its stressors as the majority of the other Realms. It is just that its impact scores have a lower average than the majority of the Realms. This is proven by the k-means clustering at figure 4.51.

- *Which Provinces are most impacted?*

  The most impacted Provinces are the Bay of Bengal, the Mediterranean Sea, the Warm Temperate Northwest Pacific, the Black Sea, and the Lusitanian Provinces. The Bay of Bengal Province has an average cumulative impact score of 0,92 and the Mediterranean Sea Province has an average cumulative impact score of 0,81. The other three Provinces have an average cumulative impact score between 0,77 and 0,78.

  - Which stressors are responsible for the biggest impact in these Provinces?

    These Provinces show the same trend as the most impacted Realms. A consistent presence of sea level rise impact that is increasingly outscored by especially organic pollution, but nutrients pollution as well. In these Provinces the impact of light and inorganic pollution increasingly play a more important role as well.

- *Which Provinces are least impacted?*

  The least impacted Provinces that fall within the research area are the Easter Island, Juan Fernandez and Desventuradas, St Helena and Ascension Islands, Marquesas, Subantarctic New Zealand Provinces. These Provinces all have an average cumulative impact score between 0,06 and 0,13.

  - Which stressors are responsible for the biggest impact in these Provinces?

    These small island (groups) are largely unaffected by anthropogenic threats relation to human presence. The islands barely experience light-, nutrients-, organic-, and inorganic pollution. The only stressor that consistently affects these Provinces is sea level rise.

- *Which Ecoregions are most impacted?*

  The most impacted Ecoregions are the Eastern India, Alboran Sea, Yellow Sea, and Adriatic Sea Ecoregions. The Eastern India Ecoregion, part of the Bay of Bengal Province, has an average cumulative impact score of 1,15. The Alboran Sea Ecoregion, part of the

Mediterranean Sea Province, has an average cumulative impact score of 1,10. The Yellow Sea Ecoregion is the only Ecoregion from these Ecoregions that isn't part of the most impacted Provinces, it has an average cumulative impact score of 1,03. The fourth most impacted Ecoregion is the Adriatic Sea with an average cumulative impact score of 0,99, it is part of the Mediterranean Sea Province.

  - Which stressors are responsible for the biggest impact in these Ecoregions?

    At these Ecoregions every stressor is relatively high. Here threats come together to create highly impacted regions of Earth. Several Ecoregions of Earth have high organic an nutrients pollution impact scores, but these Ecoregions have in addition to that high sea level rise impact scores as well as relatively high light and inorganic pollution as well.

- *Which Ecoregions are least impacted?*

  The least impacted Ecoregions are the Northern Galapagos Islands, the Prince Edward Islands and the beforementioned Eastern Island Province and Juan Fernandez and Desventuradas Province that both only consist of one Ecoregion. The Northern Galapagos Islands Ecoregion has an average cumulative impact score of 0,03 and the Prince Edward Islands Ecoregion a score of 0,05.

  - Which stressors are responsible for the biggest impact in these Ecoregions?

    Just like the least affected Provinces the least impacted Ecoregions are largely unaffected by anthropogenic threats related to human presence. The islands barely experience light-, nutrients-, organic-, and inorganic pollution. The only stressor that consistently affects these least affected Ecoregions is sea level rise.

6.2 Significance of results

The integration of terrestrial and marine anthropogenic impacts into one map with variables that are consistent and comparable is unique. The link between the terrestrial zone and the marine zone is crucial in understanding the impact that humanity has on coastal habitats (Lu, et al., 2018). Visualising the impact separately only tells half of the story and half or none of the impact. With this map the interaction between the marine and terrestrial zone is visualised and the impact that humanity has on both as well. The visualisation of the impact that certain regions have on coastal habitats can raise awareness of the problem that it causes, a decrease in biodiversity. The knowledge of where the impact is highest can be a cause for mitigation efforts and governmental action. This mitigation could consist of conservation efforts for the protection of vulnerable habitats. With the use of the integrated cumulative impact map the source of a threat to a habitat can be found whether the habitat is a marine or terrestrial habitat and whether the threat is marine based or land based. This way an approach where marine and terrestrial conservation is integrated can be achieved, something that is often missing (Monaco & Prouzet, 2014).

The results show that sea level rise has an impact at every Realm. The intensity of this impact differs, but sea level rise is a global problem. A consistent impact of sea level rise at every Realm can be observed. Sea level rise will have an impact on marine habitats that will be further removed from sunlight throughout the year and terrestrial habitats will experience increased flooding and salt water intrusion (Erban, 2014). The integration of the marine and terrestrial threats show that marine and terrestrial habitats are both affected. If countries want to protect the habitats in their coastal region against biodiversity loss countries need to reduce the emission of greenhouse gasses on a global scale (Gupta, 2014). Additionally the regional impacts at the Ecoregion level can inform governments to take action to increase mitigation. Mitigation efforts are important to reduce local impacts, something that can be done across all stressors. Efforts to reduce water consumption for domestic use as well as agricultural use can reduce the impact on habitats vulnerable to sea level rise (Monaco & Prouzet, 2014).

The visualisation of the impact that the usage of fertilizers and pesticides have on coastal habitats can motivate to reduce its consumption. Where sea level rise has a global character and requires mostly global action, the other impacts can be reduced at the national and local level. The results show that in general Realms with a higher cumulative impact especially achieve this higher cumulative impact due to a higher fertilizer and pesticides use. A reduction in fertilizer and pesticides use (Biasoli & Ajmone-Marsan, 2007), the decrease of illuminating the night skies (Ehrlich, Kremen, & Ehrlich, 2013), and a reduction in impact that inorganic pollution has on coastal habitats can be achieved with national and local action (Monaco & Prouzet, 2014). The produced integrated map will assist in locating the most important threats to a habitat and can start the debate on possible solutions.

6.3 Further research

Research on this topic can be extended on several occasions with additional research to increase the reliability of future modelled impact scores. The marine habitat map used for this thesis (Halpern, et al., 2015) could do with improvement. The fact that such a global marine habitat map exists is already a great achievement, but the map has a lot of overlap. The locations of the intertidal habitats is largely unknown, the spatial resolution is limited, and at some cells 9 habitats are located at one cell. These habitats could be classified in categories such as “soft bottom shelf with kelp” and “soft bottom shelf with seagrass”. The improvement of the marine habitat map would increase our knowledge of anthropogenic impacts on different habitats.

For this thesis I created my own coastal terrestrial habitat map because such a map doesn’t exist. This is curious because the coastal terrestrial zone is more accessible to map than the marine zone (Duarte Santos, 2014). The GlobCover dataset (ESA, 2010) and the Anthromes dataset (Ellis, Klein Goldewijk, Siebert, Lightman, & Ramankutty, 2010) show that global terrestrial land classification has been done quite successful already, but a global terrestrial habitat map is still absent. The spatial resolution of the Anthromes dataset is quiet low. This results in limited knowledge of where agriculture is located and thus the knowledge where nutrients and organic pollution is most intense.

Additional further research should be done at the intersection of the terrestrial and marine anthropogenic threats. These threats have a different effect on these two different zone, but they will likely behave different in coastal habitats as well (Lu, et al., 2018). The relative impact of anthropogenic threats as well as extended research into the vulnerability of coastal habitats will largely improve the assessment of anthropogenic impacts. Additionally there is very limited literature written about the vulnerability of (coastal) habitats to inorganic pollution.

A lot of data is missing for a successful assessment of anthropogenic impacts as well. Fertilizer and pesticides use of numerous countries and small islands is missing (FAO, 2015; Lloyd, 2016; FAO, FAOSTAT: Pesticides Use, 2019), invasive species maps are missing, and salt water intrusion databases are incomplete or not updated (EEA, 2014). An overall improvement of data coverage and availability would greatly improve further research.

An interesting observation is the 0,0 cumulative impact score at the parts of the- Yellow Sea, the Irish Sea, offshore Bahamas, and some other locations. These spots are relatively close to shore, but all experience no modelled impacts. This is because these locations are far enough from shore to be unaffected by nutrients, organic, and inorganic pollution and because these areas are soft shelf habitats. The soft shelf habitat has a vulnerability index of 0,00 to sea level rise and light pollution (Halpern, et al., 2015). I suspect that this is because this habitat are not "particularly coastal" (Halpern, et al., 2015) and is mainly located at deeper bathymetry and thus is unaffected by these two stressors. But apparently this habitat does occur within the research area, the coastal zone, and might need some further research into its vulnerability.

Chapter 7: Reflection and limitations

This thesis is the first research that links the anthropogenic impacts on the marine and the terrestrial area of the coastal zone in an integrated manner. By doing so it had to overcome a gap in data availability and required several datasets to be modelled in order to be able to make them comparable between the two parts of the coastal zone. The modelling of this data brought to light several missing datasets, essential for the further assessment of anthropogenic impacts. To be able to successfully model several anthropogenic threats several existing datasets had to be combined. Appendix 9.3 for example describes the many steps that had to be undertaken to model the impact of salt water intrusion on coastal habitats. The modelling of these impacts also highlights several highly impacted regions of Earth that require an integrated reduction of these impacts in the marine and terrestrial zone. Impacts that would have been overlooked if the two zones of the coastal zone would have been assessed separately. This research has worked with a limited availability of datasets and literature. A lot of literature research has been done to fill the gap of missing datasets and vulnerability indexes. The assessment of the vulnerability of coastal habitats to anthropogenic threats is essential in understanding the impact that we have on the coastal zone (Duarte Santos, 2014; Monaco & Prouzet, 2014), an area that so many people depend upon (Monaco & Prouzet, 2014). This research increases the knowledge of anthropogenic impacts on coastal habitats, but still there are much more threats that need modelling. What these threats are and how the currently modelled impacts have their limitations is discussed in this chapter.

In this chapter the rejected variables will be discussed (see 7.1), and several additional limitations of the research concerning the dataset selection (see 7.2), the habitat vulnerabilities (7.3), the reliability of modelled stressor intensity (7.4), the modelling of the impact on a local level (7.5), and some data management improvements are suggested (7.6).

7.1 Rejected variables

For this thesis several additional anthropogenic threats were considered, but eventually couldn't be modelled due to several limitations. What these threats are and what caused them to be rejected is listed below.

- Direct human impacts
  Initially this dataset, modelled by Halpern, et al. (2015) would be provided for this thesis. Unfortunately this marine stressor has not been provided, and was not freely available online. Making it impossible to use this variable for this thesis, thereby making the terrestrial counterpart of this stressor, land use, not suited for this thesis as well.
- Oil rigs
  This dataset is available online, as used by Halpern, et al. (2015). Only the data is limited to the actual location of the oil rigs, excluding benthic structures such as pipelines, limiting the dataset. A terrestrial counterpart is hard to find and its influence on its surroundings has to modelled as well, just like its marine counterpart. This makes the oil rigs variable a time consuming variable with little result. This variable has been excluded for this thesis.
- Invasive species
  This dataset is available online, as modelled by Halpern, et al. (2015). It is modelled from port cargo volume. A similar approach has been considered for a terrestrial counterpart, but the creation of a terrestrial invasive species variable proved too complex. Port volume, road traffic, road cargo volume, and the rate of pets released into the wild are factors that need to be taken

into account for this variable. This has proven to be too complex for this thesis and therefor invasive species has been dropped as a variable for this thesis.

- Artisanal fishing
  This dataset is available online, as modelled by Halpern, et al. (2015). It is modelled from shoreline length and unemployment rate of the adjacent country. A terrestrial counterpart of this variable could be bushmeat hunting. A variable that has been mentioned in research papers, but hasn't been modelled as a spatial dataset. This results in the drop of artisanal fishing as a variable for this thesis.
- Land use
  A dataset used by Geldmann, Joppa & Burgess (2014). A very important variable to map on land (see 2.7.6) because of its devastating effects. The dataset Anthromes could be used for this, but unfortunately a marine counterpart could not be found or modelled. Land use is used for the creation of terrestrial- nutrients, organic, inorganic, -pollution and sea live rise, but not used as a variable in itself to represent habitat fragmentation.

7.2 Dataset selection

The data that has been selected for this thesis has a strong dependence on the presence of human population. Every single terrestrial stressor is related to human population. Although human population presence is very likely to be a big cause of biodiversity degradation, there are other anthropogenic stressors as well. Threats such as UV radiation, climate change, CO2 concentration (acidification) and acid rain are such stressors (Halpern, et al., 2015). These variables have a more cross-border character than the variables that are currently used. Due to the limited resources of this thesis (time and manpower) the use of five variables (actually ten) is the limit.

7.3 Habitat vulnerabilities

Halpern, et al. (2015) have modelled a habitat map that is used for this thesis as well. They base the habitat vulnerability indexes on their expert opinion and the expert opinion of their colleague researchers. For this thesis I have familiarised myself as much as possible with the vulnerability of several habitats to the stressors of this thesis, and additionally used as many sources as I could find. Still, the habitat vulnerability indexes can use improvements by additional research and expert opinions. My knowledge on this subject is limited, thus by documenting the steps I have taken and the choices I have made I aim to shed light on possible improvements.

Scientific literature on the relative impact of inorganic pollution on different habitats is very limited and a relative index could not be found. The EC IUCN Red List of Habitats (Janssen, et al., 2016) report doesn't have inorganic pollution listed as a direct anthropogenic threat either. It does list transportation and urbanisation as anthropogenic stressors, but these phenomenon cause several different impact not just inorganic pollution. For this reason transportation and urbanisation were partly counted as indicators for inorganic pollution. The lack of scientific literature on the relative impact of inorganic pollution, and almost absence of the vulnerability of habitats to inorganic pollution, makes the constructed vulnerability indexes and modelled impacts uncertain and are likely underestimated.

Similar problems occurred for the relative vulnerability of lights pollution. A lack of scientific literature and reports results in partly using 'human disturbances' and urbanisation as indicators for the vulnerability of several habitats to lights pollution (Janssen, et al., 2016).

The creation of the habitat vulnerability indexes for terrestrial landcover classes has been done by taking the vulnerability of 8 habitat groups (see table 3.9) to the five terrestrial stressors and multiply them by the part of each habitat group that a landcover class represents (see: table 3.10). The percentages that I have used are listed at table 3.11, if these percentages do the landcover classes just is arguable. Due to a lack of scientific literature I can't guarantee that the percentages that I used are just.

7.4 Reliability of modelled stressor intensity

The modelling of salt water intrusion caused by sea level rise is modelled with taking the distance to the shoreline (Barlow & Reichard, 2010), the elevation (*ibid*), the presence of agriculture (Qi & Qiu, 2011) and human population density (Fenoglio-Marc, et al., 2012) into account. All these factors have been taken into account because they all have an effect on the likelihood of saltwater intrusion and land degradation due to sea level rise. But these factors are just the tip of the iceberg and the phenomenon is incredibly complex, due to high complexity and limited resources the model has been limited to beforementioned factors.

The influence of elevation is present, but the intensity of groundwater extraction has not been accounted for. Even at higher altitude locations an excessive groundwater extraction that causes pollution can occur (EEA, 2014). This impact is modelled with the use of human population density and agriculture presence, but this models the location where the water is most likely used, it lacks the location where the actual water is taken from. What the intensity and location of groundwater extraction is (a city can collect its drinking water tens of kilometres outside of the city limits) isn't known on a global scale so the location of impact of a high population is hard to pinpoint (Qi & Qiu, 2011). Likewise water for irrigation could be taken from a nearby lake, so the location where seawater would enter a habitats isn't at the location of the farm, but at the levee that separates the lake and the ocean due to the decreased pressure exerted by the lake (Rahmawati, Vuillaume, & Purnama, 2013).

The pressure that freshwater aquifer exerts on the salt water base depends on several factors that are impossible to accurately model on a local scale for a thesis of this size, let alone on a global scale. The level of saltwater intrusion is tide driven, depends on river water flow (Savenije, 1993), depends on the substrate of the land (Rahmawati, Vuillaume, & Purnama, 2013), and on annual rainfall as well (Loaiciga, Pingel, & Garcia, 2012).

Then there is the natural phenomenon of flooding. These floods can occur naturally but the impact of these floods can increase drastically due to human influence. A well made for the collection of groundwater is a direct connection between the surface and the groundwater. During a flood a well can be devastating for the quality of the groundwater (Barlow & Reichard, 2010).

Concluding, the intensity of saltwater intrusion could either be overestimated or underestimated in my model, but the location of impact is the factor that given uncertainty to the phenomenon.

The Anthromes dataset doesn't cover the Southern Ocean Realm. This results in an absence of the terrestrial anthropogenic threats sea level rise, nutrients pollution, and organic pollution. To accommodate for this these islands have been given the same value as the lowest fertilizer and pesticides consuming countries (FAO, 2015; Lloyd, 2016; FAO, FAOSTAT: Pesticides Use, 2019). Effectively, after standardizing, this comes down to a negligible impact. Nutrients pollution and organic pollution is expected to be very low because of a lack of agriculture on these islands as well as the very low presence of marine nutrients and organic pollution (Halpern, et al., 2015). Terrestrial sea level rise would have an impact on these islands. I expect that this impact would be the lowest mean sea level rise impact of every Realm. The Eastern Indo-Pacific seems similar because it largely consists of small islands as well, but it experiences higher local sea level rise and has a higher population and agriculture.

Light pollution is modelled from a global night lights dataset (Lloyd, 2016). The terrestrial data is a direct measurement from satellite imagery that measures the light pollution for a 100 by 100 meter area. This makes the dataset a reliable indicator for light pollution intensity. The marine light pollution is modelled from the intensity of terrestrial light pollution along the shoreline. The marine cells are influence by a radius of 100 kilometres, making this dataset quiet reliable as well. A comparison with another dataset (Falchi, et al., 2016), which is visualised online (Lightpollutionmap, 2020), indicates that the modelled intensity of light pollution for this thesis is very similar.

On uninhabited islands such as some islands from the South-Sandwich islands there is a presence of lights pollution. This means that the nightlights dataset has registered lights pollution on these locations where there is limited population (CIESIN-SEDAC, 2015) or agriculture (Ellis, Klein Goldewijk, Siebert, Lightman, & Ramankutty, 2010). There is some light pollution expected from tourism (Monaco & Prouzet, 2014), but the pattern is unexpected. There are no ‘hotspots’ of increased intensity, there is just a homogenous intensity present at every cell of the land areas close to the polar circles (Lloyd, 2016). The provider of the dataset (*ibid*) doesn’t mention this in their metadata and I couldn’t find an explanation for this anywhere else either. Although the values were only minor (0,03-0,05 out of 1) these values are still curious and decreases the reliability of light pollution impacts close to the polar circles.

Terrestrial organic- and nutrients pollution is modelled from the location of agriculture according to the Anthromes dataset (Ellis, Klein Goldewijk, Siebert, Lightman, & Ramankutty, 2010). This dataset has a relatively low resolution (5 arc minute) but is also doesn’t tell the quantity of fertilizers and pesticides used by a particular farm. This data is unavailable and would make the model too complex, but because it is not modelled it limits the accuracy of the model. The amount of national consumption is respected (FAO, 2015; Lloyd, 2016; FAO, FAOSTAT: Pesticides Use, 2019), but (large amounts of) small farms are likely unaccounted for by the Anthromes dataset. This results in the model placing all the national pollution in a limited amount of large enough agriculture cells. A good example is Belize, a small country in Central America. It has an average fertilizer consumption (FAO, 2015) but only one agriculture cell according to the Anthromes dataset. This means that the average fertilizer consumption results in the highest global fertilizer consumption per cell.

Finally there is the transportation of pesticides and fertilizers from the land by surface and ground-waters (Arias-Estévez, et al., 2008). The river or small lake itself will become the most polluted part of an area, especially after rainfall (Ehrlich, Kremen, & Ehrlich, 2013). This is something that is not accounted for in the terrestrial model. The marine nutrients- and organic pollution have been modelled from river mouths (Halpern, et al., 2015), the main location where these pollutants will enter the marine.

Inorganic pollution is modelled from human population density (CIESIN-SEDAC, 2015). Although human population is the main source of inorganic pollution (Halpern, et al., 2015), it originates from transportation and industry as well (Biasoli & Ajmone-Marsan, 2007). Although transportation and industry is more frequent with higher human population, they are present at more scarcely populated areas as well. This is not accounted for in the model.

7.5 Local impact modelling

An important note to the modelled anthropogenic impacts is the level of the modelled impacts. The threats all required to be standardized otherwise the impacts can't be compared between two different threats, let alone five threats. Due to this standardization the impact score isn't an actual impact, it is only a relative impact. When looking at high local sea level rise at the Central Indo-Pacific we can't tell how intense this impact actually is when just looking at standardized figures, we can only conclude that the mean marine sea level rise impact is the highest at the Central Indo-Pacific, but we can't say how high this impact is. The same goes for the other stressors as well.

The impact of the modelled anthropogenic stressors depends on the habitat where the stressors occurs. But the impact of a stressor doesn't just depend on the type of habitat, it also depends on local- and national legislation, economic properties and local climate. These properties are all incredibly hard to quantify or model but can have an influence on the impact of anthropogenic stressors. Additionally, the modelling of current quantities salt water intrusion, light-, nutrients-, organic-, and inorganic pollution tells little about the heritage of past pollution. A heavily polluted area could currently be unoccupied by population, industry, or agriculture thus receiving 'no impact' at the current model. But that pollution in the past is still present in the ground, threatening biodiversity. Pollutants emitted in the past arguably even have a greater impact on current biodiversity than pollutants presently being emitted (Halpern, et al., 2015).

7.6 Data management improvement

As indicated at chapter 5 the terrestrial inorganic pollution has been modelled by square rooting human population density to account for the decreased intensity per person at more populated areas. This data transformation doesn't give the data a normal distribution, while log-transformation does. Terrestrial nutrients- and organic pollution have both been log-transformed, and marine nutrients-, organic- and inorganic- pollution have been log-transformed by Halpern, et al. as well. Because the terrestrial inorganic pollution hasn't been log-transformed the high values have a bigger influence on the entire dataset than high values have on the nutrients and organic pollution datasets, this is due to the standardization of the values, resulting in lower average terrestrial inorganic pollution values.

8. References

Adam, M., Anderson, R., & Shakeel, H. (1997). Commercial exploitation of reef resources: examples of sustainable and non-sustainable utilization from the Maldives. *Proceedings of the eight international coral reef symposium*, 2015-2020.

Aktar, W., Sengupta, D., & Chowdhury, A. (2009). Impact of pesticides use in agriculture: their benefits and hazards. *Interdisciplinary Toxicology 2(1)*, 1-12.

Albert, S., Saunders, M., Roelfsema, C., Leon, J., Johnstone, E., Mackenzie, J., . . . Woodroffe, C. (2017). Winners and losers as mangrove, coral and seagrass ecosystems respond to sea-level rise in Solomon Islands. *Environmental Research Letters 12(9)*.

Alkemade, R., Oorschot, M., Miles, L., Nelleman, C., Bakkenes, M., & ten Brink, B. (2009). GLOBIO3: a framework to investigate options for reducing global terrestrial biodiversity loss. *Ecosystems 12*, 374-390.

Allan, J., Mcintyre, P., Smith, S., Halpern, B., Boyer, G., Buchsbaum, A., . . . Prusevich, A. (2013). Joint analysis of stressors and ecosystem services to enhance restoration effectiveness. *Proceedings of the National Academy of Sciences 110*, 372.

Allison, I., Colgan, W., King, M., & Paul, F. (2015). Ice Sheets, Glaciers, and Sea Level. In J. Shroder, W. Haeberli, & C. Whiteman, *Snow and Ice-Related Haxards, Risks, and Distasters* (pp. 713-747). Oxford, MA: Academic Press.

Arias-Estévez, M., López-Periago, E., Martínez-Carballo, E., Simal-Gándara, J., Mejuto, J.-C., & García-Río, L. (2008). The mobility and degradation of pesticides in soils and the pollution of groundwater resources. *Agriculture, Ecosystems & Environmen 123(4)*, 247-260.

Ban, N., & Alder, J. (2008). How wild is the ocean? Asessing the intensity of anthropogenic marine activities in British Columbia, Canada. *Aquatic Conservation 18*, 55-85.

Baretta-Bekker, H., Duursma, E., & Kuipers, B. (1998). Encyclopedia of Marine Sciences. Berlin : Springer.

Barlow, P., & Reichard, E. (2010). Saltwater intrusion in coastal regions of North America. *Hydrogeology Journal (18)*, 247-260.

Barrineau, P., Wernette, P., Weymer, B., Trimble, S., Hammond, B., & Houser, C. (2015). The Critical Zone of Coastal Barrier Systems. *Developments in Earth Surface Processes 19*, 497-522.

Bedford, B., Leopold, D., & Gibbs, J. (2013). Wetlands Ecosystems. In S. Levin, *Encyclopedia of Biodiversity* (Vol. 7, pp. 384-402). Oxford, MA: Academic Press.

Benke, A., & Cushing, C. (2005). Background and Approach. In A. Benke, & C. Cushing, *Rivers of North America* (pp. xxiv-18). Cambridge, MA: Academic Press.

Biasoli, M., & Ajmone-Marsan, F. (2007). Organic and inorganic diffuse contamination in urban soils: the case of Torino (Italy). *Journal of Environmental Monitoring 9*, 862-868.

Box, E., & Fujiwara, K. (2013). Asia, Ecosystems of. In S. Levin, *Encyclopedia of Biodiversity* (pp. 261-291). Cambridge, MA: Elsevier.

Brown, J., & Lomolino, M. (1998). *Biogeography.* Sunderland, MA: Sinauer Associates.

Bryman, A. (2012). *Social Research Methods.* Oxford: Oxford University Press.

Byrnes, J. E., Reed, D. C., Cardinale, B. J., Cavanaugh, K. C., Holbrook, S. J., & Schmitt, R. J. (2011). Climate-driven increases in storm frequency simplify kelp forest food webs. *Global Change Biology*, 2513-2524.

Cabo Verde. (2012). *Cabo Verde FAO STAT*. Retrieved from Cabo Verde Data Portal: https://caboverde.opendataforafrica.org/rkelsif/cabo-verde-fao-stat-land-use-and-agricultural-inputs

Campbell, I. C. (2012). Biodiversity of the Mekong Delta. In F. Renaud, & C. Kuenzer, *The Mekong Delta System: Interdisciplinary Analyses of a River Delta* (pp. 293-313). Dordrecht: Springer.

Carpenter, S. R., Caraco, N. F., Correll, D. L., Howarth, R. W., Sharpley, A. N., & Smith, V. H. (1998). Nonpoints pollution of surface waters with phosphorus and nitrogen. *Ecological Applications 8(3)*.

Carranza, M., Hoyos, L., Frate, L., Acosta, A., & Cabido, M. (2015). Measuring forest fragmentation using multitemporal forest cover maps: Forest loss and spatial pattern analysis in the Gran Chaco, central Argentina. *Landscape and Urban Planning 143*, 238-247.

Caruso, B. S., O'Sullivan, A. D., Faulkner, S., Sherratt, M., & Clucas, R. (2013). Agricultural Diffuse Nutrient Pollution Transport in a Mountain Wetland Complex. *Water, Air, & Soil Pollution 224(1695)*.

CCE, RIVM. (2017). *European critical loads: database, biodiversity and ecossytems at risk.* Bilthoven: National Institute for Public Health and the Environment.

Chapin, F., Zavaleta, E., Eviner, V., Naylor, R., Vitousek, P., Reynolds, H., . . . Diaz, S. (2000). Consequences of changing biodiversity. *Nature 405 (6783)*, 234.

Chen, D., & Krol, A. (2004). Geology and Hydrogeology of Carbonate Islands. In *Developments in Sedimentology.* Elsevier.

Christianen, M. J., Lengkeek, W., Bergsma, J. H., Coolen, J. W., Didderen, K., Dorenbosch, M., . . . Van Der Have, T. M. (2018). Return of the native facilitated by the invasive? Population composition, substrate preferences and epibenthic species richness of a recently discovered shellfish reef with native European flat oysters (Ostrea edulis) in the North Sea. *Marine Biology Research*, 590-597.

Church, J., & White, N. (2011). Sea-level rise from the late 19th to the early 21st Century. *Surveys in Geophysics*.

CIESIN-SEDAC. (2015). GPWv3. *Gridded Population of the World, Version 3 (GPWv3): Population Density Grid*. Palisades, NY, Columbia University and Centro Internacional de Agricultura Tropical: NASA Socioeconomic Data and Applications Center (SEDAC).

Climate Greenland. (2020, February). *Agriculture and Forestry*. Retrieved from Climate Greenland: http://climategreenland.gl/en/citizen/climate-adaptation/agriculture-and-forestry/

Constanza, R., d'Arge, R., De Groot, R., Farber, S., Grasso, M., Hannon, B., . . . Paruelo, J. (1997). The value of the world's ecosystem services and natural capital. *Nature 387*, 253-260.

Costello, C., Springborn, M., McAusland, & C. & Solow, A. (2007). Unintended biological invasions: does risk vary by trading partner? *Journal of Environmental Economics and Management 54*, 262-276.

Dame, R. (2008). Estuaries. *Encyclopedia of Ecology*, 484-490.

Davies, T. W., Jenkins, S. R., Kingham, R., Kenworthy, J., Hawkins, S. J., & Hiddink, J. G. (2011). Dominance, Biomass and Extinction Resistance Determine the Consequences of Biodiversity Loss for Multiple Coastal Ecosystem Processes. *PLoS One 6(12)*.

Davies, T., Duffy, J., Bennie, J., & Gaston, K. (2016). Stemming the Tide of Light Pollution Encroaching into Marine Protected Areas. *Conservation Letters 9*, 164-171.

Davis, R. A. (2018, September 19). *Coastal landforms*. Retrieved November 13, 2018, from Encyclopaedia Britannica: https://www.britannica.com/science/coastal-landform#ref49802

de Jonge, V., & Elliott, M. (2008). Eutrophication. In J. Steele, *Encyclopedia of Ocean Sciences* (pp. 306-323). Elsevier Ltd.

DeLong, D. (1996). Defining Biodiversity. *Wildlife Soviety Bulletin 24*, 738-749.

Depledge, M., Godard-Codding, C., & Bowen, R. (2010). Light pollution in the sea. *Marine Pollution Bulletin 60*, 1383-1385.

Di Gregorio, A., & Jansen, L. (2000). *Land cover classification system (LCCS)*. Retrieved from FAO: http://www.fao.org/3/x0596e/x0596e00.htm

Duarte Santos, F. (2014). Vulnerability, Impacts and Adaptation of Coastal Zones to Global Change. In A. Monaco, & P. Prouzet, *Vulnerability of Coastal Ecosystems and Adaptation* (pp. 131-172). London: ISTE Ltd.

Duarte, C. (2013). Seagrasses. In S. Levin, *Encyclopedia of Biodiversity* (Vol. 6, pp. 540-549). Cambridge, MA: Academic Press.

Earth Trends. (2003). *Agriculture and Food-- Comoros*. Retrieved from EarthTrends Coutrny Profiles: https://rmportal.net/framelib/comoros-agriculture.pdf

EEA. (2014, 06 10). *Waterbase - Groundwater*. Retrieved from European Environment Agency: https://www.eea.europa.eu/data-and-maps/data/waterbase-groundwater-10

Ehrlich, P., Kremen, C., & Ehrlich, A. (2013). Human Impacts on Ecosystems: An Overview. In S. Levin, *Encyclopedia of Biodiversity 4* (pp. 153-155). Cambridge, MA: Academic Press.

Eldridge, B. (2008, June). *Pesticide Application and Safety for Applications of Public Health pesticides.* Retrieved March 6, 2019, from California West Nile Virus Website: http://westnile.ca.gov/special/category_a/?page=Chapter2.htm

Ellis, E. C., Klein Goldewijk, K., Siebert, S., Lightman, D., & Ramankutty, N. (2010). Anthropogenic transformation of the biomes, 1700 to 2000. *Global Ecology and Biogeography 19(5)*, 589-606.

Ellis, E., & Ramankutty, N. (2008). Putting people in the map: anthropogenic biomes of the world. *Frontiers in Ecology and the Environment 6*, 439-447.

Erban, L. (2014). Groundwater extraction, land subsidence, and sea-level rise in the Mekong Delta, Vietnam. *Environmental Research Letters (9)*.

ESA. (2010, December 21). GlobCover 2009. ESA, UCLouvain.

Fahrig, L. (1998). When does fragmentation of breeding habitat affect survival? *Ecological Modeling 105*, 1891-1902.

Falchi, F., Cinzano, P., Duriscoe, D., Kyba, C., Elvidge, C., Baugh, K., . . . Furgoni, R. (2016). The new world atlas of artificial night sky brightness. *Science Advances 2(6)*.

FAO. (2003). *Fertilizer Use by Crop in the Democratic People's Republic of Korea*. Retrieved from FAO: http://www.fao.org/3/Y4756E/Y4756E00.htm

FAO. (2008). Occupied Palestinian. Retrieved from http://www.fao.org/nr/water/aquastat/countries_regions/PSE/PSE-CP_eng.pdf

FAO. (2015). *Fertilizers indicators*. Retrieved from FAOSTAT: http://www.fao.org/faostat/en/#data/EF

FAO. (2019, December). *FAOSTAT: Pesticides Use*. Retrieved from fao.org: http://www.fao.org/faostat/en/#data/RP

Farm Flavor. (2020, February). *Alaska Agriculture*. Retrieved from Farm Flavor: https://www.farmflavor.com/alaska-agriculture/

Feist, B. E., & Levin, P. S. (2016, June). Novel indicators of anthropogenic influence on marine and coastal ecosystems. *Frontiers in Marine Science, 3*(113).

Fenoglio-Marc, L., Schöne, T., Illinger, J., Becker, M., Manurung, P., & Khafid. (2012). Sea Level Change and Vertical Motion from Satellite Altimetry, Tide Gauges and GPS in the Indonesian Region. *Marine Geodesy, 35*, 137-150.

Franckx, E. (2007, June). *Estuaries*. Retrieved October 2018, from Oxford Public International Law: http://opil.ouplaw.com/view/10.1093/law:epil/9780199231690/law-9780199231690-e1155

Friberg, N., Bonada, N., Bradley, D., Dunbar, M., Edwards, F., Grey, J., . . . Woodward, G. (2011). Biomonitoring of Human Impacts in Freshwater Ecosystems. *Advances in Ecological Research 44*, 1-68.

Gaston, K. (1996). *Biodiversity: A Biology of Numbers and Difference.* Oxford, UK: Blackwell.

Gauthier, P., Foulon, Y., Jupille, O., & Thompson, J. D. (2013). Quantifying habitat vulnerability to assess species priorities for conservation management. *Biological Conservation 158*, 321-325.

Geldmann, J., Joppa, L., & Burgess, N. (2014). Mapping change in human pressure globally on land and within protected areas. *Conservation Biology 28*, 1604-1616.

Giambastiani, B., Antonellini, M., Oude Essink, G., & Stuurman, R. (2007). Saltwater intrusion in the unconfined coastal aquifer of Ravenna (Italy): A numerical model. *Journal of Hydrology 340*, 91-104.

Gillespie, R. (2013). Oceanic Islands: Models of Diversity. In S. Levin, *Encyclopedia of Biodiversity* (Vol. 5, pp. 590-599). Oxford, MA: Academic Press.

Gong, P., Sun, T.-H., Beudert, G., & Hahn, H. H. (1997). ECOLOGICAL EFFECTS OF COMBINED ORGANIC OR INORGANIC. *Water, Air, and Soil Pollution 96*, 133-143.

Gosh, D. (2011). Mangroves. *Resonance*, 47-60.

Griffin, L. (2018, January 09). *Environmental Impacts of Oil Extraction*. Retrieved November 29, 2018, from Sciencing: https://sciencing.com/list-7459738-environmental-impacts-oil-extraction.html

Guba, E. G., & Lincoln, Y. S. (1994). Competing paradigms in qualitative research. In N. K. Denzin, & Y. Lincoln, *Handbook of qualitative research* (pp. 105-117). Thousand Oaks, CA: Sage.

Gubbay, S., Sanders, N., Haynes, T., Janssen, J., Rodwell, J., Nieto, A., . . . Micu, D. (2016). *European Red List of Habitats. Part 1. Marine habitats.* European Union: European Commission.

Gupta, J. (2014). *The History of Global Climate Governance.* Amsterdam: Cambridge University Press.

Haines-Young, R., & Potschin, M. (2013). *Common International Classification of Ecosystem Services (CICES): Consulttation on Version 4.* Nottingham: EEA.

Halpern, & al, e. (2015). Spatial and temporal changes in cumulative human impacts on the world's ocean: Supplementary Figures. *Nature Communications*.

Halpern, B. S., Frazier, M., Potapenko, J., Casey, K. S., Koenig, K., Longo, C., . . . Walbridge, S. (2015). Spatial and temporal changes in cumulative human impacts on the world's ocean. *Nature communications*.

Halpern, B., Walbridge, S., Selkoe, K., Kappel, C., Micheli, F., D'Agrosa, C., . . . Watson, R. (2008). A global Map of Human Impact on Marine Ecosystems. *Science, New Series 319*, 948-952.

Halpern, B., Walbridge, S., Selkoe, K., Kappel, C., Micheli, F., D'Agrosa, C., . . . Watson, R. (2008). Supporting Online Material for; A Global Map of Human Impact on Marine Ecosystems. *Science 319*.

Harwood, J. (2000). Risk assessment and decision analysis in conservation. *Biological Conservation 95*, 219-226.

Hawkins, J. P., & Roberts, C. M. (2004). Effects of Artisanal Fishing on Caribbean Coral Reefs. *Conservation Biology, 18*(1), 215-226.

Hayes, M. (2005). Barrier Islands. In M. Schwartz, *Encyclopedia of Coastal Science.* London: Springer.

Heathwaite, A., Quinn, P., & Hewett, C. (2005). Modelling and managing critical source areas of diffuse pollution from agricultural land using flow connectivity simulation. *Journal of Hydrology 304(1-4)*, 446-461.

Henry, H. (1964). Effects of dispersion on salt encroachment in coastal aquifers. *U.S. Geological Survey Water-Supply*, 70-84.

Hogarth, P. (2013). Mangrove ecosystems. In S. Levin, *Encyclopedia of Biodiversity 5* (pp. 10-22). Cambridge, MA: Academic Press.

Hooper, D., Chapin, F., Ewel, J., Hector, A., Inchausti, P., Lavorel, S., . . . Wardle, D. (2005). Effects of Biodiversity on Ecosystem Functioning: a Consensus of Current Knowledge. *Ecological Monographs 75*, 3-35.

Jacobsen, C., & Hjelmso, M. (2014). Agricultural soils, pesticides and microbial diversity. *Current Opinion in Biotechnology*, 15-20.

Janssen, J., Rodwell, J., García Criado, M., Gubbay, S., Haynes, T., Nieto, A., . . . Acosta, A. (2016). *European Red List of Habitats Part 2. Terrestrial and freswater habitats.* European Union: European Commission.

Jennings, S., & Polunin, N. (1996). Effects of fishing effort and carch rate upon the structure and biomass of Fijian reef fish communities. *Journal of Applied Ecology, 33*, 400-412.

Jin, S., & Fallgren, P. H. (2014). Feasibility of Using Bioelectrochemical Systems for Bioremedation. In S. Das, *Microbial Biodegradation and Bioremediation* (pp. 389-405). Elsevier.

Johnsen, K., Jacobsen, C., Torsvik, V., & Sorensen, J. (2001). Pesticide effects on bacterial diversity in agricultural soils – a review. *Biology and Fertility of Soils 33(6)*, 443-453.

Jung, M. C., & Thornton, I. (1996). Heavy metal contamination of soils and plants in the vicinity of a lead-zinc mine, Korea. *Applied Geochemistry 11*, 53-59.

Kent, F. E., Gray, M. J., Last, K. S., & Sanderson, W. G. (2016). Horse mussel reef ecosystem services: evidence for a whelk nursery habitat supporting a shellfishery. *International Journal of Biodiversity Science, Ecosystem Services & Management 12(3)*, 172-180.

Khamis, Z., Kalliola, R., & Käyhkö, N. (2019). Spatial modelling of cumulative human pressure in the tropical coastscape of Zanzibar, Tanzania. *African Journal of Marine Science 41:4*, 337-352.

Knowlton, N., & Jackson, J. (2013). Corals and Coral Reefs. In S. Levin, *Encyclopedia of Biodiversity* (Vol. 2, pp. 330-346). Cambridge, MA, NJ, USA: Academic Press.

Levin, S. A. (2013). *Encyclopedia of Biodiversity.* Cambridge, MA: Academic Press.

Lloyd, C. (2016). 100m_nightlightsv4_00-01.web.cf_cvg.7z. *WorldPop Archive global gridded spatial datasets. Version Alpha 0.9. 100m nightlights v4*. Harvard Dataverse, V1.

Loaiciga, H., Pingel, T., & Garcia, E. (2012). Sea water intrusion by sealevel rise: scenarios for the 21st century. *GroundWater 50(1)*, 37–47.

Longcore, T., & Rich, C. (2004). Ecological light pollution. *Frontiers in Ecology and the Environment*, 191-198.

Lu, Y., Yuan, J., Lu, X., Su, C., Zhang, Y., Wang, C., . . . Sweijd, N. (2018). Major threats of pollution and climate change to global coastal ecosystems and enhanced management for sustainability. *Environmental Pollution 239*, 670-680.

Malavasi, M., Bartak, V., Carranza, M. L., Simova, P., & Acosta, A. T. (2018). Landscape pattern and plant biodiversity in Mediterranean coastal dune ecosystems: Do habitat loss and fragmentation really matter? *Journal of Biogeography 45*, 1367-1377.

Mann, K. H. (1973). Seaweeds: Their Productivity and Strategy for Growth: The role of large marine algae in coastal productivity is far more important than has been suspected. *Science 182(4116)*, 975-981.

Marba, N., & Cebrain, J. (1996). Growth and population dynamics of Posidonia oceania on the Spanish Mediteranean coast; Elucating seagrass decline. *Marine Ecology*(137), 203-213.

Matthews, J. A. (2003). *The Encyclopaedic Dictionary of Environmental Change.* London: Arnold.

McCubbin, D. (1982). Barrier-Island and Strand-Plain Facies. In *Sandstone Depositional Environments* (pp. 247-279). American Association of Petroleum Geologists.

McLachlan, A., & Defeo, O. (2013). Coastal Beach Ecosystems. In S. Levin, *Encyclopedia of Biodiversity 1* (pp. 741-751). Cambridge, MA: Academic Press.

McOwen, C., Weatherdon, L., Bochove, J., Sullivan, E., Blyth, E., Blyth, S., . . . Fletcher, S. (2017). A global map of saltmarshes. *Biodiversity Data Journal 5*, 1-13.

Mittermeier, R., Mittermeier, C., Brooks, T., Pilgrim, J., Konstant, W., da Fonseca, G., & Kormos, C. (2003). Wilderness and biodiversity conservation. *Proceedings of the National Academy of Sciences (100)*, 10309-10313.

Moberg, F., & Folke, C. (1999). Ecological goods and services of coral reef ecosystems. *Ecological Economics 29*, 215-233.

Monaco, A., & Prouzet, P. (2014). *Vulnerability of Coastal Ecosystems and Adaptation.* London: ISTE Ltd.

Mtoni, Y., Mjemah, I., Martens, K., Bakundukize, C., Mtoni, P., & Walraevens, K. (2015). Estimation of depth to fresh–salt water interface and its implications for sustainable groundwater resource management: a case study of the Coastal strip of Dar es Salaam, Tanzania. *Environmental Earth Sciences 73(10)*, 6639-6662.

Nguyen, Y., Kamoshita, A., Dinh, V., Matsuda, H., & Kurokura, H. (2017). Salinity intrusion and rice production in Red River Delta under changing climate conditions. *Paddy and Water Environment 15*, 37-48.

Nicholson, F., Smith, S., Allwoay, B., Carlton-Smith, C., & Chambers, B. (2003). An inventory of heavy metals inputs to agricultural soils in England and Wales. *Science of The Total Environment 311: 1-3*, 205-219.

NOAA. (2018, 06 25). *What lives in a kelp forest*. Retrieved 12 04, 2018, from National Ocean Service: https://oceanservice.noaa.gov/facts/kelplives.html

Ödalen, J. (2014). Underwater Self-determination: Sea-level Rise and Deterritorialized Small Island States. *Ethics, Policy & Environment*, 225-237.

Olson, D. M., Dinerstein, E., Wikramanayake, E. D., Burgess, N. D., Powell, G. V., Underwood, E. C., . . . Wettengel, W. W. (2001). Terrestrial ecoregions of the world: a new map of life on Earth. *Bioscience 51(11)*, 933-938.

Oude Essink, G. (2001). Salt Water Intrusion in a Three-dimensional Groundwater System in The Netherlands: A Numerical Study. *Transport in Porous Media 43(1)*, 137-158.

Patel, S. H., Morreale, S. J., Saba, V. S., Panagopoulou, l., Margaritoulis, D., & Spotila, J. R. (2016). Climate Impacts on Sea Turtle Breeding Phenology in Greece and Associated Foraging Habitats in the Wider Mediterranean Region. *PLoS ONE 11*.

Perry, C., Alvarez-Filip, L., Graham, N., Mumby, P., Wilson, S., Kench, P., . . . Enochs. (2018). Loss of coral reef growth capacity to track future increases in sea level. *Nature 558*, 396-400.

Philpott, S. (2013). Biodiversity and Pest Control Services. In S. Levin, *Encyclopedia of Biodiversity* (Vol. 1, pp. 373-385). Oxford, MA: Academic Press.

Pimentel, D. (2013). Agricultural Invasions. In S. Levin, *Encyclopedia of Biodiversity* (Vol. 1, pp. 75-84). Oxford, MA: Academic Press.

Priest, T., & Theriot, J. (2016). Who Destroyed the Marsh? Oil Field Canals, Coastal Ecology, and the Debate over Louisiana's Shrinking Wetlands. *Economic History Yearbook 50*, 69-80.

Pringle, C., & Triska, F. (2000). Emergent Biological Patterns and Surface-Subsurface Interactions at Landscape Scales. In J. Jones, & P. Mulholland, *Streams and Ground Waters* (pp. 167-193). Cambridge, MA: Academic Press.

Puccinelli, E., Noyon, M., & McQuaid, C. D. (2016). Doe proximity to urban centres affect the dietary regime of marine benthic filter feeders? *Estuarine, Coastal and Shelf Science, 169*, 147-157.

Qi, S.-Z., & Qiu, Q.-L. (2011). Environmental hazard from saltwater intrusion in the Laizhou Gulf, Province of China. *Nat Hazards (56)*, 563-566.

Quljas, S., & Balvanera, P. (2013). Biodiversity and Ecosystem Services. In S. Levin, *Encyclopedia of Biodiversity* (Vol. 1, pp. 341-356). Oxford, MA: Academic Press.

Rahmawati, N., Vuillaume, J.-F., & Purnama, I. (2013). Salt Intrusion in Coastal and Lowland areas of Semarang City. *Journal of Hydrology (494)*, 146-159.

Ricepedia. (2001). *Turkmenistan*. Retrieved from Ricepedia: http://ricepedia.org/turkmenistan

Roberts, H., Weimer, P., & Slatt, R. (2012). River deltas. In D. Roberts, & A. Bally, *Regional Geology and Tectonics: Principles of Geologic Analysis* (pp. 490-511). Elsevier.

Rocha, J. C., Peterson, G. D., & Biggs, R. (2015). Regime shifts in the anthropocene: Drivers, Risks, and resilience. *PLoS ONE 10(8)*.

Roser, M., & Ritchie, H. (2018). *Land Cover*. Retrieved December 3, 2018, from Our World in Data: https://ouworldindata.org/land-use

Sanderson, E., Jaiteh, M., Levy, M., Redford, K., Wannebo, A., & Woolmer, G. (2002). The human footprint and the last of the wild. *Bioscience*, 891-904.

Savenije, H. (1993). Predictive model for salt intrusion in estuaries. *International Institute for Infrastructural, Hydraulic and Environmental Engineering (148)*, 203-218.

Sharpley, A. (2013). Agriculture, Nutrient Management, and Water Quality. In S. Levin, *Encyclopedia of Biodiversity* (Vol. 1, pp. 95-110). Oxford, MA: Academic Press.

Sheppard, R., Davy, S., & Pilling, G. (2009). The Biology of Coral Reeds. Oxford, UK: Oxford University Press.

Short, A. (2008). Physical Processes Affecting. In J. Steele, *Encyclopedia of Ocean Sciences* (pp. 305-315). Elsevier Ltd.

Silliman, B. R. (2014). Salt marshes. *Current Biology*, R348-R350.

Simberloff, D. (2010). Invasive species. In N. Sodhi, & P. Ehrlich, *Conservation Biology* (pp. 131-152). Oxford: Oxford University Press.

Slevitch, L. (2011). Qualitative and Quantitative Methodologies Coompared: Ontological and Epistemological Perspectives. *Journal of Quality Assurance in Hospitality & Tourism*, 73-81.

Smith, W., & Sandwell, D. (1997). Global seafloor topography from satellite altimetry and ship depth soundings. *Science 277*, 1957-1962.

Spalding, M. D., Fox, H. E., Allen, G. R., Davidson, N., Ferdaña, Z. A., Finlayson, M., . . . Robe. (2007). Marine Ecoregions of the World: A Bioregionalization of Coastal and Shelf Areas. *BioScience 57(7)*, 573-583.

Strat, D. (2013). HUMAN INDUCED ALTERATIONS IN PLANT BIODIVERSITY OF SĂRĂTURILE STRAND PLAIN - DELTA DUNĂRII . *Analele Universităţii din Oradea, Seria Geografie 2*, 348-354.

Swingland, I. (2013). Definition of Biodiversity. In S. Levin, *Encyclopedia of Biodiversity* (pp. 399-410). Oxford, MA: Academic Press.

The World Bank. (2010, June 30). Potential Impacts of Agriculture Development on the Forest Cover in the Congo Basin. Leuven, Belgium.

TradingEconomics. (2019, December). *Fertilizer Consumption*. Retrieved from tradingeconomics.com: https://tradingeconomics.com/world/fertilizer-consumption-percent-of-fertilizer-production-wb-data.html

van der Meulen, F., & Udo de Haes, H. (1996). Nature conservation and integrated coastal zone management in Europe: present and future. *Landscape and Urban Planning 34*, 401-410.

Virginia, R., & Wall, D. H. (2013). Ecosystem Function, Principles of. In S. A. Levin, *Encyclopedia of Biodiversity* (pp. 90-95 (Volume 3)). Cambridge, MA: Elsevier.

Viwkomirski, B., Sudnik-Vójcikovska, B., Galera, H., Vierzbick, M., & Malavska, M. (2010). Railway transportation as a serious source of organic and inorganic pollution. *Water, Ail, & Soil Pollution 218*, 333-345.

Walker, C., Hopkin, S., Sibly, R., & Peakall, D. (2006). *Principles of Ecotoxicology.* Boca Raton, FL: CRC Group.

Wessel, P., & Smith, W. (2017, June 15). GSHHG. *A Global Self-consistent, Hierarchical, High-resolution Geography Database*. Honolulu, HI: University of Hawai'i.

Wilson, E. (1992). *The diversity of Life.* New York: Norton.

Wilson, J. (1999). Guilds, functional types and ecological groups. *Oikos*, 507-522.

Wilson, K., Pressey, R. L., Newton, A., Burgman, M., Possingham, H., & Weston, C. (2005). Measuring and Incorporating Vulnerability into Conservation Planning. *Environmental Management 35*, 527-543.

World Ocean Review. (2010). *Organic pollutants in the marine environment*. Retrieved 11 29, 2018, from wordoceanreview.com: https://worldoceanreview.com/en/wor-1/pollution/organic-pollutants/

WorldBank. (2019, December). *Fertilizer consumption*. Retrieved from data.worldbank: https://data.worldbank.org/indicator/ag.con.fert.zs

Worldbank. (2019). *Population density*. Retrieved from The World Bank: https://data.worldbank.org/indicator/EN.POP.DNST

worldometers. (2020, 1 2). *Global Water Use*. Retrieved from Worldometers: https://www.worldometers.info/water/

Yan, B., Passow, U., Chanton, J. P., Nöthig, E.-M., Asper, V., Sweet, J., . . . Pak, D. (2016). Sustained deposition of contaminants from the Deepwater Horizon spill. *Proceedings of the National Academy of Sciences of the United States of America*, 3332-3340.

Yousaf, B., Amina, Liu, G., Wang, R., Imtiaz, M., Rizwan, M., . . . Si, Y. (2016). The importance of evaluating metal exposure and predicting human health risks in urban–periurban environments influenced by emerging industry. *Chemosphere 150*, 79-89.

Zeng, Y., Zhou, J., Zhou, Y., & Jia, R. (2016). Assessment and Causes of Groundwater Organic Pollution in Typical Plain Areas in Xinjiang, China. *Exposure and Health 8(3)*, 401-417.

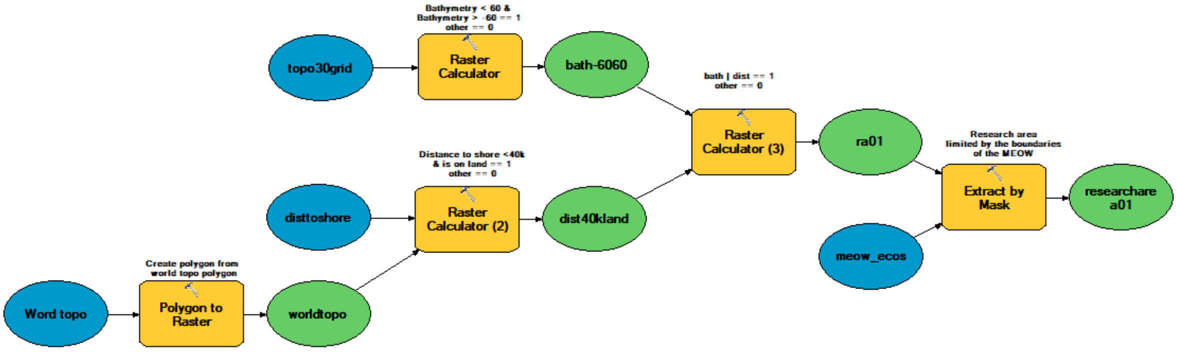
Chapter 9: Appendix

This chapter provides additional data and descriptions of this thesis. The first part is a more in depth description of the data management (9.1-10) and the second part (9.11) consists of data outputs in the form of histograms and tables.

9.1 Creating the research area layer

The research area for this research is created from several datasets. The World topo dataset is used to create a raster from the land masses and islands. This is used to make sure that only the land that lies from kilometres from the shoreline are included, and not the waters as well. To this distance to the shoreline on land (Boolean) a dataset is added that represents bathymetry. This file is created by appointing elevations above 60 meters and bathymetry below -60 meters the value 0 and the values within this range the value 1. Together with the distance dataset the bathymetry dataset is used to create a new dataset (Boolean). This dataset contains the value 1 for cells that are within the elevation range (-60 < 60m) or are within 40kms from the shoreline on land. This resulting dataset is extracted with the Marine Ecoregions of the World dataset. This excluded areas outside our units of analysis, mainly being parts of the- Siberian Lowlands, Caspian Sea, Caspian Plateau, Great Lakes, and Amazonas.

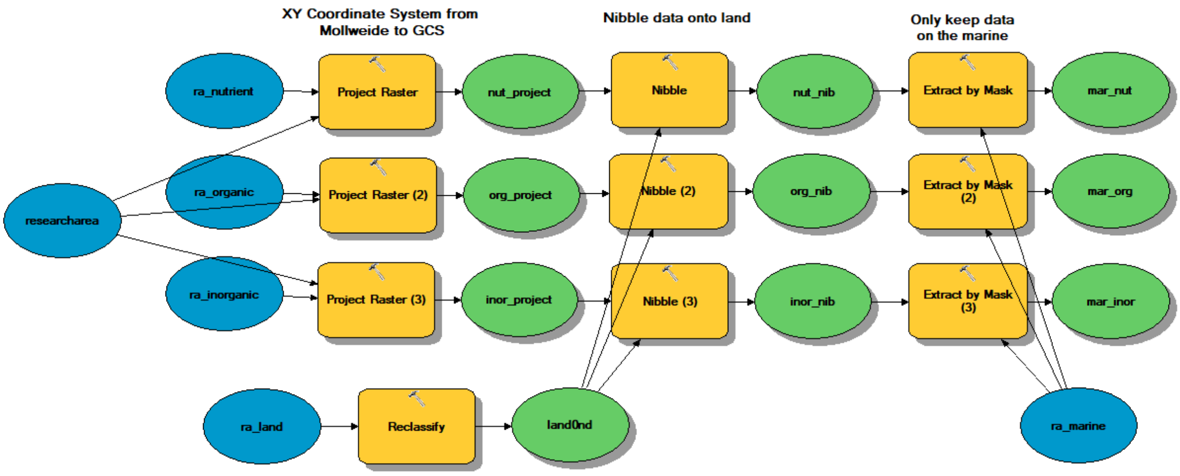
Figure 9.1: Research area creation model



9.2 Provided marine dataset data management

The three stressor datasets from the Halpern (2015) paper only need minor data management. The marine organic-, inorganic-, and nutrients- pollution datasets need to be transformed to the spatial reference as used for the other datasets (GCS_WGS_1984), during this transformation they will also receive the same cellsize as the other datasets. Because Halpern, et al. might have used a different shoreline or land dataset the data might have some cells along the coast without data. To accommodate this the data is nibbled onto land. The cells on land will receive the same value as the closest value in the marine datasets. Finally only the values on the marine, within the research area, are kept, all other cells will now have NoData values.

Figure 9.2: Marine Nutrients, Organic, Inorganic pollution management model



9.3 Sea level rise impact modelling

The marine and terrestrial layers of the pressure of sea level rise on biodiversity in coastal habitats need to be created 'entirely'. The sea level rise grids are downloaded from CSIRO here as a 1° x 1° grid between 65°S to 65°N. The dataset with barometer correction, seasonal signal removed, and the GIA correction is used.

The data management steps are referring to a model, the names of the datasets are referred in *(parenthesis)* and are in *italics*.

9.3.1 Marine Sea level rise

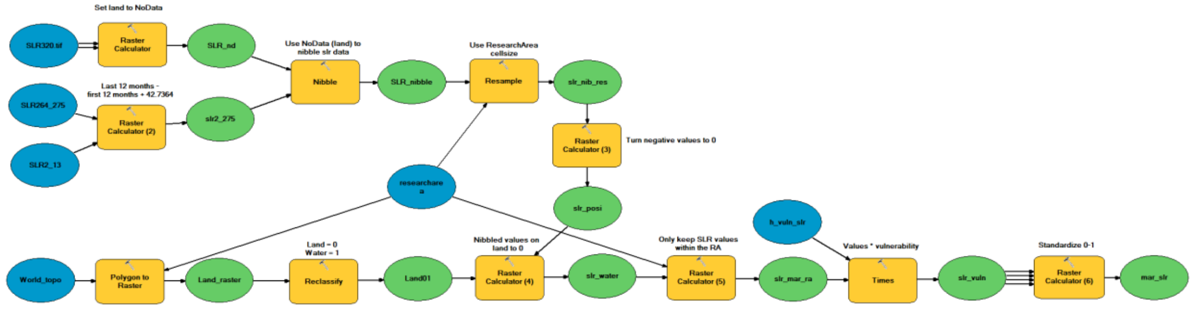
The dataset is created by averaging the local sea level rise (LSLR) rasters (12 months) of 2015 *(SLR264_275)* and subtracting these values by the averaged local sea level rise of the first 12 months of the dataset (1993) *(SLR2_13)*. These values are a rise or drop in sea level compared to an index moment (somewhere in 2006), the global mean sea level rise (GMSLR) at this index moment was 43.7364 mm higher than at the start of the measurement in 1993. This value, 43.7364 is added to the difference in LSLR. Now we have a LSLR dataset of the LSLR in 2015 compared to 1993 *(slr2_275)*.

The problem with this dataset is its accuracy, it is a lot less than the other datasets that are used for this thesis. This means that some areas near the coast will not have data because these cells are mainly situated on land, where the marine part of that cells is lost. This is why the LSLR values are 'nibbled', this means that the values on land will get the value of the closest LSLR values. Next the cell size resampled to the cell size used for this thesis (0,008333333 DD).

The negative values (where the LSL is lower in 2015 than in 1993) are turned to 0 (*slr_posi*) as Halpern *et al* (2015) did in their research. They did this because a possible positive influence of a sea level drop is beyond the scope of their and this research. The next step is to extract the LSRL values that are actually situated on the marine part of the research area of this thesis. Then the values are multiplied by the vulnerability of the habitats to sea level rise. After this is done the values are standardized from 0-1 (*mar_slr*).

Data standardization is done by using the following Raster Calculator expression: `("raster" - "raster".minimum) / ("raster".maximum - "raster".minimum).`

Figure 9.3: Marine sea level rise creation model



9.3.2 Salt water intrusion due to sea level rise

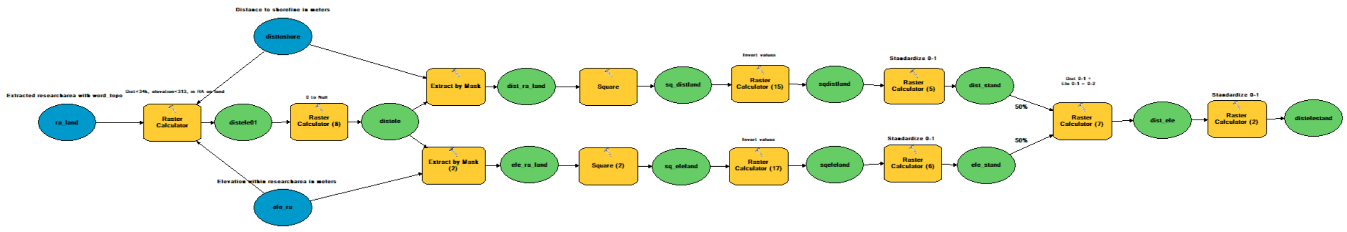
Based on the LSLR dataset the salt water intrusion is estimated. The LSLR values of the marine SLR dataset are used, the *slr_posi* dataset to be precise. This dataset has a cell size of 0,008333333 decimal degrees (DD), has no negative values (these are set to 0) and the cells that are situated on land contain the SLR values of the closest marine cell.

9.3.2.1 Influence of distance to shoreline and elevation

The level of saltwater intrusion into groundwater and soil are influenced by the elevation of a location and the distance to the shoreline. The maximum distance to the shoreline is set at 34km and the maximum elevation is set to 313m. Why these values are chosen can be found at the theory chapter 2.6.1.

A Boolean dataset is created (*distele01*), here the cells with value 1 have a maximum elevation of 313m and a maximum distance from the shoreline of 34km. This is used as a mask for both the distance (to shoreline) and elevation raster. The values of these datasets are squared because it gets progressively less likely to have salt intrusion at greater altitude and distance from shore. Currently a greater value represents a lower chance of salt water intrusion (1000 meters is further from shore than 100 meters, but is less likely to experience saltwater intrusion), so the values are inverted. Next, the values are standardized and added together. The resulting dataset contains a map within the research area with a maximum distance from shore of 34.16km and a maximum altitude of 313m and the values have a maximum of 2 where the values represent both squared elevation and the squared distance to shore.

Figure 9.4: SLR; distance and elevation creation model



9.3.2.2 Agricultural production as indicator

In addition to the elevation and the distance to shore, the presence of groundwater extraction has an effect as well. Agriculture and human population density are indicators for groundwater extraction (Barlow & Reichard, 2010; Qi & Qiu, 2011). This extraction increases the chance of saltwater intrusion at coastal habitats.

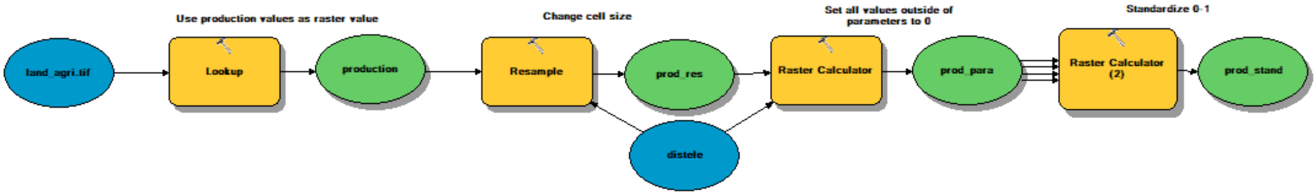
The presence of agriculture is derived from the Anthromes dataset, their net primary production is taken from ecotope.org/Anthromes:

Anthrome	Net primary production (kg C/m^2/yr)
Rice villages	0,5
Irrigated villages	0,37
Rainfed villages	0,41
Pastoral villages	0,46
Residential irrigated croplands	0,46
Residential rainfed croplands	0,56
Populated croplands	0,40
Residential rangelands	0,21

The net primary production indicates the intensity of the agricultural production. Using this figure is a way of reflecting its impact on groundwater levels.

First the primary production values are added to the Anthromes raster, the dataset that contains the locations of these Anthromes on Earth. These values are extracted and used as the value field of a new raster (*production*). Next, the cell size is changed to prevent loss of data due to a difference in cell size between datasets. The resampled production raster is multiplied by the parameters (<313m & <34km). The resulting dataset is standardized (*prod_stand*).

Figure 9.5: SLR; agriculture creation model

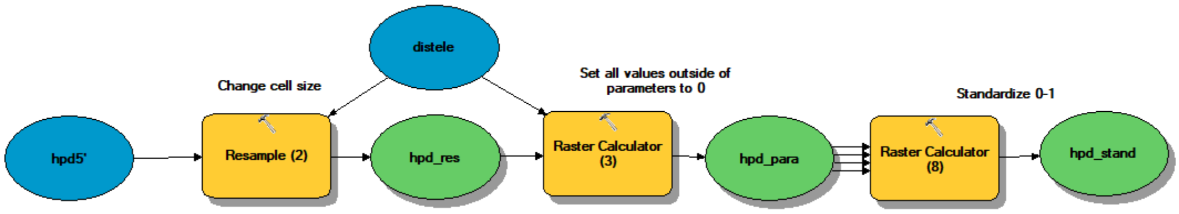


9.3.2.3 Influence of human population density

Human population density is an indicator for levels of groundwater extraction (Geldmann, Joppa, & Burgess, 2014). The dataset is downloaded from NASA-SEDAC, it is a 5 arcminute Population Density Grid of the year 2000. I have chosen for this year for consistency, because the Anthromes dataset is of this year as well.

First, the cell size is resampled and the values outside of the parameters are set to 0. Finally the values are standardized.

Figure 9.6: SLR; HPD creation model



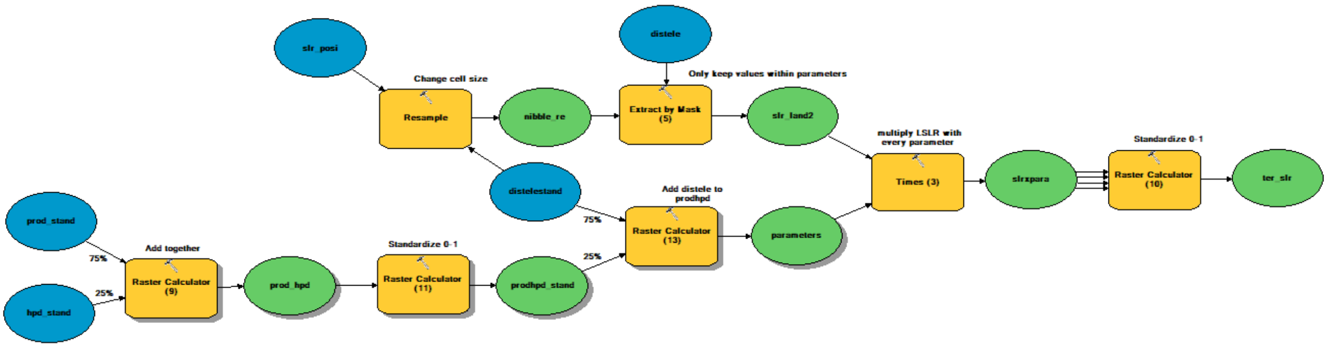
9.3.2.4 Adding all the steps together

The produced datasets together are used to estimate the impact of saltwater intrusion on coastal habitats. First the dataset that contains the production of each agricultural cell is multiplied by three and added to the human population dataset *(prod_hpd)*. This is done because agriculture uses roughly 70% of the world water consumption, where industry uses 20%, and 10% is for domestic use (worldometers, 2020). My model doesn't take industry into account, so this consumption is partly added to agriculture and partly added to human population density. *Prod_hpd* is standardized and added to the distance and elevation values as 25% of the total.

The distance to shore and elevation make up 75% because this is far more important than the other parameters. Extracting groundwater close to shore is more likely to cause saltwater intrusion than further away from shore or at an elevation (Barlow & Reichard, 2010; Qi & Qiu, 2011; Halpern, et al., 2015). Based on the literature a factor of 3:1 is chosen.

After the *parameters* dataset is created it is multiplied by the LSLR. This is the nibbled dataset from the marine SLR and represents the nearest SLR value of at the shore. The outcome is standardized and the terrestrial sea level rise dataset is created. The final step, which was done a bit later in time is described at section 9.9. Here the terrestrial datasets are multiplied with the terrestrial habitat vulnerability index.

Figure 9.7: Terrestrial sea level rise creation model

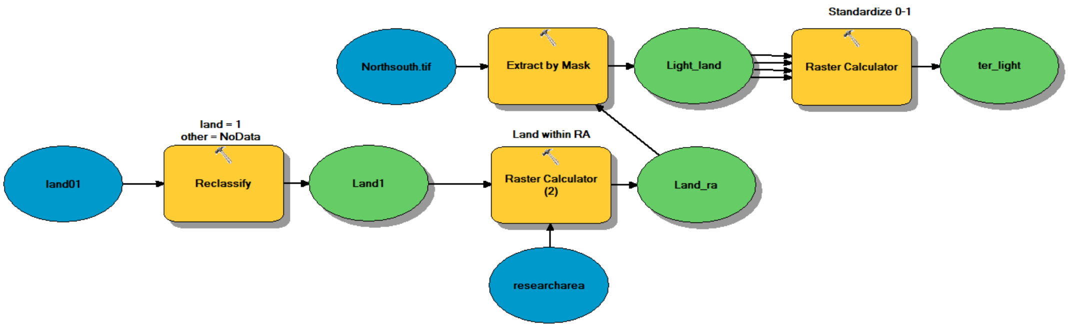


9.4 Light pollution impact modelling

The light pollution dataset is retrieved from Harvard Dataverse. It is a 100x100m dataset containing thousands of rasters with light intensity values between 0 and 63 of the year 2013. There is a mosaic for each degree of Earth within 75°N and 60°S, this comes down to about 135x180 rasters, excluding several remote ocean mosaics without any islands in it. All of these mosaics are added together into a global Nightlights dataset.

The light pollution on land is simply extracted by a mask of the research area on land and the output is standardized.

Figure 9.8: Terrestrial light pollution creation model



The light pollution dataset doesn't contain light values on the seas and big lakes. So the marine light pollution values need to be modelled.

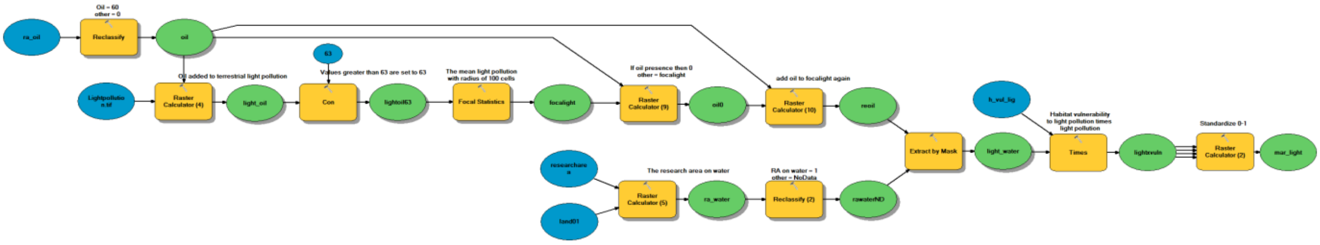
First, the oil presence of oil rigs (Halpern, et al., 2015) is added to the global light pollution dataset. In the model below these are only the only rigs that fall within the research area. The values of oil rigs are set from 1 to 60. The maximum value of the light on land is 63. After studying the lightpollutionmap.info online I noticed that the location of the oil rig is the center of very high levels of light pollution. Of course some are more bright than others, but generally they are as polluting as highly populated areas on land. The light pollution map also showed that highly populated areas on land are able to decrease night sky visibility up to 140km from shore. This is important knowledge for 'Focal Statistics' step (as can be seen at the figure below).

After the oil rig locations are added to the light pollution on land the maximum values are set back to 63. Although there were very few, some oil rigs are very close to land and actually overlap with the land dataset (which slightly covers the marine as well).

The next step covers the radiance of the land to the marine. For every cell on Earth a circle of 100km is drawn around it and the mean value within that circle is calculated. The result is that cells up to 100km from the shoreline into sea are influenced by light intensity within the circle.

The problem with this approach is that the oil rigs are quiet small and tend get very faded (about 30% of its original value remains). To compensate for this the dataset *focalight* gets the value 60 if there is an oil rig present at that cell, this way at least the actual location of the oil rig contains its value even though its influence on its surroundings is underestimated.

Figure 9.9: Marine light pollution creation model



Next, only the values on the marine are retained and these values are multiplied by the vulnerability of each habitat to light pollution. Next, the values are standardized. The final step, which was done a bit later in time is described at section 9.9. Here the terrestrial datasets are multiplied with the terrestrial habitat vulnerability index.

9.5 Nutrients pollution impact modelling

In their research Halpern, et al. (2015) have used pollution data from the Food and Agriculture Organization (FAO) to model the quantity of the land-based drivers. National statistics for each country on the average annual use of fertilizers (nutrients), and pesticides (organic pollutants) has been used. These quantities have been randomly scattered over known agricultural locations, and their runoff modeled with river-flow models. Modeling this the same way as Halpern, et al. did would being too time consuming. The amounts of fertilizers and pesticides used per country per hectare will be divided over the known agricultural land uses.

Data on where the land use is agricultural comes from the Laboratory for Anthropogenic Landscape ecology: http://ecotope.org/Anthromes/v2/data/. The Anthromes that are considered as agricultural are Rice villages, Irrigated villages, Rainfed villages, Pastoral villages, Residential irrigated croplands, Residential rainfed croplands, Populated croplands & Residential rangelands. The other Anthromes are not considered as agricultural because their primary production is considerably lower than the other Anthromes. The Anthromes raster could be considered as outdated since it was created for 2000, but Geldmann, Joppa, & Burgess (2014) state that, on a global scale, the

Anthromes only slightly change on such a short period of time. This means that the Anthromes of the year 2000 is sufficient to be used.

9.5.1 Data gathering

Nutrients pollution mainly comes from the use of N, P2O and K2O as fertilizers for agriculture. The data on fertilizer use mainly comes from FAOstat,. For some countries the annual fertilizer use per area of cropland data was unavailable at FAOstat. Data from other websites are used as alternatives. The following countries were missing at FAOstat and the data was found at Trading economics:

For 1994: Chad, Sierra Leone, Guinea-Bissau.
For 2015: Ireland, Mali
For some countries the fertilizer use was 0: Western-Sahara, Solomon Islands, Vanuatu.

Another alternative source for fertilizer use data is the World Bank. The World Bank had useful data on Bahrain for 2016, and on New-Zealand, Jordan, Kuwait, and Qatar for 2015.

Next, several individual sources were used to determine the fertilizer use of countries where none of the before mentioned sources had data on;
North-Korea 1994, Comoros 1998, Turkmenistan 2001, Cape Verde 2012, Equatorial Guinea value=0.

For Palestine no exact data could be found, only terms such as "excessive". For French Guiana the Average use of fertilizers from Suriname and France was taken (which were almost the same) because of the colonial history with France and since Surinam is a neighboring country. The fertilizer use of the Dominican Republic was copied and used for Puerto Rico since this is a neighboring country and has a similar economy.

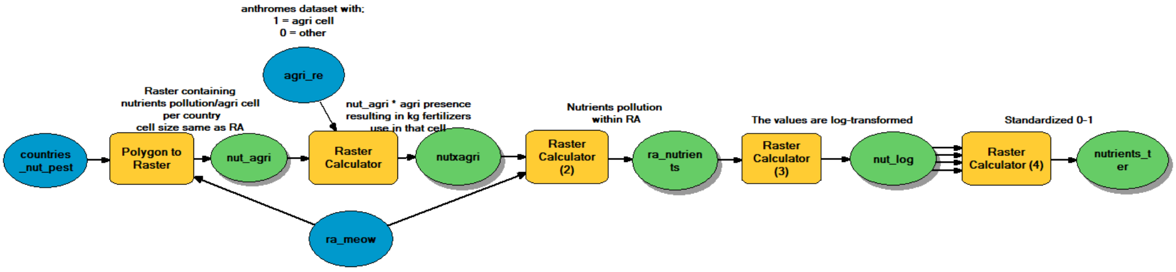
The only country where no data on fertilizer use whatsoever could be found was Timor-Leste. Hong Kong and Macau have, according to the FAO, no or nihil agricultural area. Their values were set to 0.

The World Bank data is in kg/hectare of arable land. This unit is inconvenient so this number is multiplied by the hectares of arable land of that country. The hectares of arable land per country is available on the website of the World Bank. The World Bank has data on the majority of the world's countries and the total hectares of arable land per country from 2000 are used because this is the same year as the Anthromes dataset.

The countries that had no data on total hectares of arable land in 2000 on the World Bank web source, but that I do have kg/ha data on are listed below. The hyperlink brings you to the location that did provide me with the amount of arable land for that country. Cook Islands, French Guiana, Montenegro (2006 was used instead), Saint Lucia, Serbia (2006 was used instead), Taiwan, Western Sahara, and Sudan (2011 was used instead).

Finally, the amount of agricultural cells per country are calculated in ArcGIS with a Zonal Statistics. The amount of fertilizers used per country is divided by the amount agricultural cells in that country.

Figure 9.10: Terrestrial nutrients pollution creation model



9.5.2 Nutrients pollution raster creation

The dataset that contains the amount of fertilizers use per agricultural cell is joined to a World topography shapefile. The resulting shapefile is transformed to a raster file with the fertilizer use in kg per agricultural cell as the value field, the cell size is the same as the research area (0,00833333DD). This file is multiplied by the Boolean raster *agri_re*, this way only the cells where an agricultural cell is present keep their value. The resulting dataset is multiplied by the research area, keeping only the cells within the research area. Next the values are log-transformed, and then standardized.

The values of nutrients, organic and inorganic pollution have been log-transformed log(x+1), similar to how Halpern, et. al (2015) log-transformed their data. This transformation has been chosen because this transformation gives a good data fit. The transformation resulted in a normal distribution. This was necessary because each variable had some extreme values that strongly influenced the properties of the dataset. The final step, which was done a bit later in time is described at section 9.9. Here the terrestrial datasets are multiplied with the terrestrial habitat vulnerability index.

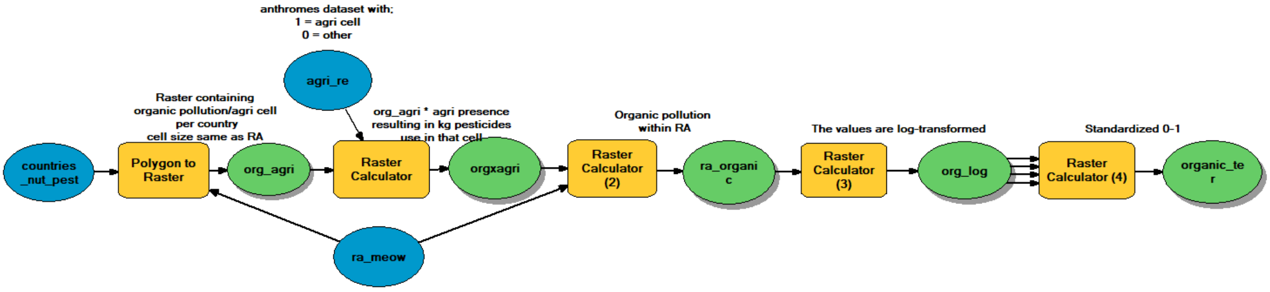
9.6 Organic pollution impact modelling

Pesticides use is available at total consumption per country. This data is mainly retrieved from the FAO (pesticides use, tonnes of active ingredients).

Like Nutrients inputs, the FAO does not have data on each country on Earth. Data on pesticides use is not as freely available as fertilizer use, so no alternative sources have been found. The countries that have been left with the value 0 are Benin, Bosnia and Herzegovina, Cambodia, Cuba, Djibouti, Equatorial Guinea, French Guiana, Gabon, Georgia, Greenland, Liberia, Nauru, Philippines, Solomon Islands, Somalia, United Arab Emirates, and Western Sahara. There also was no data available for Afghanistan, Mongolia, Uzbekistan, and Serbia, but these countries are outside of the research area of this research.

The process of the creation of the dataset is identical (except for the actual values) to the terrestrial nutrients pollution dataset and I advise to read 9.5.2. The organic pollution model can be seen below. The final step, which was done a bit later in time is described at section 9.9. Here the terrestrial datasets are multiplied with the terrestrial habitat vulnerability index.

Figure 9.11: Terrestrial organic pollution creation model



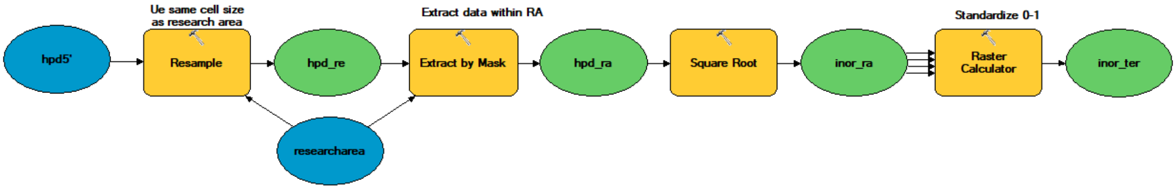
9.7 Inorganic pollution impact modelling

In their researches Halpern, et al. (Halpern, et al., 2008; Halpern, et al., 2015) stated that the majority of inorganic pollution comes from urban runoff. In my research I will assume the same. This means that urban areas with more inhabitants produce more inorganic pollution. For their research Geldmann, Joppa, & Burgess state that heavily populated areas produce more pollution, but that the pollution per inhabitant decreases. It is stated that the square root transformation represents this decreased pressure per person the most accurate. I will use the same data transformation.

The dataset is downloaded from NASA-SEDAC, it is a 5 arcminute Population Density Grid of the year 2000, the same as used for the estimation of saltwater intrusion.

The raster dataset with the human population density is resampled to match the cell size of the research area. From the result the cells that fall within the research area are extracted. Next, the cell values are square rooted and finally standardized. The final step, which was done a bit later in time is described at section 9.9. Here the terrestrial datasets are multiplied with the terrestrial habitat vulnerability index.

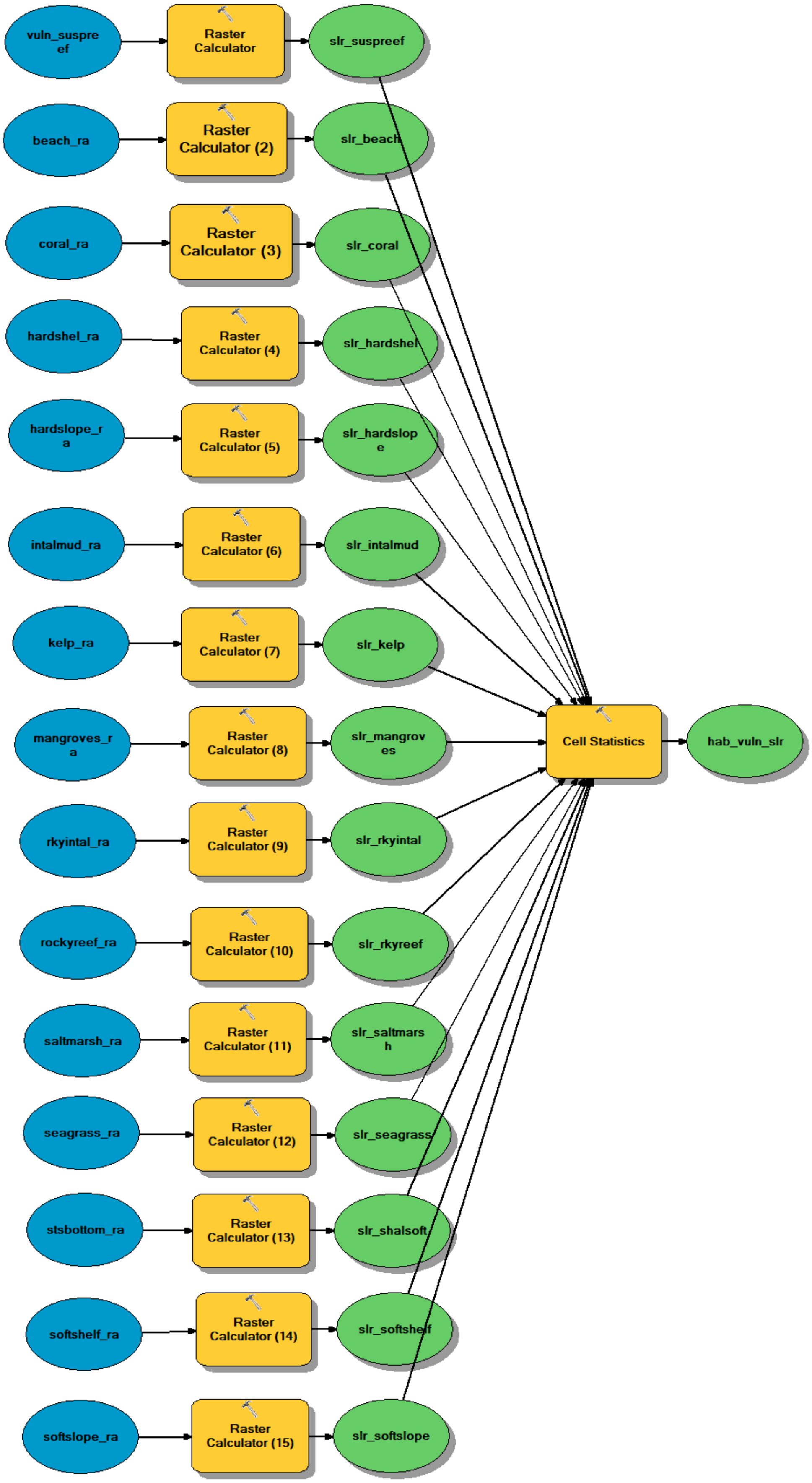
Figure 9.12: Terrestrial inorganic pollution creation model



9.8 Creation and use of the marine habitat vulnerability maps

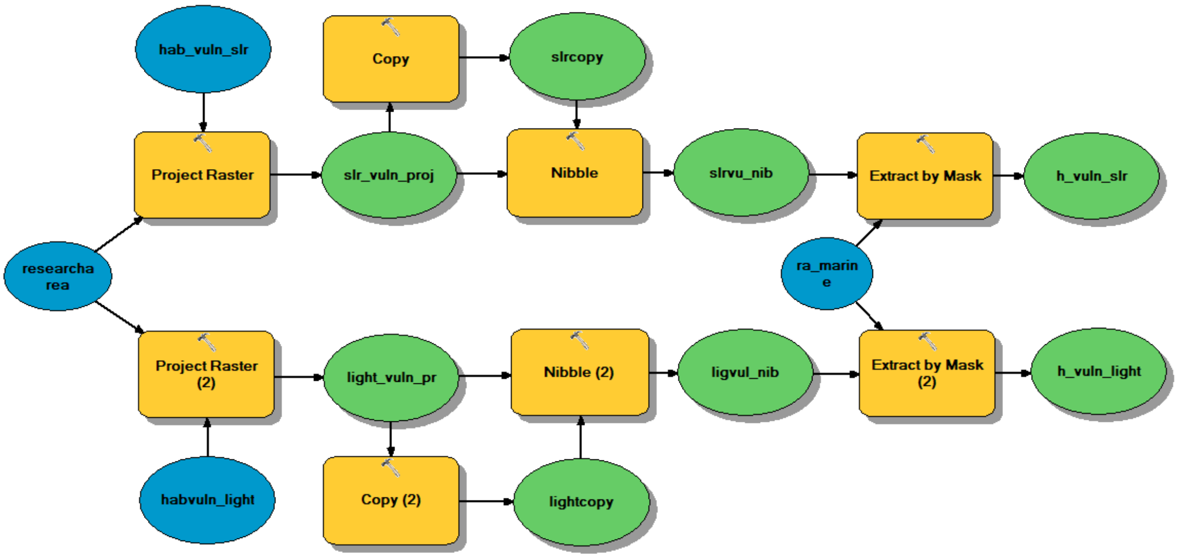
The habitat map as modelled by Halpern, et al. (2015) contains 19 habitats, from these habitats 11 are, according to Halper, et al., coastal. All 19 habitats were used to create a habitat map. This is to make sure that all habitats that are present within the research area are included and to make sure that all cells within the marine part of the research area have a vulnerability index. All habitat layers have a single value, where a certain habitat is present the raster has a value of 1, and where it isn't present the raster has a value of NoData. Every habitat is multiplied in the raster calculator with either their vulnerability to light pollution or sea level rise (see figure 3.2). The figure below is the model for sea level rise, the model for light pollution is identical, but only the value in the raster calculator is different. The habitats have a lot of overlap; rocky intertidal, intertidal mud, beach, salt marsh, and suspension feeder reefs are all located at the same cells for instance. To accommodate this, Cell Statistics is used that to calculate the MEAN of all cells. This means that for the five beforementioned intertidal habitats only the mean vulnerability of these five habitats together is accounted for. Other places have even more overlap due to the limited knowledge of the location of these habitats.

Figure 9.13: Creation of the marine sea level rise vulnerability map



The next step is depicted in figure 9.14**,** the raster files that contain the values with the vulnerability of each habitat to respectively sea level rise and light pollution are managed. They are reprojected to GCS_WGS_1984, during this transformation they will also receive the same cell size as the research area. In the next step the possible empty cells along the shoreline are filled up within the research area with a nibble. For this nibble I used a copy of the reprojected dataset because using the same raster as a mask to nibble and as the input raster didn't work in the Model Builder. Finally only the values within the research area at the marine are kept, this is done with the 'Extract by Mask' function.

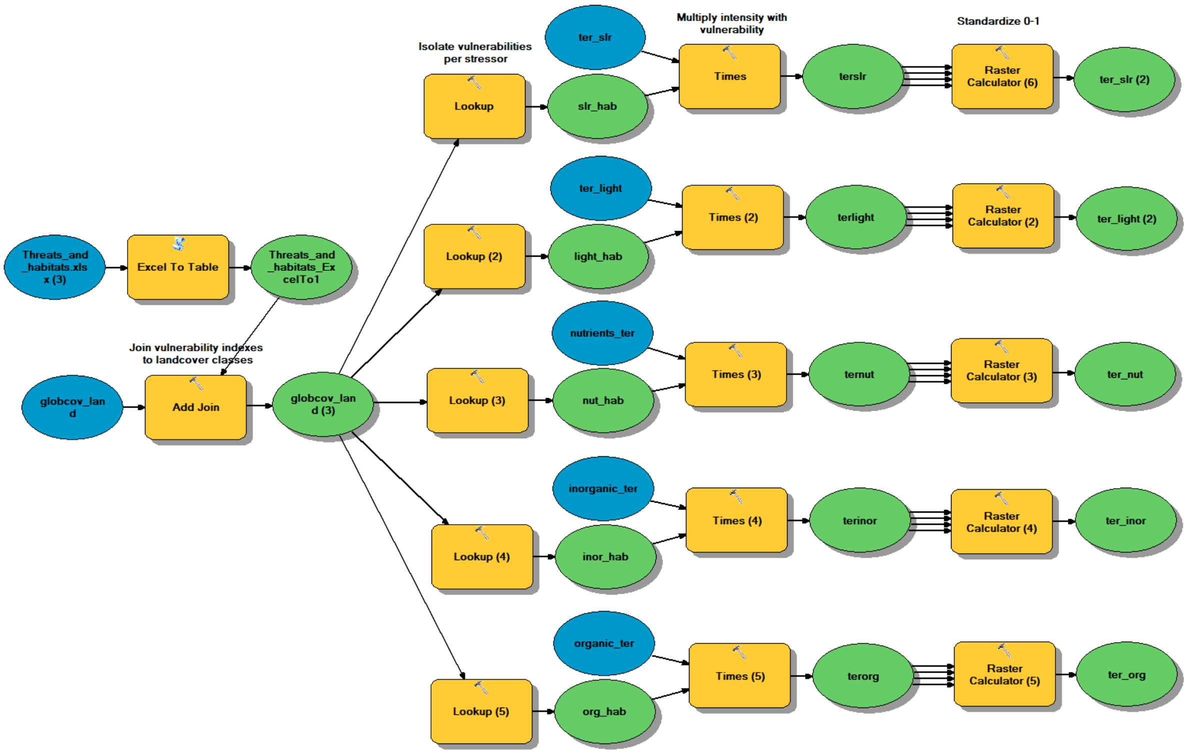
Figure 9.14: Use of the vulnerability maps



9.9 Creation and use of the terrestrial habitat vulnerability map

The terrestrial habitat map is created from the GlobCover landcover classes from the ESA (ESA, 2010). This dataset contains 23 landcover classes, the biggest being the water bodies (oceans etc.). The size of this landcover class is greatly reduced because only the classes on land within the research area are retained. Each of the 23 classes is still present within the research area and for each of these classes a vulnerability to sea level rise, light pollution, nutrients pollution, organic pollution, and inorganic pollution is calculated. What these vulnerability indexes are, and how they are calculated is discussed in detail at section 3.4. The Excel file that contains all of the vulnerability indexes (see table 3.9) is imported to ArcGIS. This table is joined to the GlobCover raster that contains the location of each habitat. Then five raster are created with the Lookup Tool. One for each threat containing the vulnerability indexes of each terrestrial habitat to that threat. Then the (modelled) intensity raster of each threat is multiplied with the vulnerability to that threat with the Times Tool. Finally the values are standardized.

Figure 9.15: Creation and use of the terrestrial habitat/vulnerability map



9.10 Analysis

Due to the amount of unique values I was unable to create histograms for the datasets. When looking at the Realms separate there were still too many unique values to create Histograms, so the values needed to be turned into integers. Before this was done all values were multiplied by 20 to prevent loss of data (the maximum possible value was now 100). The five terrestrial stressors together, Extracted by a land Mask, and the five marine stressors together, Extracted by a marine Mask were Cut per Realm. Now there are 12x2 rasters, which were exported to Excel for analysis to create figures 9.26-28. The cumulative scores per Realm were calculated after multiplying the average terrestrial score with the amount of terrestrial cells in the research area and adding them to the multiplication of the marine score with the amount of marine cells within the research area, and finally dividing them by the total amount of cells.

For the creation of figures 9.16-26 each threat was multiplied by 20, turned into integers and extracted per Realm, resulting in about 110 rasters. The rasters were then exported to Excel for analysis to create the histograms.

For the analysis of the small islands the raster for this Ecoregion was exported in the same way to improve its mapping. This resulted in a maximum value for that particular Ecoregion, improving its visualisation.

To calculate the amount of threats that have an impact on how many cells within the research area (see: table 4.48) a Cell Statistics was performed. Each stressor was managed with a Conditional Statement, if the cell value is above 0 the cell value is set to 1, if not the value remains 0 (same as reclassify). This was done for each stressor and a Cell Statistics turned out how many stressors had overlap at how many cells within the research area.

9.10.1 R Code: k-means clustering and correlation matrix

```
setwd("E:/Analysis/GeoDa magic/MDS")
install.packages("cluster")
install.packages("factoextra")
install.packages("magrittr")
install.packages("readr")
install.packages("tidyverse")
library("tidyverse")
library("readr")
library("cluster")
library("factoextra")
library("magrittr")
library("dendextend")

#import and data management for MDS method
MDS_Realms <- read_delim("MDS_Realm.csv", ",",
            escape_double = FALSE, trim_ws = TRUE)
View(MDS_Realms)

MDS <- MDS_Realms[12:13]                       #only keep the MDS variables
MDS_scale <- scale(MDS)                        #scale variables
MDS_scale <- as.data.frame(MDS_scale)          #turn into data frame

rownames(MDS_scale) <-c("Arctic","CIP","EIP","SO","Taus","TNA","TNP","TSAm","TSAfr","TrAtl","TrEP","WIP") #add names to rows
MDS_k4 <- kmeans(MDS_scale, 4)                 #this will perform a k-means clustering with 4 clusters
fviz_cluster(MDS_k4, data = MDS_scale)         #visualise the k-means clustering based on the MDS variables

# find the optimal amount of clusters (result = 4)
fviz_nbclust(MDS_scale, kmeans, nstart = 25,  method = "gap_stat", k.max = 10, nboot = 10)
             +    labs(subtitle = "Gap statistic method")

fviz_nbclust(MDS_scale, kmeans, method = "wss") +
  geom_vline(xintercept = 4, linetype = 2)
            +    labs(subtitle = "Elbow method")

fviz_nbclust(MDS_scale, kmeans, method = "silhouette")
+    labs(subtitle = "Silhouette method")

# create correlation matrix
Realms <- MDS_Scale[1:10]
Realms <- as.data.frame(Realms)

Realms_t <- t(Realms)                          #transpose
cort <- rcorr(Realms_t)                        #create pearson correlation matrix
cort_r <- cort$r                               #matrix with correlations
cort_p <- cort$P                               #matrix with significance
corrplot(cort_r, method="number", type="upper", col="black", order="hclust",
            p.mat = cort_p, sig.level = 0.01, insig = "blank")        #visualise upper triangle of matrix, black values, order by hierarchical
                                                                      clustering, only show correlations with a significance above 0.01
```

9.11 Outputs

9.11.1 Histograms of each stressor impact per Realm

Starting from the next page, the Histograms of each individual stressor in the terrestrial zone, in the marine zone and the combined histogram is presented. The scale of the Y-axis varies to be able to compare the spread of data within each Realm with the other Realms, it also allows for the data to be visible in the case of a Realm with a small research area. The X-axis starts with value 0 or value 0,01. This is due to the high frequency of 0 values in that particular histogram, in that case the frequency of the 0-value is given.

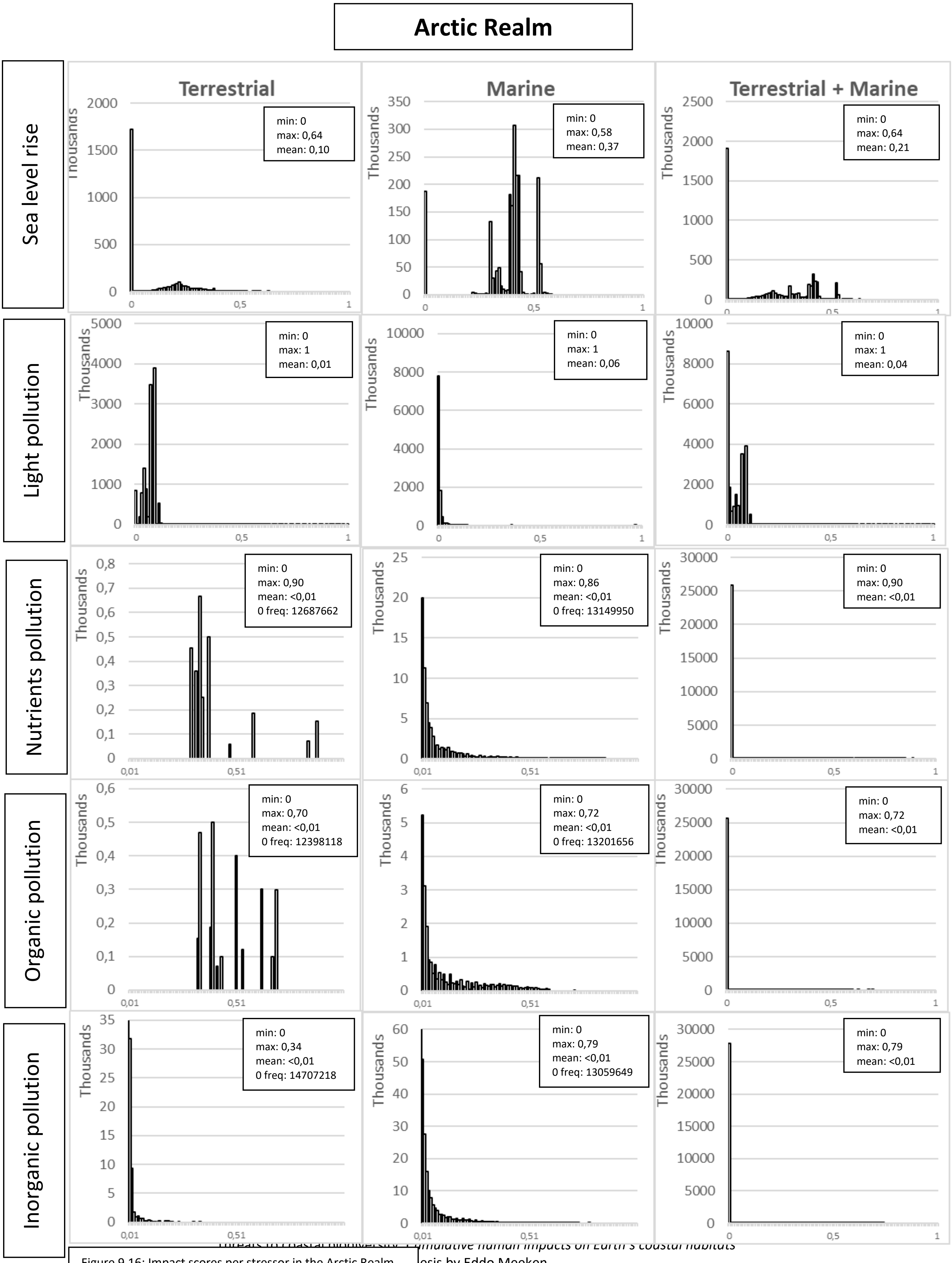


Figure 9.16: Impact scores per stressor in the Arctic Realm

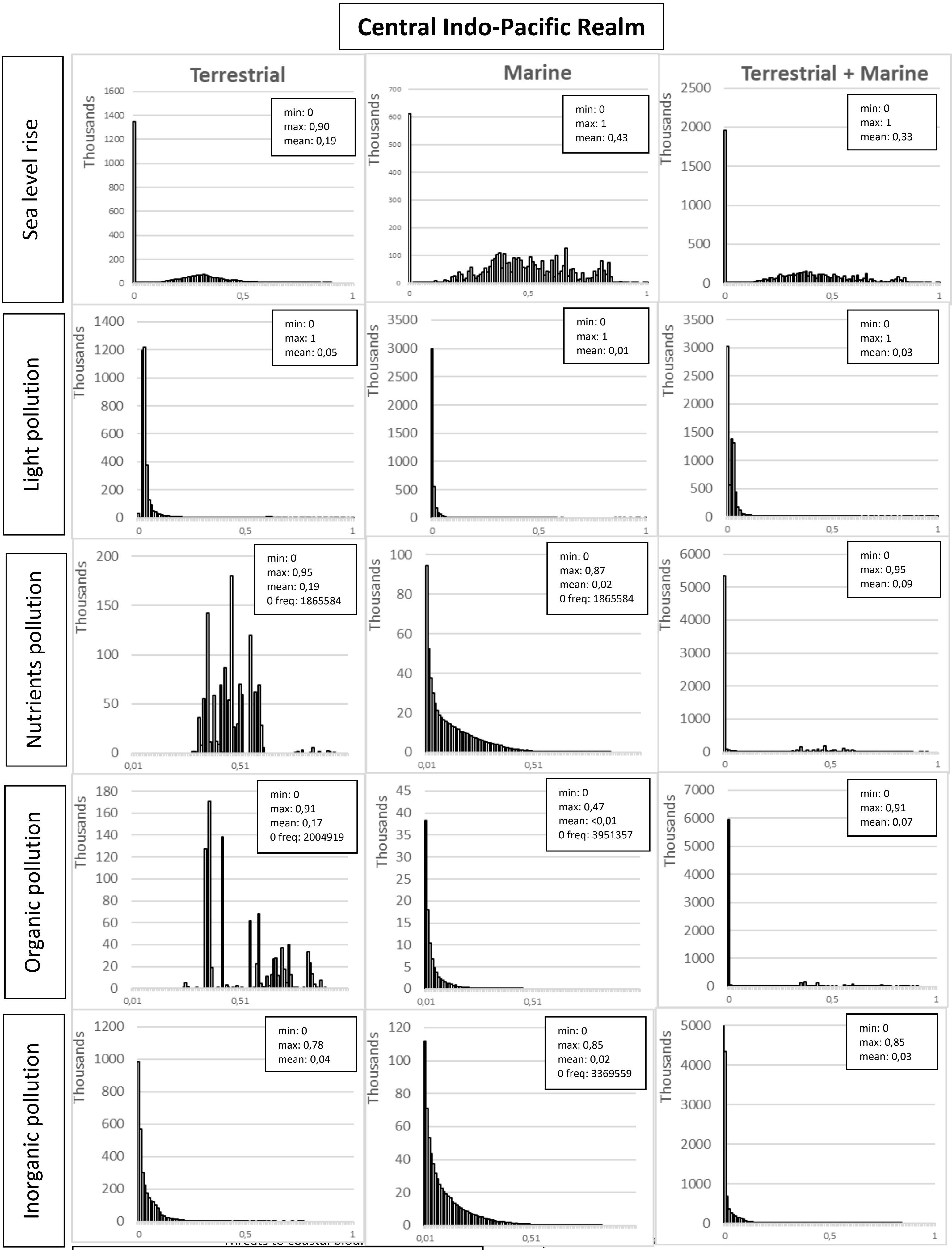


Figure 9.17: Impact scores per stressor in the Central Indo-Pacific Realm

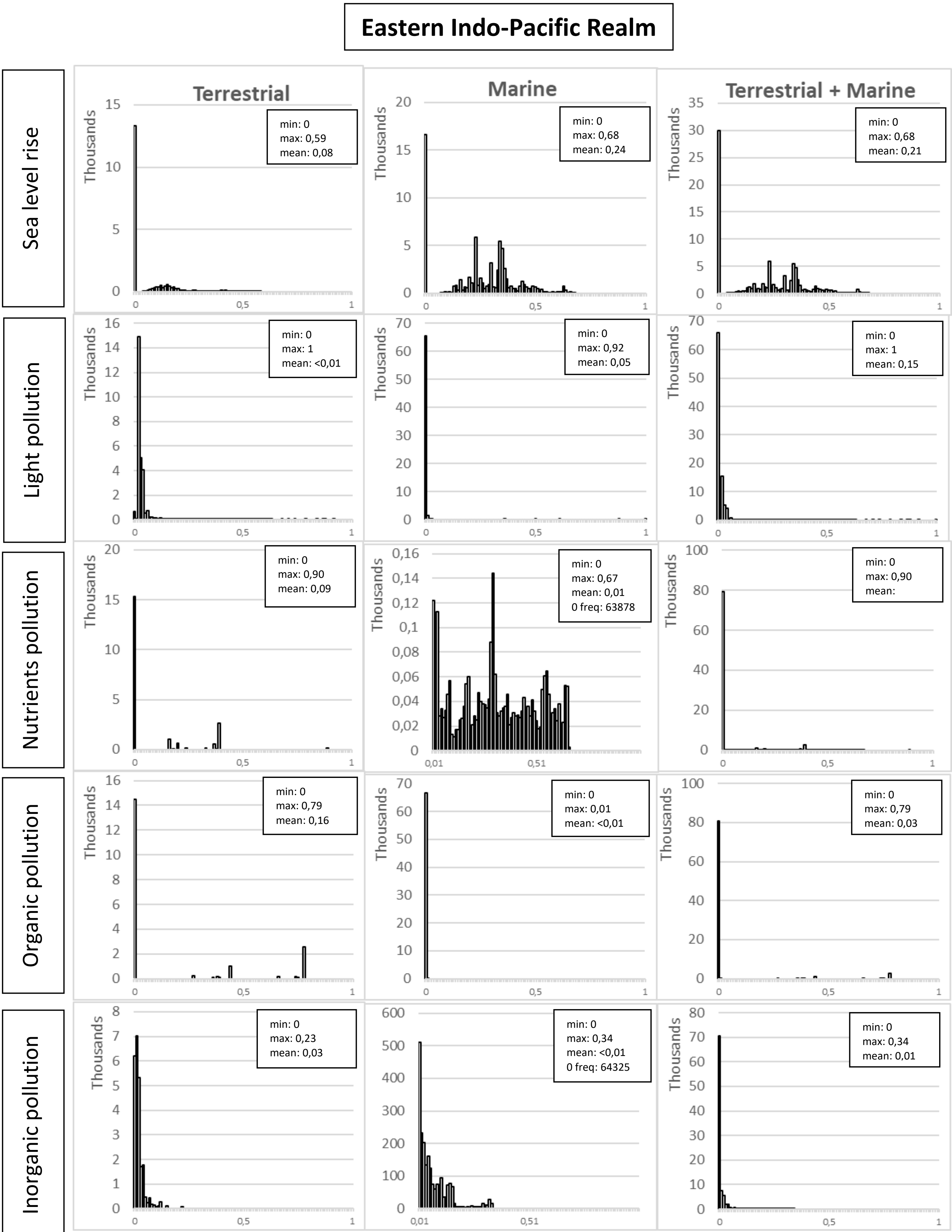


Figure 9.17: Impact scores per stressor in the Eastern Indo-Pacific Realm

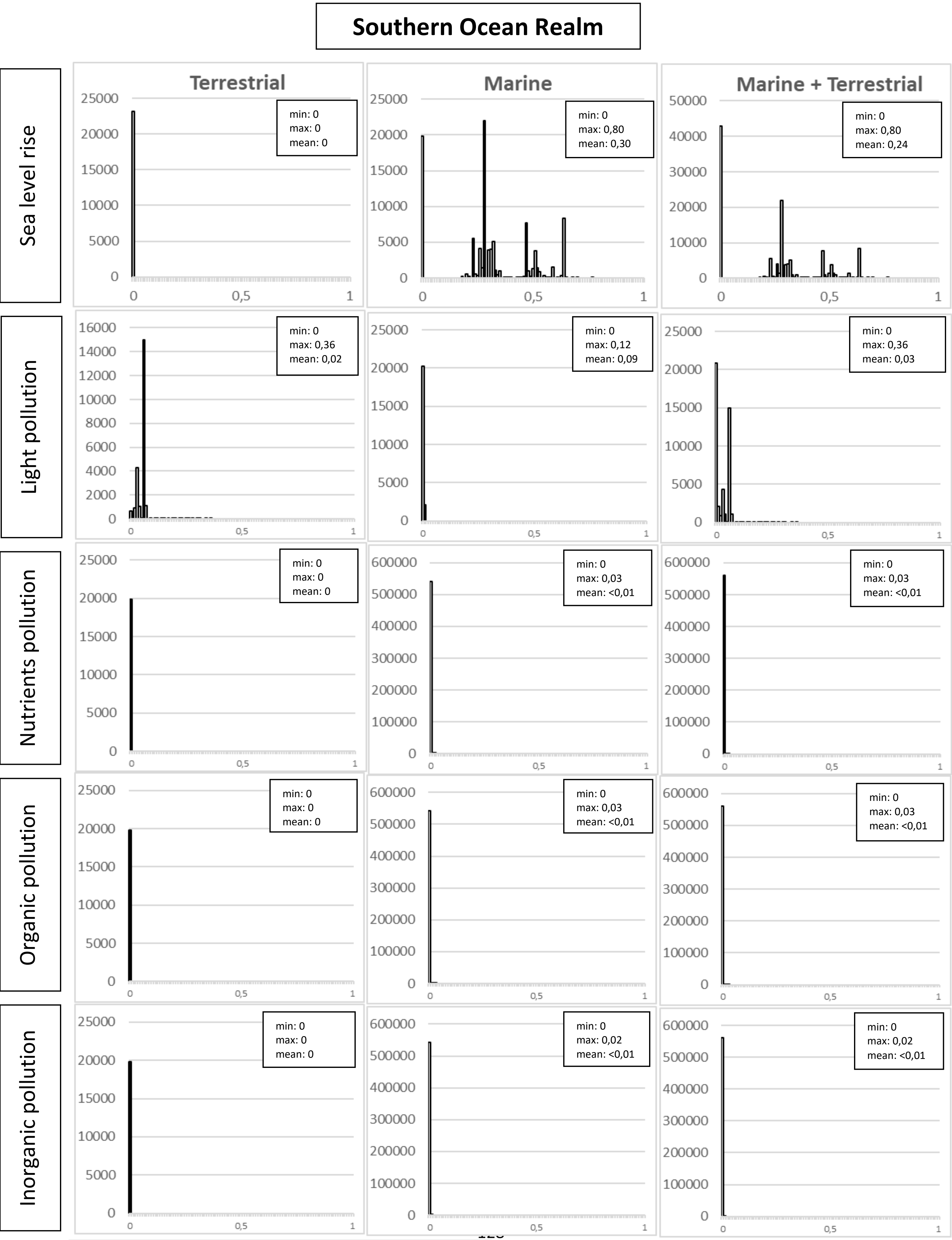


Figure 9.18: Impact scores per stressor in the Southern Ocean Realm

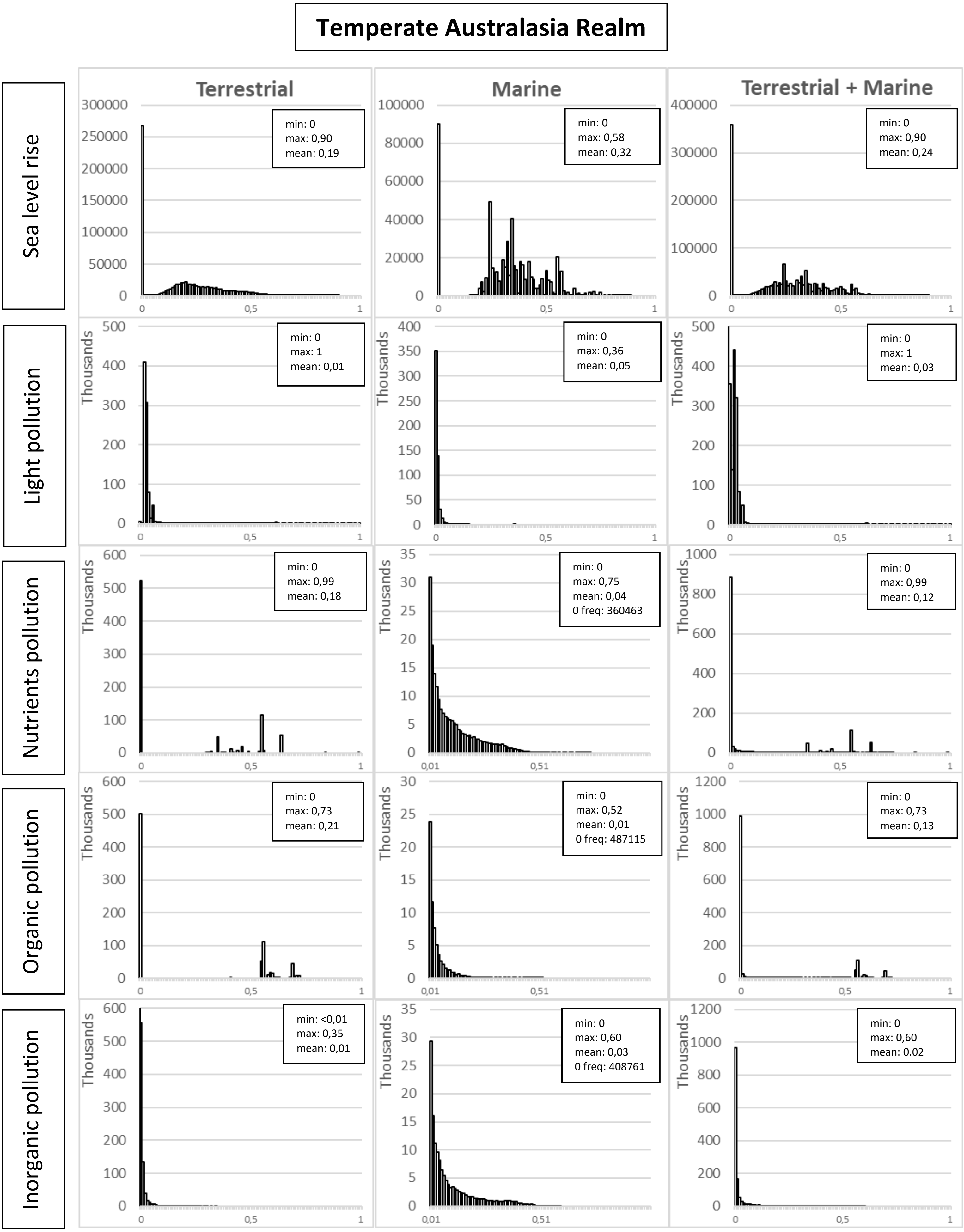


Figure 9.19: Impact scores per stressor in the Temperate Australasia Realm

Temperate Northern Atlantic

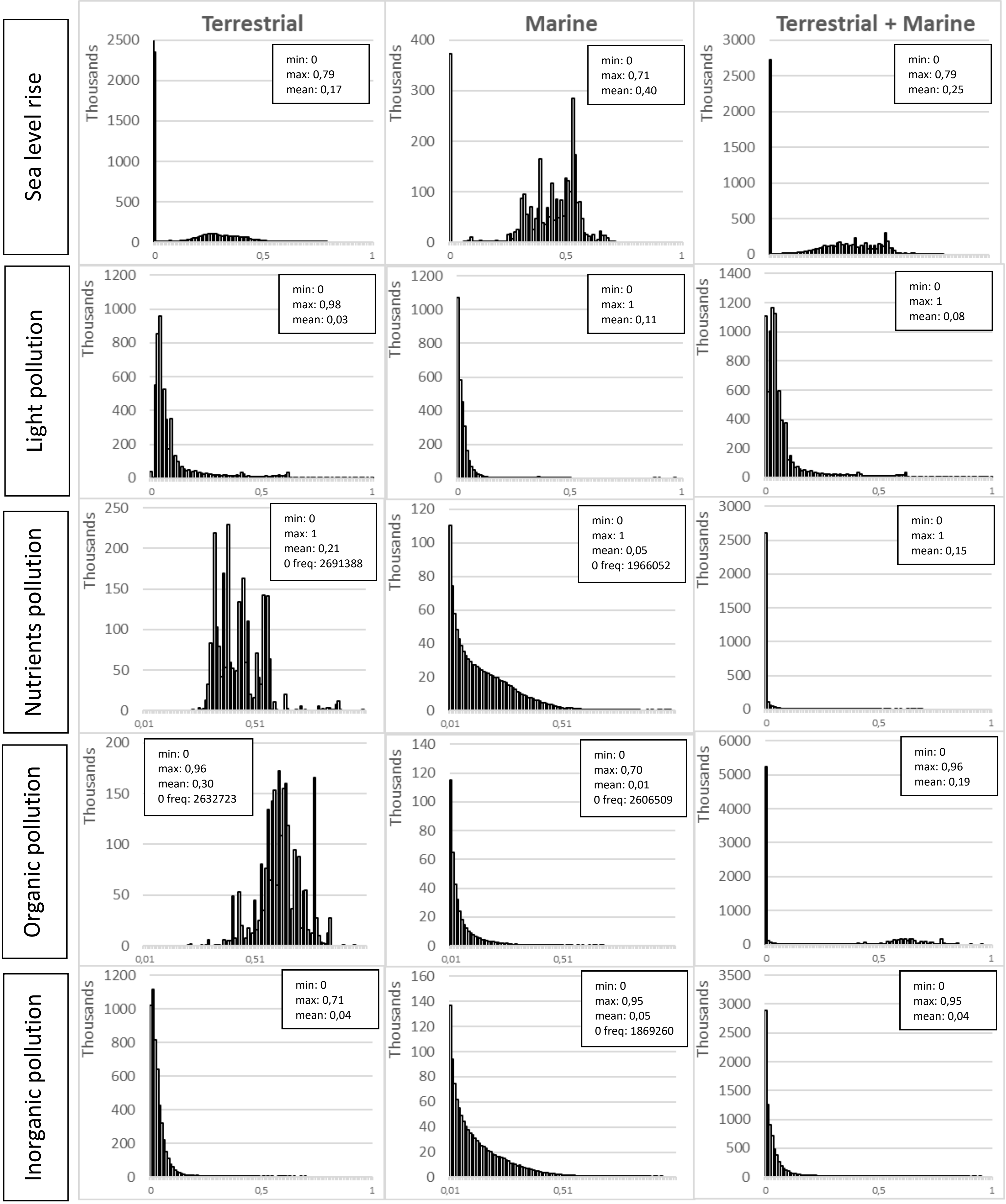


Figure 9.20: Impact scores per stressor in the Temperate Northern Atlantic Realm

Temperate Northern Pacific Realm

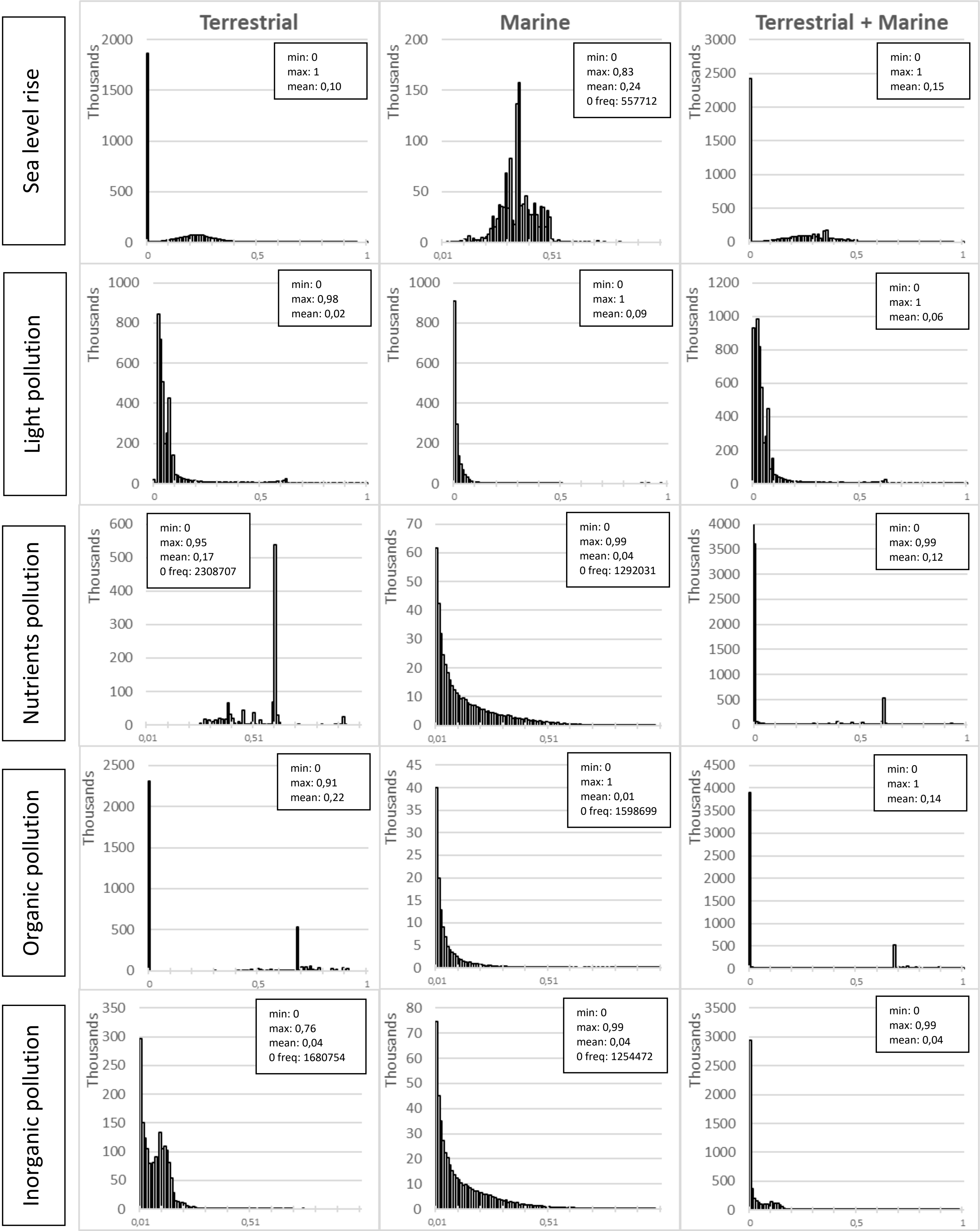


Figure 9.21: Impact scores per stressor in the Northern Pacific Realm

Temperate South America Realm

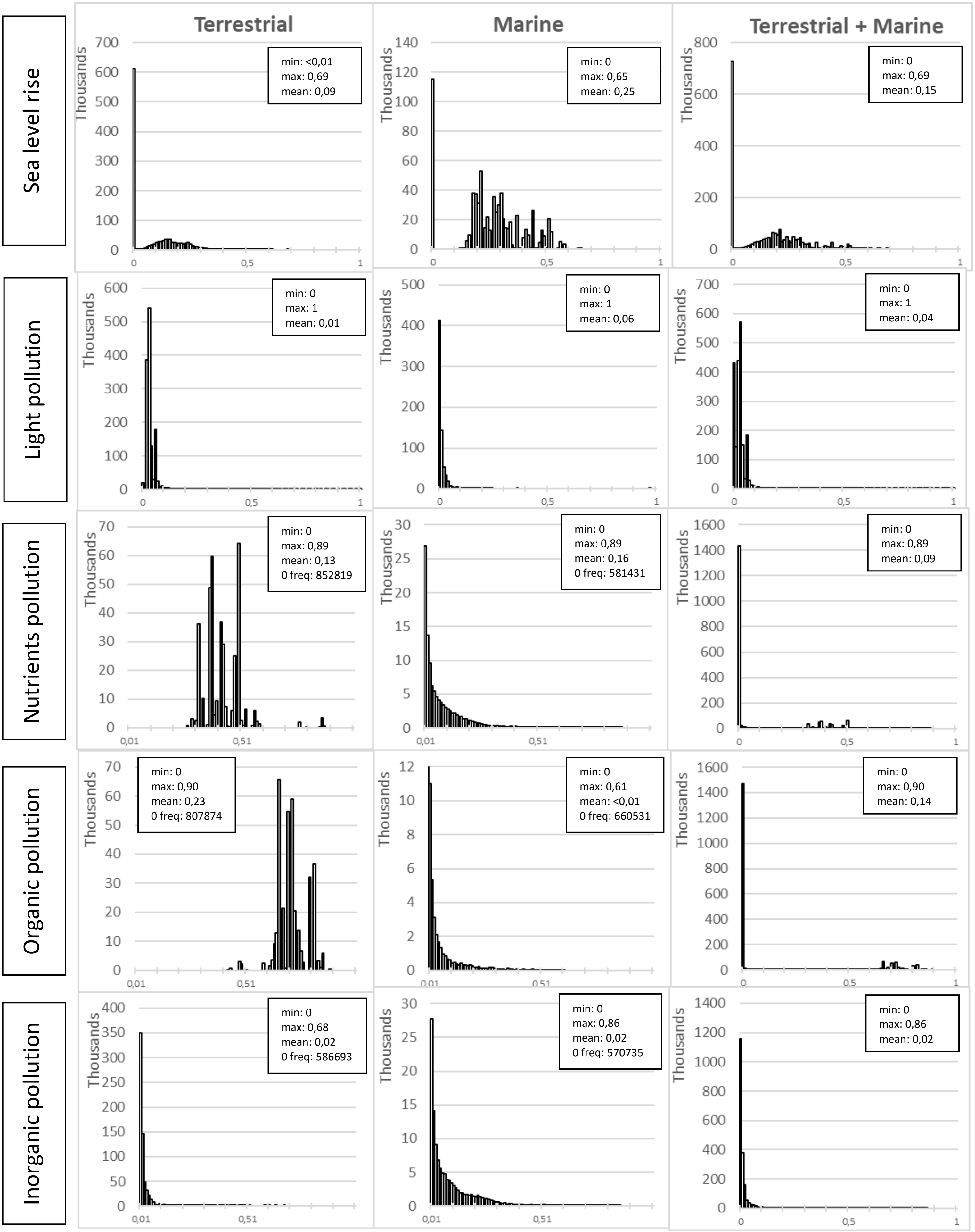


Figure 9.22: Impact scores per stressor in the Temperate South America Realm

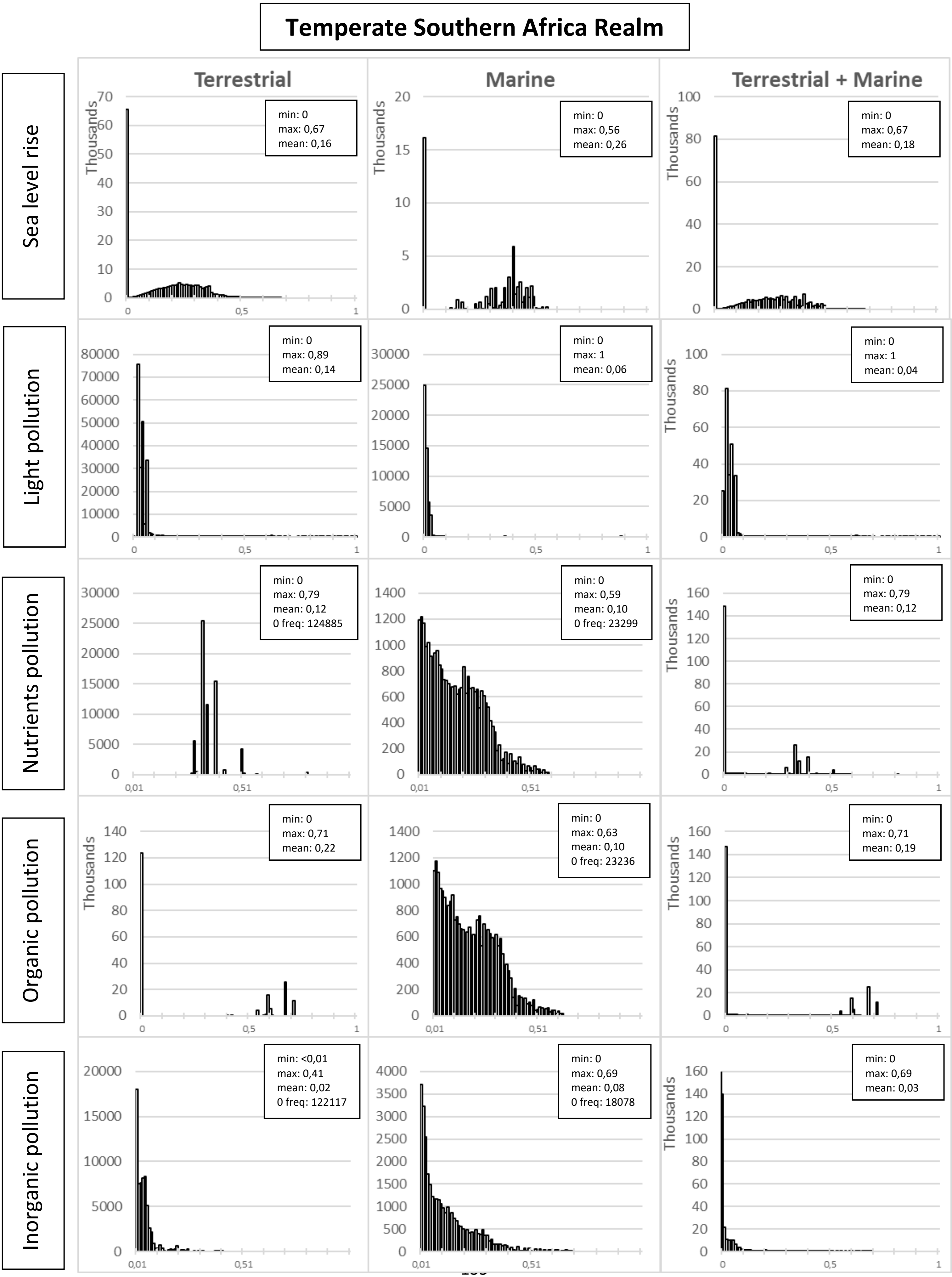


Figure 9.23: Impact scores per stressor in the Temperate Southern Africa Realm

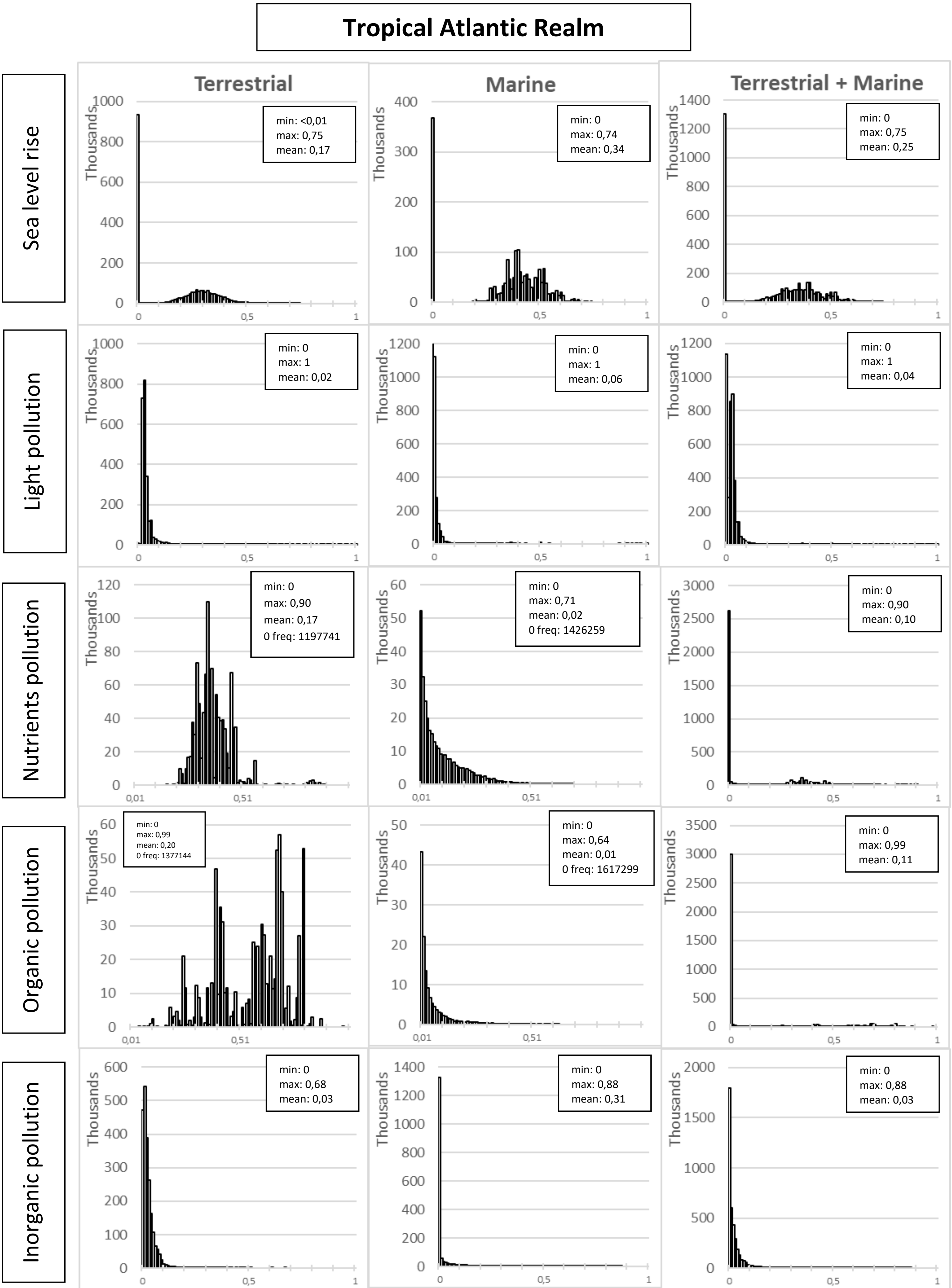


Figure 9.24: Impact scores per stressor in the Tropical Atlantic Realm

Tropical Eastern Pacific Realm

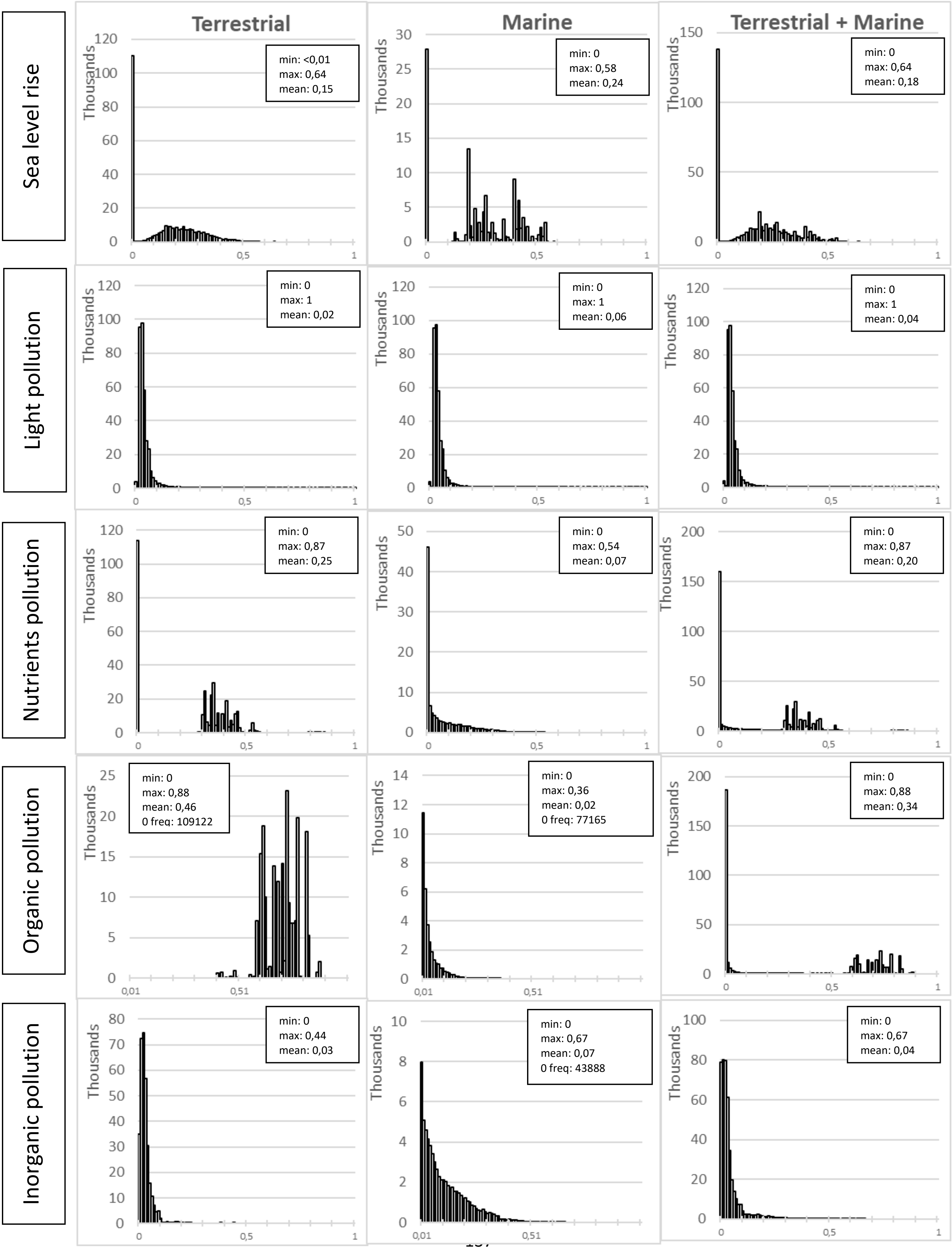


Figure 9.25: Impact scores per stressor in the Tropical Eastern Pacific Realm

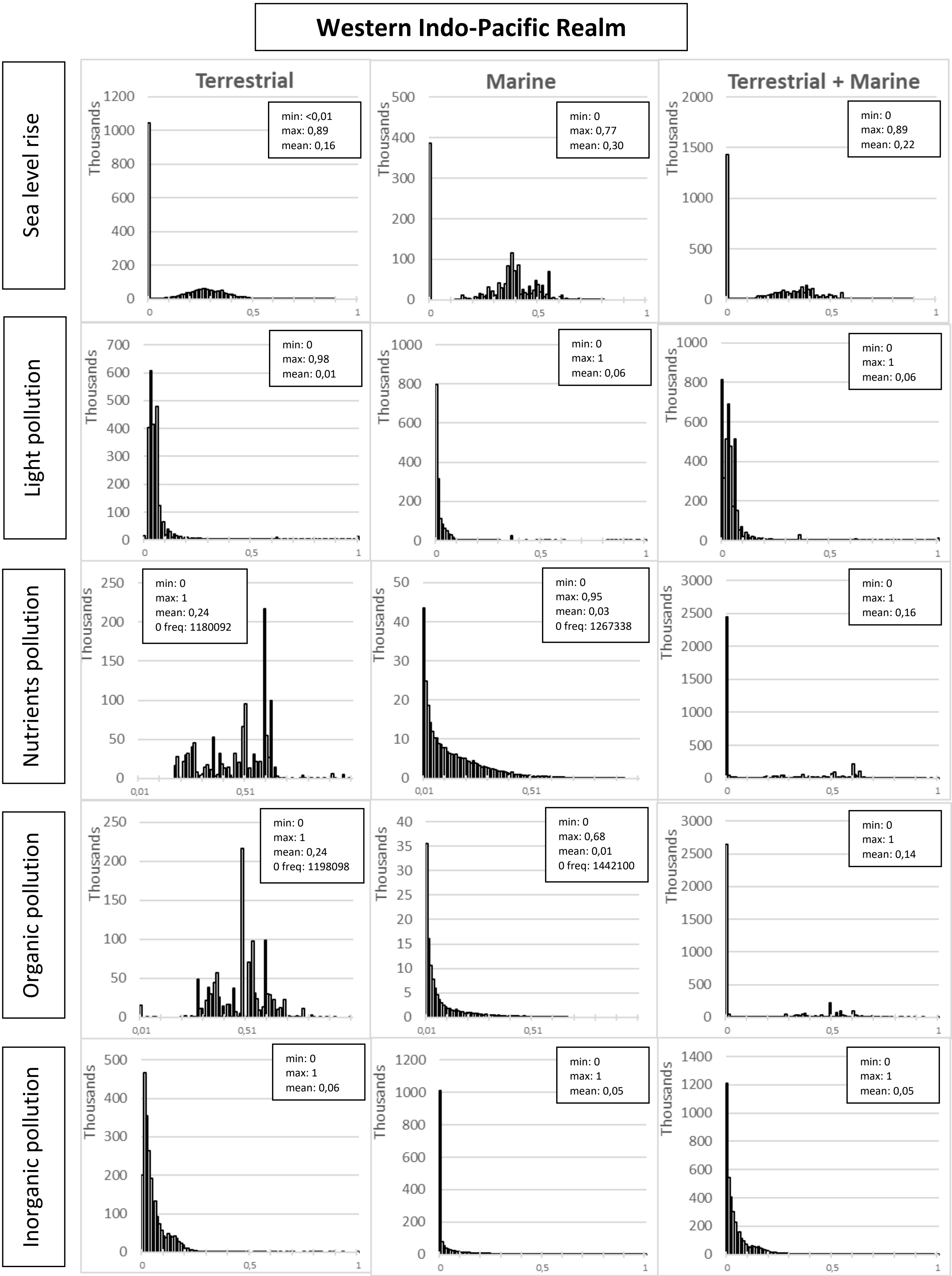


Figure 9.26: Impact scores per stressor in the Western Indo-Pacific Realm

9.11.2 Histograms of cumulative impacts per Realm

Here, for each Realm the impact score per stressor, terrestrial and marine, is visualised in a histogram. Each page shows the results per Realm for the terrestrial part, marine part, and the marine and terrestrial part combined for ‘sea level rise’, ‘light pollution’, ‘nutrients pollution’, ‘organic pollution’, and ‘inorganic pollution’. The first column of histograms are the terrestrial impact scores, the second column of histograms are the marine impacts scores, and the third column of histograms are the marine and terrestrial scores combined. The horizontal axis of the graph always has a maximum value of 3,9 because this is the highest cumulative impact score modelled. Each histogram has a box that informs about the minimum value-, the maximum value-, and the mean value of the stressor within the Realm.

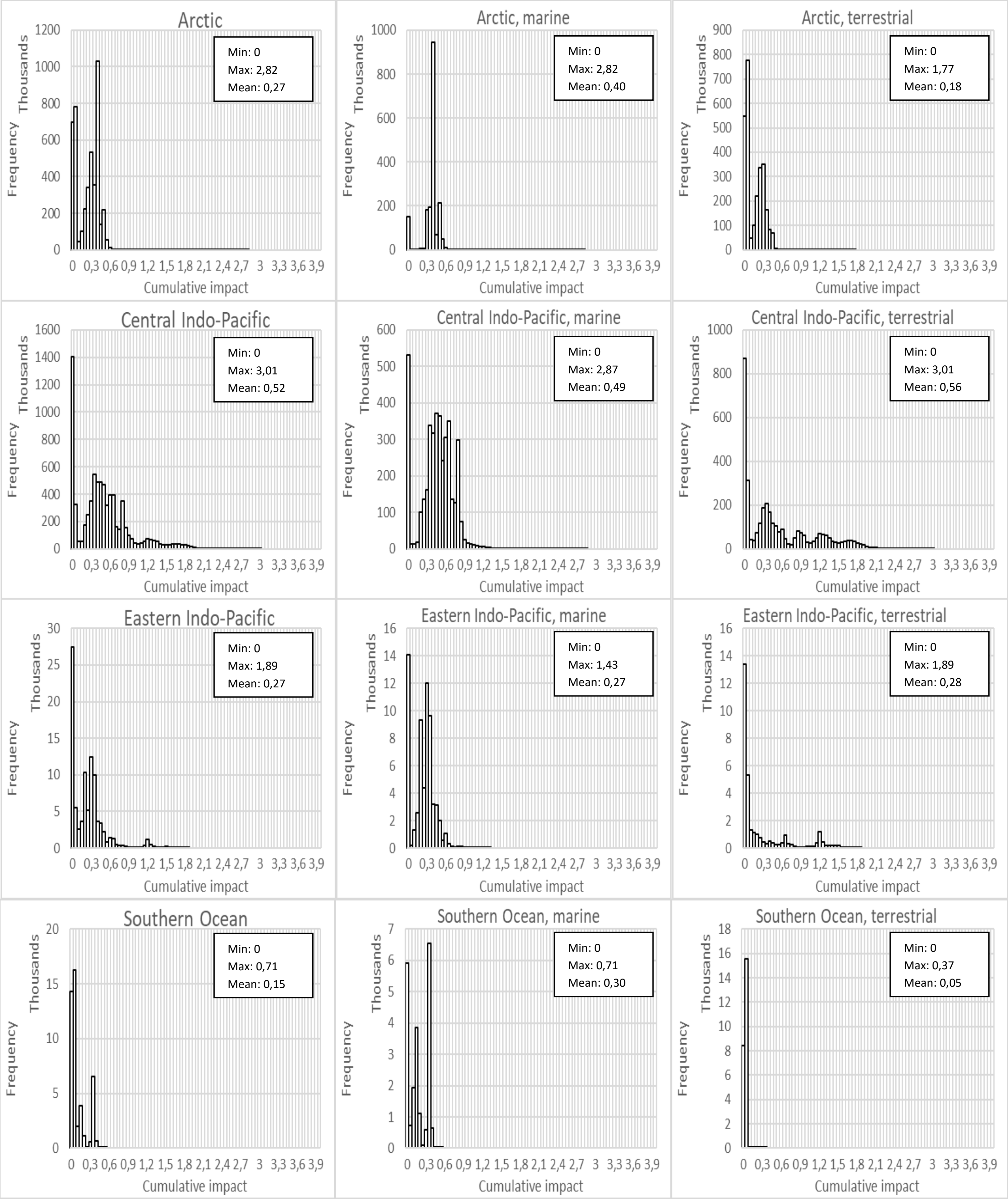
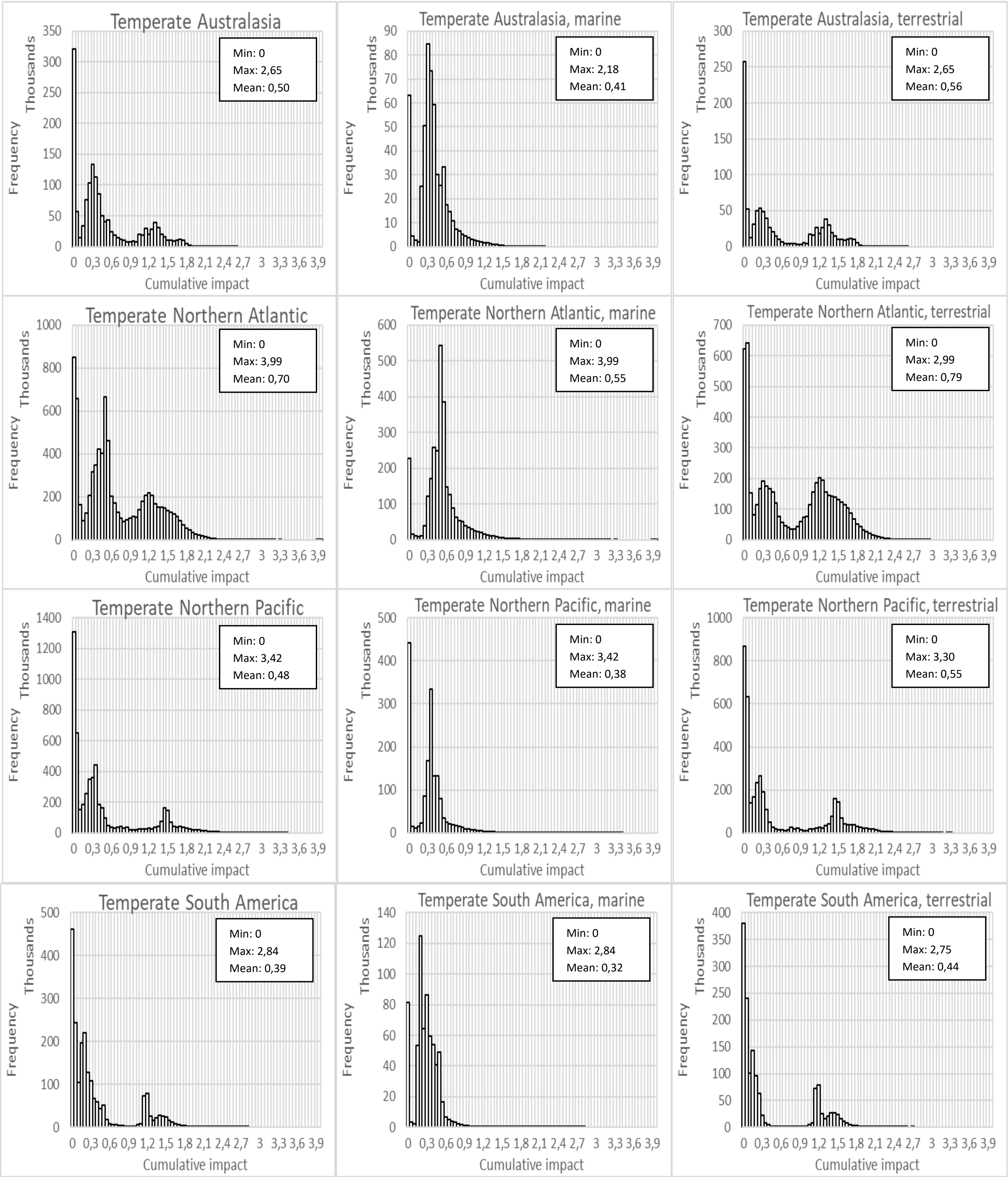


Figure 9.26: Cumulative, split by marine and terrestrial, human impacts per MEOW Realm. Visualised by means of histograms.



Temperate Australasia

Temperate Australasia, marine

Temperate Australasia, terrestrial

Temperate Northern Atlantic

Temperate Northern Atlantic, marine

Temperate Northern Atlantic, terrestrial

Temperate Northern Pacific

Temperate Northern Pacific, marine

Temperate Northern Pacific, terrestrial

Temperate South America

Temperate South America, marine

Temperate South America, terrestrial

Figure 9.27: Cumulative, split by marine and terrestrial, human impacts per MEOW Realm. Visualised by means of histograms.

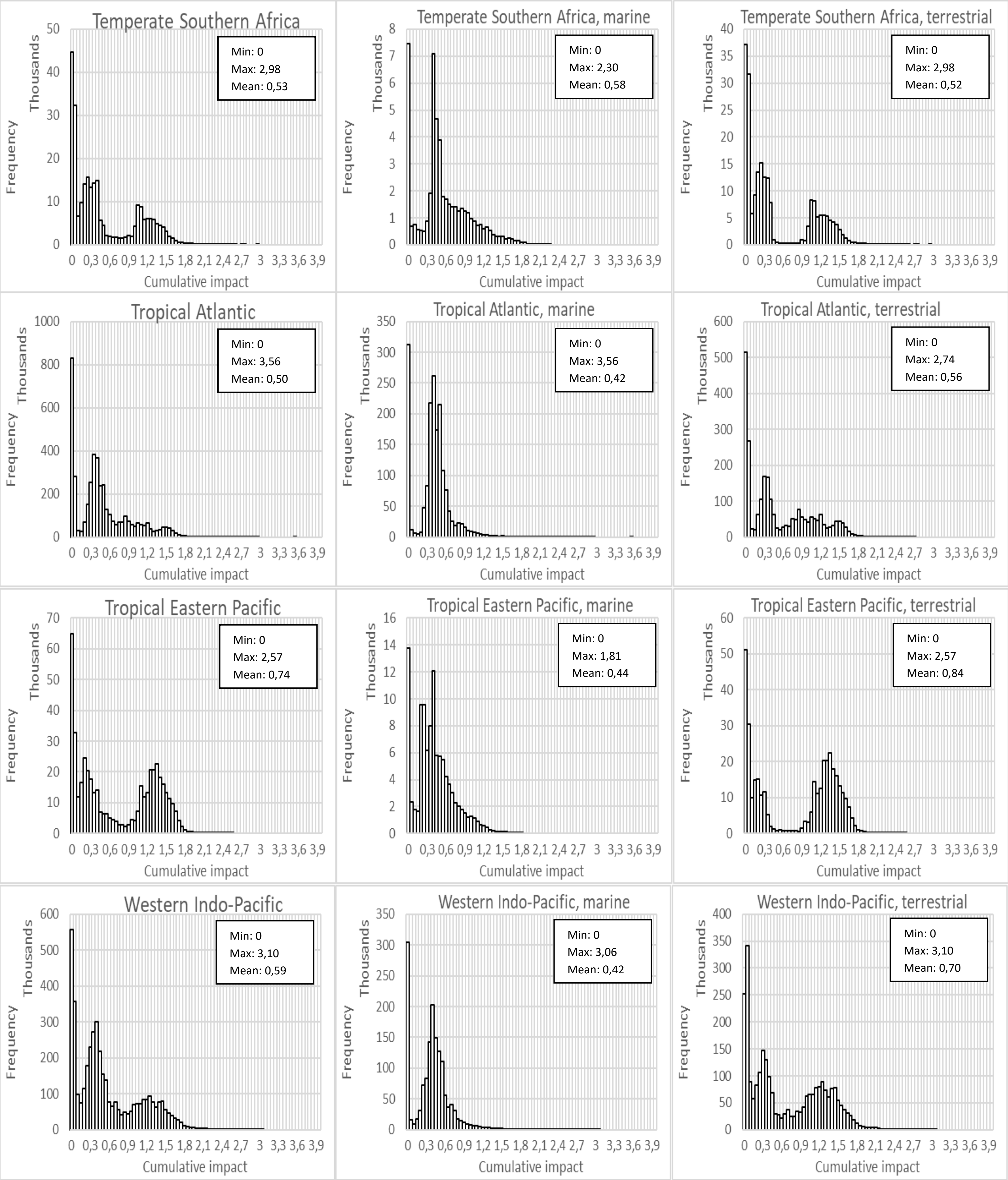


Figure 9.28: Cumulative, split by marine and terrestrial, human impacts per MEOW Realm. Visualised by means of histograms.

9.11.3 Cumulative impact score per Province

Table 9.29: Statistics per Province

VALUE	MIN	MAX	RANGE	MEAN	STD
Agulhas	0	2,98	2,98	0,77	0,56
Amsterdam-St Paul	0	0,54	0,54	0,14	0,20
Andaman	0	2,28	2,28	0,44	0,42
Arctic	0	2,82	2,82	0,27	0,18
Bay of Bengal	0	2,89	2,89	0,92	0,61
Benguela	0	2,63	2,63	0,32	0,38
Black Sea	0	2,67	2,67	0,78	0,54
Central Indian Ocean Islands	0	0,77	0,77	0,38	0,19
Central Polynesia	0	1,24	1,24	0,36	0,31
Cold Temperate Northeast Pacific	0	2,22	2,22	0,21	0,28
Cold Temperate Northwest Atlantic	0	2,47	2,47	0,49	0,40
Cold Temperate Northwest Pacific	0	3,30	3,30	0,53	0,61
East Central Australian Shelf	0	2,55	2,55	0,44	0,38
Easter Island	0	0,31	0,31	0,06	0,08
Eastern Coral Triangle	0	1,71	1,71	0,29	0,26
Galapagos	0	0,49	0,49	0,20	0,14
Gulf of Guinea	0	3,56	3,56	0,50	0,37
Hawaii	0	1,89	1,89	0,27	0,37
Java Transitional	0	2,17	2,17	0,69	0,48
Juan Fernandez and Desventuradas	0	0,35	0,35	0,06	0,12
Lord Howe and Norfolk Islands	0	0,69	0,69	0,27	0,22
Lusitanian	0	2,88	2,88	0,77	0,63
Magellanic	0	2,60	2,60	0,15	0,17
Marquesas	0	0,68	0,68	0,10	0,15
Marshall, Gilbert and Ellis Islands	0	0,68	0,68	0,25	0,18
Mediterranean Sea	0	2,96	2,96	0,81	0,64
North Brazil Shelf	0	2,50	2,50	0,33	0,34
Northeast Australian Shelf	0	2,35	2,35	0,39	0,23
Northern European Seas	0	3,15	3,15	0,70	0,54
Northern New Zealand	0	2,18	2,18	0,59	0,52
Northwest Australian Shelf	0	2,05	2,05	0,29	0,20
Red Sea and Gulf of Aden	0	3,08	3,08	0,46	0,47
Sahul Shelf	0	2,38	2,38	0,47	0,33
Scotia Sea	0	0,48	0,48	0,09	0,11
Somali/Arabian	0	3,10	3,10	0,45	0,41
South China Sea	0	3,01	3,01	0,75	0,71
South Kuroshio	0	2,40	2,40	0,58	0,58
Southeast Australian Shelf	0	2,26	2,26	0,52	0,49
Southeast Polynesia	0	1,43	1,43	0,23	0,15
Southern New Zealand	0	2,38	2,38	0,60	0,59
Southwest Australian Shelf	0	2,65	2,65	0,43	0,43
St. Helena and Ascension Islands	0	0,42	0,42	0,14	0,17
Subantarctic Islands	0	0,55	0,55	0,17	0,21
Subantarctic New Zealand	0	0,71	0,71	0,13	0,21
Sunda Shelf	0	2,99	2,99	0,63	0,46
Tristan Gough	0	0,55	0,55	0,17	0,22
Tropical East Pacific	0	2,57	2,57	0,75	0,60
Tropical Northwestern Atlantic	0	2,74	2,74	0,56	0,46
Tropical Northwestern Pacific	0	1,13	1,13	0,16	0,15
Tropical Southwestern Atlantic	0	2,72	2,72	0,68	0,57
Tropical Southwestern Pacific	0	1,88	1,88	0,34	0,32
Warm Temperate Northeast Pacific	0	2,40	2,40	0,44	0,46
Warm Temperate Northwest Atlantic	0	3,99	3,99	0,65	0,49

Warm Temperate Northwest Pacific	0	3,42	3,42	0,78	0,69
Warm Temperate Southeastern Pacific	0	2,57	2,57	0,36	0,48
Warm Temperate Southwestern Atlantic	0	2,84	2,84	0,64	0,55
West African Transition	0	2,31	2,31	0,47	0,42
West and South Indian Shelf	0	3,06	3,06	0,76	0,57
West Central Australian Shelf	0	2,45	2,45	0,41	0,36
Western Coral Triangle	0	2,33	2,33	0,42	0,37
Western Indian Ocean	0	2,57	2,57	0,49	0,40

9.11.4 Cumulative impact score per Ecoregion

Table 9.30: Statistics per Ecoregion

Rowid	VALUE	MIN	MAX	RANGE	MEAN	STD
1	Agulhas Bank	0	2,98	2,98	0,64	0,58
2	Aleutian Islands	0	1,05	1,05	0,17	0,18
3	Amazonia	0	2,43	2,43	0,35	0,35
4	Amsterdam-St Paul	0	0,54	0,54	0,14	0,20
5	Andaman and Nicobar Islands	0	1,95	1,95	0,35	0,37
6	Andaman Sea Coral Coast	0	2,28	2,28	0,47	0,43
7	Arabian (Persian) Gulf	0	3,01	3,01	0,56	0,44
8	Araucanian	0	2,50	2,50	0,53	0,54
9	Arnhem Coast to Gulf of Carpenteria	0	1,86	1,86	0,48	0,35
10	Arafura Sea	0	2,38	2,38	0,54	0,34
11	Auckland Island	0	0,59	0,59	0,13	0,21
12	Azores Canaries Madeira	0	2,81	2,81	0,57	0,63
13	Bahamian	0	1,49	1,49	0,31	0,24
14	Baltic Sea	0	2,82	2,82	0,64	0,51
15	Banda Sea	0	1,98	1,98	0,40	0,38
16	Bassian	0	2,26	2,26	0,50	0,48
17	Beaufort-Amundsen-Viscount Melville-Queen Maud	0	0,11	0,11	0,07	0,03
18	Bermuda	0	0,76	0,76	0,35	0,21
19	Bismarck Sea	0	1,71	1,71	0,22	0,23
20	Black Sea	0	2,67	2,67	0,78	0,54
21	Bonaparte Coast	0	2,16	2,16	0,37	0,23
22	Bounty and Antipodes Islands	0	0,71	0,71	0,15	0,28
23	Bouvet Island	0	0,50	0,50	0,08	0,14
24	Campbell Island	0	0,63	0,63	0,10	0,21
25	Cape Howe	0	2,24	2,24	0,44	0,40
26	Cape Verde	0	1,40	1,40	0,24	0,20
27	Cargados Carajos/Tromelin Island	0	0,80	0,80	0,22	0,28
28	Carolinian	0	2,61	2,61	0,63	0,44
29	Celtic Seas	0	2,50	2,50	0,75	0,54
30	Central Chile	0	2,57	2,57	0,30	0,45
31	Central Kuroshio Current	0	2,74	2,74	0,58	0,65
32	Central New Zealand	0	2,38	2,38	0,64	0,60
33	Central Peru	0	2,49	2,49	0,50	0,54
34	Central Somali Coast	0	0,79	0,79	0,19	0,16
35	Chagos	0	0,77	0,77	0,53	0,20
36	Channels and Fjords of Southern Chile	0	1,85	1,85	0,11	0,12
37	Chatham Island	0	0,91	0,91	0,35	0,35
38	Chiapas-Nicaragua	0	2,46	2,46	0,83	0,60
39	Chiloense	0	2,13	2,13	0,17	0,23
40	Chukchi Sea	0	0,11	0,11	0,04	0,01
41	Clipperton	0	0,38	0,38	0,19	0,19
42	Cocos-Keeling/Christmas Island	0	0,48	0,48	0,16	0,15
43	Cocos Islands	0	0,42	0,42	0,13	0,15

44	Coral Sea	0	0,57	0,57	0,21	0,22
45	Cortezian	0	2,07	2,07	0,49	0,50
46	Crozet Islands	0	0,44	0,44	0,17	0,13
47	Delagoa	0	2,34	2,34	0,61	0,45
48	East Caroline Islands	0	0,64	0,64	0,17	0,15
49	East China Sea	0	3,42	3,42	0,86	0,70
50	East Greenland Shelf	0	0,49	0,49	0,12	0,12
51	Easter Island	0	0,31	0,31	0,06	0,08
52	Eastern Bering Sea	0	1,82	1,82	0,31	0,17
53	Eastern Brazil	0	2,72	2,72	0,61	0,54
54	Eastern Caribbean	0	2,33	2,33	0,37	0,32
55	Eastern Galapagos Islands	0	0,49	0,49	0,21	0,14
56	Eastern India	0	2,85	2,85	1,15	0,61
57	Eastern Philippines	0	1,75	1,75	0,46	0,32
58	Exmouth to Broome	0	2,05	2,05	0,29	0,19
59	Faroe Plateau	0	0,82	0,82	0,31	0,23
60	Fernando de Naronha and Atoll das Rocas	0	0,41	0,41	0,17	0,19
61	Fiji Islands	0	1,88	1,88	0,50	0,42
62	Floridian	0	2,37	2,37	0,69	0,43
63	Gilbert/Ellis Islands	0	0,68	0,68	0,28	0,24
64	Great Australian Bight	0	1,67	1,67	0,30	0,22
65	Guayaquil	0	2,57	2,57	0,87	0,60
66	Guianan	0	2,50	2,50	0,30	0,30
67	Gulf of Aden	0	2,45	2,45	0,32	0,30
68	Gulf of Alaska	0	1,57	1,57	0,20	0,18
69	Gulf of Guinea Central	0	3,56	3,56	0,54	0,40
70	Gulf of Guinea Islands	0	0,82	0,82	0,28	0,23
71	Gulf of Guinea Upwelling	0	2,03	2,03	0,71	0,43
72	Gulf of Guinea West	0	1,45	1,45	0,46	0,31
73	Gulf of Maine/Bay of Fundy	0	2,26	2,26	0,40	0,26
74	Gulf of Oman	0	2,85	2,85	0,32	0,29
75	Gulf of Papua	0	1,25	1,25	0,36	0,23
76	Gulf of St. Lawrence - Eastern Scotian Shelf	0	2,24	2,24	0,41	0,37
77	Gulf of Thailand	0	2,90	2,90	0,75	0,53
78	Gulf of Tonkin	0	2,78	2,78	0,76	0,71
79	Halmahera	0	1,37	1,37	0,28	0,23
80	Hawaii	0	1,89	1,89	0,27	0,37
81	Heard and Macdonald Islands	0	0,52	0,52	0,10	0,15
82	Houtman	0	2,45	2,45	0,53	0,45
83	Hudson Complex	0	2,82	2,82	0,30	0,18
84	Humboldtian	0	2,47	2,47	0,18	0,30
85	Juan Fernandez and Desventuradas	0	0,35	0,35	0,06	0,12
86	Kamchatka Shelf and Coast	0	1,42	1,42	0,14	0,13
87	Kara Sea	0	1,07	1,07	0,08	0,10
88	Kerguelen Islands	0	0,55	0,55	0,18	0,22
89	Kermadec Island	0	0,60	0,60	0,15	0,24
90	Leeuwin	0	2,65	2,65	0,53	0,49
91	Lesser Sunda	0	2,01	2,01	0,54	0,45
92	Line Islands	0	0,60	0,60	0,21	0,23
93	Lord Howe and Norfolk Islands	0	0,69	0,69	0,27	0,22
94	Macquarie Island	0	0,49	0,49	0,08	0,16
95	Magdalena Transition	0	1,91	1,91	0,27	0,20
96	Malacca Strait	0	2,48	2,48	0,75	0,53
97	Maldives	0	0,51	0,51	0,29	0,12
98	Malvinas/Falklands	0	0,34	0,34	0,20	0,09
99	Manning-Hawkesbury	0	2,55	2,55	0,62	0,48
100	Mariana Islands	0	1,13	1,13	0,20	0,21
101	Tuamotus	0	1,43	1,43	0,25	0,14

102	Marshall Islands	0	0,57	0,57	0,23	0,14
103	Mascarene Islands	0	2,24	2,24	0,40	0,41
104	Mexican Tropical Pacific	0	2,50	2,50	0,92	0,54
105	Namaqua	0	2,63	2,63	0,42	0,49
106	Namib	0	1,50	1,50	0,23	0,18
107	Natal	0	2,64	2,64	0,91	0,51
108	New Caledonia	0	1,49	1,49	0,27	0,21
109	Nicoya	0	2,20	2,20	0,68	0,62
110	Ningaloo	0	1,70	1,70	0,31	0,26
111	North American Pacific Fijordland	0	1,43	1,43	0,11	0,10
112	North Patagonian Gulfs	0	2,60	2,60	0,18	0,24
113	Northeast Sulawesi	0	1,92	1,92	0,34	0,39
114	Northeastern Brazil	0	2,59	2,59	0,75	0,59
115	Northeastern Honshu	0	3,16	3,16	0,69	0,70
116	Northeastern New Zealand	0	2,18	2,18	0,60	0,52
117	Northern and Central Red Sea	0	3,08	3,08	0,46	0,55
118	Northern Bay of Bengal	0	2,89	2,89	0,87	0,60
119	Northern California	0	2,22	2,22	0,69	0,54
120	Northern Galapagos Islands	0	0,39	0,39	0,03	0,10
121	Northern Grand Banks - Southern Labrador	0	1,48	1,48	0,24	0,16
122	Northern Gulf of Mexico	0	3,99	3,99	0,66	0,51
123	Northern Labrador	0	1,22	1,22	0,16	0,12
124	Ogasawara Islands	0	0,64	0,64	0,17	0,20
125	Oregon, Washington, Vancouver Coast and Shelf	0	2,20	2,20	0,20	0,27
126	Oyashio Current	0	2,68	2,68	0,31	0,43
127	Palawan/North Borneo	0	2,33	2,33	0,43	0,43
128	Panama Bight	0	2,27	2,27	0,55	0,55
129	Papua	0	1,58	1,58	0,27	0,22
130	Patagonian Shelf	0	2,50	2,50	0,17	0,14
131	Phoenix/Tokelau/Northern Cook Islands	0	0,57	0,57	0,33	0,21
132	Prince Edward Islands	0	0,41	0,41	0,05	0,08
133	Puget Trough/Georgia Basin	0	2,18	2,18	0,28	0,36
134	Rapa-Pitcairn	0	0,47	0,47	0,16	0,20
135	Revillagigedos	0	0,37	0,37	0,08	0,12
136	Rio de la Plata	0	2,84	2,84	0,78	0,59
137	Rio Grande	0	2,54	2,54	0,67	0,59
138	Saharan Upwelling	0	2,83	2,83	0,57	0,55
139	Samoa Islands	0	1,24	1,24	0,40	0,33
140	Scotian Shelf	0	1,15	1,15	0,37	0,17
141	Sea of Japan/East Sea	0	3,11	3,11	0,43	0,52
142	Sea of Okhotsk	0	2,23	2,23	0,17	0,18
143	Seychelles	0	0,61	0,61	0,26	0,24
144	Shark Bay	0	2,22	2,22	0,30	0,20
145	Snares Island	0	0,58	0,58	0,37	0,23
146	Society Islands	0	0,60	0,60	0,15	0,14
147	Solomon Archipelago	0	1,19	1,19	0,39	0,31
148	Solomon Sea	0	1,16	1,16	0,30	0,23
149	South Australian Gulfs	0	2,12	2,12	0,47	0,49
150	South China Sea Oceanic Islands	0	0,57	0,57	0,17	0,17
151	South European Atlantic Shelf	0	2,88	2,88	0,93	0,64
152	South Georgia	0	0,35	0,35	0,09	0,10
153	South India and Sri Lanka	0	2,50	2,50	0,89	0,59
154	South Kuroshio	0	2,40	2,40	0,58	0,58
155	South Sandwich Islands	0	0,48	0,48	0,07	0,13
156	Southeast Madagascar	0	1,59	1,59	0,78	0,46
157	Southeast Papua New Guinea	0	1,14	1,14	0,28	0,22
158	Southeastern Brazil	0	2,75	2,75	0,58	0,55
159	Southern California Bight	0	2,40	2,40	0,37	0,39

160	Southern Caribbean	0	2,74	2,74	0,45	0,49
161	Southern China	0	3,01	3,01	0,78	0,71
162	Southern Grand Banks - South Newfoundland	0	1,19	1,19	0,31	0,21
163	Southern Gulf of Mexico	0	2,43	2,43	0,69	0,48
164	South New Zealand	0	2,24	2,24	0,53	0,58
165	Southern Red Sea	0	2,92	2,92	0,53	0,43
166	Southern Vietnam	0	2,99	2,99	0,92	0,59
167	Southwestern Caribbean	0	2,49	2,49	0,48	0,46
168	St. Helena and Ascension Islands	0	0,42	0,42	0,14	0,17
169	Sulawesi Sea/Makassar Strait	0	2,31	2,31	0,45	0,37
170	East African Coral Coast	0	2,22	2,22	0,59	0,41
171	Northern Monsoon Current Coast	0	2,03	2,03	0,29	0,30
172	Bight of Sofala/Swamp Coast	0	2,57	2,57	0,53	0,39
173	Three Kings-North Cape	0	0,67	0,67	0,43	0,21
174	Tonga Islands	0	0,73	0,73	0,29	0,22
175	Trindade and Martin Vaz Islands	0	0,50	0,50	0,21	0,23
176	Tristan Gough	0	0,55	0,55	0,17	0,22
177	Marquesas	0	0,68	0,68	0,10	0,15
178	Tweed-Moreton	0	1,97	1,97	0,35	0,29
179	Uruguay-Buenos Aires Shelf	0	2,59	2,59	0,52	0,46
180	Vanuatu	0	1,55	1,55	0,27	0,26
181	Virginian	0	2,47	2,47	0,73	0,46
182	West Caroline Islands	0	0,52	0,52	0,10	0,10
183	West Greenland Shelf	0	0,89	0,89	0,14	0,12
184	Western and Northern Madagascar	0	1,71	1,71	0,45	0,36
185	Western Arabian Sea	0	3,10	3,10	0,27	0,27
186	Western Bassian	0	2,18	2,18	0,60	0,55
187	Western Caribbean	0	2,24	2,24	0,40	0,40
188	Western Galapagos Islands	0	0,41	0,41	0,19	0,13
189	Western India	0	3,06	3,06	0,73	0,56
190	Yellow Sea	0	3,30	3,30	1,03	0,66
191	Southern Java	0	2,17	2,17	0,69	0,48
192	Western Sumatra	0	2,00	2,00	0,43	0,42
193	Torres Strait Northern Great Barrier Reef	0	1,92	1,92	0,50	0,23
194	Central and Southern Great Barrier Reef	0	2,35	2,35	0,32	0,20
195	Sunda Shelf/Java Sea	0	2,45	2,45	0,53	0,36
196	North and East Iceland	0	1,73	1,73	0,17	0,21
197	South and West Iceland	0	2,15	2,15	0,23	0,20
198	North Sea	0	3,15	3,15	0,88	0,54
199	Southern Norway	0	2,65	2,65	0,26	0,33
200	North and East Barents Sea	0	0,71	0,71	0,05	0,05
201	White Sea	0	1,75	1,75	0,30	0,25
202	Greater Antilles	0	2,43	2,43	0,71	0,42
203	Southern Cook/Austral Islands	0	0,55	0,55	0,22	0,21
204	Gulf of Guinea South	0	2,43	2,43	0,39	0,35
205	Angolan	0	2,01	2,01	0,39	0,31
206	Sahelian Upwelling	0	2,31	2,31	0,47	0,42
207	Adriatic Sea	0	2,84	2,84	0,99	0,64
208	Levantine Sea	0	2,95	2,95	0,74	0,68
209	Tunisian Plateau/Gulf of Sidra	0	2,72	2,72	0,44	0,53
210	Ionian Sea	0	2,78	2,78	0,93	0,59
211	Aegean Sea	0	2,81	2,81	0,88	0,57
212	Alboran Sea	0	2,90	2,90	1,10	0,52
213	Western Mediterranean	0	2,96	2,96	0,91	0,64

9.11.5 Difference from trendline per Ecoregion

Table 9.31: Cumulative mean terrestrial and marine impact score per ecoregion and the variation from the trendline, ordered by the fourth column

Ecoregion	Terrestrial mean impact score	Marine mean impact score	Deviation from trendline, absolute values
Manning-Hawkesbury	0,60	0,79	0,35
Arafura Sea	0,27	0,70	0,34
Namaqua	0,37	0,71	0,33
Kara Sea	0,08	0,00	0,31
Beaufort-Amundsen-Viscount Melville-Queen Maud	0,07	0,00	0,30
North and East Barents Sea	0,05	0,00	0,30
Chukchi Sea	0,04	0,00	0,30
Natal	0,94	0,82	0,29
Arnhem Coast to Gulf of Carpenteria	0,25	0,62	0,27
Gulf of Tonkin	1,22	0,34	0,26
Northeastern Honshu	0,69	0,72	0,26
Carolinian	0,59	0,69	0,25
Northern Monsoon Current Coast	0,28	0,61	0,25
Northern Bay of Bengal	1,11	0,33	0,25
Chagos	0,01	0,54	0,25
Torres Strait Northern Great Barrier Reef	0,27	0,60	0,24
Western Bassian	0,76	0,26	0,22
Southern China	1,31	0,41	0,22
Chatham Island	0,02	0,51	0,22
Central New Zealand	0,64	0,66	0,21
Southern Norway	0,24	0,56	0,21
Andaman and Nicobar Islands	0,64	0,25	0,21
Northeastern New Zealand	0,59	0,64	0,20
Gulf of Papua	0,27	0,55	0,20
Western Sumatra	0,55	0,24	0,19
East African Coral Coast	0,58	0,62	0,19
Yellow Sea	1,43	0,47	0,19
White Sea	0,22	0,53	0,19
Kamchatka Shelf and Coast	0,15	0,14	0,19
Floridian	0,74	0,66	0,19
Solomon Archipelago	0,31	0,55	0,18
Sea of Okhotsk	0,18	0,15	0,18
West Caroline Islands	0,04	0,12	0,18
Juan Fernandez and Desventuradas	0,02	0,11	0,18
Prince Edward Islands	0,04	0,12	0,18
Western Mediterranean	0,95	0,71	0,17
Amsterdam-St Paul	0,03	0,47	0,17
North Patagonian Gulfs	0,19	0,16	0,17
Samoa Islands	0,53	0,26	0,17
Southeastern Brazil	0,84	0,34	0,16
Mariana Islands	0,23	0,18	0,16
Levantine Sea	0,77	0,65	0,16
Panama Bight	0,64	0,29	0,16
South New Zealand	0,53	0,58	0,16
Bounty and Antipodes Islands	0,02	0,45	0,16
South Shetland Islands	0,00	0,13	0,16
Angolan	0,35	0,53	0,16
Patagonian Shelf	0,17	0,18	0,15
Gulf of Guinea Central	0,53	0,58	0,15
Faroe Plateau	0,22	0,50	0,15
Eastern Brazil	0,95	0,38	0,15
Bismarck Sea	0,18	0,48	0,15
East China Sea	1,20	0,45	0,15
Rio Grande	0,94	0,38	0,15
Saharan Upwelling	0,72	0,33	0,14
Houtman	0,77	0,34	0,14
Agulhas Bank	0,66	0,60	0,14
South European Atlantic Shelf	1,02	0,69	0,14
Bonaparte Coast	0,26	0,49	0,13
Baltic Sea	0,68	0,60	0,13
Oyashio Current	0,38	0,25	0,13
Hawaii	0,30	0,24	0,12

Virginian	0,84	0,63	0,12
Northern and Central Red Sea	0,46	0,52	0,12
Line Islands	0,03	0,41	0,12
Fernando de Naronha and Atoll das Rocas	0,07	0,18	0,12
Southeast Papua New Guinea	0,23	0,46	0,12
Azores Canaries Madeira	0,67	0,34	0,12
Southern Java	0,84	0,39	0,12
East Caroline Islands	0,05	0,18	0,11
Heard and Macdonald Islands	0,07	0,19	0,11
Bassian	0,60	0,33	0,11
Cocos Islands	0,03	0,18	0,11
Mexican Tropical Pacific	0,96	0,64	0,11
Sahelian Upwelling	0,50	0,31	0,11
Channels and Fjords of Southern Chile	0,10	0,20	0,11
South China Sea Oceanic Islands	0,00	0,18	0,11
Palawan/North Borneo	0,55	0,32	0,11
Banda Sea	0,37	0,49	0,11
Snares Island	0,00	0,39	0,10
Western and Northern Madagascar	0,54	0,32	0,10
Three Kings-North Cape	0,35	0,48	0,10
Eastern Caribbean	0,53	0,32	0,10
Halmahera	0,23	0,45	0,10
Eastern India	1,32	0,73	0,10
Phoenix/Tokelau/Northern Cook Islands	0,00	0,39	0,10
Guayaquil	1,00	0,45	0,10
Northern California	0,71	0,57	0,10
Gulf of Guinea West	0,59	0,34	0,10
Mascarene Islands	0,37	0,48	0,10
Puget Trough/Georgia Basin	0,27	0,45	0,10
Uruguay-Buenos Aires Shelf	0,74	0,38	0,10
East Greenland Shelf	0,10	0,41	0,09
Northeastern Brazil	1,02	0,45	0,09
Northern Galapagos Islands	0,01	0,19	0,09
Eastern Philippines	0,51	0,32	0,09
St. Helena and Ascension Islands	0,04	0,20	0,09
Andaman Sea Coral Coast	0,64	0,36	0,09
Solomon Sea	0,20	0,43	0,09
Southern Vietnam	1,18	0,68	0,09
Gulf of Aden	0,29	0,45	0,09
Central Somali Coast	0,18	0,25	0,09
Western India	0,90	0,43	0,08
South Australian Gulfs	0,54	0,34	0,08
Central Peru	0,56	0,35	0,08
North American Pacific Fijordland	0,10	0,23	0,08
Crozet Islands	0,03	0,21	0,08
Vanuatu	0,25	0,43	0,08
Gulf of St. Lawrence - Eastern Scotian Shelf	0,39	0,47	0,08
Malvinas/Falklands	0,16	0,25	0,08
Celtic Seas	0,94	0,45	0,08
Southern Caribbean	0,50	0,34	0,08
Cocos-Keeling/Christmas Island	0,05	0,22	0,08
Black Sea	0,92	0,45	0,08
Easter Island	0,04	0,22	0,08
Hudson Complex	0,24	0,42	0,08
Revillagigedos	0,02	0,21	0,08
Gulf of Maine/Bay of Fundy	0,38	0,46	0,08
Kerguelen Islands	0,05	0,37	0,07
Oregon, Washington, Vancouver Coast and Shelf	0,16	0,40	0,07
Marquesas	0,03	0,22	0,07
Ningaloo	0,29	0,43	0,07
Shark Bay	0,23	0,41	0,07
Kermadec Island	0,02	0,22	0,07
Auckland Island	0,03	0,23	0,07
Tristan Gough	0,03	0,23	0,07
Adriatic Sea	1,15	0,65	0,06
Northern Gulf of Mexico	0,74	0,54	0,06
South Georgia	0,06	0,24	0,06

Coral Sea	0,00	0,22	0,06
Cargados Carajos/Tromelin Island	0,02	0,23	0,06
Delagoa	0,63	0,51	0,06
Leeuwin	0,62	0,38	0,06
New Caledonia	0,26	0,29	0,06
Northeast Sulawesi	0,33	0,43	0,06
Eastern Bering Sea	0,18	0,39	0,06
Central Chile	0,30	0,42	0,06
Southern Red Sea	0,58	0,49	0,06
Western Caribbean	0,39	0,44	0,06
Rapa-Pitcairn	0,03	0,24	0,06
Nicoya	0,77	0,43	0,06
Gulf of Thailand	0,94	0,58	0,05
Papua	0,23	0,40	0,05
Southwestern Caribbean	0,56	0,38	0,05
Southern California Bight	0,36	0,43	0,05
Malacca Strait	0,95	0,48	0,05
Rio de la Plata	0,82	0,54	0,05
Gilbert/Ellis Islands	0,01	0,34	0,05
Gulf of Guinea South	0,37	0,43	0,05
Cape Verde	0,23	0,30	0,04
Marshall Islands	0,00	0,24	0,04
Great Australian Bight	0,28	0,32	0,04
South Orkney Islands	0,00	0,24	0,04
Bahamian	0,28	0,32	0,04
Western Arabian Sea	0,26	0,31	0,04
Clipperton	0,00	0,33	0,04
Chiloense	0,15	0,29	0,04
Southern Gulf of Mexico	0,83	0,54	0,04
Alboran Sea	1,15	0,62	0,04
Tunisian Plateau/Gulf of Sidra	0,47	0,37	0,04
Seychelles	0,06	0,27	0,04
Lesser Sunda	0,57	0,47	0,03
Bight of Sofala/Swamp Coast	0,62	0,41	0,03
Arabian (Persian) Gulf	0,63	0,48	0,03
Exmouth to Broome	0,25	0,32	0,03
Gulf of Guinea Upwelling	0,80	0,52	0,03
Trindade and Martin Vaz Islands	0,02	0,32	0,03
North Sea	1,16	0,61	0,03
Cortezian	0,51	0,45	0,03
Southern Cook/Austral Islands	0,04	0,32	0,03
Bouvet Island	0,03	0,27	0,03
Ogasawara Islands	0,02	0,32	0,03
Aegean Sea	0,96	0,56	0,02
Eastern Galapagos Islands	0,18	0,31	0,02
Greater Antilles	0,80	0,52	0,02
Macquarie Island	0,03	0,27	0,02
Northern Labrador	0,14	0,30	0,02
Scotian Shelf	0,36	0,40	0,02
Namib	0,21	0,32	0,02
Araucanian	0,55	0,45	0,02
South and West Iceland	0,20	0,36	0,02
Fiji Islands	0,58	0,46	0,02
South Sandwich Islands	0,03	0,31	0,02
Sulawesi Sea/Makassar Strait	0,48	0,43	0,02
Magdalena Transition	0,25	0,33	0,02
Bermuda	0,25	0,37	0,02
Amazonia	0,33	0,39	0,02
Campbell Island	0,03	0,28	0,02
North and East Iceland	0,16	0,31	0,02
Gulf of Guinea Islands	0,23	0,36	0,02
Maldives	0,00	0,30	0,01
Tonga Islands	0,15	0,34	0,01
Lord Howe and Norfolk Islands	0,05	0,29	0,01
Southeast Madagascar	0,85	0,52	0,01
West Greenland Shelf	0,11	0,30	0,01
Sunda Shelf/Java Sea	0,71	0,46	0,01

Western Galapagos Islands	0,18	0,34	0,01
Society Islands	0,07	0,31	0,01
Northern Grand Banks - Southern Labrador	0,23	0,34	0,01
Ionian Sea	1,01	0,55	0,01
Central and Southern Great Barrier Reef	0,26	0,36	0,01
South India and Sri Lanka	1,15	0,58	0,01
Tuamotus	0,00	0,28	0,01
Southern Grand Banks - South Newfoundland	0,27	0,35	0,01
Sea of Japan/East Sea	0,44	0,40	0,00
Aleutian Islands	0,11	0,31	0,00
Humboldtian	0,17	0,33	0,00
Cape Howe	0,48	0,41	0,00
Central Kuroshio Current	0,64	0,45	0,00
South Kuroshio	0,71	0,47	0,00
Gulf of Alaska	0,16	0,33	0,00
Gulf of Oman	0,31	0,37	0,00
Guianan	0,25	0,35	0,00
Tweed-Moreton	0,34	0,37	0,00
Chiapas-Nicaragua	0,97	0,54	0,00