Development of Regional Joint Master Program in Maritime Environmental Protection and Management
- MEP&M -

Coastal risks and vulnerability: Basics and strategies for protection and monitoring

WP3. Capacity Building through staff training and equipment purchase .
DEV 3.4.4 KNOW-HOW TRANSFER TO TEACHING STAFF RELATED TO THE MEP&M

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July 11th 2022

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1. Coastal Risks

- 1.1. Definitions
- 1.2. Risk study methods
- 1.3. Erosion and flooding
- 1.4. Problems and processes associated to climatic change

2. Vulnerability

- 2.1. Coastal Vulnerability Index
- 2.2. Mitigation strategies against coastal erosion

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1. Coastal risks

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1.1. Definitions

HAZARD: any natural process that can become a risk insofar as it can interfere with human activity

RISK: capacity for personal and material damage of a phenomenon with respect to time

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1.1. Definitions

VULNERABILITY: possibility that an area, a human activity, etc., suffers certain losses due to the action of a natural phenomenon.

DISASTER: effect of a risk on society, usually in the form of an event that occurs in a limited period of time and in a specific geographical area.
Deals considerable damage.

CATASTROPHE: Massive disaster that requires considerable expenditure of time and money for recovery.

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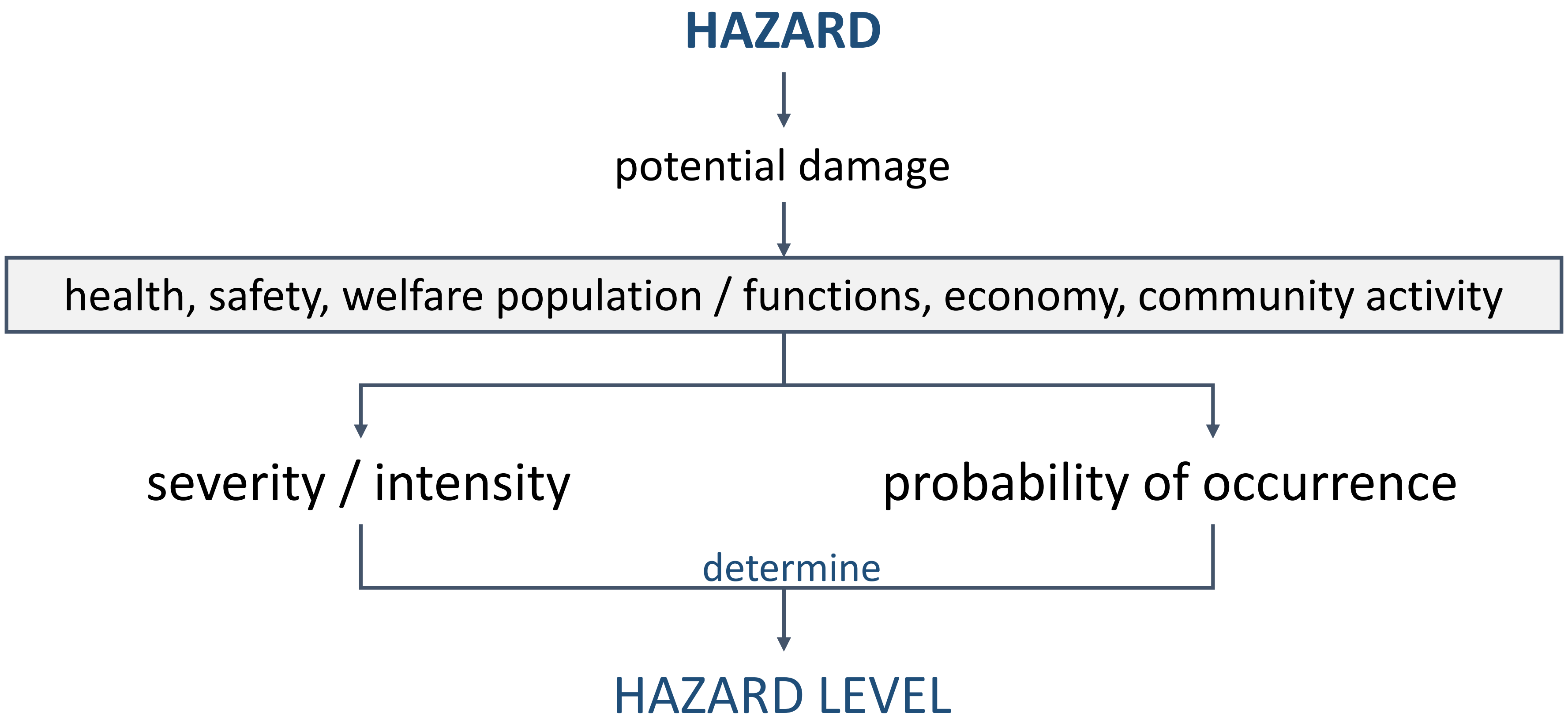
1.1. Definitions



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1.1. Definitions

RISK = HAZARD LEVEL x IMPACT

EXPOSURE

set of assets/elements to be preserved from a HAZARD

VULNERABILITY

susceptibility of an asset to damage from a hazard

RISK = HAZARD LEVEL x EXPOSURE x VULNERABILITY

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1.1. Definitions

Population in risk ⟶ **RESPONSE**

Prevention
Mitigation

better the response, lower the risk

RISK = (HAZARD LEVEL x IMPACT) – RESPONSE

↓

capacity of resistance/response of the system to environmental conditions

RESILIENCE

Resilience ≠ Vulnerability

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1.2. Risk study methods

there are different strategies depending on the circumstances

PREDICTION: definition in space (location) and in time (moment) of the development and intensity of a risk

PREVENTION: set of structural and non-structural measures based on prediction that seek to minimize the economic and social damage that a risk can cause

MITIGATION: measures to reduce the severity of economic and social damage that a risk has already caused

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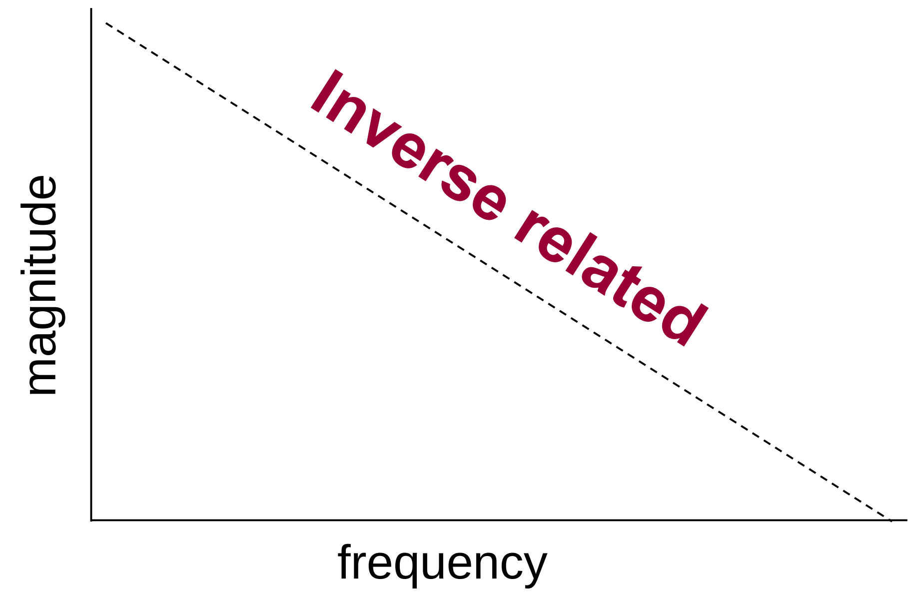
1.2. Risk study methods

The methodology to be followed to study the risk has different phases that are generally summarized in

- Analysis and identification
- Occurrence or probability
- Population and activities affected
- Protection.



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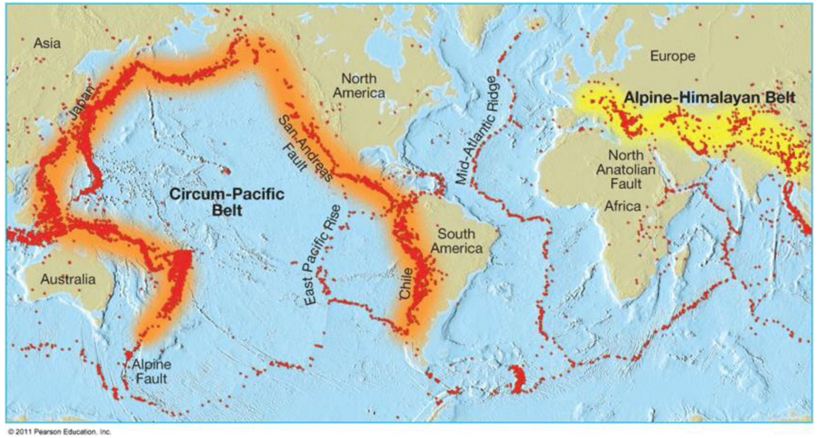
1.3. Coastal risks

The origin of the risks can be

Internal
- Tectonics
- Magmatism

External
- Atmospheric agents
- Marine agents
- Human activities



2011 Pearson Eductation Inc.

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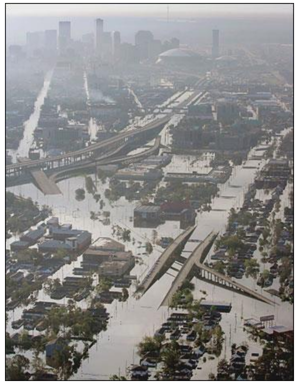
1.3. Coastal risks

Coastal risks are associated with erosion and flooding processes due to storms, hurricanes, cyclones, tsunamis, etc.

To these must be added the role of climate change

- Variations in the characteristics, intensity, spatial and temporal distribution of storms and hurricanes
- Sea level rise, changes in rainfall patterns, etc.



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1.3. Coastal risks

A loss of natural areas were observed due to coastal erosion and anthropic occupation and activities

In UK, during the last 200 years, it was registered an annual loss between a 0.2 and 0.7% due to coastal erosion and a 0.5% due to anthropization

Long term rate of relative land- and sea-level change in the British Isles

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1.3. Coastal risks

Long-term

- Sea level variations
- Sedimentary contribution changes
- Large storms and tsunamis

Erosion processes produce important retreat, with no or partial associated recovery

Mid- and short-term

- Storms

Coast erosion/acretion cycles are recorded at an inter-annual time scale and are related to seasonal wave climate variations due to temporal and spatial distributions of high latitude storms

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1.3. Coastal risks

Sea level fluctuations modify the dynamics and extent of coastal environments, affect morphological systems and human activities.

In environmental and economic terms, coastal storms are among the most important risk generating processes

Great socio-economic importance

↓

between 100-200 million people live in low-lying areas potentially subject to coastal flooding

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1.4. Problems and processes associated to climate change

There is a wide variety of processes associated with climate change that directly and indirectly affect coastal risks

- Variations in the characteristics, intensity, spatial and temporal distribution of storms and hurricanes
- Sea level rise, changes in rainfall patterns, etc.

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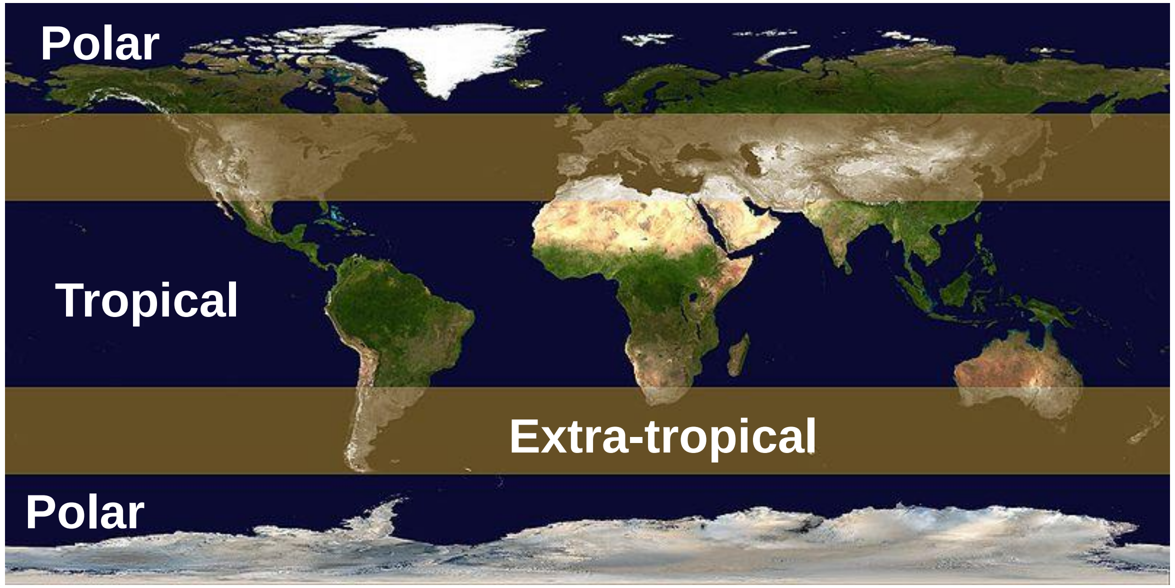
1.4. Problems and processes associated to climate change

Hurricanes and tropical and extra-tropical storms are associated with cyclonic weather situations, with the rise of air masses in a helical way

Depending on the latitude they can be divided into:

- Polar
- Extra-tropical
- tropical



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1.4. Problems and processes associated to climate change

Tropical cyclones

They form in the inter-tropical convergence zone (ITCZ), associated with disturbances generated by the trade winds from the East

According to their intensity they are called:

- Tropical depressions (winds < 8 Beaufort scale)
- Tropical storms (between 8 and 12)
- Tropical cyclones (> 12):
  - Hurricanes (in Atlantic and Indian)
  - Typhoons (in the Pacific)

Category	Central pressure (millibars)	Wind (m/s)	Surge (meters)	Damage
1	>980	32-42	1.32	minimal
2	965-979	42-49	2.13	moderate
3	945-964	50-57	3.20	extensive
4	920-944	58-68	4.57	extreme
5	<920	>69	5.49	catastrophic

Saffir/Simpson Hurricane Scale

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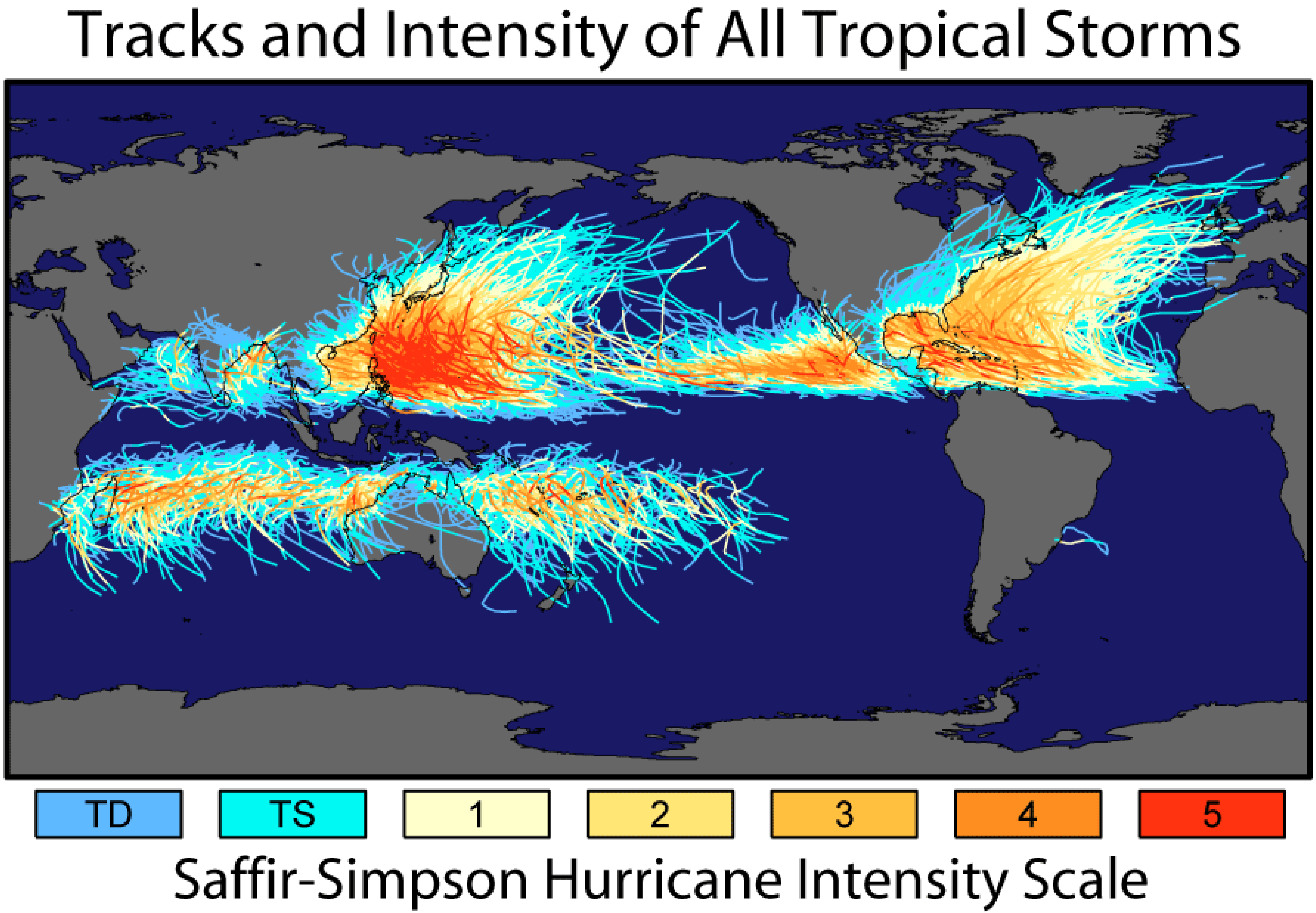

Historic Tropical Cyclone Tracks, NASA Earth Observatory [https://earthobservatory.nasa.gov/]

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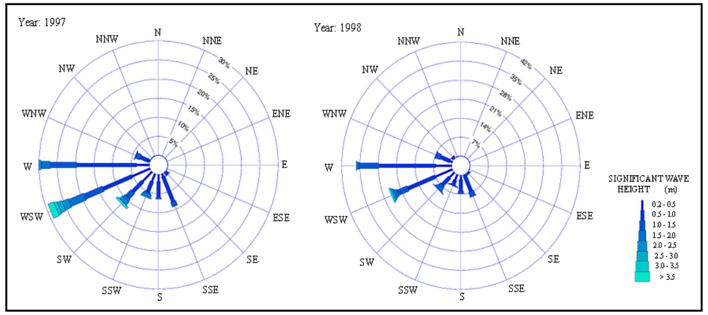
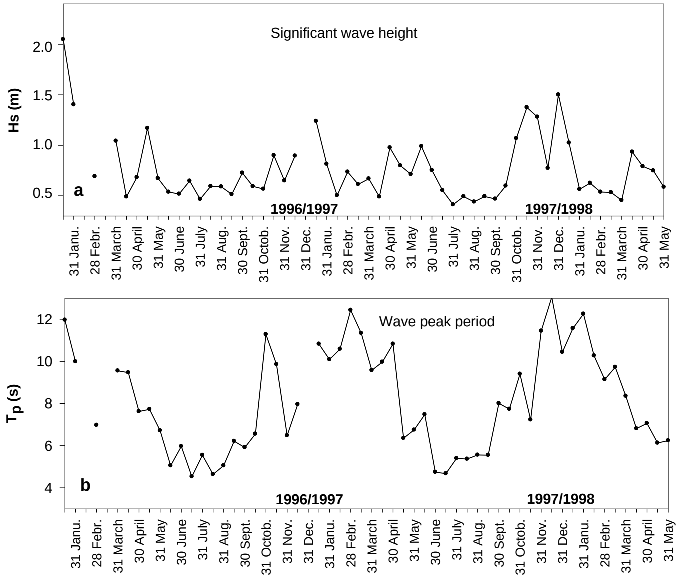
1.4. Problems and processes associated to climate change

Storms

Sea storm is a sequence of sea states in which the spectrally significant wave height exceeds a threshold h_t and does not fall below this threshold for a continuous time interval greater than 12 h and the time interval between consecutive single storms must be greater than 12 h.





Parameters — significant wave height (*Hs*), peak period (*Tp*), mean wave direction (*ϑ*) — wave forecast data, data from wavemeter buoys

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1.4. Problems and processes associated to climate change

Storms

Allen (1981) storm index based on wind speed which reflects energy.

Halsey (1986) classification of North Atlantic storms (northeasters or nor'easters) into 5 classes based on the index of potential damage.

Dolan & Davis (1992) index based on wave height and storm duration.

Orford et al. (1992) and **Orford & Carter (1995)** incorporated the role of storm surges in a new index.

Kriebel & Dalrymple (1995) risk index as a result of the relationship between the effects of storm surge, waves and duration.

Saffir-Simpson Scale

The chart color codes intensity (category based on Saffir-Simpson scale):

Type	Category	Pressure (mb)	Winds (knots)	Winds (mph)	Surge (ft)	Line Color
Depression	TD	<980	< 34	< 39		Green
Tropical Storm	TS	<980	34-63	39-73		Yellow
Hurricane	1	> 980	64-82	74-95	4-5	Red
Hurricane	2	965-980	83-95	96-110	6-8	Light Red
Hurricane	3	945-965	96-112	111-130	9-12	Magenta
Hurricane	4	920-945	113-135	131-155	13-18	Light Magenta
Hurricane	5	< 920	>135	>155	>18	White

NOTE: Pressures are in millibars and winds are in **knots** where one knot is equal to 1.15 mph

Storm Class	Frequency N	Frequency %	Significant Wave Height (m) $\bar{x}$	Significant Wave Height (m) s	Duration (hr) $\bar{x}$	Duration (hr) s
1 Weak	670	49.7	2.0	0.3	8	4.3
2 Moderate	340	25.2	2.5	0.5	18	7.0
3 Significant	298	22.1	3.3	0.7	34	17
4 Severe	32	2.4	5.0	0.9	63	26
5 Extreme	7	0.1	7.0	1.3	96	47

Storm Class	Power (m^2hr) $\bar{x}$	Power (m^2hr) s	Range (m^2hr)	Range (ft^2hr)
1 Weak	32	20	power ≦ 71.63	power ≦ 771
2 Moderate	107	25	71.63 < power ≦ 163.51	771 ≤ power ≦ 1760
3 Significant	353	178	163.51 < power ≦ 929.03	1,760 < power ≦ 10,000
4 Severe	1,455	378	929.03 < power ≦ 2,322.58	10,000 < power ≦ 25,000
5 Extreme	4,548	2,370	power > 2322.58	power > 25,000

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1.4. Problems and processes associated to climate change

Storms - Example

Wave data from 1958 – 2001 obtained from HIPOCAS points (SIMAR – 44) and modelled by WAve Model (WAM)
Data resolution was 12.5 x 12.5 Km

The Dolan & Davis (1992) Storm Power Index

$$Hs^2 X\ td$$

The minimal duration of a single storm was fixed in 12h because of the semi-diurnal tide of the area, so a single storm affects the coast at least during a tidal cycle.

The time interval between single storms was fixed in 1 day following Morton et al. (1977) and Dorsch et al. (2008)

EARTH SURFACE PROCESSES AND LANDFORMS
Earth Surf. Process. Landforms **36**, 1997–2010 (2011)

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Coastal storm characterization and morphological impacts on sandy coasts

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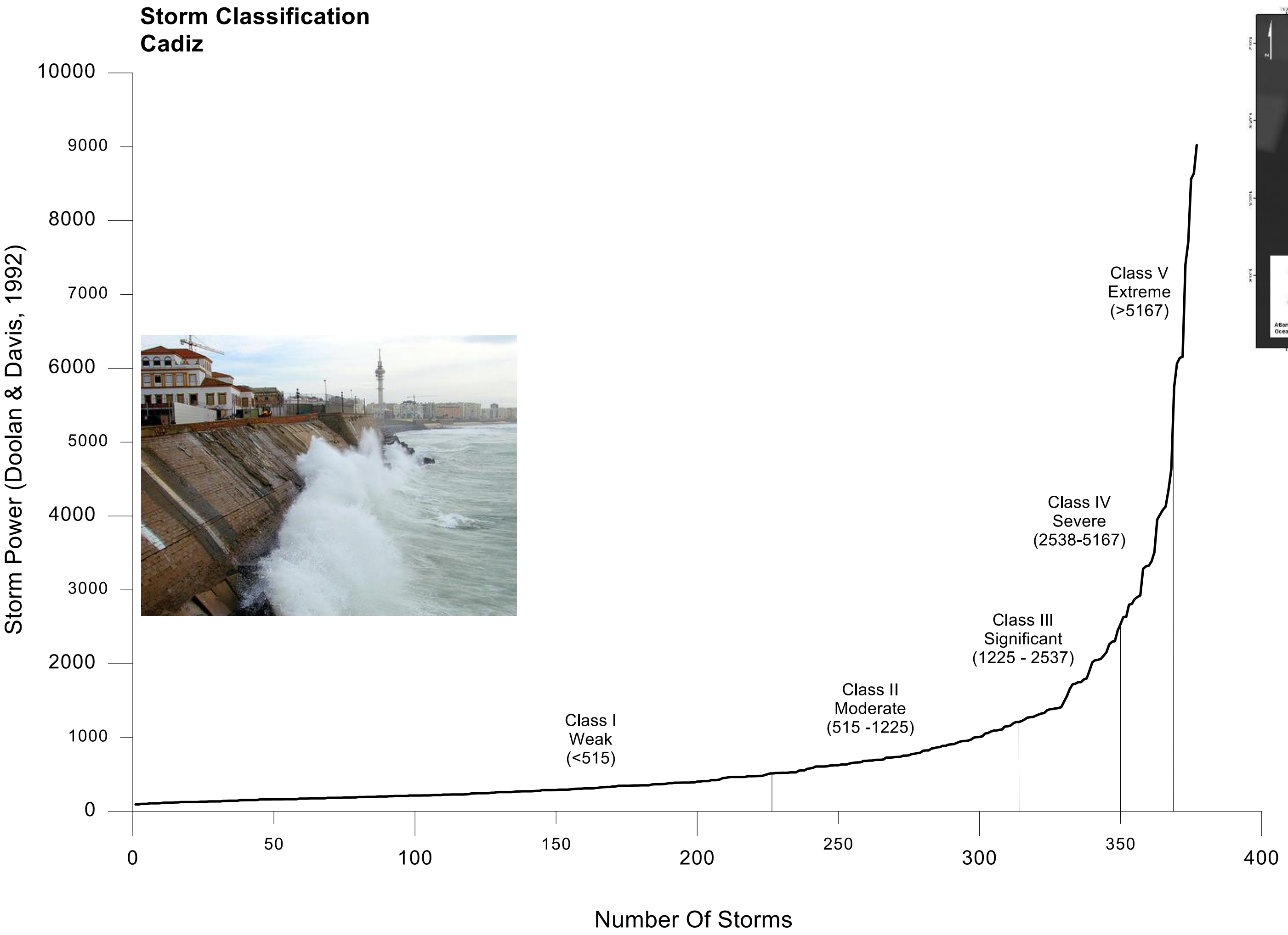
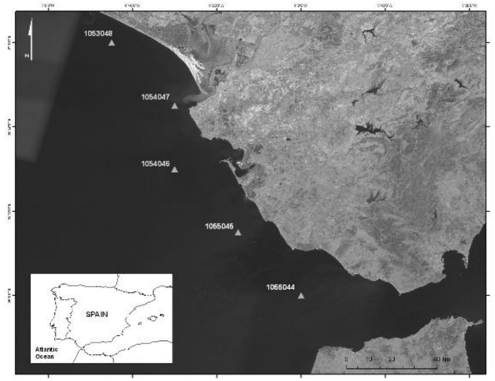
1.4. Problems and processes associated to climate change

Storms - Example

They used the Natural Breaks Function by Jenks & Caspall to classify the storms, that consists in groupping similar values by means of the sum of averages and absolute deviations





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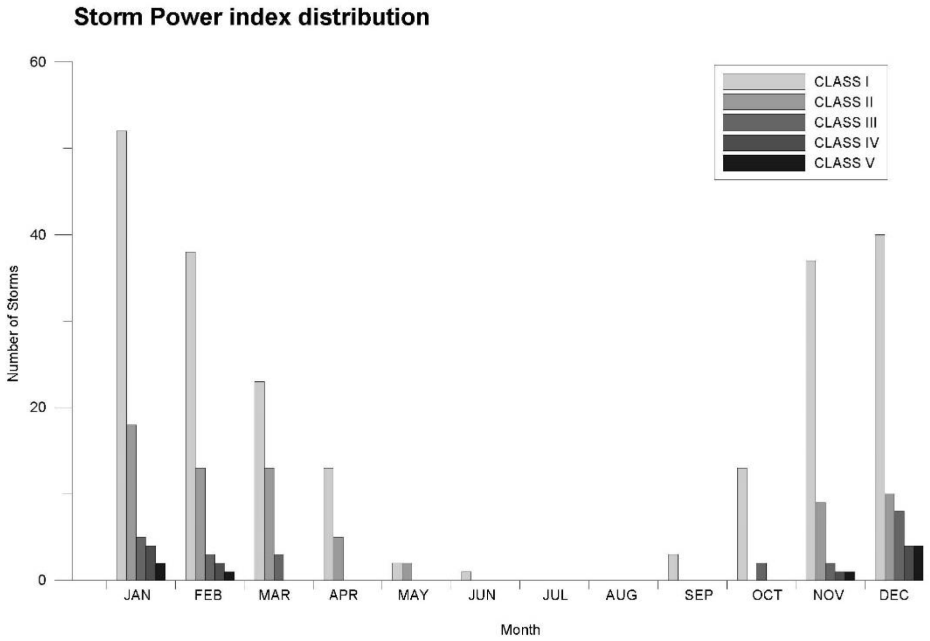
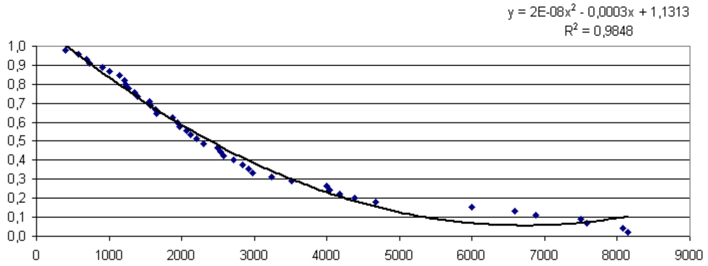
1.4. Problems and processes associated to climate change

Storms - Example





PERIODO RETORNO AÑOS	Reliability	Storm Power Esperado
100	0,01	8439,38
50	0,02	7623,89
20	0,05	6456,17
15	0,066	6076,62
10	0,1	5479,95
2	0,5	2593,96
1,1	0,9	802,19

- Distribution by classes
- Temporal distribution
- Return period

Journal of Coastal Research | SI 64 | 1886-1890 | ICS2011 (Proceedings) | Poland | ISSN 0749-0208

Morphological changes at Levante Beach (Cadiz, SW Spain) associated with storm events during the 2009-2010 winter season

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Journal of Coastal Research | SI 64 | 1891 - 1895 | ICS2011 (Proceedings) | Poland | ISSN 0749-0208

An application of Dolan and Davis (1992) classification to coastal storms in SW Spanish littoral

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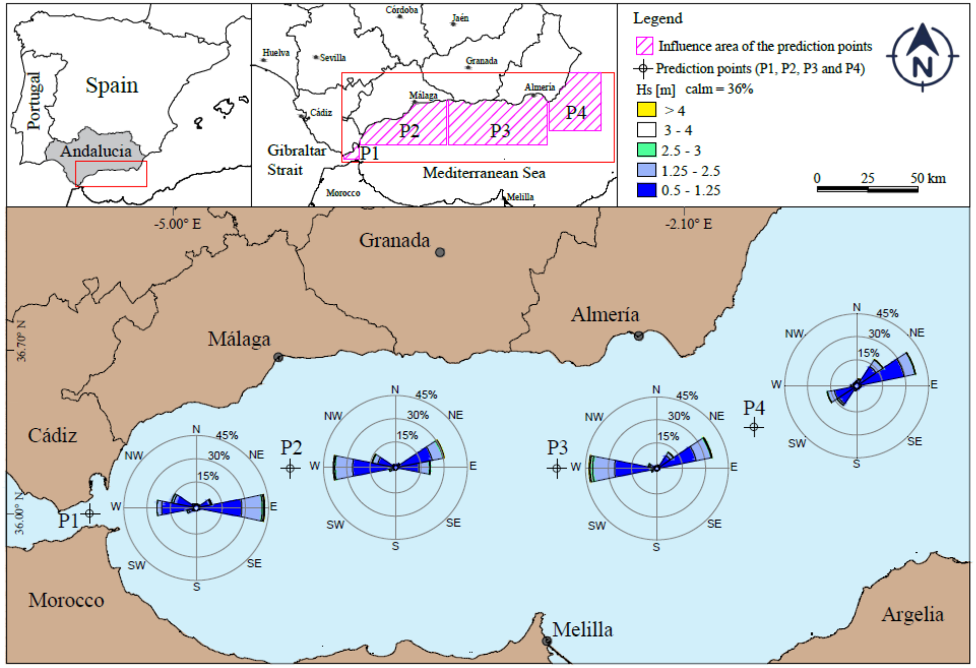
1.4. Problems and processes associated to climate change

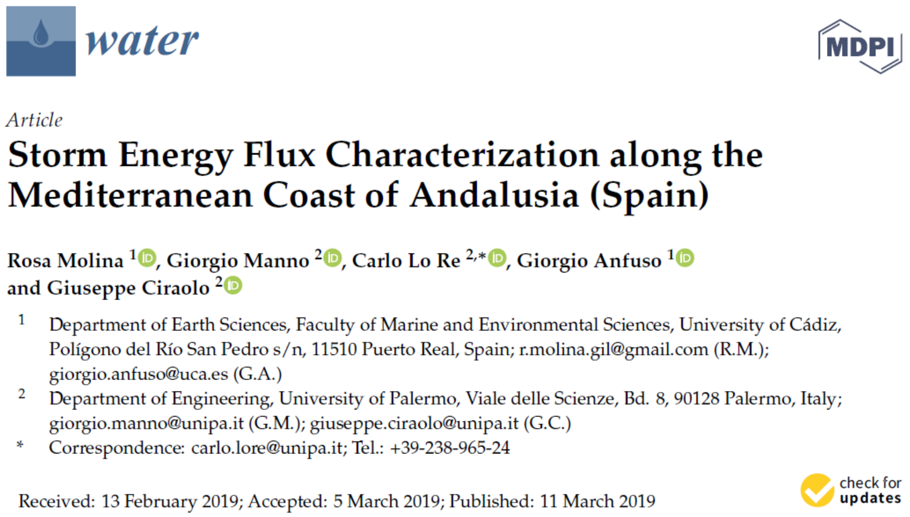
Storms - Example

- Wave data modelled by the ECMWF by means of the
- WAve Model (WAM)
- Four predictions points
- 51,860 data points recorded over a period of 35 years (1 January 1979–30 January 2014)



Wave energy flux, or wave power per unit of wave-front length (P):

$$P = \frac{\rho g^2}{64\pi} T_e H_{m_0}^2 \left[\frac{W}{m}\right] \qquad E_{tot}^i = \int_0^{d_i} P dt \left[\frac{Wh}{m}\right]$$


water MDPI

Article

Storm Energy Flux Characterization along the Mediterranean Coast of Andalusia (Spain)

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1.4. Problems and processes associated to climate change

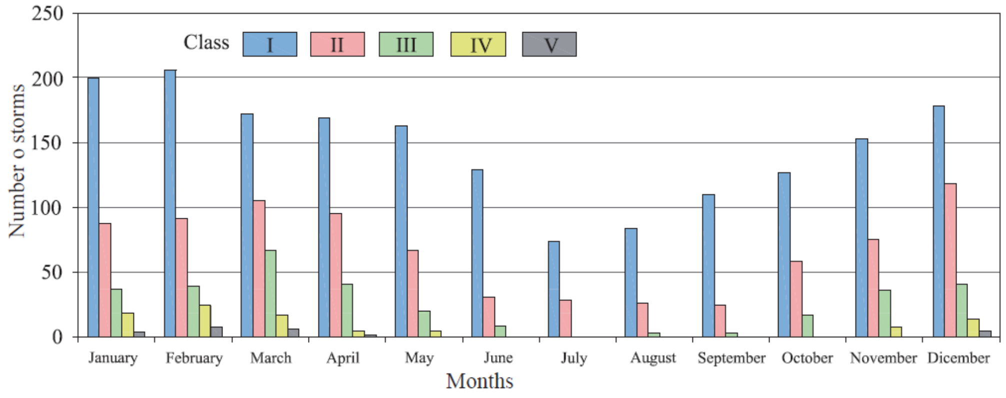

Figure 6. Monthly distribution of all storm events per class and month.

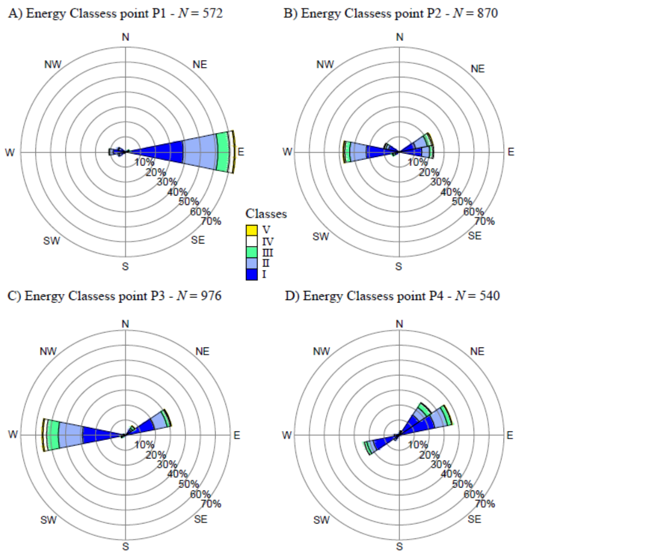

Figure 7. Energy flux roses at all prediction points. (**A**) Point P1, (**B**) Point P2, (**C**) Point P3, (**D**) Point P4. *N* is the total number of storm events.

Weibull Cumulative Distribution Function

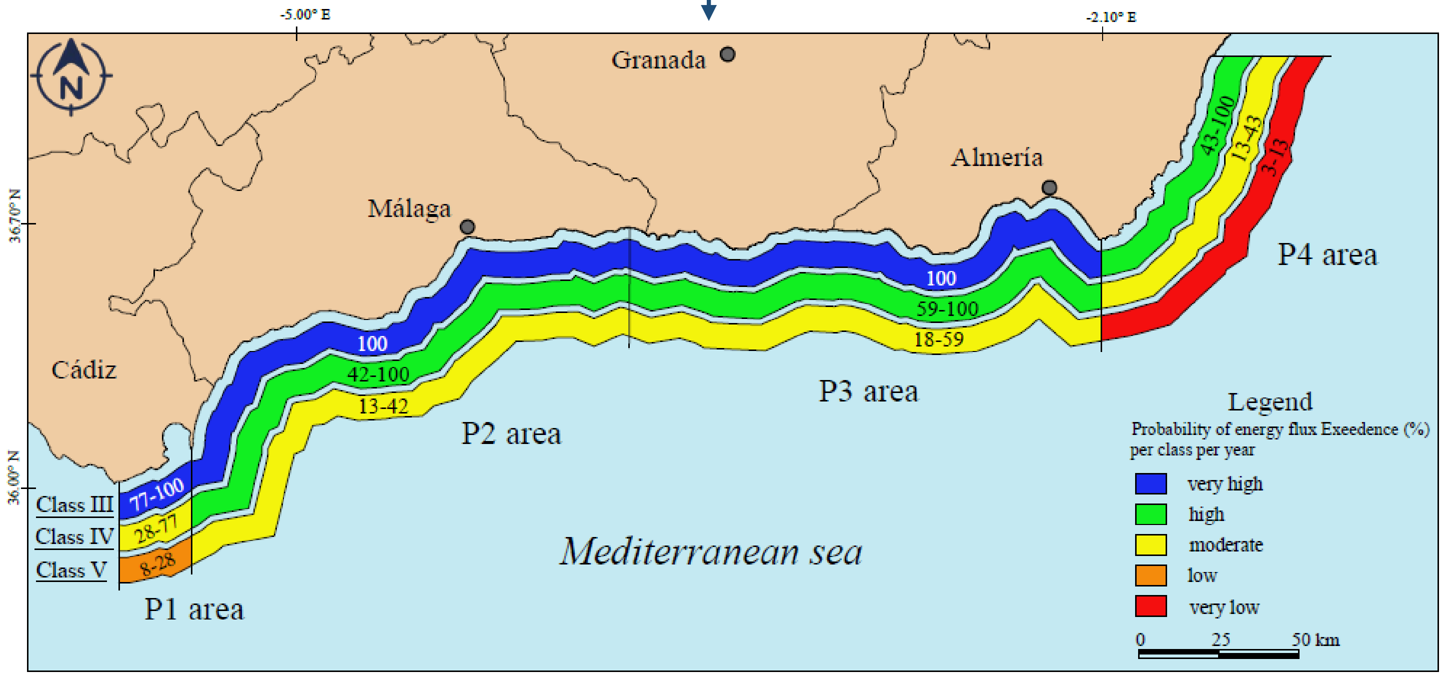

Figure 8. Energy flux probability of exceedance (%) of storms per class III, IV, and V at each point in the coastal area of influence. The percentage values per class as reported on Table 2 are superimposed in the colored stripes.

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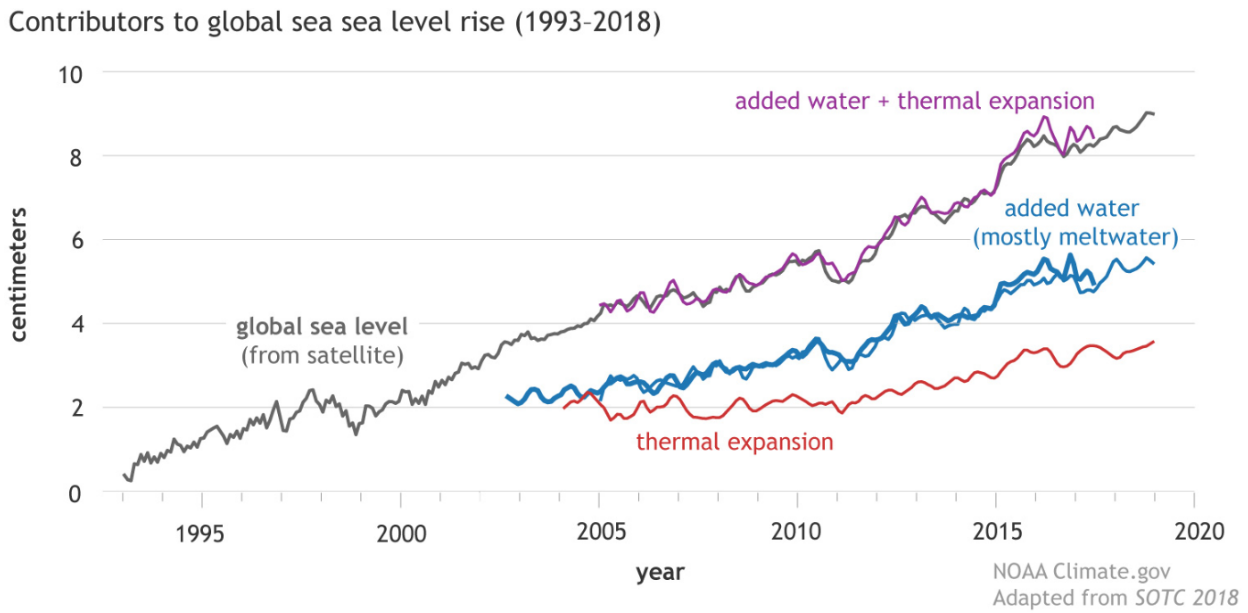
1.4. Problems and processes associated to climate change

SLR

Global warming → melt of glaciers and ice sheets
→ ocean volume expansion



Tide gauges	measure the daily high and low tides for more than a century, using a variety of manual and automatic sensors
Satellite altimeters	determine the height of the sea surface by measuring the return speed and intensity of a radar pulse directed at the ocean

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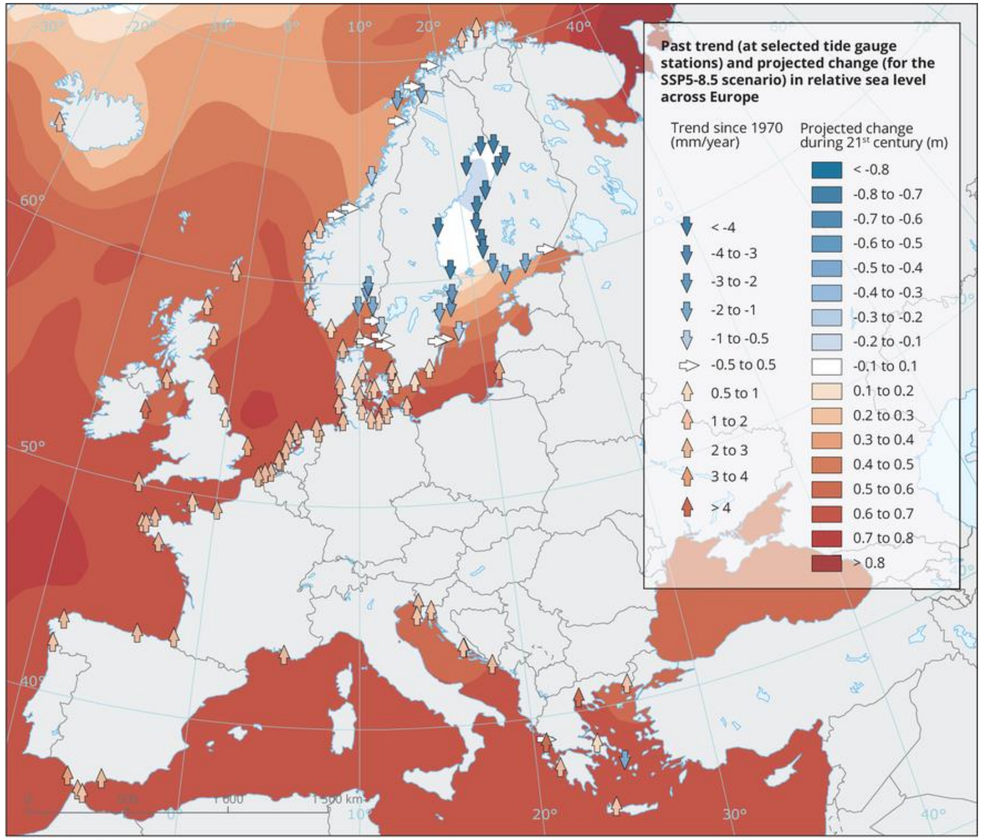
1.4. Problems and processes associated to climate change

SLR

The global mean sea level (GMSL) in 2020 was the highest ever measured. GMSL reconstructions based on tide gauge observations show a rise of 21cm from 1900 to 2020 at an average rate of 1.7 mm/year

Most European coastal regions experience increases in both absolute sea level (as measured by satellites) and relative sea level (as measured by tide gauges), with appreciable differences at local scale.



Reference data: ©ESRI

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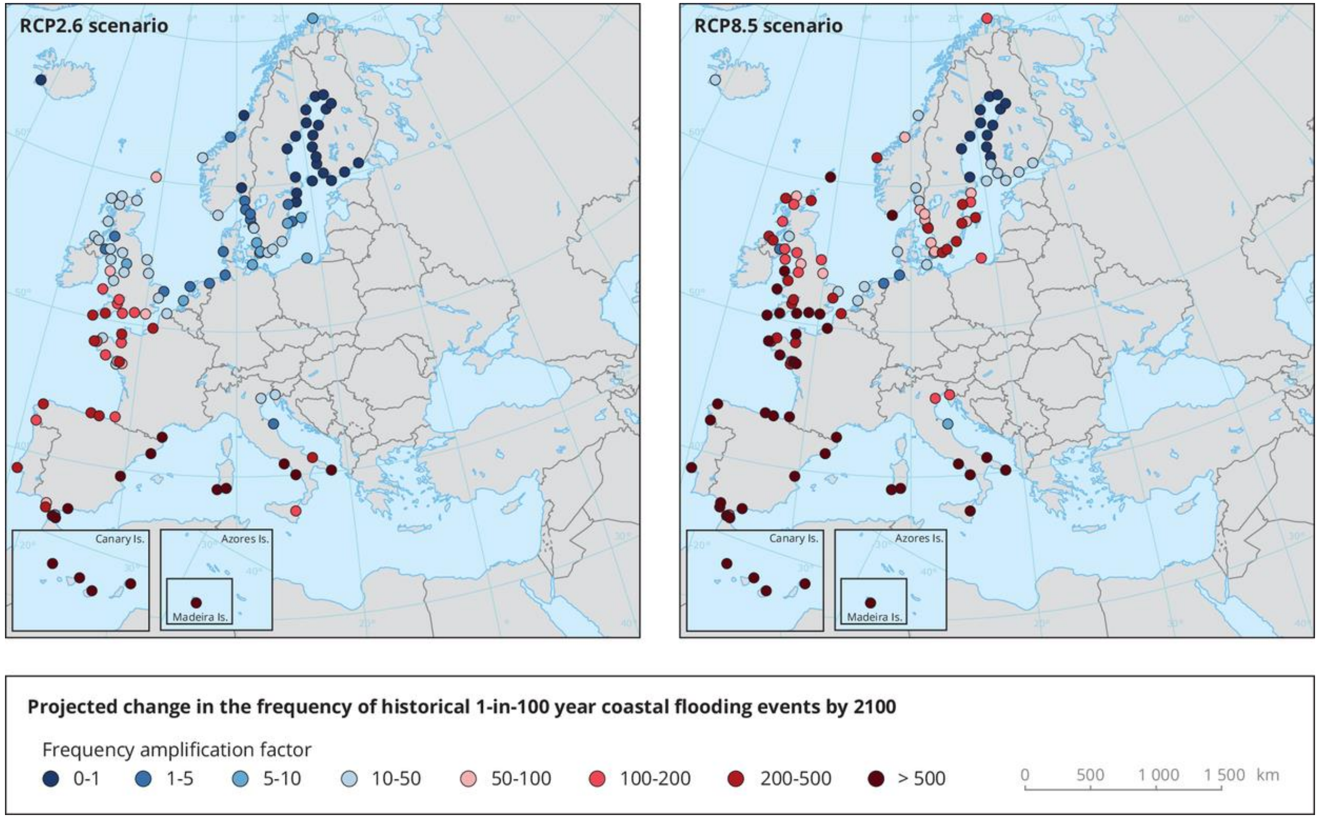
1.4. Problems and processes associated to climate change

SLR

By 2100, 1-in-100-year coastal floods are projected to occur at least once a year along the Mediterranean and Black Sea coasts and at least once a decade along almost all remaining European coasts, even under a low emissions scenario

Under a high emissions scenario, 1-in-100-year coastal floods are expected to occur at least once a year



IPCC SROCC data on sea level rise
European Environment Agency, 2021

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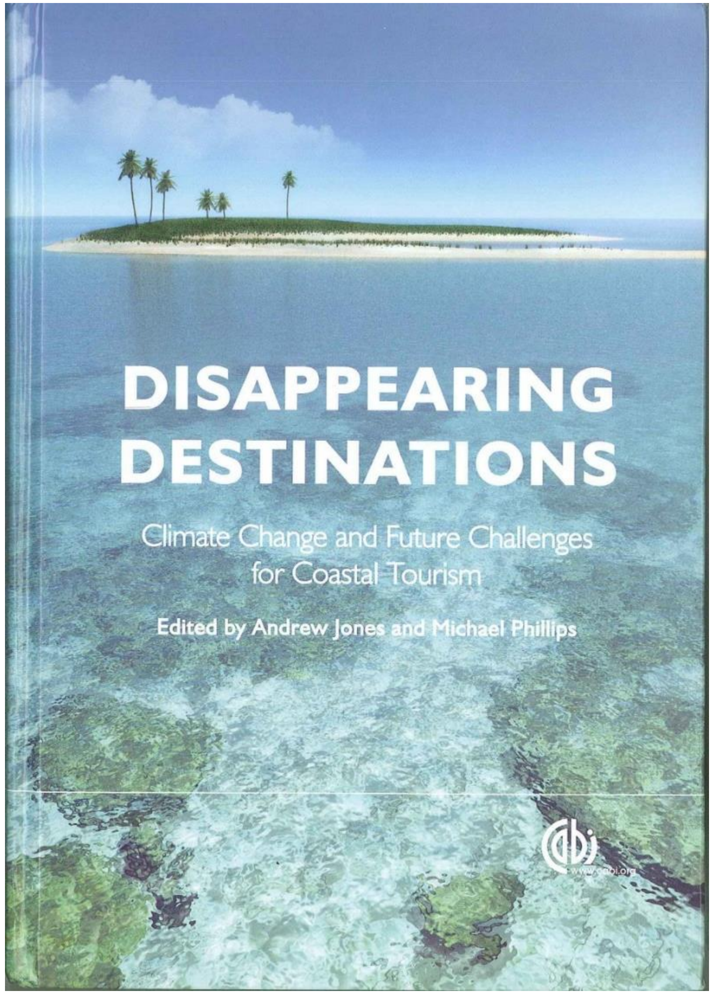
1.4. Problems and processes associated to climate change

SLR - Examples



8. Climate Change and the Mediterranean Southern Coasts

G. ANFUSO AND D. NACHITE

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1.4. Problems and processes associated to climate change

SLR - Examples

Cazenave et al. (2001) obatained SLR values of 5 – 10 mm/year in the western Mediterranean Sea

Naizi (2007) proposed 2.5 mm/year SLR values in the Tetuan región, based in the Topex/Poseidon and Jason-1 satellites for the 1993-2006 period

Warrick et al. (1996) in different areas of the Mediterranean Sea, proposed 20 and 86 cm/year SLR values for the 2100

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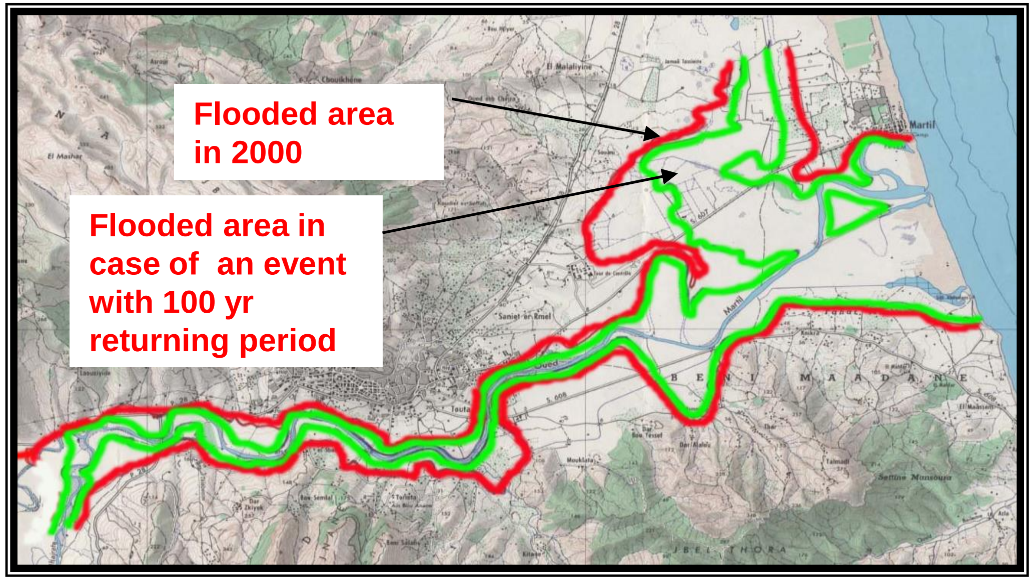
1.4. Problems and processes associated to climate change

SLR - Examples



Tetouan-Martil (1996, 1998, 2000) and Al Hoceima (2003, 2004, 2008) floodings

Tetuán flooding
December 26, 2000

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2. Vulnerability

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2.1. Coastal Vulnerability Index

One of the most important tools to assess the effects of climate change, used since the first International Panel on Climate Change (IPCC) in 1990, are those related to vulnerability assessment

There are many vulnerability indices, which were initially created to meet local needs and later adapted for other contexts

Coastal vulnerability is related to the degree to which a certain sector of the coast can be affected by a specific event

it is a semi-quantitative estimate of different variables that allows identifying the most fragile areas of the coast

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2.1. Coastal Vulnerability Index

The Coastal Vulnerability Index (CVI) is one of the most commonly used and simple methods to assess coastal vulnerability to sea level rise, in particular due to erosion and/or inundation

Four methodological steps

1. Identification of key variables representing significant driving processes influencing the coastal vulnerability and the coastal evolution in general
2. Quantification of the identified key variables. Is generally based on the definition of semi-quantitative scores according to a 1-5 scale
3. Key variables are aggregated in a single index, through a mathematical formula
4. Classification of CVI values in n different groups (usually 3 or 4) using n-1 percentiles as limits

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2.1. Coastal Vulnerability Index

Regarding the variables, different aspects are taken into account

Physical characteristics
Ecological characteristics
Anthropic activities

processed →

multivariate analysis

geographic information systems (GIS)

BIRD:

RAR#	Species	ST	S/F	T/E	Concen	J	F	M	A	M	J	J	A	S	O	N	D	Nesting	Laying	Hatching	Fledging
24	Gulls				MED			X	X	X	X	X	X					-	-	-	-
	Piping plover	DE	S/F	T/T	LOW		X	X	X	X	X	X	X	X				APR-AUG	MAY-JUN	MAY-JUL	JUN-AUG
	Terns				LOW			X	X	X	X	X	X					-	-	-	-
25	American wigeon				800	X	X	X							X	X	X	-	-	-	-
	Bald eagle	DE	S/F	E/T	LOW	X	X	X	X	X	X	X	X	X	X	X	X	NOV-JUL	JAN-MAR	FEB-APR	MAY-JUL
	Black duck				400-4000	X	X	X	X	X	X	X	X	X	X	X	X	MAR-AUG	MAR-JUL	APR-AUG	APR-AUG
	Blue-winged teal				200-500				X	X	X	X	X	X	X			-	-	-	-
	Canada goose				150-200				X	X	X	X	X					APR-JUN	APR-MAY	JUN-JUN	JUN-JUL
	Canada goose				5000	X	X	X						X	X	X	X	-	-	-	-
	Gadwall				50-1200	X	X	X	X	X	X	X	X	X	X	X	X	MAY-JUL	MAY-JUN	JUN-JUL	JUL-JUL
	Green-winged teal				40000	X	X	X							X	X	X	-	-	-	-
	Mallard				300-3000	X	X	X	X	X	X	X	X	X	X	X	X	MAR-AUG	MAR-JUL	APR-AUG	APR-AUG
	Northern pintail				21000	X	X	X	X					X	X	X	X	-	-	-	-
	Northern shoveler				600-1500	X	X	X								X	X	-	-	-	-

It must have a reasonable number of parameters and it must be simple and easy to apply

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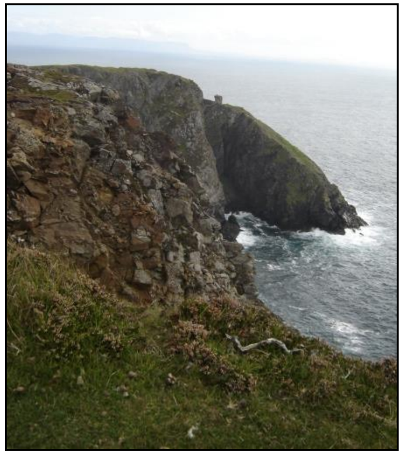
2.1. Coastal Vulnerability Index

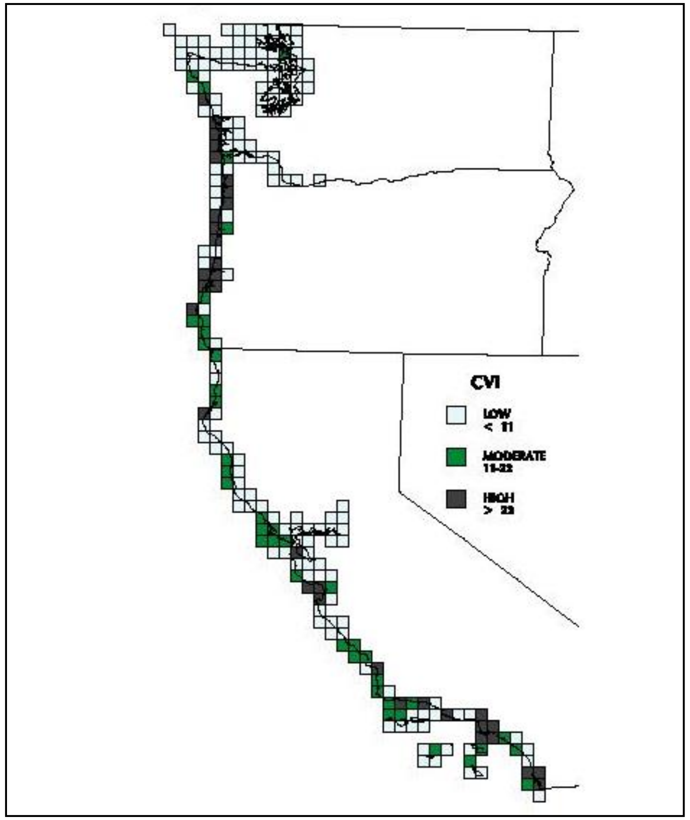
Examples

Gornitz (1991), identifies US areas subject to flooding/erosion from sea level rise

6 variables — Relief, lithology, landforms, vertical land movements, horizontal movements and tidal range



Obtained indices of "inundability" and "erodibility"



A Coastal Hazards Data Base for the U.S. West Coast

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2.1. Coastal Vulnerability Index

Examples

Gornitz et al. (1994), identified US areas subject to flooding/erosion, units of 5.3 km

13 variables

Multivariate analysis, 3 classes, permanent and episodic inundation, erosion potential

Figure 6a. Distribution of low, moderate, high, and very high risk shorelines (Texas). Boxes are equivalent to 7.5 minute USGS topographic quadrangles.

Figure 6b. Distribution of low, moderate, high, and very high risk shorelines (Texas and Louisiana).

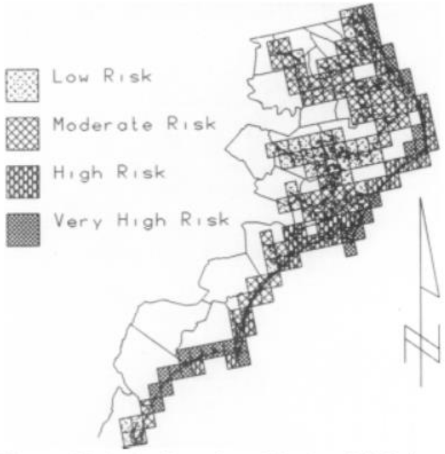

Figure 6g. Distribution of low, moderate, high, and very high risk shorelines (South Carolina and North Carolina).

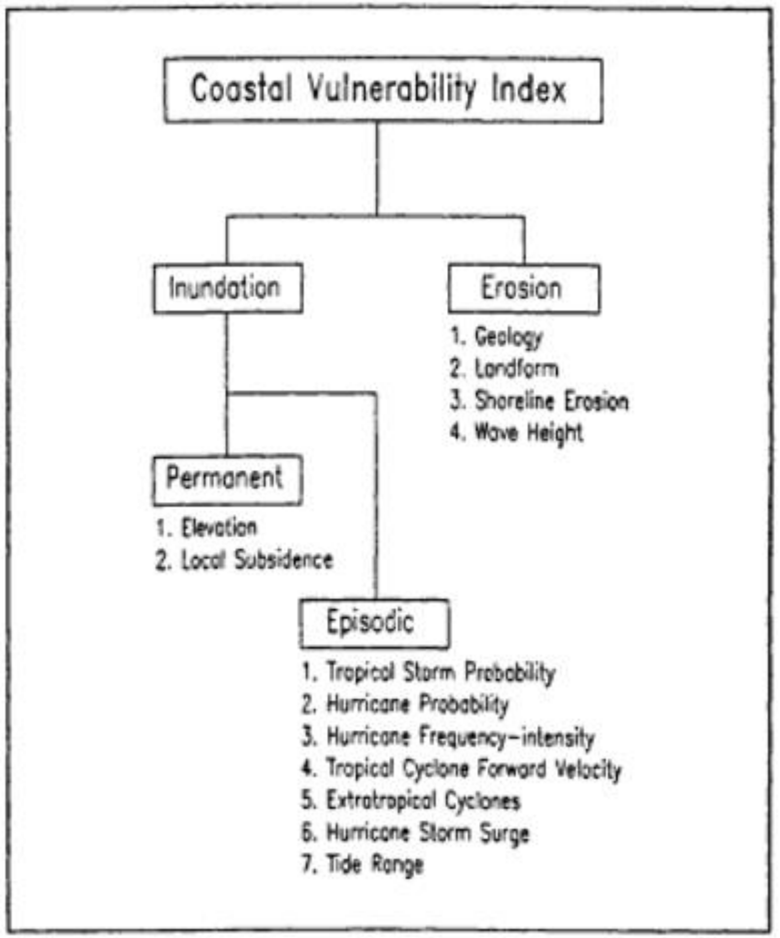

Figure 4. Listing of the variables, by group, used in calculating the Coastal Vulnerability Index.

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2.1. Coastal Vulnerability Index

Examples

Williams et al. (1993), carried out dune vulnerability studies

They used 54 variables

The main categories are:
A Site and dune morphology (8 parameters)
B Condition of the beach (9 parameters)
C Character of the seaward 200 meters of the dune system (12 parameters)
D Pressure of use (12 parameters)
E Recent protection measures (11 parameters)

The use of many variables can falsify the results because some of them are related

2.1. Coastal Vulnerability Index

Examples

McLaughlin, McKenna and Cooper (2002), Northern Ireland, developed a **Coastal Vulnerability Index**

CVI = (coastal characteristics + coastal forcing + socio-economic)/3

Sub-index Sub-index Sub-index

Different scales: national, provincial and local

Several variables, three sub-indices: resistance to erosion, wave energy, socio-economic activities

Socio-economic activities represent the most "new" point, which is missing in the previous classifications

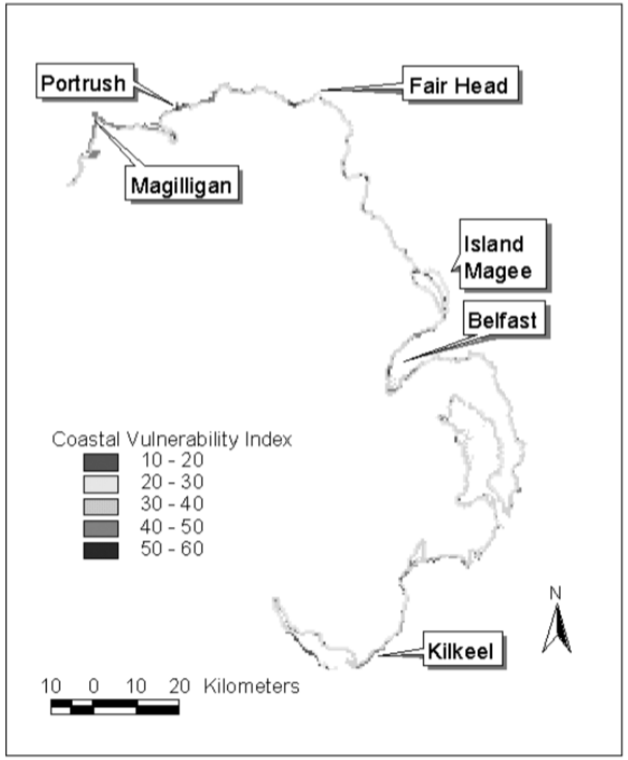

Figure 4. Coastal vulnerability index for Northern Ireland*.

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2.1. Coastal Vulnerability Index

Examples

Socio-economic sub-index

Population	Collect data on inhabitants per km^2	larger numbers of people being affected by (or causing) erosion are directly correlated with increasing vulnerability
Cultural heritage	It is difficult to put a value on a cultural heritage resource. Although one site may be better preserved than another, this does not mean that it is more important	
Roads Railways	In terms of costs, roads and railways are the easiest variables to quantify	
Landuse	Sparsely vegetated areas (1), coastal areas (2), forest (3), agriculture (4) and urban and industrial areas (5)	
Conservation status	Economic criteria. National areas were allocated higher vulnerability ratings as resources are fewer in terms of both expertise and finance →	

Table 2. Classification scheme for conservation designations in Northern Ireland.

INTERNATIONAL	Score
Ramsar site Special Protection Areas Special Areas of Conservation World Heritage Site	3
NATIONAL	
Areas of Special Scientific Interest Areas of Outstanding Natural Beauty National Nature Reserves Environmentally Sensitive Areas	5

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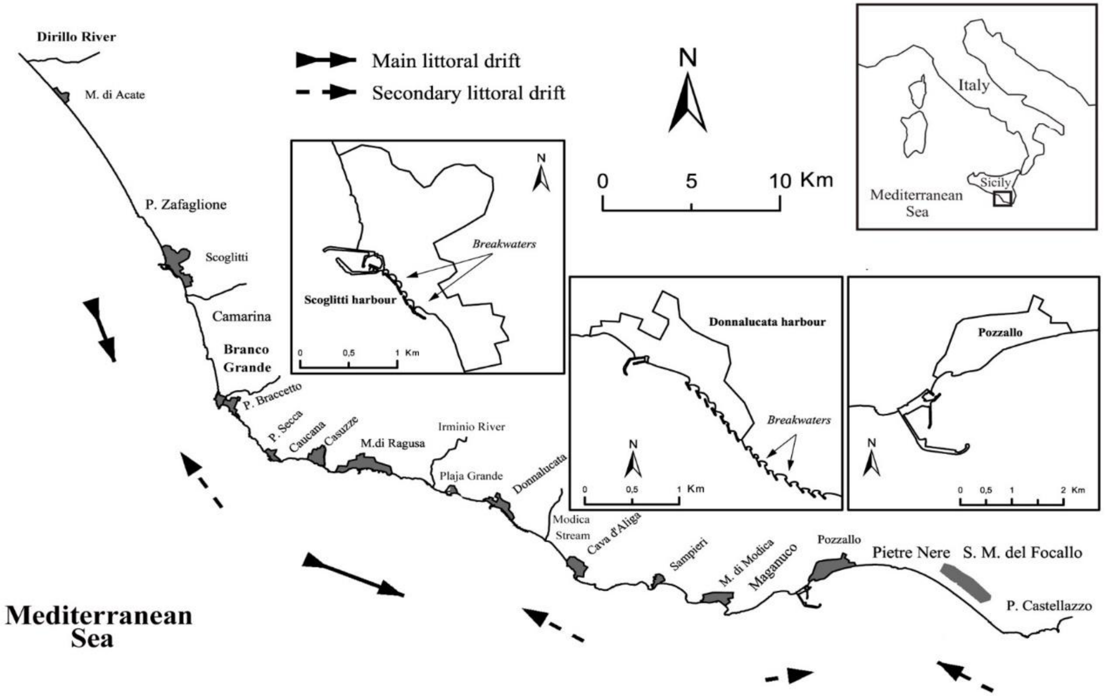
2.1. Coastal Vulnerability Index

Examples

Environmental Management (2009) 43:533–545
DOI 10.1007/s00267-008-9238-8

Assessment of Coastal Vulnerability Through the Use of GIS Tools in South Sicily (Italy)

Giorgio Anfuso · José Ángel Martínez Del Pozo



Vulnerability matrix

Land uses / Coastal evolution	Very high capital use (4)	High capital use (3)	Moderate capital use (2)	No capital use (1)
Strong erosion (4)	16	12	8	4
Erosion (3)	12	9	6	3
Stability (1)	4	3	2	1
Accretion (2)	8	6	4	2

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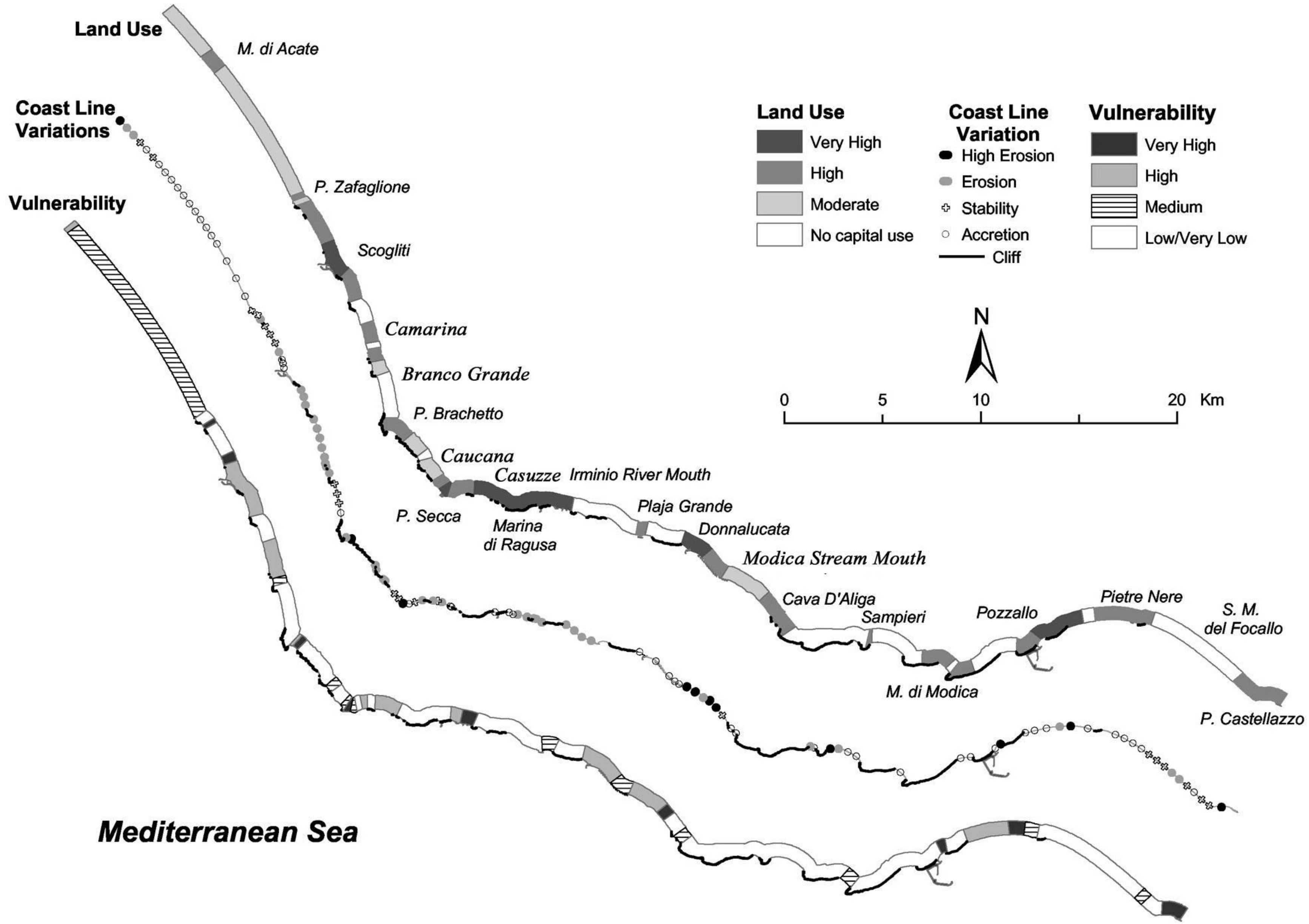

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2.2. Mitigation strategies against coastal erosion

There are several mitigation or response strategies to counteract coastal erosion processes

Do nothing

coastal area has land uses of low economic value that are at null or low risk

when the costs of other strategies are very high -- abandonment

Adaptation

- **Accommodation**

  the modification of existing infrastructures and/or the change in land use

- **Relocation**

  the landward movement of infrastructures

Protection

the establishment of hard structures as well as the execution of nourishment works, when land use at risk is of great economic value

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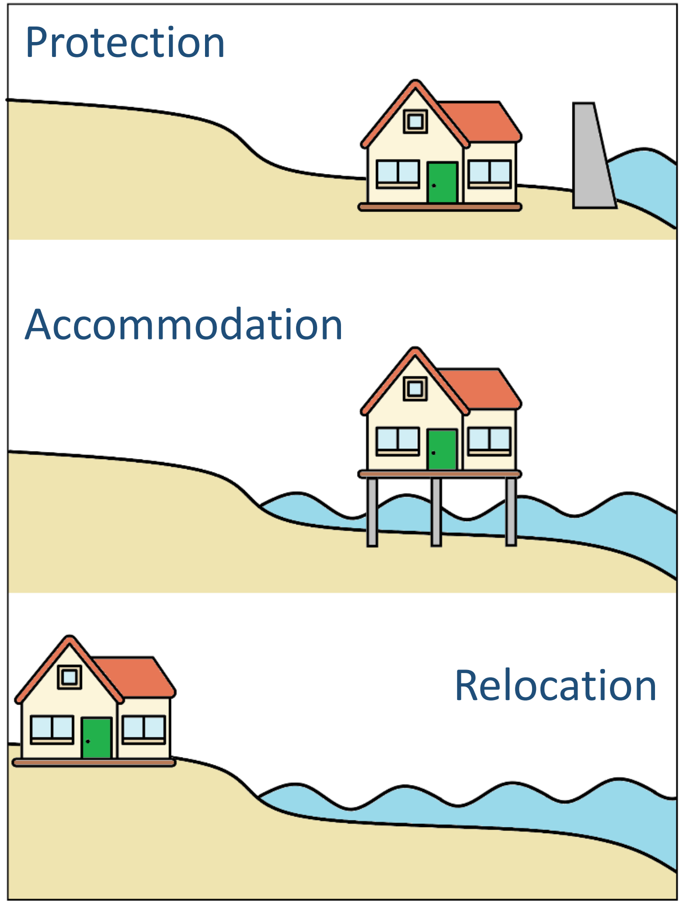
2.2. Mitigation strategies against coastal erosion

Management strategy choice must be based on the knowledge of the erosion processes (magnitudes-causes), property rights, funding/legislation and aesthetics

Until now, a high percentage of decision-making within coastal erosion management is strongly conditioned by economic considerations, based on a cost-benefit analysis approach or an action reaction basis



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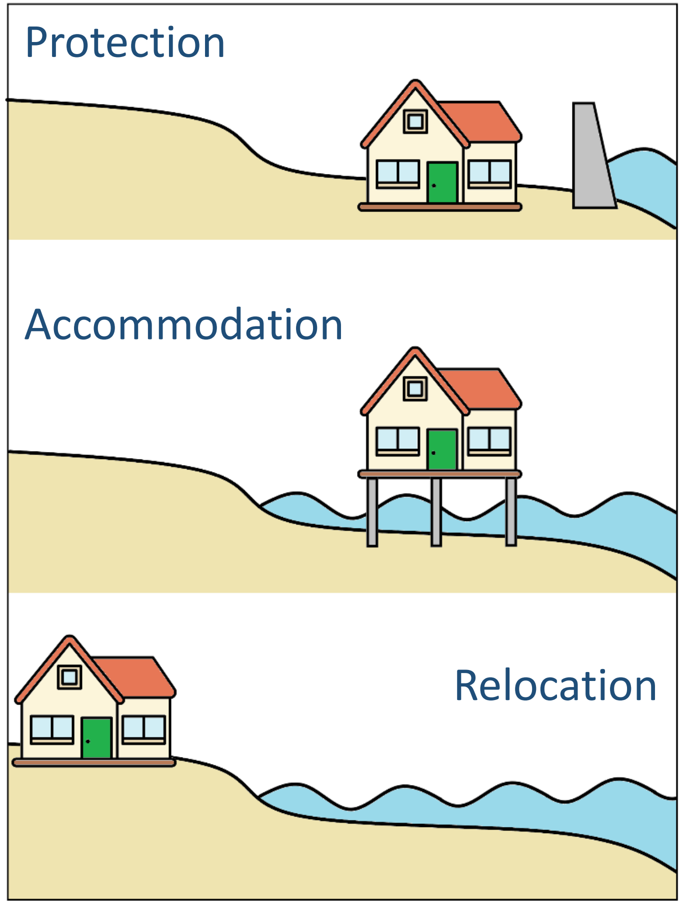
2.2. Mitigation strategies against coastal erosion

Protection or defence is costly and frequently temporary, consisting of ‘hard’ and/or ‘soft’ techniques

Seaward side defences are built to either:

- hold the existing defence line so that shoreline position remains intact,
- or to advance it, claiming further land



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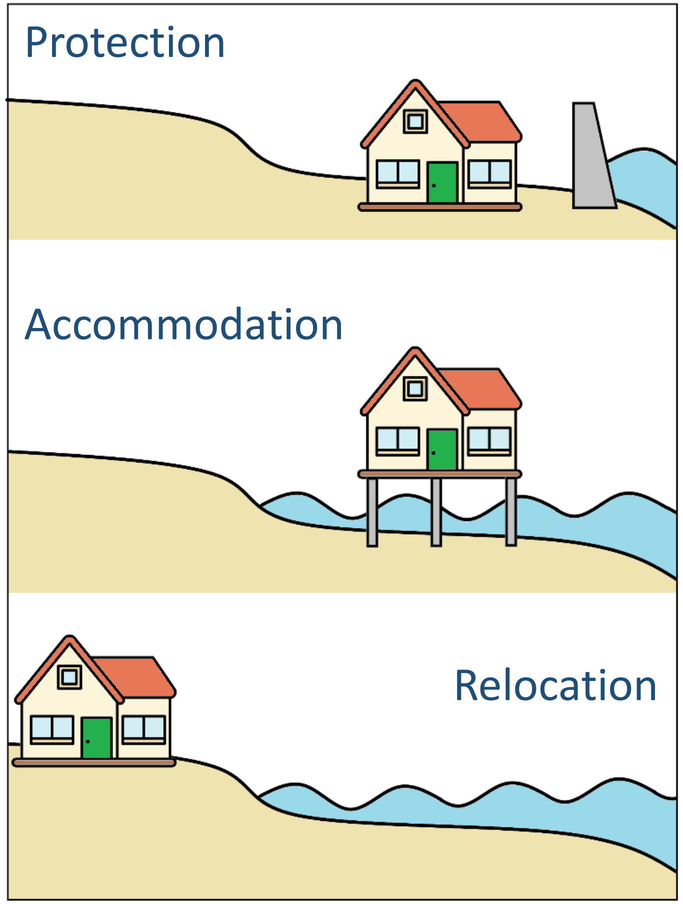
2.2. Mitigation strategies against coastal erosion

Accommodation includes continued usage of land at risk without attempting to prevent land from being damaged by natural events allowing conservation/migration of ecosystems

Examples would include: wetland restoration, modifying building codes - if possible, buildings can be elevated, changing land use, i.e. growing salt tolerant crops

It is an option more characteristic of flood prone areas and flood hazard warnings, as flood proofing and agricultural threats tend to be the major issues involved



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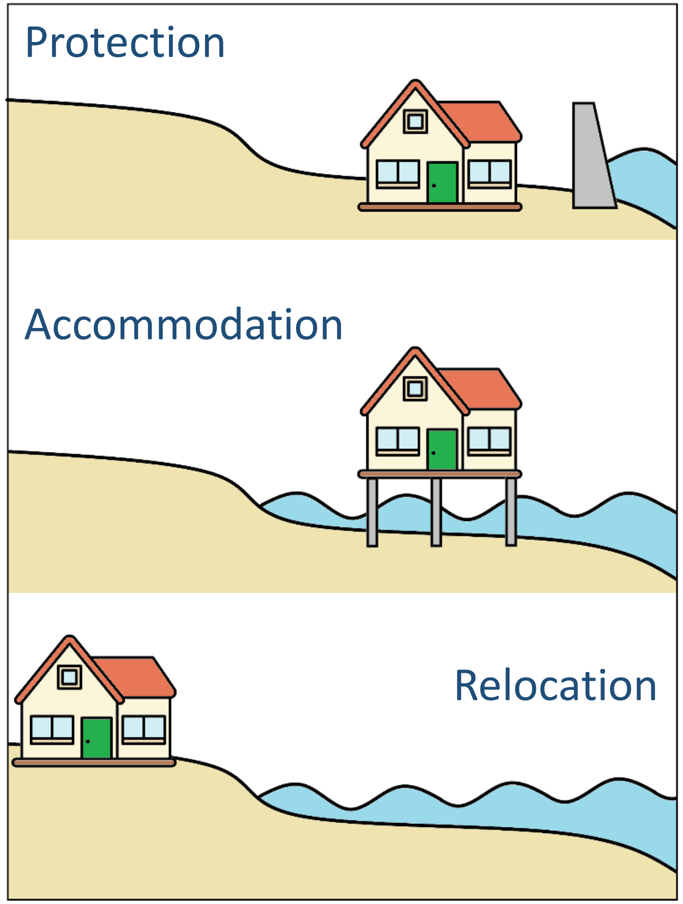
2.2. Mitigation strategies against coastal erosion

Relocation consists in move inland/demolishing/letting structures degrade

Due to sea level rise, is becoming more frequent but is still little used despite an increase in planning options

Retreat actions tend to be retroactive rather than proactive but provides enhanced adaptability

Implicit in the retreat philosophy is that cost effective protection is non-viable for the location in question. However, it has pointed out the advantages of a policy of enhanced resilience to the biophysical and socio-economic systems



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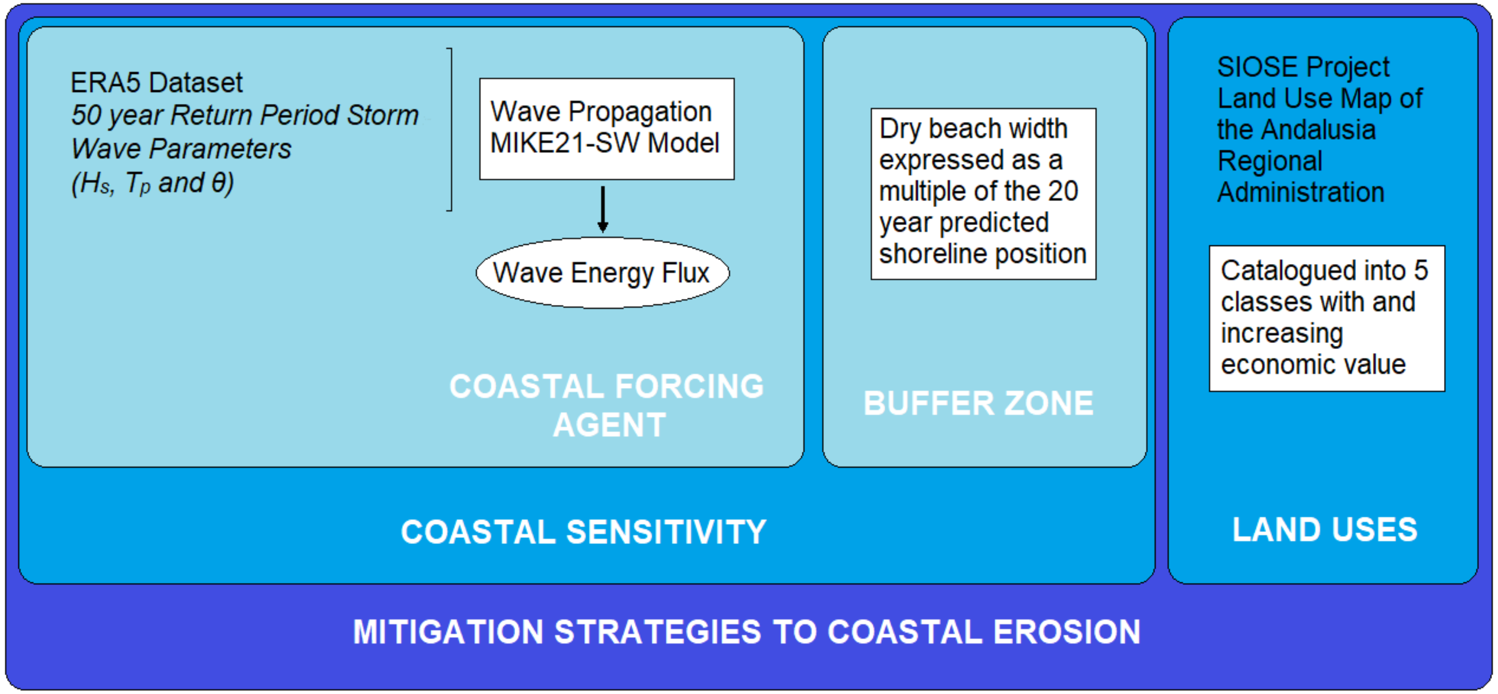
2.2. Mitigation strategies against coastal erosion

Example



Information concerning **coastal sensitivity** and **land uses** was crossed to determine the best mitigation strategies to cope with erosion processes

Table 5. Combination of coastal sensitivity and land uses to obtain the response strategies. Blue color corresponds to the "no action" option, yellow corresponds to the "adaptation" option, and red corresponds to the "protection" option.

		Land Use				
		A	B	C	D	E
Coastal Sensitivity	1	1A	1B	1C	1D	1E
	2	2A	2B	2C	2D	2E
	3	3A	3B	3C	3D	3E
	4	4A	4B	4C	4D	4E
	5	5A	5B	5C	5D	5E

Journal of Marine Science and Engineering
MDPI

Article

A Methodological Approach to Determine Sound Response Modalities to Coastal Erosion Processes in Mediterranean Andalusia (Spain)

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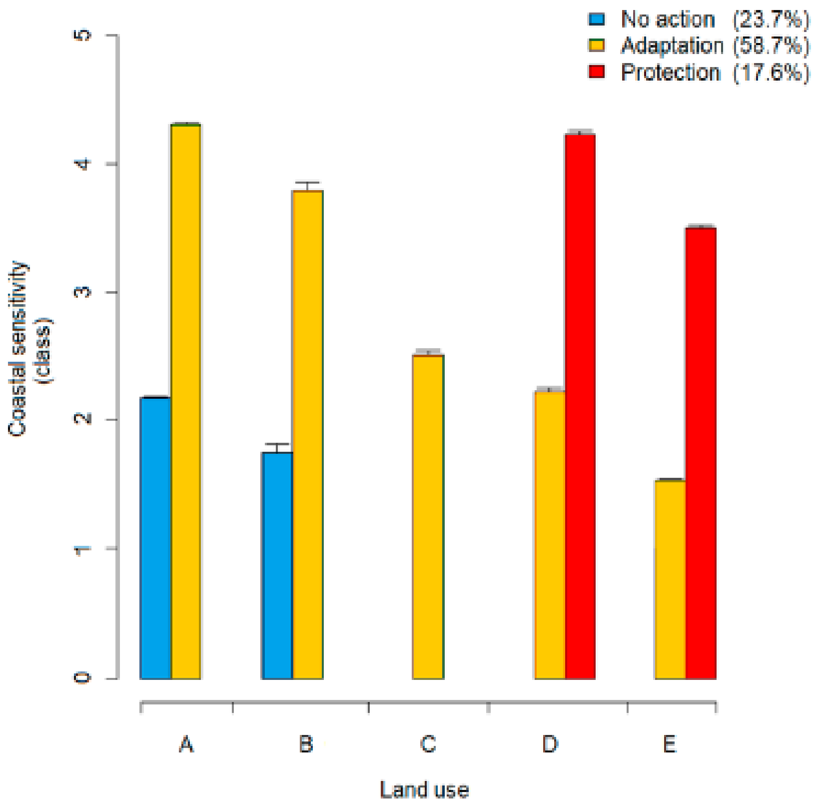
2.2. Mitigation strategies against coastal erosion

Example

In the case in which a coastal area with a low economic value (e.g., agricultural areas, etc., corresponding to land use classes "A" and "B") presented low sensitivity (i.e., classes 1 to 3), the area was not considered at risk and hence no action was required.



The "No Action" option was observed where both coastal sensitivity and land use classes show low values

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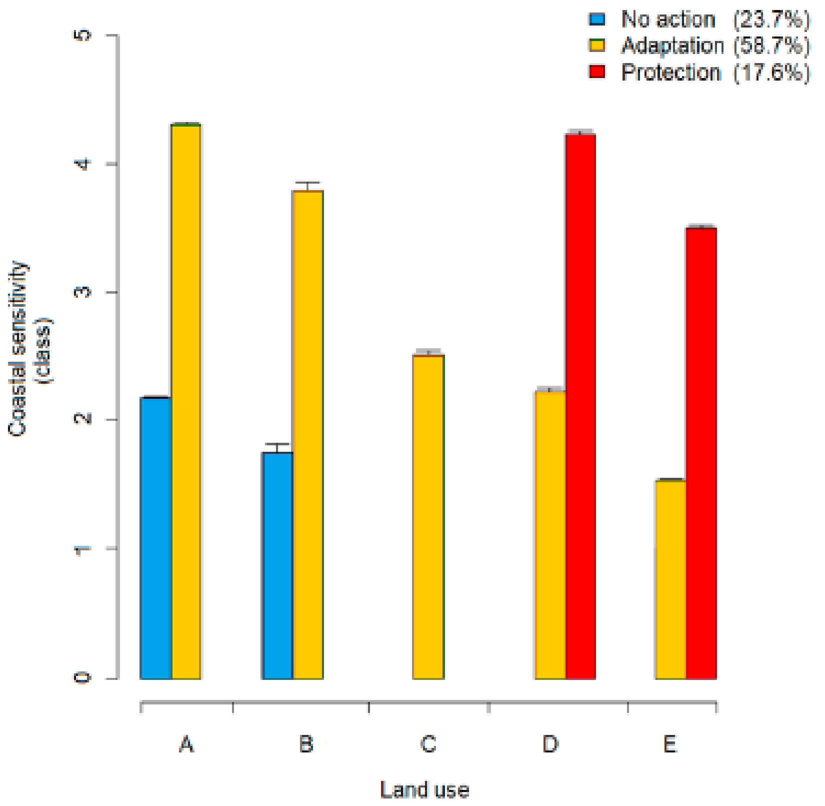
2.2. Mitigation strategies against coastal erosion

Example

In the case in which a coastal area with a very relevant economic value (i.e., extended urban and industrial areas, etc., corresponding to land use classes "D" and "E") presented high sensitivity (i.e., classes 4 and 5), the area was considered at the highest risk and hence protection measures were mandatory



The "Protection" option was observed where both coastal sensitivity and land use classes presented high values.

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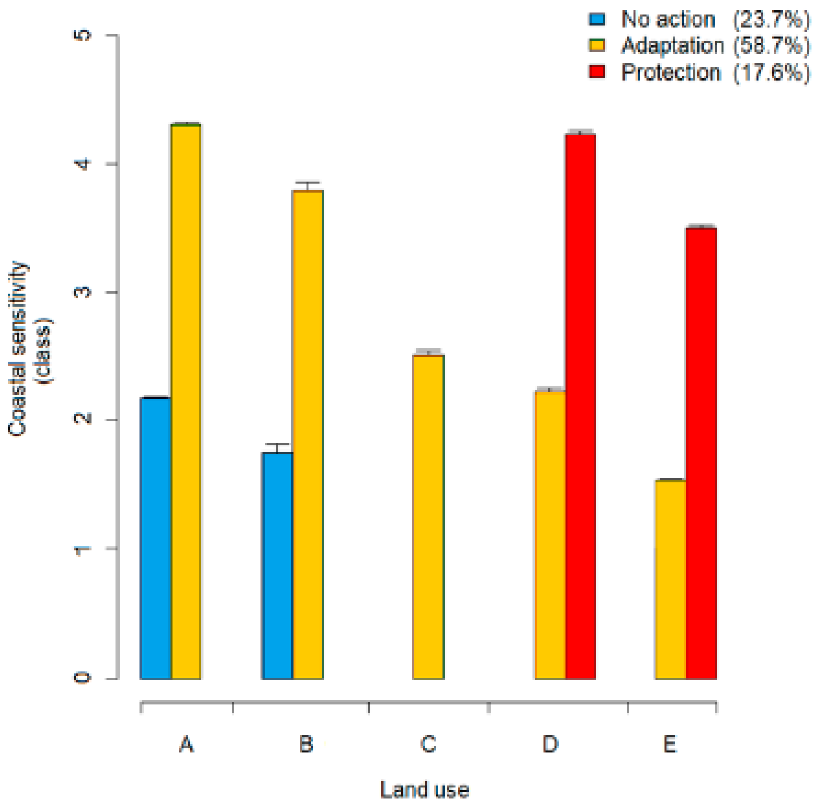
2.2. Mitigation strategies against coastal erosion

Example

All situations in between the two mentioned cases were considered at a medium level of risk and hence likely needed some kind of action; further studies are required in order to decide the necessary sound actions depending on the specific typology of the menaced infrastructure and level of sensitivity



The “Adaptation” option was recorded along more than one half of the coast studied, essentially at natural areas with high sensitivity and at urbanized areas with low sensitivity

¡GRACIAS! Thank you

Faleminderit Hvala.

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OTHER INFORMATION:
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