Studies of environmental coastal impacts in small islands: a review

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Abstract: Fragile or closed maritime-terrestrial ecosystems of small islands, where the intromission of entropies can damage the ecosystem's stability, have been harmed by human intervention. This systematic review examines studies concentrating on anthropogenic impacts on the coastal environments of small islands. Based on a keyword search, a total of 507 papers were found for the period 1985–2021. The North Atlantic and North Pacific islands were the most studied. Studies assessing the typologies of human impacts and ecosystem services were the most numerous. Climate change, environmental policy, and tourism and recreation, together with biological transformations, were the most studied sources of environmental problems in marine-terrestrial environments. Others studied to a lesser extent include industry, basic activities such as agriculture, fishing or mariculture, certain coastal infrastructures, marine litter, human settlements, maritime trade, extractive activities or the protected status of natural areas and the resulting conflicts with local agents.

Keywords: small islands; coast; near-shore; environmental problems; human impacts; anthropogenic pressures.

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1 Introduction

Coastal cities and agglomerations host 21% of the world's population (De Andrés and Barragán, 2016; De Andrés et al., 2018). These provide multiple natural and social resources that explain the increasing occupation of the first 100 km of coastline (Noon, 1987; Martínez et al., 2007). Demographic pressure, the perception of resources, greater leisure time and technological advances contributed to the generation of a succession of transformations of coastal areas throughout the 20th century (Nordstrom, 2004). These modifications have altered the ecosystem balance of coastal areas due to human intervention (Paskoff, 1993; Barragán, 1994; Woodroffe, 2002). In addition, coastal areas have attracted many new tourism-related activities, replacing traditional sea-related activities and allowing seasonal patterns of occupation (Liu and Yin, 2022; Zahedi, 2008).

Given the transformations that are taking place at global scale, small islands are facing huge challenges. The Intergovernmental Panel on Climate Change (IPCC) has warned in its different reports of the enormous risks to which the coastal areas of small islands are exposed, particularly their proneness to natural disasters and climate extremes, the extreme openness of their economies, and their low adaptive capacity (IPCC, 2014, 2022; Mimura, 2012). The coasts serve as home to a large proportion of the population centers on small islands (Larjosto, 2020). The continuous transformations and changes in land use associated with anthropic activities have resulted in the increased vulnerability of these coastal areas (Mimura, 2012). In addition, coastal occupation fosters the proliferation of uses and activities such as maritime trade, fishing, and agriculture, as well as urban sprawl, tourism and recreation, port and energy infrastructures, and mineral and sand mining (Botero et al., 2020). These pose risk both for the local populations, due to the loss of habitability conditions of the population centers, and for the ecosystems and the landscape of the maritime-terrestrial areas. Thus, such activities have been presented as being the main drivers behind the decline of ecosystem balances (Dias et al., 2013), the loss of biological diversity (Davenport and Davenport, 2006), landscape deterioration (Larjosto, 2020), shoreline alterations (Pereira et al., 2019), the modification of estuaries and marshes (Wilby and Perry, 2006), and alterations to dune systems (Ferrer-Valero et al., 2017).

Knowledge about the human activities and land uses that are intervening with these ecosystems, as well as the elements affected by both factors, is fundamental to understand the transformations of coastal territories (Botero et al., 2015). That is, it is necessary to acknowledge and diagnose the extent of land use and human activities in the marine environment in order to assess the magnitude of their impact on the coastal territories of small islands. Such knowledge additionally facilitates proposals of appropriate management, mitigation and/or remediation measures. In this sense, small island coastal territories are often affected by a multiplicity of activities that act

individually or in combination, enhancing their impacts and increasing a greater degree of alteration. In addition, the effect of anthropogenic pressure and the potential sum of the repercussions of the effects of climate change increase vulnerability, potentially producing irreversible transformations not only for the terrestrial and marine environment of the coast but also for the socioeconomic system of the local populations. The predicted sea level rise (Onat et al., 2018a), higher temperatures (Nicholls et al., 2018) and the increased likelihood of extreme events (Krien et al., 2017) pose risks to the general coastal populations and their lifestyles. However, as stressed by several authors, these potential damages are particular relevance in overpopulated islands where anthropogenic action has been stronger (Delgado and Riera, 2020), especially in terms of:

i the effects of the loss of basic ecological niches for marine fauna on fishing activities (Puryono et al., 2018; Romero Manrique de Lara and Corral, 2017)

ii coastline retraction creating a danger for human constructions (Ng et al., 2014).

Such concerns have forced the administrative bodies of many small islands to make contingency or mitigation plans for the effects of climate change, in addition to adapting the socioeconomic system to new or future conditions present in coastal areas (Porro et al., 2020).

1.1 Small island territories

Small islands are predominantly classified by their land surface area. Divergent definitions exist; Larjosto (2020) defines them as geographic land entities with less than 2000 km^2 of land surface. In contrast, Beller et al. (1990) and Hess (1990) extend this threshold to 10,000 km^2 and Dolman (1985) to 13,000 km^2. This variance in definitions underscores the diverse perspectives regarding what constitutes a 'small' island. Alternatively, some definitions also consider demographic criteria (Beller et al., 1990; Hess, 1990), categorising islands with fewer than 500,000 inhabitants as small, and those with a population of one million or less, according to Dolman (1985). and those with a population of one million or less, according to Dolman (1985). Many authors concur in highlighting the following particularities of small islands:

i their propensity to natural disasters and climate extremes (Mimura, 2012)

ii foreign-dependent economies (Satumanatpan et al., 2017)

iii low adaptive capacity (Savage et al., 2020)

iv intensive land use and landscape transformation processes with a high concentration of urban uses on the coast (Sealey et al., 2014; Tassi and Gil, 2020)

v limited natural resources (Mimura, 2012)

vi high biodiversity levels (Richmond et al., 2015)

vii vulnerable ecological habitats (Foo et al., 2021)

viii phenomena associated with mass tourism (Garau-Vadell et al., 2018)

ix dependence on marine resources (Rabassó and Hernández, 2015) or

x challenges in managing water resources (Lal and Datta, 2019).

Small islands often also share a set of coastal-related threats, including:

a intensive cover changes, particularly the transformation of virgin natural areas or those with low levels of anthropic use into urban or agricultural areas (Pérez-Hernández et al., 2020)

b construction of hydraulic, port or energy infrastructures that modify the coastline, the landscape, maritime-terrestrial biodiversity or the chemical composition of the seawater (Zhu et al., 2019)

c emission of noxious gases or chemical substances harmful to maritime-terrestrial environments (Vikas and Dwarakish, 2015)

d irreversible degradation of ecosystems caused by extractive and mining activities (Babinard et al., 2014)

e tourism or recreational systems exceeding the coastal ecosystems carrying capacity (Schuhmann et al., 2019)

f intensive agriculture activities, especially monocultures (Cabili and Cuevas, 2010), and pesticide use (Knee et al., 2010) that homogenise existing habitats and alter the soil chemical composition or change the water table (Boehm et al., 2011)

g industrial fishing causing damage to artisanal fisheries and marine biodiversity reduction due to fish stocks depletion (Fauzi et al., 2021)

h aquaculture, a significant food source for wild fish communities, disrupts the balance of pelagic fish populations (Riera and de-la-Ossa-Carretero, 2014)

i introduction of external pathogens or new invasive species degrading local biodiversity (Parretti et al., 2020)

j solid waste discharges, generating microplastics or marine litter that affects both biodiversity and the food chain (Reinold et al., 2021)

k socioeconomic conflicts arisingrom the management of protected natural areas with local population and economic activities (Cruz et al., 2011)

l planning, conservation and management tools for maritime-terrestrial areas may conflict with marine ecosystems and biodiversity preservation objectives (Friedlander et al., 2014).

Small islands have developed and maintained unique lifestyles, adapted to their natural environment (Mimura, 2012), which, like the habitability of their territories, are in many cases currently undergoing change. This is largely due to modifications to the socioeconomic system and environmental impacts associated with population growth as the result of migratory movements to coastal areas, increased dependence on the outside world, the problems of waste management and the development of the tourism industry (Mimura, 2012). These changes often occur much faster and have much stronger impacts on the coastal areas of small islands compared to continental coastal areas.

The literature review conducted for the present study was based on a search of peer-reviewed papers. Papers that consider the anthropogenic impacts and environmental

problems of the coastal areas of small islands were selected in order to recognise the challenges and tools used to diagnose, confront and mitigate their effects. Given the growing number of environmental problems, this work aims to know the typologies and elements studied in the research that have focused on anthropic impacts on the coasts of small islands in order to improve future holistic vulnerability studies. Other specific objectives include:

i an evaluation of the studies carried out on threats that affect the coastal spaces of small islands, with special attention to impacts derived from anthropic actions

ii a territorial analysis of the distribution of the studies carried out

iii an analysis of the use of spatial tools such as Geographic Information Systems in small island anthropogenic impact studies.

2 Materials and methodology

Following Moher et al. (2015), the systematic literature review was performed as two distinct phases: a literature search and a paper selection process (Figure 1).

I *Literature search*. A list of references obtained from Scopus and the Web of Science (WOS) database was analysed. This search employed the following inclusion and filtering criteria:

   i 'Near-shore island", "Coast island' and 'coastal island' were used as the main search terms. These terms had to appear in the paper title, abstract or keywords

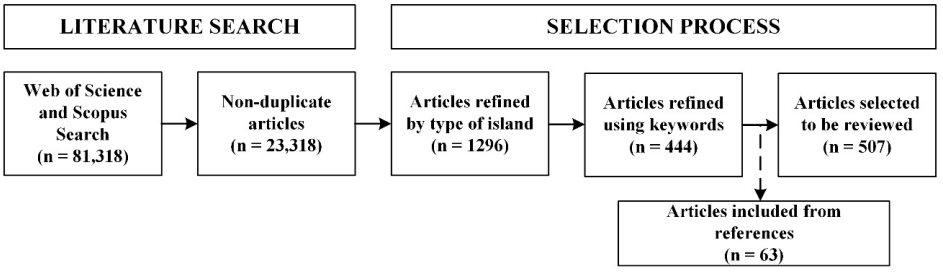
   ii 23 terms related with the pressures on the coast or coastal island environments were also employed (see Supplementary Material, Table 1)

   iii Only publications in English were considered

   iv Only papers published in peer-reviewed scientific journals were included.

II *Paper selection process*. A combination of the papers found in both databases was done using bibliographic management software. After removing duplicate papers, non-duplicate papers were selected using the terms and keywords: 'Small islands' and SIDS (Small Island Developing States, representing the types of islands scrutinised in this review. These keywords were incorporated in the title, abstract, or keywords. Given that a primary objective of this study was to scrutinise publications with a principal focus on human interventions, any papers containing the term 'climate change' within the title, abstract, or keywords were excluded. Additionally, we filtered those containing at least one of the principal terms associated with human interventions in the title, abstract, or keywords, as per Botero et al., (2020): : "settlement", "infrastructure", "activities", "industries", "maritime trade", "tourism", "recreation", "litter", "extractive".

Figure 1 Flowchart of the systematic literature review methodology



After a preliminary reading, different characteristics of the papers were analysed, including:

i year of publication

ii period of study

iii geographic origin

iv coastal type

v research purpose

vi source of environmental problems

vii the affected natural or anthropogenic elements that were studied; and

viii type of geospatial analysis used.

The study periods were evaluated to determine the temporal scope of the studies, distinguishing between those that considered periods of one year, between 1 and 10 years, between 10 and 20 years, between 20 and 50 years, and those exceeding 50 years.

The following seas and oceans were used to geographically classify the papers selected (Ugwu et al., 2021): "Arctic Ocean", "North Atlantic Ocean", "Baltic Sea", "Caribbean Sea", "Indian Ocean", "Mediterranean Sea", "North Pacific Ocean" and "South Atlantic Ocean". Country names recognised by the United Nations were also specified to analyse the contribution by nationality (https://www.un.org/en/member-states/). We also specified the territorial scope of the publications, classifiying it as:

i international (more than one country)

ii national (several regions of a country)

iii regional (exclusively a region or an archipelago)

iv local (one island or a part of one island).

Additionally, the type of island territory was defined as:

i small island in conjunction with a continental study

ii small island dependent on a continental country

iii small island developing state

iv outermost region (OR) of the European Union (EU).

Following de Andrés et al. (2018), coastal zones were defined as shorelands, intertidal habitats, coastal waters, coastal uplands, coastal ocean waters, inland areas, and coastal-influence ocean waters (Table 1).

The main analysed review elements are summarised in Figure 2. The purposes of the studies was classified as:

i human impacts, included mainly studies about impact assessment, biotic homogenisation, land change process or seawater intrusion

ii coastal management, considering research focusing on beach management, protected area management, waste management, legal bases and remediation actions or technological improvements for ecosystem recovery

iii climate adaptation, centered on adaptive strategies against climate change

iv ecosystem services valuation, focusing on studies of maritime and terrestrial ecosystem, paleographic reconstruction, perception of change in ecosystem services or ecosystem evaluation for tourism activities

v coastal squeeze, studying geomorphological and coastal erosion research

vi natural hazards

vii GIS and mapping studies, focused on using of spatial tools.

In addition, following Botero et al. (2020), the sources of the environmental problems were classified as:

i climate change

ii tourism and recreation

iii industry

iv infrastructure

v human settlements

vi extractive activities

vii environmental policy

viii biological

ix basic activities

x marine litter

xi maritime trade

xii protection of natural areas, approached from a socioeconomic conflictive point of view.

Table 1 Coastal zone analysed

Type of coastal zone	*Characteristics*
Shorelands	Terrestrial part closest to the sea, where there are islets, dune fields, sandy plains, cliff coronations, coastal gully cliffs, coastal gullies, areas with vegetation resistant to the influence of saline environments, etc. Its extension is usually small: between a few hundred metres and a few kilometres towards the centre of the island, counting from the coastline
Intertidal habitats	Spaces flooded by the effects of the tide, or comprised of cliff forms where processes of abrasion are observed, rocky platforms and islets, sandy flood plains, salt marshes, tidal channels, shallows, deltas and ecosystems of tidal influence such as beaches (including their berm), marshes, etc.
Coastal waters	Waters where there are submerged beaches, or semi-confined bodies of water such as mouths, bays or estuaries. This includes bodies of water where fresh and salt water are mixed: coastal lagoons, marshy areas, estuaries, etc.
Coastal uplands	These constitute, from a qualitative point of view, the coastal terrestrial part par excellence: islands, mountain ranges and coastal plains and coastal forests. They also coincide, sometimes, with the amplitude of what could be called the coastal plain. Their dimensions range from a few hundred metres to several kilometres
Coastal ocean waters	Where geographical features such as large bays or gulfs would be included, but also ecosystems that may be farther from the coast, such as kelp or marine phanerogam meadows. The depth of 50 m, linked to light penetration and therefore to chlorophyll function, provides an extraordinary reference for integrated management (limit of phanerogam meadows, limit for trawling). Certain metric criteria are sometimes used specifically to regulate certain activities, such as small-scale fishing
Inland areas	Territory where human activities such as agriculture or watershed management are carried out that affect the coastline and the coast. These tend to have large surface areas, and their interior boundaries can be more than 200 km from the coastline
Coastal-influence ocean waters	The widest marine part and the farthest from the coast; usually associated to the 12 nautical miles of the territorial waters or, in extraordinary cases, the 24 nautical miles of the contiguous zone

We also classified the affected elements studied as:

i ecosystem, considering aquifers, atmosphere, fauna, flora, intertidal habitats, seawater quality, freshwater quality, terrestrial ecosystems and maritime ecosystems

ii landscape, including changes in land use such as transformation of agricultural land or forest uses

iii social system, focusing on human health, human infrastructures, human settlements, human system adaptation, local or artisanal fisheries, socioeconomic, tourism and cultural heritage

iv geomorphological forms and processes, including the shoreline, sandy or pebble-boulder beaches, dunes and marine or terrestrial soil composition

v environmental policy, considering legal protections and management instruments

vi a mix of affected elements.

We also examined additional aspects including:

a mention of the concept of integrated coastal zone management (ICZM) in order to identify use of this key management strategy (Mullard, 1995)

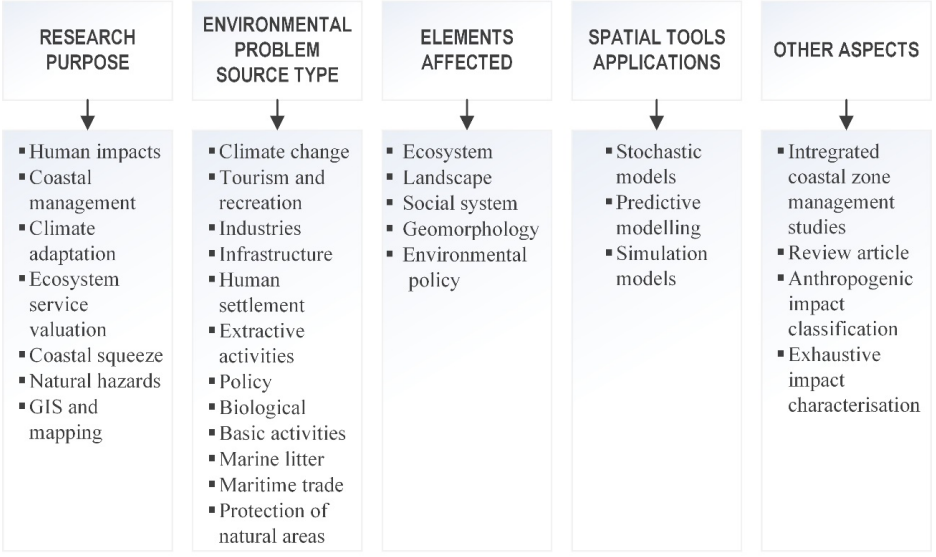
b the presence of partial or comprehensive reviews detailing the state-of-the-art relevant to the paper's focus

c a categorisation of anthropogenic impacts, defining various human impacts or pressures are defined

d the inclusion of a detailed impact characterisation, providing an in-depth analysis and characterisation of a specific impact.

Finally, the papers were classified based on different spatial applications to discern the utilisation of stochastic, predictive, or simulation models, for instance (Quesada-Ruiz et al., 2022).

Figure 2 Review elements analysed



Appendix A shows the bibliographic references used in the initial selection of papers. It is possible to consult the aforementioned criteria included in the search process. All the criteria required to extract the information from the papers that were found were fulfilled.

3 Results and discussion

3.1 Field, spatial and temporal distribution

After the systematised literature review process, 507 papers were found, 24 of which belonged to the pre-2000 period, 78 to the 2000–2009 period, and 402 to the 2010–2021 period (Figure 3). The inaugural publication pertaining to anthropogenic impacts on the coasts of small islands was a scholarly paper focusing on exploring the potentials of geothermal exploitation in the Hawaiian archipelago (Thomas, 1986). In the beginning of 1990, the effects of sea level rise on SIDS started to be examined from a comprehensive, recognising human activity as a modifier or a climate (Lewis, 1990). Furthemore, more focused studies, such as those investigating the impacts of tourism on smaller islands like Barbados (Burskens, 1990), started to emerge. Subsequent to the publication of the initial results of the first IPCC and the convening of the 1992 Rio Earth Summit, there was a modest increment in studies concerning both the impacts of climate change on small islands and the transformation and contamination of their coastal environments. Concurrently, the initial public documents incorporating the concept of ICZM and associated strategies were introduced (Mullard, 1995). Land-based sources of marine, along with other activities degrading the marine environment, were acknowledged at the outset of the 1990s as being amongst the most persistent of environmental challenges, given their involvement with numerous essential and prevalent human activities (Dahl, 1993). Environmental issues became increasingly relevant following the publication of the 2nd and 3rd IPCC reports and the Johannesburg Earth Summit. This was reflected in a greater number of publications related not only to climate change, but also to the impacts of human activity on the coasts of small islands (Bigot et al., 2006; Zea et al., 1998), with an increase in the number of papers dedicated to other topics such as biodiversity loss (Foo et al., 2021; Sobhee, 2006), the introduction of allochthonous species (Celesti-Grapow et al., 2016; Gizzi et al., 2020; Souto et al., 2018), fishing (Richmond et al., 2015; Sangil et al., 2013), or chemical changes in sea water composition (Montesdeoca-Esponda et al., 2021; Zhu et al., 2019). Publications related to the coastal areas of small islands increased exponentially from 2010 onwards. coinciding with a period when there was a substantial rise in the declaration of laws or public recommendations for the control and mitigation of the effects of human activity on coasts (EC, 2008; EP, 2014). In addition, the topics under study became more diverse, with numerous studies published in relation to marine geomorphology (Borges et al., 2002; Hernández-Cordero et al., 2018; Sanromualdo-Collado et al., 2021), and, though to a lesser extent, studies in which the use of geographic information technologies served as a tool for the evaluation and diagnosis of coastal environmental problems (Daniel and Abkowitz, 2003; Hafezi et al., 2020a; Martín-García et al., 2013).

The spatial distribution of the number of papers reviewed showed an imbalance on a global scale (Figure 4). Publications on North Atlantic islands (152) and North Pacific islands (103) accounted for 50.3% of the total number of publications reviewed, while the Caribbean Sea islands (54), Indian Ocean islands (53) and Southeast Asian islands (41) accounted for 21.1% of the publications. The South Pacific (23), Mediterranean Sea (17), Baltic Sea (5), South Atlantic (4) and Arctic Ocean (1) together accounted for just 8.9% of the publications. Meanwhile, studies that considered small islands located in different

oceanic areas (72) accounted for 14.20%. In terms of country distribution, Spain was the country with the highest number of published studies related to anthropogenic impacts on small islands (90), with the Canary Islands the most researched archipelago (Delgado and Riera, 2020). USA was the second most studied country with 68 papers, with Hawaii the most analysed archipelago (Kim et al., 2022; Panelo et al., 2022; Saingam et al., 2021). Also notable was:

i the number of studies realised in Portugal (47), where the Azores and Madeira archipelagos have received a lot of attention (Bernal-Ibáñez et al., 2021; Cunha et al., 2017; Faria et al., 2022; Henriques et al., 2017)

ii the number of studies carried out in Reunion Island (20). Thus, studies in the northern hemisphere were the most numerous, both in terms of their distribution by ocean/sea and by country.

In this sense, industrialised countries or those associated with supranational states such as the EU, which have strict environmental legislation, may have encouraged this type of study for purposes related to conservation and/or protected status (EC, 2008; EP, 2014).

Figure 3 Number of papers published by year

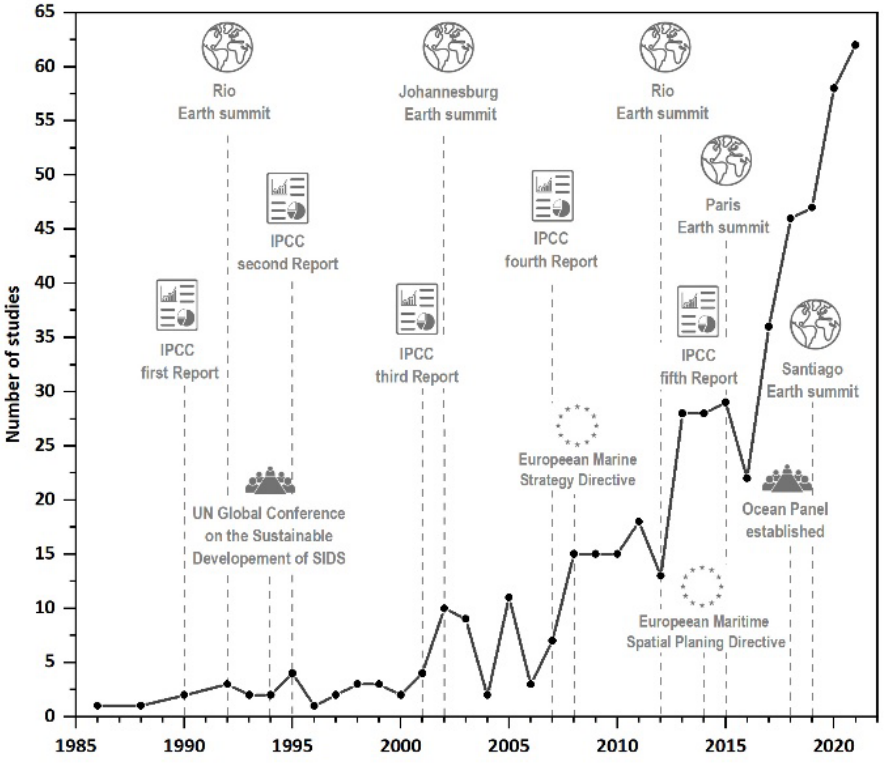
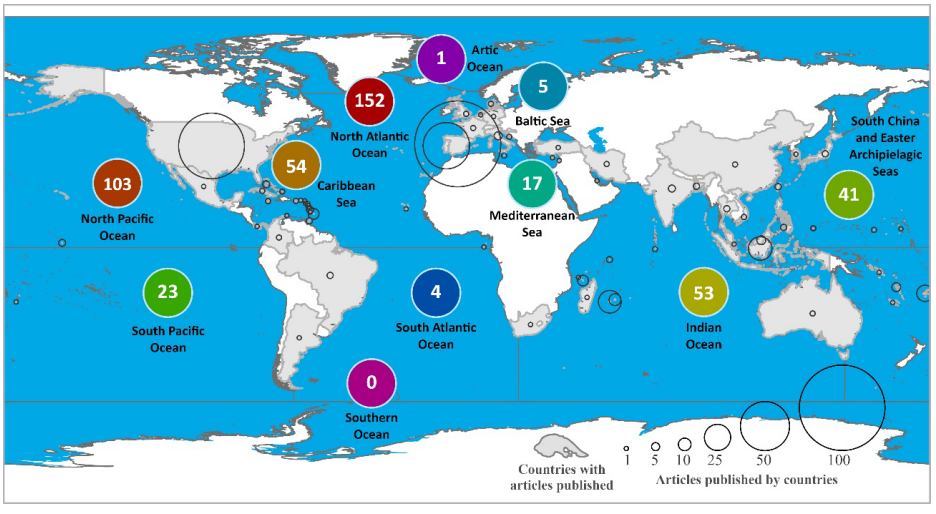


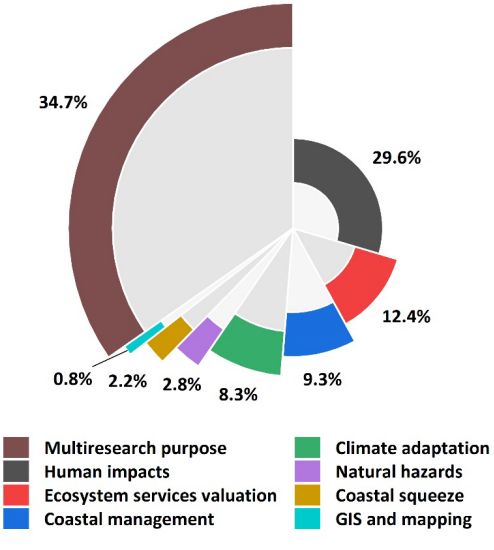
Figure 4 Papers published by oceans and countries (see online version for colours)



3.2 Typology and overview of the anthropogenic threads and pressures studied

Figure 5 illustrates the proportional distribution of the research purposes of the papers reviewed. Studies that shared two or more objectives are the most numerous, representing 34.7% of the papers reviewed, followed by papers focused on direct human impacts (29.6%). Papers related to the assessment of ecosystem services (12.4%) and coastal management (9.3%) were in third and fourth place, respectively. Finally, papers based on the study of climate adaptation (8.3%), natural hazards (2.8%), coastal squeeze (2.2%), and those focusing on GIS and mapping (0.8%) were in fifth, sixth, seventh and eighth place, respectively.

Figure 5 Research purpose of the published papers (see online version for colours)



Multi-objective studies can incorporate numerous aspects of interest for ICZM in small islands. Thus, there are many papers that assessed the impact of both ecosystem services and human activities on coastal management (Abdulla and Naser, 2021; Adrianto et al., 2021; Rabassó and Hernández, 2015). This encourages the treatment of environmental issues together with human impacts in an integrated and holistic manner, avoiding undervaluing fundamental aspects and allowing global assessments of specific coastal environmental problems in small islands. By way of example, Sealey et al. (2014) paid special attention to the protection of biodiversity, showing the usefulness of a comprehensive coastal impact assessment to facilitate marine sampling, water quality monitoring and coastal management. The specific study of human impacts involves assessment and quantification work to address issues such as:

i biotic homogenisation (Gizzi et al., 2020)

ii seawater intrusion (Aris et al., 2012) or

iii change in land uses (Van Rees and Reed, 2014, 2018).

The importance of assessing and analysing these impacts lies in the need to obtain accurate information and propose future conservation, remediation or mitigation strategies (Sanromualdo-Collado et al., 2021; Zhu et al., 2021).

Likewise, the assessment of ecosystem services can reinforce the diagnosis of the conservation status of particular natural habitats, evaluating their carrying capacity or vulnerability to possible external impacts or activities. Examples of this can be found in studies on:

i marine ecosystems, assessing the behaviour of dolphins, where knowledge of movement patterns was needed to define zones of protection from interaction with human activities (Stack et al., 2020)

ii intertidal ecosystems, analysing the state of mangrove biodiversity for their conservation (Ribero et al., 2020)

iii shoreland ecosystems, studying the resilience of sedimentary systems to anthropic action (Marrero-Rodríguez et al., 2021)

iv paleogeographic reconstruction, recognising the impacts of climate change and anthropic actions on certain natural elements, with the aim of measuring the effects of future ecosystem transformations on, for instance, the evolution of limpets in the Madeira and Canary archipelagos (Sousa et al., 2021)

v the carrying capacity of a coastal environment, evaluating the effects of a socio-economic activity such as tourism on coastal ecosystems (Adrianto et al., 2021).

The papers dedicated to coastal management are mostly based on coastal zone management systems, with an emphasis on policy and governance evaluation and considering the relationship between the social and economic agents of maritime-terrestrial spaces and protected natural spaces.

Their orientation tends towards:

i the participatory process between administration and local stakeholders, such as the creation of an Integrated Coastal Management Zone (Ramsey et al., 2015)

ii remediation actions and technological improvements to restore ecosystems (Ng et al., 2013)

iii beach management (Peña-Alonso et al., 2019; Zheng et al., 2020)

iv waste management (Abdulla and Naser, 2021; Quintela et al., 2012).

Studies focused on adaptation to climate change and its impact on natural and urban environments of small island coasts have been mostly oriented towards analyses of the vulnerability and resilience of the natural and human elements of the coast in future scenarios (Hafezi et al., 2020b). An example can be found in the study by Keyzer et al. (2020) of coastal ecosystems as mitigators of sea level rise. As occurs in climate change studies, the reviewed papers related to natural hazards focus on the study of the vulnerability of human and natural systems to extreme events such as tropical storms (Krien et al., 2017). The reviewed papers on coastal squeeze were mainly oriented towards the analysis of coastal erosion and coastal geomorphology. Examples of these types of study can be found in Browning and Sawyer (2021), where coastal shrinkage in tropical islands was analysed, or in Porro et al. (2020), where strategies to mitigate coastal erosion were evaluated.

Figure 6 shows the distribution of the sources of environmental problems for the coasts of small islands studied in the reviewed papers. Climate change, as a human-induced process, is the most studied source of such environmental problems. The impact of climate change on specific natural or human elements accounted for 18.8% of the studies, followed by environmental policy (Sridhar et al., 2020; Tan et al., 2018) and tourism and recreation (Arefipour et al., 2022; Couce-Montero et al., 2015) with 16.6% and 14.9%, respectively. Impacts derived from biological transformations of the marine-terrestrial environments, such as the introduction of allochthonous species or pathogenic organisms (Ribeiro et al., 2019; Souto et al., 2018), accounted for 13% of the studies, while studies focusing on environmental problems caused by industry constituted 8.8%. (Afonso et al., 2018; Fonseca et al., 2013), were ranked fourth and fifth, respectively. The papers that focused on the effects on the coast of basic activities, such as agriculture (Van Rees and Reed, 2014), fishing (Sangil et al., 2013) or mariculture (Rabassó and Hernández, 2015), represented 8.6% of the studies. The study of the effect of certain coastal infrastructures on the coastal environment, such as water treatment plants (Capdeville et al., 2019) or port infrastructures (Riera et al., 2013), accounted for 8.1% of the papers reviewed The effects of marine litter were studied to a lesser degree, accounting for 3.9% of the papers (Rodríguez et al., 2020), the impact of human settlements (2.9%) (Perez-Hernandez et al., 2020), maritime trade (1.5%) (Cunha et al., 2017), extractive activities (1.5%) (Tolia and Petterson, 2005), and studies focusing on effects arising from the protection of natural areas accounted for 1.5% (Friedlander et al., 2014).

Figure 7 shows the percentage distribution of the elements affected by environmental problems. Ecosystems were the most studied elements, representing 42%, particularly in reference to marine fauna (51 papers) and flora (29 papers). Numerous studies were found that focused on:

i impacts on marine fauna, especially in relation to endangered species such as the whale shark (Diamant et al., 2018), or on coral reef (Eddy et al., 2021)

ii environmental impacts on marine ecosystems, including the reefs and fishery resources of Hawaii where pollutants and fishing pressure have been considered in detail (Foo et al., 2021)

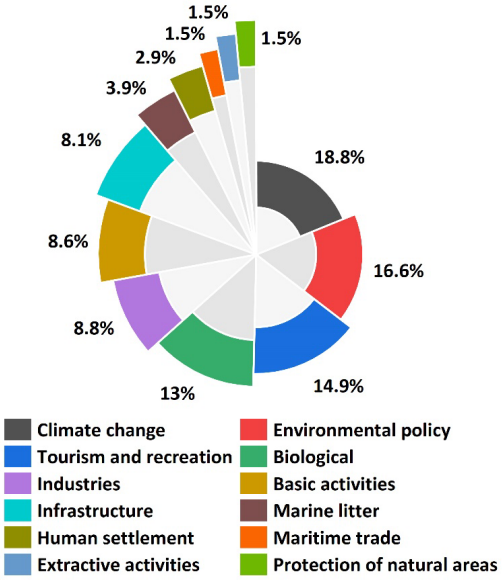
iii intertidal habitats, as in Sousa et al. (2019) where the evolution of limpets in the Madeira archipelago was addressed considering shell fishing pressure

iv freshwater or marsh habitats, as in Capdeville et al. (2019) who analysed the resistance of mangroves in Mayotte to anthropogenic disturbances

v marine water quality, as in the study by Montesdeoca-Esponda et al. (2021) which assessed the chemical effects of the use of UV filters in the bathing areas of Gran Canaria

vi aquifer conditions, including the work by Aris et al. (2012) on seawater intrusions on Manukan Island.

Figure 6 Distribution of the sources of environmental problems studied in the published papers (see online version for colours)



Studies that considered a mix of affected elements were in second place, representing 26.4% of the papers reviewed. Examples of this type of study could be found in the global analysis of changes in dune geomorphology, landscape and the socio-economic system in the south of Gran Canaria (Marrero-Rodriguez et al., 2020), where the effects of tourism development were studied. In third place, 13.8% of the studies focused on the social system or its adaptability to socio-environmental changes. These studies mainly concentrated on:

i systems of human adaptation to the future effects of extreme natural events, as studied in the Lesser Antilles (Hofman et al., 2021)

ii effects of coastal phenomena on human settlements (Mycoo et al., 2021)

iii impacts on human health, as in Reinold et al. (2021) who evaluated the ingestion of microplastics by fish and their introduction into the food chain

iv impacts on the socio-economic system, as in Rodríguez et al. (2020) where an analysis was conducted of the damage caused by marine litter to marine activities in the Azores

v the tourism system, studying the carrying capacity of the social and ecological system to sustain tourism activity, as in the case of the Tidung Islands (Adrianto et al., 2021)

vi management and conservation models of local and artisanal fishing systems in the face of industrial fishing pressure (Romero Manrique de Lara and Corral, 2017); or

vii coastal cultural heritage management (Blake et al., 2021).

Studies on the impacts on elements of the geomorphological forms and processes of the coast represented 8.7% of the papers reviewed. These included:

i changes in dune morphology, as in Marrero-Rodríguez et al. (2020) who analysed changes in dune geomorphology in Tenerife as a consequence of changes in land use

ii erosion processes on the coastline, as in Browning and Sawyer (2021) who assessed coastal degradation on tropical islands smaller than 5000 m^2

iii transformations in sandy beaches or creeks, as in Doorga et al. (2021) where the evolution of sand deposition on the coastline of Mauritius was monitored

iv the composition of the seafloor and near-shore terrestrial areas, as in Abreu et al. (2016) where the sedimentary characteristics and microbiological contaminants of the sandy bottoms of the Madeira archipelago were detailed.

In fifth place, studies focusing on policy-related legislative represented 8.5% of the reviewed papers. Examples of this type of study include Morin (2015), which discussed the agreements adopted by Pacific Ocean SIDS on tuna fisheries management, and Singh and Mee (2008) which analysed the legislative actions taken by Caribbean SIDS to address marine pollution issues and the management of marine activities. Finally, the impact on landscape elements was studied in only 0.6% of the papers reviewed. Examples of these types of studies that could be transferable to other territories include Quesada-Ruiz et al. (2019), where the territorial damage caused by illegal waste deposited in coastal environments was analysed, and Pedersen Zari et al. (2020), who set out the methodological requirements for the evaluation of urban development projects on the coast.

3.3 Methodological orientations

Although the consideration of an ICZM perspective is necessary in order to holistically integrate all the elements and entropies that affect the functioning of a coastal system (Mullard, 1995), it was only considered in 20.11% of the papers reviewed. In Arefipour et al. (2022), an assessment was made of the state of ICZM in the coastal communities of northern Cyprus, and in Milanés Batista et al. (2020) consideration was given to aspects of citizen participation in ICZM in Cuba. Only 5.12% of the reviewed papers undertook a global classification of anthropogenic impacts on the coast. Such an exercise may be

necessary as a preliminary step before assessing the degree of conservation and the measures needed to ensure the balance of the maritime-terrestrial environment. An example of this type of classification can be found in Sealey et al. (2014), where an analysis was performed of the impacts on the Bahamian coastal environment of physical alterations, the destruction of uses, the invasion of species and the displacement of vegetation by constructions.

Of the papers reviewed, 39.64% carried out an exhaustive characterisation of specific impacts. In this regard, Steibl and Laforsch (2019) analysed the repercussions of different anthropogenic activities on coastal ecosystems, and Sanromualdo-Collado et al. (2021) considered the spatio-temporal impact of tourist facilities on dune ecosystems. The remaining 60.36% of the papers reviewed refer to the impacts in a cursory manner, avoiding in-depth discussions on the causes of the impacts and their effects on the different elements of the landscape and environment. On the other hand, 20.31% of the papers reviewed addressed a complete or partial literature review on specific anthropogenic conditions. Reviews of different environmental problems can be found in:

i Ugwu et al. (2021), reviewing publications related to the ingestion of microplastics by marine biota and their presence in archipelagic environments

ii Polido et al. (2014) who considered studies that focused on the evaluation of environmental strategies in small islands

iii Delgado and Riera (2020), who compiled a list of publications focused on human impacts on oceanic islands

iv Davenport and Davenport (2006), who illustrated the impacts of ecosystem transformations on coastal tourism activity.

Figure 7 Elements affected (see online version for colours)

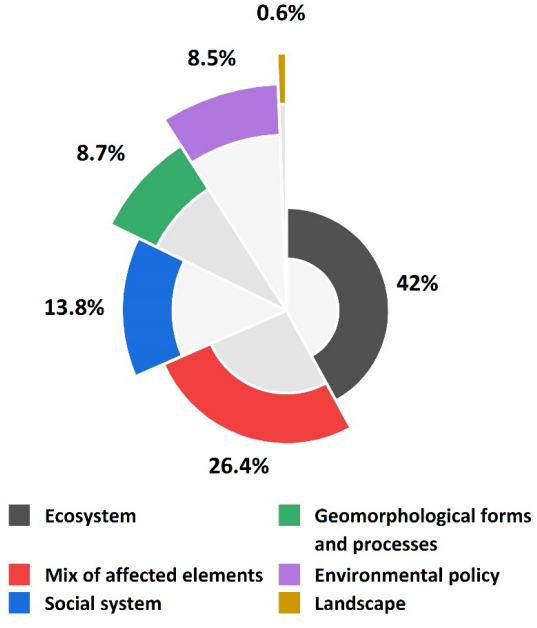


Figure 8(a) shows the distribution of the scale of the study area in the reviewed papers. Papers focusing on the local level (Longépée et al., 2021; Schäfer et al., 2021) were the most numerous (241), followed by those focusing on the regional or archipelagic level (113), as in Onat et al. (2018b) which analysed the erosion of beaches in the Hawaiian archipelago. In third place were papers on an international scale (100), such as those that compare specific anthropogenic impacts between different islands or archipelagos, as in Brodie et al. (2020) where anthropogenic impacts on seagrasses in Pacific SIDS were assessed. In fourth place, papers at the national level (55) were identified. These usually worked with comparisons between continental and archipelagic areas, as in Martín-Lara et al. (2021) who analysed the degree of plastic pollution on continental and archipelagic coastal areas in Spain The prevalence of local papers may suggest a coordination deficit in human and physical resources among archipelagic and/or national scientific institutions, leading to a scarcity of studies with a broader, international perspective that jointly assess small islands' problems. Figure 8(b) shows the type of island studied according to its political or territorial status. The ORs of the EU were the islands with the largest presence in the papers reviewed. Despite the fact that the number of OR archipelagos is much smaller than the number of SIDS or small islands belonging to other states. This may be largely due to the protective interest in environmental matters that the EU has in ORs (EP, 2017).

Figure 8 Scale of the studies analysed (see online version for colours)

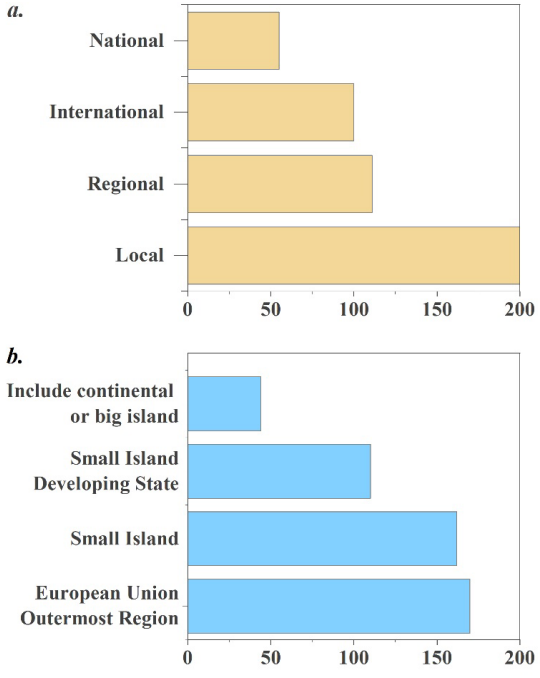


Figure 9 illustrates how studies on small islands have mainly focused on coastal ocean waters, followed by ICZM, intertidal habitats, shorelands, coastal waters, coastal uplands, inland areas and finally coastal-influence ocean waters. In this regard, the coastal ocean

waters, as areas of geographical influence affected by human activities (Andrés et al., 2018), were markedly more emphasised much more relevant considering the number of studies of studies than the other area of influence, the coastal uplands. Althought many studies included both areas of influence in ICZM, it's noteworthy that, comparatively speaking, less emphasis was given to the environmental problems associated to coastal uplands that directly affect ICZM than to those related to coastal ocean waters, intertidal habitats, shorelands or coastal waters. Regarding the temporal scope of the studies (Figure 10), 63.5% of the papers reviewed considered study periods of less than 1 year, followed by those between 1 and 10 years (15.6%), more than 50 years (9.7%), between 21 and 50 years (6.7%); and between 11 and 20 years (4.5%). In this regard, the large number of studies using data of less than one year is perhaps indicative of:

i a lack of information or resources to work with longer periods; or

ii the urgency of certain studies that may be limiting the temporal scope of the analyses (Mycoo et al., 2021).

The consideration of longer study periods, in principle, allows more accurate environmental diagnoses and assessments which, in turn, serve to highlight the need for more exhaustive and longer-term monitoring of certain activities or anthropic impacts on coastal systems (Marrero-Rodríguez et al., 2020).

Figure 9 Type of coastal area analysed. Integrated coastal zone management (ICZM) corresponds to the global joint consideration of intertidal area, shoreland and coastal waters (see online version for colours)

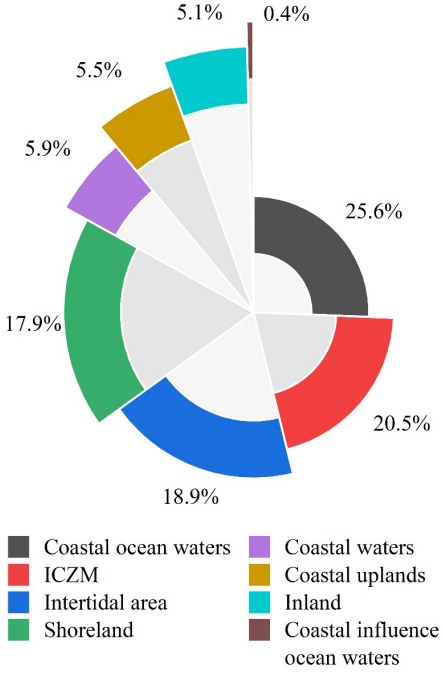
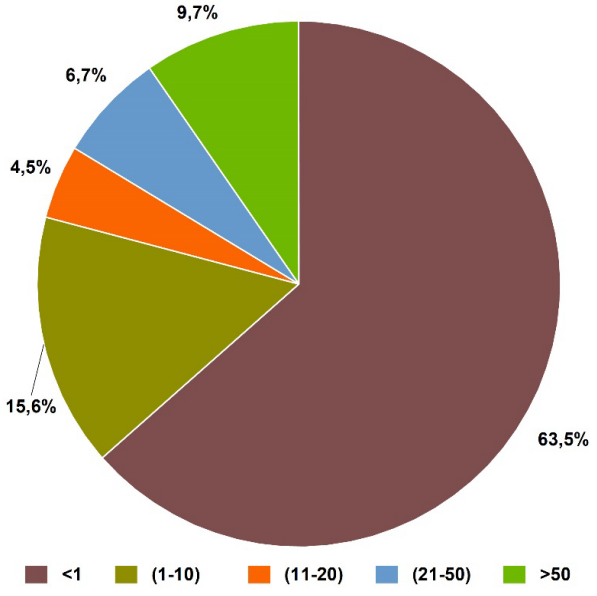


Figure 10 Period studied by the papers reviewed (see online version for colours)



4 Conclusions

Publications on environmental problems on small islands have risen to prominence since the mid-1980s. After selecting 507 papers in WoS and Scopus, 402 were discerned to be published since 2010. The number of publications diverges based on the geographic region in focus, with North Atlantic Ocean and North Pacific Ocean islands being the most studied. Spain and the USA are the countries where most analyses originate from. Regarding research objectives, studies with two or more objectives dominated, constituting 34.7% of the papers reviewed, succeeded by those concentrating on human impacts (29.6%) and ecosystem services (12.4%). Despite limitations in literature search, climate change was the most studied source of environmental problems, representing 18.8% of the researches. The repercussions of environmental policy, alongside tourism and recreation, were the next in line in terms of significance, succeeded by influences stemming from biological alterations of the marine-terrestrial environment. The impact on the coast of industry and basic activities such as agriculture, fishing or mariculture, along with the effect of certain coastal infrastructures on the coastal environment, received relatively sparse attention during the literature review study period. Moreover, the impacts of marine litter, human settlements, maritime trade, extractive activities or the extent of positive or negative effects arising from the management of protected natural areas have yet to undergo thorough examinations. The study of ecosystems perceived as principal entities influenced by environmental problems accounted for 42% of the papers reviewed, with marine flora and fauna the elements most often considered. Studies focused on a mix of affected elements accounted for 26.4% of the papers reviewed, subsequently by those centering on facets of the social system, geomorphological forms and processes, and environmental policies. Additional methodological perspectives gleaned from the review process revealed that:

i a mere 20.11% of the scrutinised papers incorporate ICZM

ii only 39.64% of the studies reviewed provided an exhaustive characterisation of specific impacts

iii small island coasts were analysed in most instances, and were examined solely at a local scale

iv coastal uplands, as areas of geographical influence affected by human activities, were notably less emphasised in studies compared to another influential area, the coastal ocean waters

v the application of data-driven and simulation models in addressing environmental coastal issues remains notably sparse.

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Compulsory brief authorship statement

LQR conceptualised and devised the review process. All authors supervised the work. All authors discussed the results. LQR wrote most of the original draft. All authors reviewed and edited the manuscript.

Supplementary material is available on request from the corresponding author, Lorenzo Carlos Quesada-Ruiz.

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