Coastal urban ecology systematic review: Research gaps, challenges and needs

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1 Abstract

Coastal urban areas have dramatically increased during the last decades, however, coastal research integrating the impacts and challenges facing urban areas is still scarce. To examine research advances and critical gaps, a systematic review of the literature on coastal urban ecology was performed. Articles were selected following a structured decision tree and data were classified into study disciplines, approaches, type of analysis, main research objectives, and Pickett's paradigms in-, of-, and for- the city, among other categories. From a total of 237 publications, results show that most of the research comes from the USA, China, and Australia, and has been carried out mostly in large cities with populations between 1 and 5 million people. Focus has been placed on ecological studies, spatial and quantitative analysis and pollution in coastal urban areas. Most of the studies on urban ecology in coastal zones were developed at nearshore terrestrial environments and only 22.36% included the marine ecosystem. Urban ecological studies in coastal areas have mainly been carried out under the paradigm in the city which is consistent with the focus on disciplines of biology and ecology. Results suggest a series of disciplinary, geographical, and approach biases which can present a number of risks. Foremost among these is a lack of knowledge on social dimensions which can impact on sustainability. A key risk relates to the fact that lessons and recommendations of research are mainly from developed countries and large cities which might have different institutional, planning and cultural settings compared to developing and mid-income countries. Scientific research on coastal urban areas needs to diversify towards an ecology of and for the cities, in order to support coastal development in a diversity of countries and settings.

2 Introduction

The world's population is increasing annually. In 2018, 55% of the human population lived in urban areas. Cities have been constantly growing in number and size, forming large megacities with 10 million inhabitants or more (United Nations 2018). The high levels of urbanisation during the last decades have triggered increasing research and policy interest on the impacts and sustainability of these human-dominated ecosystems (Grimm et al. 2000, Griggs et al. 2013). Initial research hypothesized urban areas were not able to sustain wildlife and complex ecological processes. However, this began changing in the first part of the 70's when urban ecology began studying species distributions in cities and its drivers (Noyes & Progulske 1974, Dorney et al. 1984, Sukopp 1998; Grimm et al. 2008). Since then, urban ecology research topics have evolved to include ecological and social science approaches (Grimm et al. 2000) and currently, urban ecosystems are recognized as a complex coupling of ecological processes and human dynamics, as defined by Alberti 2008 and Pickett et al. 2008. Research on urban ecology is diverse and includes studies on biodiversity patterns (e.g. urban biodiversity in Faeth et al. 2011; biotic homogenization in McKinney 2006), species distributions (e.g. birds in Marzluff 2001), ecosystem functions (Groffman et al. 2004, Rosenzweig et al. 2018), development processes (e.g. Antrop 2004), drivers of change (e.g. Grimm et al. 2008), ecosystem services (Bolund and Hunhammar 1999, Daily 2003), human wellbeing (Pacione 2003, Van Kamp et al. 2003, Dallimer et al. 2012), social-ecological systems (Barthel et al. 2010, Grimm et al. 2013), and sustainability (Wu 2008, Wu 2014).

Pickett et al. (2016) introduced three phases in the way urban ecology has evolved. They provide a typology of paradigms for urban ecology, which are termed: in, of, and for the city. Each one of these paradigms exposes historical differences according to changes in urban ecology research, and resulted by the comparison of three variables: chronology, model approach, and complexity. Studies under the paradigm in the city fall mainly into using ecological approaches, studies of the city are mainly based on social-ecological interactions, and studies for the city represent research about environmental policies and planning. The urban ecology paradigms also represent increasing level of complexity of the system studied, where research which subscribe to the of the city paradigm include interdisciplinary research; the urban ecology for the city is more intricate and includes in and of the city studies, engaging scientific knowledge in practice for action (Pickett et al. 2016).

Most of the theoretical and empirical developments in urban ecology have used green areas (e.g. Chiesura 2004, Tzoulas et al. 2007, Wolch et al. 2014), freshwater streams (e.g. Allan et al. 1997, Paul & Meyer 2001, Walsh et al. 2005), and organisms such as birds (e.g. Blair et al. 1996, Chace & Walsh 2006) or plants (e.g. Ulrich 1984, Donovan & Prestemon 2012, Donovan et al. 2013) as their preferred research subjects. Coastal settings and species have not received the attention they deserve, and only 5% of urban ecology research in Web of Science is focused in coastal or marine ecosystems. This is unfortunate because coastal cities present a variety of environments, including the land-marine ecotone interaction, and they are an important place for people to settle (Weinstein 2009). According to the United Nations in 2017, 40% of the world's population live less than 100 Km from the sea, and these cities have increased their population 6.6 times between 1945 and 2012 (Barragán and Andrés 2015). These factors and specific features such as interactions with watersheds in estuaries, the establishment of structures as ports (Cadenasso et al. 2006), and the social importance of access to the waterfront (Sairinen and Kumpulainen 2006) reflect a particular vulnerability for coastal urban areas. During the last decades, studies on risks have increased due to predicted changes in winds, waves or sea-level rise due to climate change (Benveniste et al. 2019, Torresan et al. 2008, Kumar et al. 2010). Despite recent interest on vulnerabilities, research has mainly focused on geomorphological contexts.

This article reviews scientific publications of coastal urban ecology with the aim of examining spatial and temporal changes in time and evaluating the evolution of urban ecology in these vulnerable areas through identifying the interconnection in existing literature given by the urban ecology paradigms (Pickett et al. 2016). Here, studies are classified according to theoretical and empirical dimensions of urban ecology. Biases in the literature are highlighted as a way to call attention to the needs for developing coastal urban ecology studies that can inform ongoing urbanization trends, especially in developing and mid-income countries.

3 Methods

A systematic review of the literature was performed through the Web of Science database (https://webofknowledge.com/). Eligibility criteria included any publication following keywords in the topic: ("urban ecology" or "urban environment") and (coast or marine), where words as "environment" and "coast" were truncated to use their derivations. The period of the search included from 1975 until December 2019. Selection of articles was made with a decision tree (Fig. 1), where the urban centre, marine studies, and biodiversity approach had to be checked for any articles to be included. Fulfilling the requirement for inclusion, publications were classified in ecology in the city, ecology of the city or ecology for the city following the paradigms established by Pickett et al. (2016). Grey-literature was not incorporated in the selection.

Each article collected was categorized by publication year, author's name, type of publication, author's affiliation country, study country, and study city. After examinig each paper they were categorized according to disciplinary focus, study approach, type of analysis, main research object, study model, and coastal environment. A list of categories, their definitions and example references can be found in Table 1. Articles were classified by two of the authors independently. Results were then compared and discrepancies resolved with the participation of a third author.

City's population data were obtained from the United Nations (2019) compendium. Urban centres classification was modified from the United Nations (2014) and Barragán and Andrés (2015). This classification includes: 1) Non-urban areas, which have less than 100,000 inhabitants, 2) small cities, between 100,000 and 500,000 inhabitants, 3) medium cities, between 500,000 and 1 million, 4) large cities, between 1 and 5 million, 5) very large cities, between 5 and 10 million, and 5) megacities, with more than 10 million.

Characterization of articles according to urban ecology paradigms included the number of studies found for each paradigm, countries, year of publications, disciplinary focus, research approach, type of analysis, and main research objective. To examine the interaction among articles´ paradigms, we analysed the co-citations to other articles in our data base using the web of Science database, and carried out a network analysis. The analysis included extracting every reference from each article that was selected in this review and the selection of cited articles that were already part of the article selection. Consequently, there was a tagging for each article cited with corresponding paradigm classification and these were plotted to unveil the relationship among paradigms used.

Classification, data analysis, and figures were prepared in R (R Core Team 2020) using RStudio (RStudio Team 2019). For data analysis, packages tidyverse (Wickham 2017a), dplyr (Wickham et al. 2017), purrr (Henry and Wickham 2017), broom (Robinson 2017), and stringr (Wickham 2017b) were used. Graphs and maps were plotted with ggplot2 (Wickham 2009) and gridextra (Auguie 2016). Network analysis was developed with package bibliometrix (Aria and Cuccurullo 2017), which allowed modifications in the code to create a new relationship between articles and their co-citations.

4 Results

4.1 Coastal urban ecology tendencies

Coastal urban ecology studies that met selection criteria included a total of 237 articles from 51 countries, involving 137 different coastal cities. Most of the research was carried out in three countries: USA presenting 38 articles published, which included 20 different cities, China with 20 articles from 10 different cities, and Australia also with 20 articles, including 10 different cities (Fig. 2). The timeline of publications shows that urban ecology in coasts appeared for the first time in 1979, however, it was not until 1995 that another study related to the field was published. Between 1995 and 2005, the number of publications was below five articles per year (Fig. 3). After 2005 more articles can be found, particularly in years 2016, 2018, and 2019, which showed more than 20 publications per year. According to the type of publication found at the Web of Science database, publications are mostly journal articles with 84.97% of the total, proceedings papers represented 9.7%, indexed book chapters 2.11%, and reviews 2.11%.

General aspects and tendencies since 1995 are shown in Figure 3. The main disciplinary focus of research has consistently come from ecology with an average representation of 48.79% of studies for the whole study period. Social-ecological studies came second (24.47%), research in this discipline has remained relatively constant during the years (an average 2.2 publications per year between 2005 and 2009, a 4.4 between 2010 and 2014, and a 3.8 between 2015 and 2019; Fig 3a).

Coastal ecology research has mainly considered spatial approaches searching for patterns based on differences in urban morphology (Mgelwa et al. 2019, Kantamaneni et al. 2019, Heery et al. 2018, Hosannah et al. 2014, Schwartz et al. 2013) and have increasingly included temporal dimensions (Fig. 3b). Quantitative studies have dominated the literature during the past 20 years and modelling studies which include simulation of urban conditions, have begun to emerge in the past six years (Fig. 3c). When looking at the main research objectives it is interesting to note that the study of pollution and human impacts have dominated the literature (Fig. 3d). These articles mainly focus on the effects of stressors over coastal urban ecosystems and cities. Habitat use and city design are less frequent, but they have been increasing in the last 10 years.

According to study models, a significant number of publications focused on physical aspects (48.10%) such as pollutants and risk towards natural hazards (Fig. 4). The second most frequent study model was biological, centred on specific species (21.94%). In this group birds were the most studied, followed by invertebrates (marine and terrestrial) and plants, leaving other marine species such as fishes and algae behind. Studies centred on ecosystems, social and social-eco-technological systems showed fewer articles published (less than 10).

Most of the articles published in coastal urban ecology have been developed in large cities of 1 to 5 million inhabitants (41%), while other city categories do not exceed 18%. More than 55% of articles were carried out in cities with more than 1 million people, including very large cities and megacities with more than 10 million people. Coastal areas with less than 100,000 inhabitants presented only 10% of articles.

Research in coastal urban ecology has focused mostly in near-shore terrestrial environments, presenting more than 68% of articles. Intertidal areas presented 17.30% of the publications, near-shore coastal benthic a 3.38%, and those pelagic environments near the coast only 1.69%. Coastal atmosphere showed 8.86% of total articles published.

4.2 Coastal urban ecology in, of, and for the city.

Paradigms in, of, and for the city have been addressed globally (Fig. 5). The focus in the city is represented in more than 60% of articles, including 37 countries. The US showed the highest number of articles with 29 publications. The focus of the city is shown at a lower percentage than the previous paradigm, with 20.25% of publications and performed in 21 countries. The US also dominated this paradigm with 9 articles. Research addressing the for the city paradigm represented 19.41% of total articles and came from 25 different countries. China presents six articles, which is the highest number of papers in a country which addresses this paradigm.

Paradigms in, of, and for the cities have shown differences, not only in the total number of articles published (143, 48, and 46, respectively) but also in their first year of publishing and subsequent tendencies (Fig. 6). In this way, it is not until 2004 that the paradigm for the city appeared in coastal urban ecology studies. Before that, the paradigm in the city (since the beginning in 1979) dominated this research area, with some occurrence of the paradigm of the city since 1997. The three paradigms show to be increasing in the number of publications during the last decade, although the paradigm in the city is doing it faster than the others.

Evidence suggests that the three paradigms are different according to disciplinary focus, research approach, type of analysis, and the main research objectives presented in their articles (Fig. 7). As expected, categorization by discipline showed that the paradigm in the city is mostly focused in ecological research, the paradigm of the city in socio-ecological research, and paradigm for the city in environmental policies, and also some social-ecological and social policies. Research approaches are similar among paradigms, the spatial approach of studies is the most common, followed by spatio-temporal approach. Experiments and the interplay with temporal approaches are poorly represented in coastal urban ecology studies. Studies in the city presented mostly quantitative assessments, however, studies presented under paradigms of and for the city showed similar proportions between quantitative and qualitative analysis. The paradigm of the city has centred research on themes related to human adaptation, being this topic also taken by paradigm for the city added to city design, a consequence of the predominant focus on policy and planning implications of these studies.

When analysing the whole database of coastal urban ecology articles, only 34 publications showed connections among citations, presenting a total of 24 interactions (Fig. 8). These interactions varied in strength from one article citing a single article of the one included in our study, two cited the same article (Chen et al. 2018, Lopes et al. 2011), three cited the same article (Shepard et al. 2016, Washburn et al. 2013, Campbell 2010), or four cited the same article (Leclerc and Viard 2018, Heery et al. 2018, Bertocci et al. 2017, Bugnot et al. 2019). Network analysis showed a marginal interaction among articles' paradigms. Here the paradigm in the city cited only seven in the city articles from a total of 16 citations, the paradigm of the city quoted three articles in the city and one of the city from a total of seven citations, paradigm for the city cited only one article under the paradigm of the city. These results suggest that coastal urban ecology article citation have a subtle connection among publications, and it is not reinforced when the three paradigms are considered.

5 Discussion

Coastal urban ecology encompasses a diversity of disciplines and research models aimed at understanding the links between the natural and built environments. Results show that coastal urban ecology has focused primarily on ecological studies and those studying physical characteristics of urban centers in coastal areas, dominated by research on pollution. However, there is an increasing

contribution of studies on social dimensions. Studies that address coastal urban ecology from an in the city perspective have significantly increased during the last three decades. Interestingly, results show that coastal urban ecology is beginning to address issues which relate to planners and policy makers through some key studies on green infrastructure (Chen et al. 2015, Zhang et al. 2016, Conticelli and Tondelli 2018), eco-cities (Surjan and Shaw 2008, Wong 2011), and sustainable cities (Pizarro 2008, Song et al. 2016, Arif 2017). Despite the diversity of research on coastal urban ecology, there are still important geographic and disciplinary gaps in research foci.

Coastal urban ecology research has drawn from ecological studies more than any other discipline (Fig. 3). Even when it seems that social dimensions have been integrated slowly during the years under the knowledge of human-nature coupling (Liu et al. 2007a, Lui et al. 2007b) and the importance to include people and their relationship with the urban environment (Redman et al. 2004), interdisciplinary studies are still infrequent. An interesting interdisciplinary line of research is emerging associated with designing new infrastructures in coastal cities aimed at the provision of sustainable alternatives as new habitats for protection and even promotion of biodiversity (Kates et al. 2001, Perkol-Finkel et al. 2018, Burt & Bartholomew 2019). However, these interdisciplinary efforts have been performed in a few coastal areas (Morris et al. 2019), showing similar geographical bias.

Coastal urban ecology has centered mainly in understanding spatial patterns and variability, showing a bias towards short time scale research (Fig. 3). Consequently, there is a shrotfall in long-term dynamic perspectives in the study of coastal cities. Results show research is also biased towards quantitative approaches with few qualitative analyses (e.g. Giovene di Girasole 2014, Cleland et al. 2015, Guerrero et al. 2018, Villagra et al. 2016). This supports the results which show little social science research based on methods such as grounded theory or ethnography, among others (Creswell et al. 2007). Coastal urban ecology would benefit from encouraging these long-term and disciplinary dimensions.

Many coastal urban ecology studies focus on pollutants. The focus on pollution has been maintained during the whole period analysed, with 35% of total articles dealing with this issue. Accordingly, the effects of urbanization over sea breeze and the reactions of aerosols have had an important increase in this line of research (Castro et al. 1999, Mejia & Morawska 2009, Shanquan et al. 2016, Pushpawela et al. 2018). A predominant focus on pollution is not difficult to understand in coastal urban ecology given urbanization and increases in CO2 emissions (Cole & Neumayer 2004). Water pollution also has an important number of articles published (27.7% from the total of articles that mentioned pollution), considering marine (23 articles: e.g. Wang 2010, Noble et al. 2006) and river basin pollution (4 articles: e.g. Mgelwa et al. 2019, Abdul-Aziz & Ahmed 2019), both important elements in coastal environments.

Risk assessments towards natural disasters and particularly flooding represented approximately 18% of the studies (Fig. 4; e.g. Goh 2019, Patel et al. 2019), which were carried out mainly in the USA and Japan. Expansion of coastal cities undermine natural protection (Sherbinin et al. 2007), hence an increase in natural disasters and city's vulnerability (Chang & Huang 2015). While research has been performed in developed countries, developing ones are the most vulnerable in terms of natural disasters in coastal zones, such as flooding events (Ogie et al. 2020) or in specific areas under risk of tsunamis (Villagra et al. 2016). This same tendency is repeated in relation to studies which address mitigation strategies, with projections to make cities more resilient to natural disasters (Watson & Adams 2010, Serre et al. 2010, Aerts et al. 2014, Sutton-Grier et al. 2015, Morris et al. 2020) and even ecoengineered shoreline strategies as nature-based alternative design (Bergen et al. 2001,

Mitsch 2012, Morris et al. 2019, O'Shaughnessy et al. 2020). As a consequence, there is an urgent need to extend this type of research towards developing and mid-income countries.

Our review shows that research on coastal urban ecology has mainly focused in cities between 1 and 5 million people in 15 different countries. However, more than a half of articles have been performed in the USA, China and Australia (Fig. 2). While results from these specific studies can be important to develop theoretical frameworks and assess specific impacts, the focus on these high GDP countries makes it hard to extend insights to other cities in developing and mid-income countries, where growth dynamics, institutional support and adaptive capacity are very different (Chauvin et al. 2017, Nagendra et al. 2018). For example, urban concentration (when country resources are over-concentrated in one or two large cities, raising cost of production of goods) is described as part of country development, and decreases as income rises (Davis & Henderson 2003). This phenomenon is often presented in coastal cities, where there is a physical infrastructure capital. Urban concentration can be affected significantly by a range of political variables, including democratization, federalism, and whether a country was a former planned economy (Davis & Henderson 2003). We therefore strongly advocate for the need to support programs for coastal urban ecology research in these settings. Research in cities smaller than 1 million inhabitants would extend the variety of conditions in terms of the size of the human group, transitioning to bigger cities, and configuration of environmental variables, considering more than 70% of cities in the world have between 500,000 and 1 million inhabitants.

Research has been mainly performed in near-shore terrestrial environments, resulting in a lack of information in coastal-marine urban environments that reveals the limited integration in the coastal urban interface (seawater-land configuration and dimensionality). This bias can have negative consequences such as generating false dichotomies for conservation (Bulleri 2006), which can undermine the effectiveness and need for healthy marine ecosystems in urban areas (Bulleri 2006, Shochat et al. 2006). It is key to extend research on the interaction between marine and terrestrial realms associated with urbanization.

Results show that more than half of the reviewed articles can be classified as belonging to the paradigm in the cities. Studies contributing to this paradigm have been growing in number, faster than the others, during the last years (Fig. 6). This result synthesizes the main biases found in this review which relate to the predominant focus on ecological research, understanding urban impacts such as pollution, the non-human components, and in spatial and quantitative analysis (Fig. 7). Only 20% of the articles in coastal urban ecology focused on interdisciplinary research such as socio-ecological studies (included in the paradigm of the city). This represents an important research gap associated to the lack of social knowledge in a system where humans are both objects and subjects of urbanization, who use space to live, extract subsistence and non-subsistence resources, perform recreational activities, and deposit waste, among other activities (Weinstein 2009). Because of that, a lack of research on people with nature represents the loss of an integral part of the ecosystem (McDonnell et al. 1993, Rees 1997, Collins et al. 2000), decoupling human dynamics and ecological processes of this urban ecosystem (Alberti 2008). Lessons from urban ecology in other systems have shown the importance of transitioning towards these interdisciplinary dimensions. Accordingly, coastal research in urban areas must advance toward an urban sustainability-centred perspective, transdisciplinary in terms of focuses and approaches, with the ability to inform urban design and planning (Wu 2014). Current imbalance among paradigms and the lack of interaction among research paradigms undermine urban coastal sustainability.

While biophysical and ecological approaches to coastal urban systems are important, urban ecology necessarily operates in a human context. Therefore, coastal cities need to be seen from the point of view of people, their interaction with the environment and the implementation of concepts that contribute to sustainability in cities through public policies and planning. That is why more research is needed focusing on the three paradigms equally. In addition, better consideration of the diversity of cities, the integration across marine and terrestrial ecosystems, and the inclusion of developing country coastal urban areas will allow to support ongoing urbanization trends and cultural settings in coastal zones across the globe. Trans-disciplinary collaboration will provide the opportunity to fill these knowledge gaps.

Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Author Contributions

GG, NN, JC, and SG contributed to design of the study. GG and NN organized the database. GG performed the statistical analysis and wrote the first draft of the manuscript. SG, NN, JC, NL, PP, and PM wrote sections of the manuscript. All authors contributed to conception and manuscript revision, read, and approved the submitted version.

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Data Availability Statement

The datasets generated and analyzed for this study can be found in the CoastalReviewGit repository, https://github.com/GiorgiaGraells/CoastalReviewGit.

Figures

Figure 1. Decision tree of articles selected. Description of the selection process for articles in coastal urban ecology review. After four passes for selection filters, the remainig 237 studies where classified in 3 categories: ecological paradigms in, of, and for the cities.

Figure 2. Global distribution of publications. Articles in coastal urban ecology according to the city where the investigations were carried out, the population size of each city and the number of articles published in them. For each city the size of the circle is proportional to the number of articles published (from 1 to 7); the colour of the circle represents the size of the city given its population.

Figure 3. Temporal distribution of categories. Articles in coastal urban ecology were categorised according to disciplinary focus, research approach, type of analysis, and main research objectives.

Figure 4. Distribution of articles, according to study models of research. Coastal urban ecology models were grouped by Physical, Social-Ecological-Technological, Social, Biological-ecosystem, and Biological-species.

Figure 5. Contribution of countries by paradigms. Coastal urban ecology studies ascribed to Picketts's paradigms in, of, and for the city (presented in blue colours from light to dark); Countries that not present coastal urban ecological articles are show in grey.

Figure 6. Paradigms' temporal changes. Number of articles published considering paradigms in, of, and for the cities. Trend lines represent quadratic regression fit (in the city $R2=0.656$, $p< 0.001$, of

the city R2=0.382, p< 0.05, for the city R2=0.460, p<0.05); colour areas represent the 95% confidence interval.
Figure 7. Proportional contribution of categories. Articles in coastal urban ecology were categorised according to disciplinary focus, research approach, type of analysis, and main research objectives in coastal urban ecology studies ascribed to Picketts´s paradigms in, of, and for the cities.
Figure 8. Network analysis. Analisys for co-citations of articles presented in this coastal urban ecology review, considering the three paradigms proposed. Each dot represents a study and the colour indicates the paradigms (in, of and for the cities). Directed edges go from the article citing to the article being cited.

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Table

Table 1. Classification of articles in coastal urban ecology.

Category	Classification	Description	Examples
Disciplinary focus	Ecological	Study of relationships and interaction between organisms and their coastal urban environment.	Tait *et al. (*2005), Smith & Munro (2010).
	Social	Study of social behaviour, including its origin, evolution and organization within a coastal urban environment.	Abarca-Álvarez *et al. (*2018).
	Social-ecological	Study of interaction between humans and their coastal urban environment, using multidisciplinary approaches including anthropology, geography, sociology and ecology.	Dodman (2009), Cohen *et al.* (2013).
	Environmental policy	Study of the environment with a focus in organization, law, regulations or policy solutions.	Alcoforado *et al.* (2009), Vye & Rousseaux (2010).
	Social policy	Provides practical guidelines and principles to improve human welfare.	Guerrero Valdebenito & Alarcon Rodriguez (2018), Kuhnlein *et al.* (2003).
Study approach	Spatial	Focus on landscape, land cover or urban geomorphology changes.	Lim & Sodhi (2004), Cui & Yuan (2009).
	Spatiotemporal	Landscape, land cover or urban geomorphology changes, including some changes over time on small scale.	Li *et al.* (2011), Grossmann (2008).
	Temporal	Focus in changes over time.	Yu *et al.* (2019), Semadeni-Davies *et al.* (2008).
	Temporal	Focus in changes over time in a	Leclerc & Viard (2018),

	experiment	controlled environments and simulations.	Chabas *et al.* (2015).
	Experimental	Including all lab procedures.	Zhen *et al.* (2007), Charalambous *et al.* (2012).
Type of analysis	Qualitative analysis	Non-numerical descriptions and ethnographic studies.	Arif (2017), Gardner (2003)
	Quantitative analysis	Collection and evaluation of measurable data of either social or environmental aspects.	Yamazaki, *et al.* (2007), Videla & Herrera (2017).
	Modelling studies	Mostly computational simulations.	Kehl & de Haan (2013), Santos & Freire (2015).
Main research object	City design	Mainly urban planning.	Kantamaneni *et al.* (2019), Alcoforado *et al.* (2009).
	Demographic change	Variation in the population in terms of size, average age, life expectancy, family structures,or birth rates, among others.	Race *et al.* (2010), Abarca-Alvarez et al. (2018).
	Habitat use	Variation in the distribution of species within cities.	Lim & Sodhi (2004), Reyes-Lopez & Carpintero (2014).
	Human adaptation	People's reaction to urban changes and creation of new spaces	Weinstein (2009), Chen *et al.* (2015).
	Natural disaster	City's risks or damage associated to floods, hurricanes, storms, tsunamis, or another geophysical process.	Yin *et al.* (2016), Su *et al.* (2019).
	Pollution and human impacts	Effects of city growth and/or increase in urbanization as a measurement of contamination.	Ip *et al.* (2007), Arruti *et al.* (2011).
	Shoreline changes	New infrastructure in the shoreline, waterfronts and other constructions.	Wu (2007), Alberico *et al.* (2018).
Study model	Physical	Physical space comprises research with aerosol, geomorphological elements, land structures, meteorological elements, pollutants, remote sensing data, risk models, seawater, surface deterioration, and water resources.	Pollutants: Pallarés *et al.* (2019). Remote sensing: Peng *et al.* (2017).

	Social-ecological-technological.	Includes marine and green structures, eco-cities, and sustainable cities.	Marine structures: Gumusay *et al.* (2016). Eco-cities: Surjan *et al.* (2008).
	Social	Social space comprises bioclimatic comfort, demographic, human activities and culural heritage, perceptions, public health, and sustainable development.	Human activities and cultural heritage: Cleland *et al.* (2015). Perceptions: Nunkoo & Ramkissoon (2010).
	Biological-species	Biological in terms of studied organisms or their parts, including algae, antibiotics, bacteria, birds, fishes, invertebrates, lichens, mammals, and plants.	Birds: Belant (1997). Fishes: Naidoo *et al.* (2016).
	Biological-ecosystems	Biological in terms of studied ecosystems, including studies in diversity, ecological processes and patterns, ecosystems, and environmental management.	Environmental management: Tu & Shi (2006). Ecosystems: Branoff (2017).
Study habitat	Near-shore terrestrial	Includes dunes, coastal xeromorphic habitats, rocky and sandy shores, urban, agricultural and industrial landscapes in the coast.	Whisson *et al.* (2015), Watson (2015).
	Intertidal	Estuaries, deltas, mangrove forests, coastal lagoons, salt marshes, other coastal wetlands, marinas and ports.	Kuwae *et al.* (2016), Jonkman *et al.* (2013)
	Near-shore coastal benthic	Seagrass beds, artificial structures and soft bottom environments above the continental shelf.	Eddy & Roman (2016), Bolton *et al.* (2017).
	Coastal pelagic	Open waters above the continental shelf.	Zhen *et al.* (2007), Wang (2010).
	Coastal atmosphere	The aerial space.	Clarkson (1996), Dominick *et al.* (2018).

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