Coastal urban ecology: Research gaps, challenges and needs

Graells G1,2, Nakamura N3, Celis-Diez Juan L.5 Lagos NA4, Marquet PA, Pliscoff P, Gelcich S1,2

1 Pontificia Universidad Católica de Chile, Departamento de Ecología, Santiago, Chile.

2 Center of Applied Ecology and Sustainability (CAPES).

3 Australian Research Council Centre of Excellence for Coral Reef Studies, James Cook University, Townsville, QLD 4811 Australia.

4 Centro de Investigación e Innovación para el Cambio Climático, Facultad de Ciencias, Universidad Santo Tomás, Santiago, Chile

5 Pontificia Universidad Católica de Valparaíso, Escuela de Agronomía, Quillota, Chile.

Junio 2020

## Abstract

Coastal urban areas have dramatically increased during the last decades, however, coastal research integrating urban areas are 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 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 near shore terrestrial environments and only 22.36% included the marine ecosystem. Urban ecology in coasts has mainly performed research 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 dimension 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 very different institutional, planning and cultural settings in 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.

### In a nutshell:

• Population in coastal urban cities is increasing, however urban ecological research on the coast has lagged behind.

• A literature review on coastal urban ecology shows that while studies have been increasing, most focus on ecological aspects. Few studies target social-ecological interactions and environmental policy-planning.

• Studies are disciplinary, geographically, and environmentally biased.

• Addressing critical biases in coastal urban ecology research is key to inform ongoing urbanization trends, especially in developing and mid-income countries.

## 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 mega-cities 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 changed in the first part of the 70’s when urban ecology began studying species distributions in cities and its drivers (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 (Alberti 2008, 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), social-ecological systems (Barthel *et al.* 2010, Grimm *et al.*  2013), and sustainability (Wu 2008, Wu 2014).

Recently, 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 expose 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 complexity of the types of knowledge synthesised in the research questions. Studies which subscribe to the *of the city* paradigm contemplate 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 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. This is unfortunate because coastal cities present a variety of environments, including the land- marine ecotone interaction, and they seem to be one of the preferred places for people to settle (Weinstein 2009). According to United Nations in 2017, 40% of the world’s population live less than 100 Km from the sea, and these cities present only between 1945 and 2012 a growth of 6.6 times (Barragán and Andrés 2015). These factors and specific features as interaction with watersheads in estuaries, the establishment of structures as ports (Cadenasso *et al.* 2006), and the social importance of access to waterfront (Sairinen and Kumpulainen 2006), reflect a particular vulnerability for coastal urban areas. During the last decades, the risk has increased in front of winds, waves or sea-level rise due to climate change (Benveniste *et al.* 2019, Torresan *et al*. 2008, Kumar *et al.* 2010 ).

Accordingly, there is a need to synthesize urban ecology research that has been carried out on the coast and see if they have the approach that is needed. This article reviews coastal urban ecology scientific publications 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. 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 on the needs for developing coastal urban ecology studies that can inform ongoing urbanization trends, especially in developing and mid-income countries.

**Methods**

A systematic review of the literature was performed through the Web of Science (<https://webofknowledge.com/>). Eligibility criteria included any publication following keywords in 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 urban centre, marine studies, and biodiversity approach had to be checked for any articles to be included. Fulfilling the requirement to be a “coastal urban ecology” study, 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 in publication year, author’s name, type of publication, author´s affiliation country, study country, and study city. Categories that required further reading were 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 United Nations (2019). Urban centres classification was modified from United Nations (2014) and Barragán and Andrés (2015). This classification comprehends: 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. A map was made using this information and the total number of articles published under coastal urban ecology selected in this review.

Characterization of articles according to urban ecology paradigms included number of studies found for each paradigm, countries, year of publications, disciplinary focus, research approach, type of analysis, and main research objective. To examine interaction among articles paradigms through quotation, a network analysis was made with the information provided by Web of Science. The analysis included extracting every reference from each article that was selected in this review and the selection of quoted articles that were already part of the article selection. Consequently, there was a tagging for each article quoted with corresponding paradigm classification and these were plotted with the relationship among paradigm quotations.

Classification, data analysis, and figures were prepared in R (Team R Core 2018). 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.

## Results: Coastal urban ecology tendencies

Coastal urban ecology studies that met the defined keywords 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 with the type of publication found at Web of Science, 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 be included 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 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 (40%), while other city categories do not exceed 20% (Fig. 5). In general, cities with more than 1 million people tent to have more studies than expected. However, the large amount of “large cities” studies is countered by “small cities” under representativiy, given more than 70% of cities in the world correspond to this category.

Research in coastal urban ecology has focused mostly in near shore terrestrial environments, presenting more than 68% of articles (Fig. 6). Intertidal areas presented 17.30% of the publications, near-shore coastal benthic a 3.38%, and coastal pelagic environments only a 1.69%. Coastal atmosphere showed 8.86% of total articles published.

## Coastal urban ecology *in*, *of*, and *for the city.*

Paradigms *in*, *of*, and *for the city* have been addressed globally (Fig. 7). The focus *in the city* is presented 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 tendencies (Fig. 8). 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 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. 9). As expected, categorization by discipline showed that the paradigm *in the city* is mostly focused in ecological research, 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, spatial approach of studies is the most common, followed by spatio-temporal approach. Temporal approaches are generally lacking in coastal urban ecology studies. Studies *in the city* presented almost only 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, reflecting the 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. 10). These interactions where presented when one article quotes a single article, 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* quoted 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* quoted only one article under the paradigm *of the city.* These results suggest that coastal urban ecology article quotation have a subtle connection among publications, and it is not reinforced when the three paradigms are considered.

## 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 coasts, dominated by research on pollution. However, there is an increasing contribution of studies on social dimensions. Studies that address the coastal urban ecology from an *in the city* perspective have significantly increased during the last three decades. Interestingly, results show 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 the main focus of research.

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 to designing new infrastructures in coastal cities aimed at the provision of sustainable alternatives (Brundtland et al. 1987, Loucks 1994, Kates et al. 2001). However, these interdisciplinary efforts have been performed in few coastal areas (Morris et al. 2019), showing similar geographical bias identified here.

Coastal urban ecology has centered mainly in understanding spatial patterns and variability, showing a bias towards short time scale research (Fig. 3). Consequently, there has been a loss of a dynamic perspective in the study of coastal cities. This is unfortunate, as urban systems have been described as highly dynamic scenarios (Ramalho and Hobbs 2012) and coastal ecosystems are being threatened by urbanization, as well as sediment diversion and other activities (Constanza *et al.* 1990). Results show research is also biased towards quantitative approaches with few qualitative analysis (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 (Creswell *et al.* 2007). Coastal urban ecology would benefit from encouraging these dimensions.

Many coastal urban ecology studies focus on pollutants. The focus on pollution has been maintained during the whole period analysed, with a 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 boom in this line of research (Castro *et al.* 1999, Mejia & Morawska 2009, Shanquan *et al.* 2016, Pushpawela *et al*. 2018). Focus in 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 performed mainly in USA and Japan. Expansion of coastal cities undermine natural protection (Sherbinin *et al.* 2007), thus natural disasters relate to a 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, globally with flooding events (Ogie *et al.* 2020) or in specific areas with events as tsunamies (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 only 15 different countries. However, more than a half of articles have been performed in 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 fenomena is often presented in coastal cities, where there is a physiscal 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 of support programs for coastal urban ecology research in these settings. Research in cities smaller than 1 million inhabitants would extend the variation 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 (Fig. 5).

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 effect 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 to urbanization.

Results show 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. 8). This result synthesizes the main biases found in this review which relate to the focus on ecological research, understanding urban impacts such as pollution, the non-human components, spatial and quantitative analysis found in most of the articles reviewed (Fig. 9). 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 has 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 be applied through urban design and planning (Wu 2014). Current imbalance among paradigms and the lack of network of citation among articles must improve in urban ecology studies in coastal zones as a way for research framed under the different paradigms to effectively act as building blocks for improving urban coastal sustainability.

**Conclusion**

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. More research is needed focusing on the three paradigms. In addition, a 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 in coastal zones across the globe. Trans-disciplinary collaboration will provide the opportunity to fill these knowledge gaps.

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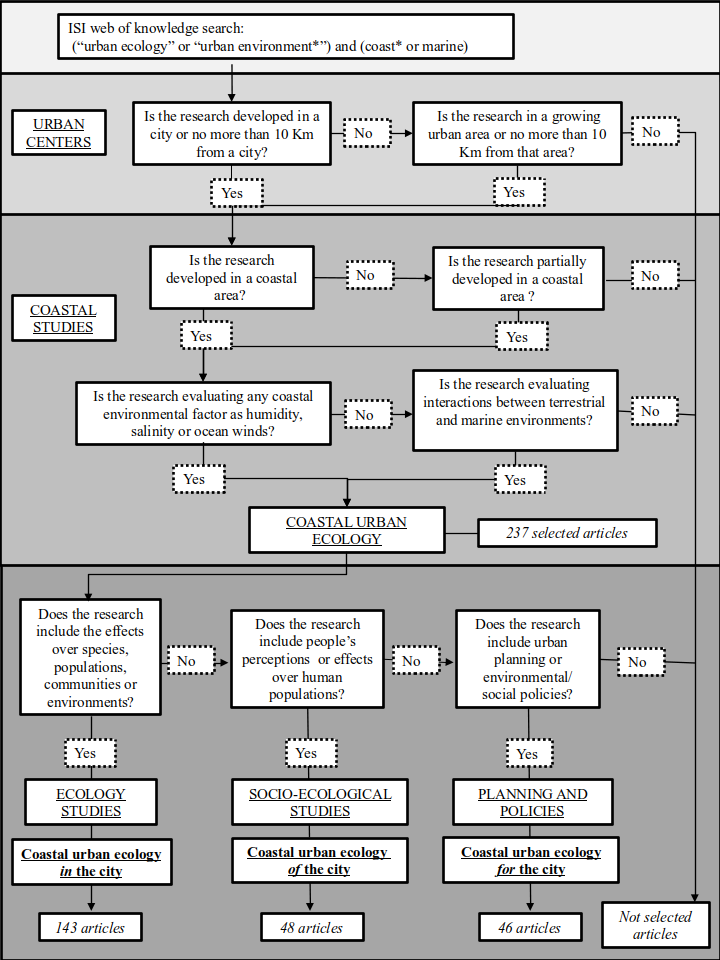
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**Tables**

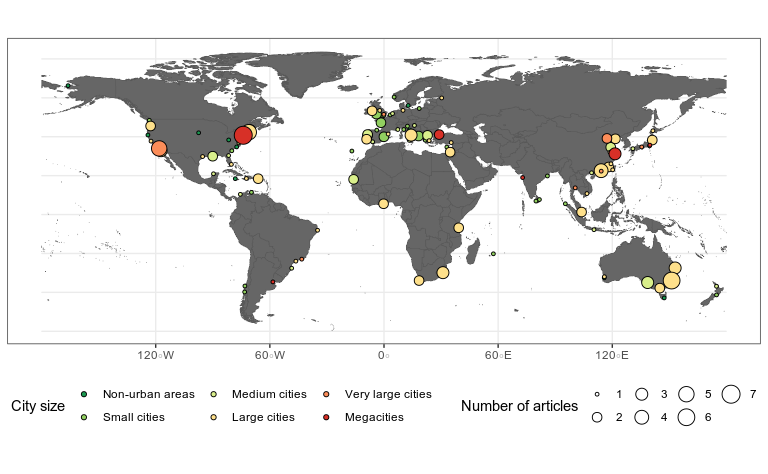
**Table 1.** Classification of articles in coastal urban ecology revision

|  |  |  |  |
| --- | --- | --- | --- |
| 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, multidiscipline including anthropology, geography, sociology and ecology. | Dodman (2009), Cohen *et al.* (2013). |
| Environmental policy | Study of environment, to organize, manage the laws, regulations or find a solution. | 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 geographical or urban morphology changes. | Lim & Sodhi (2004), Cui & Yuan (2009). |
| Spatiotemporal | Geographical or urban morphology 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 experiment | Focus in changes over time in a controlled environment and simulations. | Leclerc & Viard (2018), 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 | Collect and evaluation of measurable data. | 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 population. | Race *et al.* (2010), Abarca-Alvarez et al. (2018). |
| Habitat use | Variation in distribution of species. | 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 in front of floods, hurricanes, tsunamis, or another geologic process | Yin *et al.* (2016),  Su *et al.* (2019). |
| Pollution and human impacts | Effects of city growth as 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 culural 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, 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). |

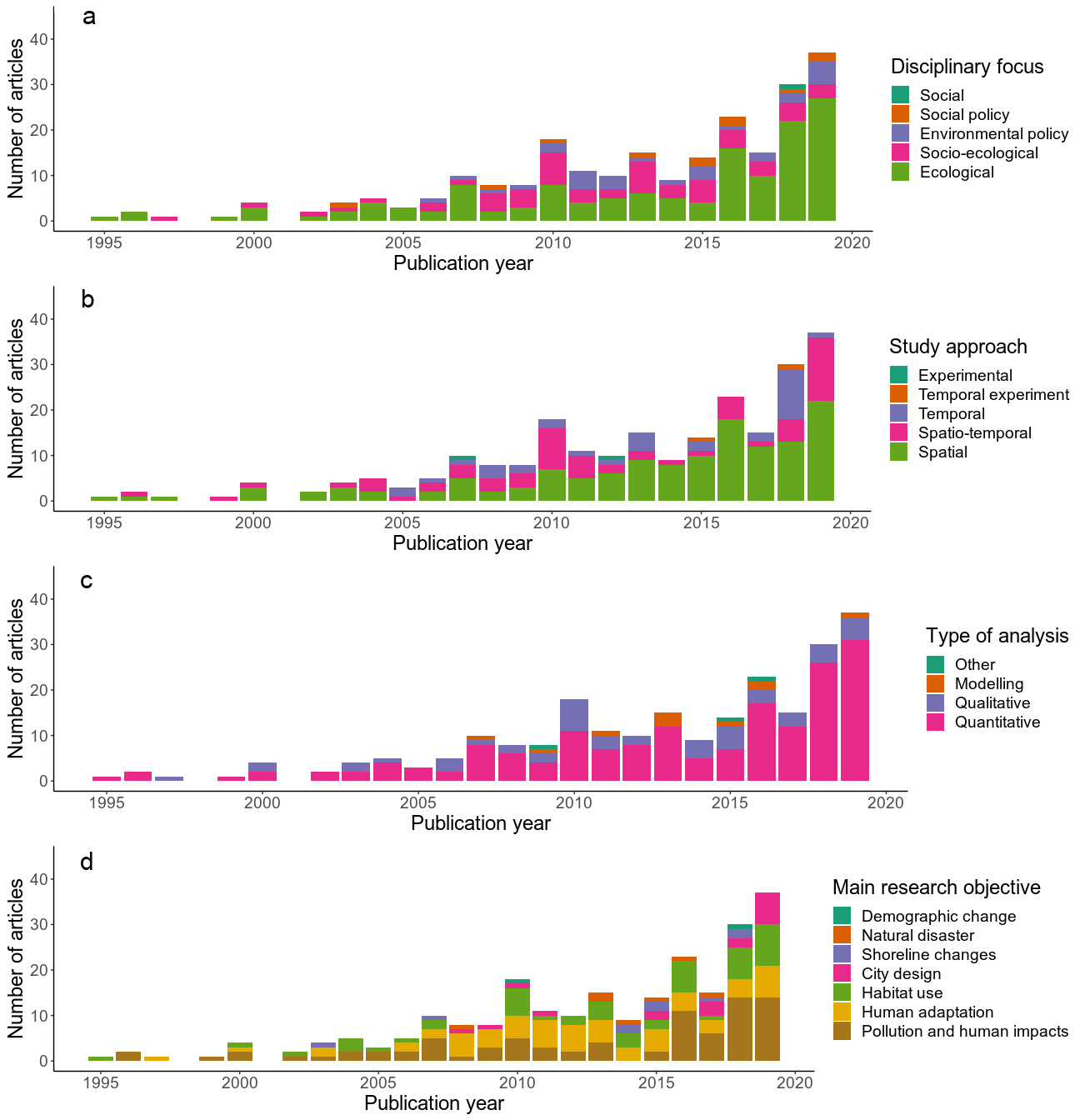
**Figures**



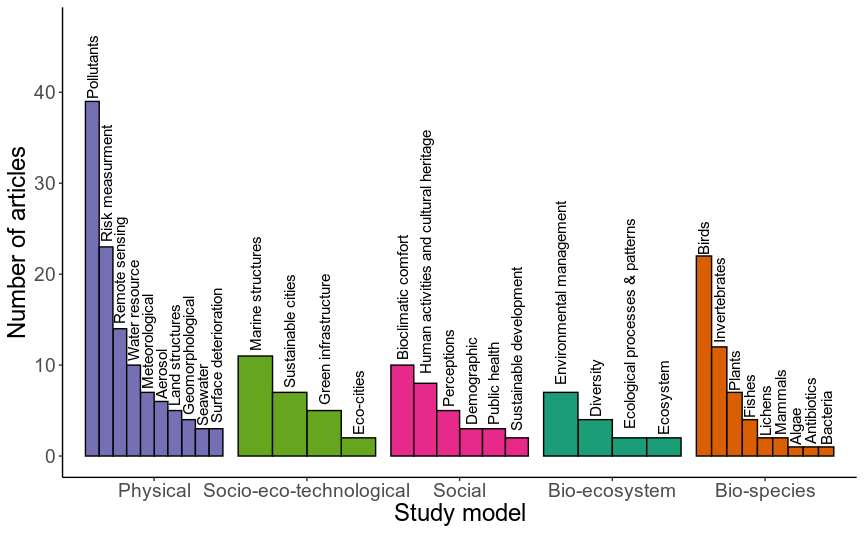
*Fig 1: Decision tree of articles selected for coastal urban ecology in literature.*

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*Fig 2. Map of the world where the articles published in coastal urban ecology are presented 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 represents the number of articles published (increasing size with the number of articles, from 1 to 7) and the colour of the circle represents the size of the city given its population (city’s population data were obtained from United Nations 2019 and urban centres classification was modified from United Nations 2014 and Barragán & Andrés 2015).*



*Fig 3. Distribution of articles during the years according to disciplinary focus, research approach, type of analysis, and main research objectives.*

Fig 4. Distribution of articles, according to study models of research: Physical, Social-Ecological-Technological, Social, Biological-ecosystem, and Biological-species.

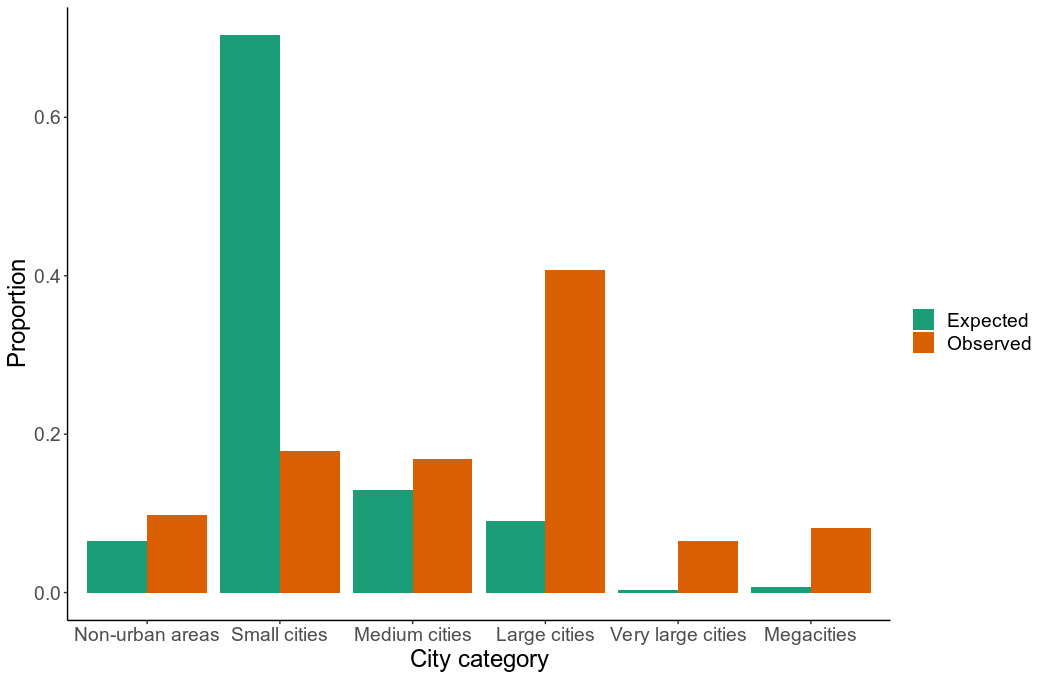


Fig 5. Proportions of cities by urban centres classification according to United Nations (2014) and Barragán and Andrés (2015) categories, and population data from United Nations (2019). Expected proportions indicates the number of cities in each category and observed proportions, the representation of articles mentioned in each city category found in this revision.

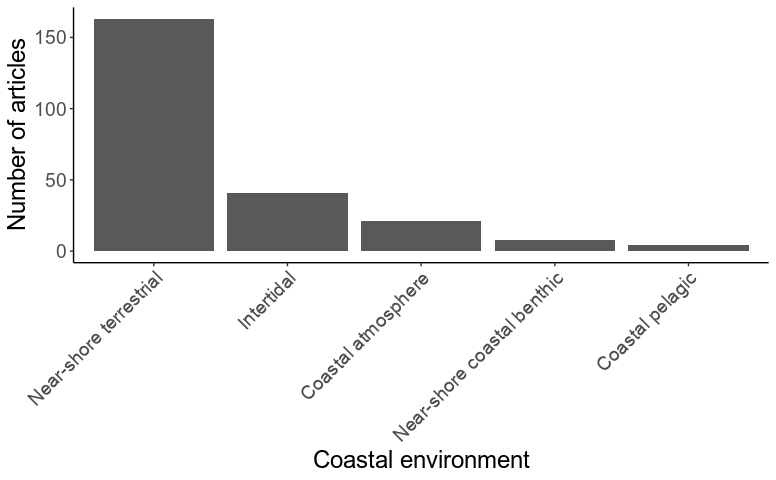


Fig 6. Distribution of articles, according to coastal environments where research was done.

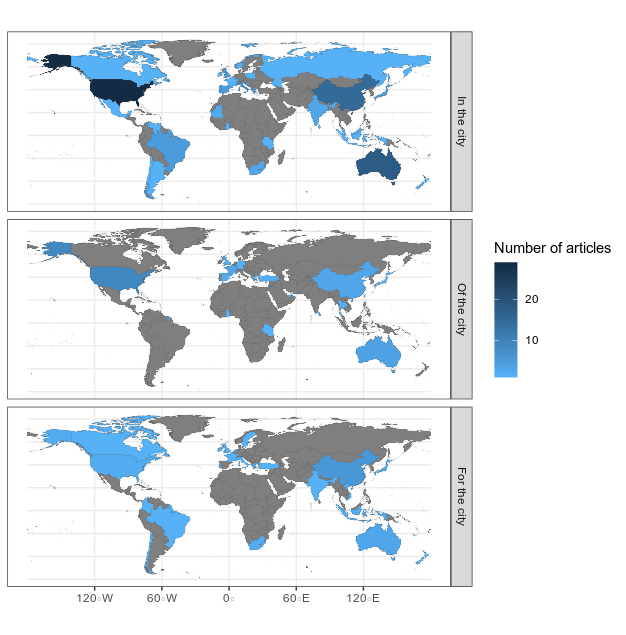


Fig 7. Ecological paradigms in, of, and for the city for coastal urban ecology, according to the number of studies developed in each country. Countries that not present coastal urban ecological articles are show in grey, and those with publications are presented in blue colours from light to dark.

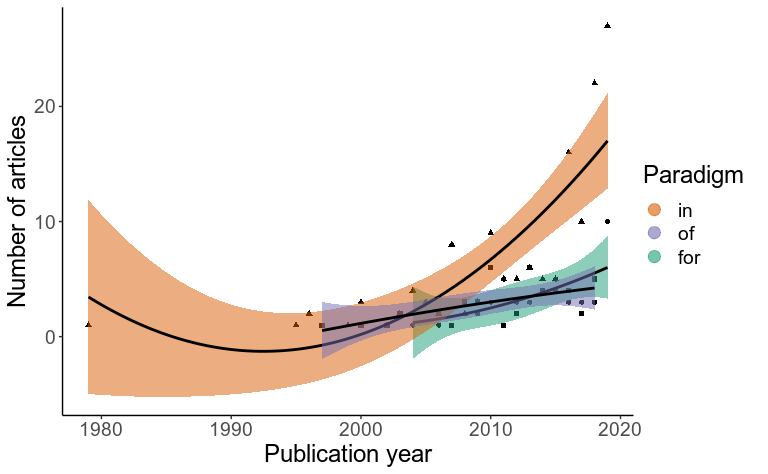


Fig 8. Number of articles published during the years considering paradigms in, of, and for the cities. Trend lines represent quadratic regression fit, colour areas represent the 95% confidence interval.

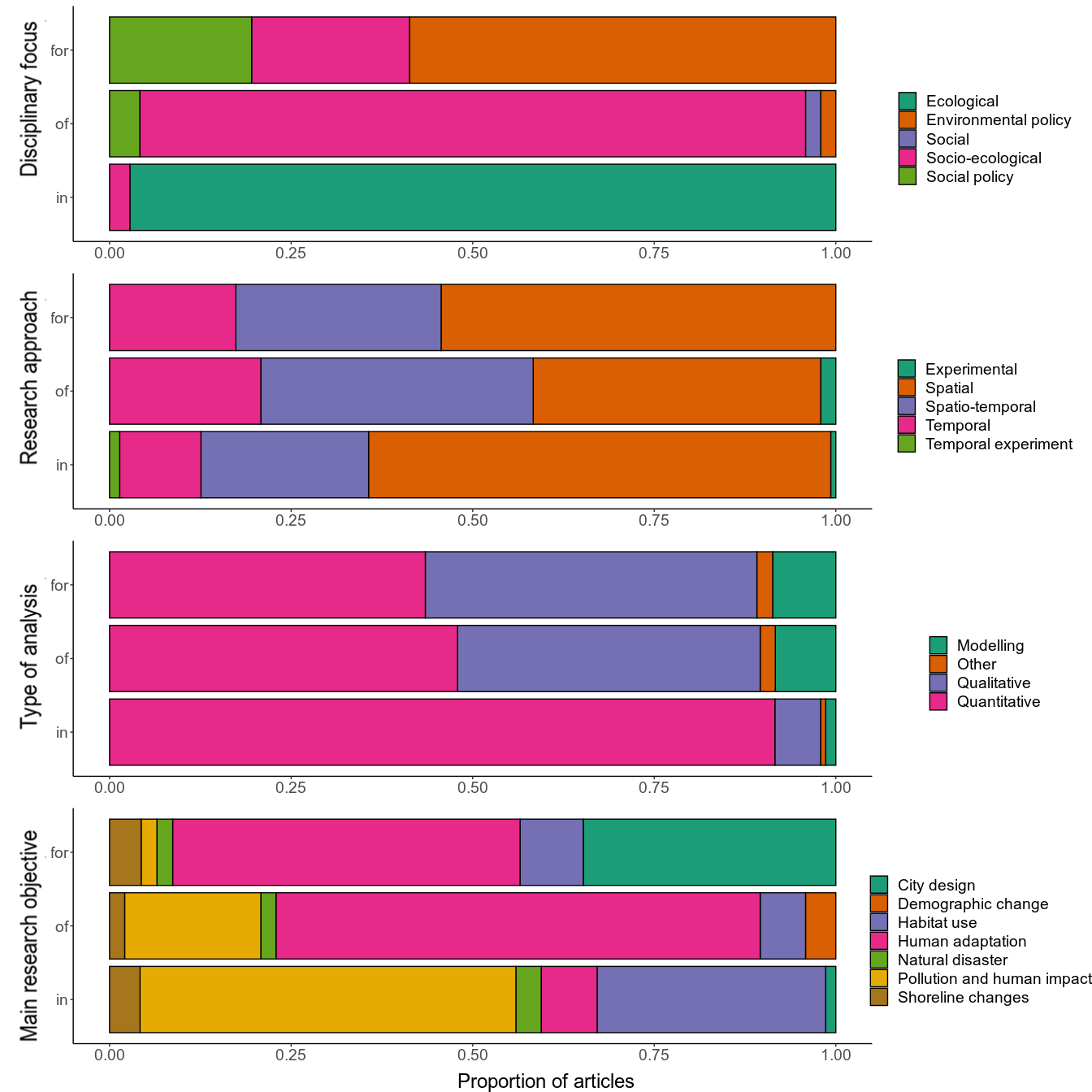
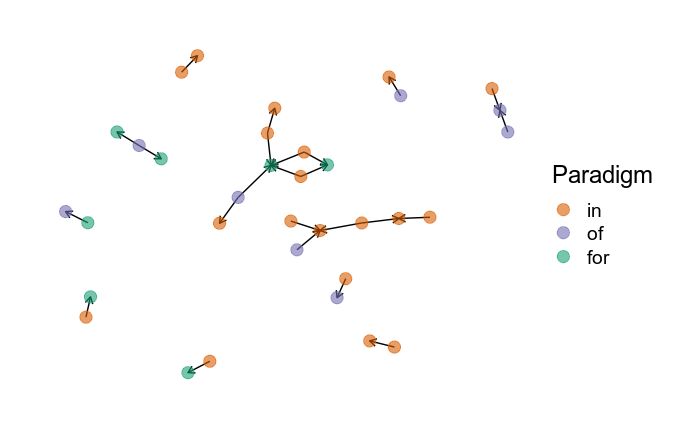


Fig 9. Distribution of articles’ paradigms according to disciplinary focus, research approach, type of analysis, and main research objectives.

Fig 10. Network analysis 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.