Coastal urban ecology. Exploring tendencies of research in a developing world.

Graells G1,2, Nakamura N3, Lagos N4, Celis-Diez Juan L.5 Gelcich S1,2

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Leclerc and Viard (2018), Heery *et al.* (2018), Bertocci *et al.* (2017), Bugnot *et al.* (2019), Shepard *et al.* (2016), Washburn *et al.* (2013), Campbell (2010) Chen *et al.* (2018), Lopes *et al.* (2011)

## Abstract

Coastal urban centres have dramatically increased during the last decades. In spite of global pressures, coastal research integrating urban areas are still very scarce. To examine what aspects have been investigated in this area, a systematic revision of literature under the concept of coastal urban ecology was made. Articles were selected following a decision tree and data was classified using the Pickett’s paradigms *in-*, *of-*, and *for- the city* plus other categories of classification. A total of 237 publications, developed in 49 countries fit our criteria. Most of 38 % of the articles were made in only three countries. Human dimension research in coastal urban areas emerged as a critical gap. Results suggest that coastal urban ecology is still growing and presents a big challenge to integrate marine and terrestrial studies to represent coastal ecosystems. Further research should explore social-ecological linkages and stewardship incentives in coastal urban areas to generate sustainable cities and conserve the remaining natural areas on the coast

### In a nutshell:

• Population in coastal urban cities is increasing over the years, generating one of the biggest perturbation to a marine-terrestrial ecotone.

• The literature review shows that urban coastal studies have been increasing, of these many have focused on ecology and few in human dimensions, such as social-ecological impacts and environmental policy and planning.

• Coastal urban ecology studies show an important bias in where the research is made, marine ecosystems within coastal environments have been under looked.

• One of the biggest challenges for coastal urban ecology research is to begin research in countries with high rate of population growing, to understand city expansion and to guarantee sustainable coastal cities in the future.

## Urban ecology in a developing world

The world’s population is increasing annually. By 2018, 55% of people lived in urban areas (United Nations and Social Affairs 2018), where cities grow in number and size, forming large mega-cities (United Nations and Social Affairs 2014). This high level of urbanisation stress presented during the last years have required science-based information about the effects of humans over natural areas and the change of patterns and processes linking cities and natural elements (e.g. Lubchenco *et al.* 1991; Grimm *et al.* 2008).Initial research in urban environments believed these areas were not able to sustain wildlife and the complex processes involved. However, this idea started to change in the first part of the ’70s when urban ecology began studying species distributions in cities and its drivers (Sukopp 1998; Grimm *et al.* 2008).

Historically, urban ecology studies were centred in ecological research, focusing on natural gradients and biotic homogenization (Blair 1996; McKinney and Lockwood 1999; Marzluff 2001; McKinney 2006). In these studies, abundance and species richness, mostly birds or plants, harnessed attention (Ulrich 1984; Shanahan *et al.* 2015). However, urban ecology research topics have changed over the past years, extending towards different ecosystem approaches, which include people’s interactions with the urban environment, environmental policies and planning, through interdisciplinary social-ecological research approaches. Recently, Pickett *et al.* (2016) introduced three phases in urban ecology evolution, as belonging to different paradigms which were termed: *in*, *of*, and *for* the city. Each one of these paradigms expose historical differences according to changes in urban ecology research, and result by the comparison of three variables or axes: chronology, model approach, and complexity.  
With this, studies under the paradigm in the city are mainly ecological, studies of the city are social-ecological, 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).

## Coastal urban areas growth and research

Within urban environments, coastal cities seem to be one of the preferred places for people to settle (Weinstein 2009). In fact, 40% of the world’s population live less than 100 Km from the sea (United Nations 2017), with coastal cities growing 6.6 times between 1945 and 2012 (Barragán and Andrés 2015). If coastal urban urban environments have been increasing over the years, we would expect that the need of research in this ecosystems would be also incremented. In this case, is possible to suggest that these studies has focused on marine pollution (Wang and others 2010; Naidoo *et al.* 2016), urban impacts (Buggy and Tobin 2008; Arruti *et al.* 2011), changes in shoreline (Wu *et al.* 2003; Alberico *et al.* 2018), habitat use, (Eguchi *et al.* 2010; Smith and Munro 2010), human adaptation and sustainability (Lebassi *et al.* 2013; Villagra *et al.* 2016), demographic changes (Race *et al.* 2010; Abarca-Álvarez *et al.* 2018), and city design (Garcez and Braga Carmello 2017; Conticelli and Tondelli 2018), among other concerns in regarding coastal urban development.

This article reviews coastal urban ecology scientific publications with the aim of examining spatial and temporal changes and its primary focus. Knowing coastal urban ecology research gives the opportunity to determine the gaps between the level of coastal urbanization and the existing preoccupation of the countries of knowing the effects of urbanization, embracing from theoretical to applied approaches in one of the most human-dominated ecosystems.

## Literature search

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 2018. Selection of articles was made with a decision tree (Fig. 1), where the research areas 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.

## Classification and data analysis

Each article collected was categorized in 16 sections: publication year, author’s name, type of publication, author´s affiliation country, study country, study city, city size, model, habitat, ecological paradigm, spatial scale, type of analysis, disciplinary focus, component, approximation, and study subject. In particular, categories as publication year, author’s name, type of publication, author´s affiliation country, study country, and study city were factors obtained directly from each paper, the rest of them had to be checked with further reading.

City’s population data were obtained from Brinkhoff (2018). Urban centres classification was modified from United Nations and Social Affairs (2014). This classification comprehends 1) Urban areas, which have less than 500,000 inhabitants, 2) small cities, between 500,000 and 1 million, 3) medium-size cities, between 1 and 5 million, 4) Large cities, between 5 and 10 million, and 5) Megacities, with more than 10 million.

The rest of the categories (model, habitat, spatial scale, type of analysis, disciplinary focus, study component, approximation of the research, study subject, and ecological paradigms) were classified through a conscious reading of the authors. Study model refers to the minimum unit which was studied in each article, including three significant areas: physical, biological, and social. Here, physical space comprises research with particle concentrations, spatial data, water flow, physical risk models, anthropogenic constructions, temperature, rainfall, harbours, seawater, and waves; biological with birds, environmental management, plants, marine invertebrate, insects, diversity measurements, fishes, bacteria, green areas, theoretical ecology, ecosystem services, lichens, mammals, amphibians, and wetlands; and social with human perceptions, economics, health, aspects of demography, and human development. Study habitat were divided in relation with the coastal environment where the research was done or which ecosystem was focused on. The classification includes four main areas according to Burke *et al.* (2001): 1) Near-shore terrestrial, which includes dunes, coastal xeromorphic habitats, rocky and sandy shores, urban, agricultural and industrial landscapes; 2) Intertidal, with estuaries, deltas, mangrove forests, lagoons, salt marshes, other coastal wetlands, marinas and ports; 3) Benthic, with seagrass beds, artificial structures and soft bottom environments above the continental shelf; 4) Pelagic, with open waters above the continental shelf. To this classification the component “urban atmosphere” was added because the amount of studies focused in this area.

Classification of coastal urban paradigms in, of, and for the city, was based on Pickett *et al.* (2016). Specifically, the paradigm in the city corresponds to those articles focused on ecological research, the paradigm of the city on social-ecological research, and paradigm for the city on environmental policies and city planning.

Spatial scale considered the urban dimensions: city scale (no distinction between big and small cities), sub-city (smaller than city scale, local areas, e.g. harbours, parks) or supra-city (bigger than city scale, e.g. region). On the other hand, study subject summarises the central theme of each article. Study subjects selected to be part of this classification were anthropogenic pollution, city design, demographic change, habitat use, human adaptation, natural disaster, shoreline changes, and urban impacts.

Disciplinary focus was categorized into five sections where inter-disciplines were considered. The five disciplinary focus were: 1) Ecology: Study of relationships and interaction between organisms and their coastal urban environment, 2) Sociology: Study of social behavior, including its origin, evolution and organization within a coastal urban environment, 3) Study of interaction between humans and their coastal urban environment, multidiscipline including anthropology, geography, sociology and ecology, 4) Environmental policy: Study of environment, to organize, manage the laws, regulations or find a solution, 5) Social-policy: Provides practical guidelines and principles to improve human welfare. Study component was divided in three classes: abiotic, biotic, and human. These three presented combinations that were considered as well: abiotic-biotic, abiotic-human, biotic-human, and abiotic-biotic-human.

Finally, study approach was categorised in three: temporal, spatial, spatiotemporal, and experimental (referring to laboratory studies). Type of analysis comprises quantitative (descriptive analysis), qualitative (collecting and evaluating measurable data) or modelling studies (mostly computational simulations).

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.

## Coastal urban ecology tendencies

Coastal urban ecology studies that meet the defined keywords presents a total of 237 articles (Fig. 2.C). The timeline of publications shows that coastal urban ecology appeared for the first time in 1979. However, it was not until 1993 that another study related to the field was published. After that year, two periods can be defined: between 1993 and 2000, and between 2002 and the present. During the first period, the number of publications was below five articles per year. During the second period, articles were increasing with time. Particularly, years 2016 and 2018 showed more than 20 publications per year. The publications are mostly journal articles with 83.97% of the total, proceedings papers represented 9.7%, book chapters 2.11%, reviews 2.11%, and editorial material 0.84%.

Although, authors’ affiliation countries are just 40, these studies are developed in 55 countries over the world, reaching 141 coastal cities cities where research has been performed. According with the relation between these two factors, only three countries demonstrate a preference of investigators to research in the same country of affiliation, such as the United States (33 articles), China (20 articles), and Australia (19 articles). Some other countries, as France, Germany, and the UK, demonstrated to have developed research abroad (more than three study countries). USA, China, and Australia have more than 16 articles published. A second category for publications includes only European countries (Italy, Spain, Portugal, and the UK) with six to 15 articles in the area. Most of the countries found in this review present less than five research articles in coastal urban ecology, representing the third category.

During the years, most of the articles published in coastal urban ecology have been developed in urbanised areas smaller than 5 million inhabitants. Considering city size, urban areas and medium-sized cities had the most significant number of publications in coastal urban ecology. On the contrary, megacities presented the least amount (Fig. 3). The distribution of research according to cities’ population and country showed that coastal urban ecology research has studies in the smallest place with 500 people in the US, and the largest city with more than 20 million in China. Some countries showed dispersion in city’s population given research done in more than one city. Highest dispersion was shown by China and Turkey, where coastal urban ecology research was made from cities with more than 500,000 to megacities with more than 10 million people (Fig. 4).

According to study models in coastal urban ecology, a significant number of publications were focused on physical aspects (52.74%), biological (21.94%%), (9.28%) ecological, and social (16.03%%) (Fig. 5). Aerosol was the study subject with the highest number of articles (2.53%), followed by birds (9.28%), spatial data (0%), and human perceptions (2.11%).  
Habitats where coastal urban ecology publications were developed showed a decreasing tendency where near shore terrestrial environment was the most frequent, with more than 100 articles (Fig. 6). This is followed by intertidal areas, coastal atmosphere, benthic, and pelagic environments. A category called “none” was added to the classification for those theoretical articles that did not fit within any other category.

From the total of articles, a great number of investigations were centered in ecology (58.65%), a few in socio-ecology approaches (23.21%) and less in environmental policy (10.55%). The two first approaches have been increasing considerably over the years in the number of articles published. Considering the type of analysis, quantitative analysis is dominant (73.42%) versus qualitative studies (21.1%). Additionally, the abiotic component is the most studied in coastal urban ecology (26.58%), followed by both abiotic and human (30.8%), biotic (13.92%), and both abiotic and biotic (7.59%).

Art\_in <- Articulos\_final %>% dplyr::filter(paradigm=="in") %>%   
dplyr::filter(!(study\_country %in% c("Other", "Review", "Many", NA)))  
unique(Art\_in$study\_country)

## [1] "Argentina" "Australia" "Brazil" "China"   
## [5] "hong kong s.a.r." "Croatia" "France" "Ghana"   
## [9] "Greece" "India" "Indonesia" "Ireland"   
## [13] "Israel" "Italy" "Japan" "Malaysia"   
## [17] "Malta" "Mauritania" "Mexico" "New Zealand"   
## [21] "Norway" "USA" "Poland" "Portugal"   
## [25] "Russia" "South Africa" "Spain" "Sri Lanka"   
## [29] "Taiwan" "Tanzania" "UK" "Venezuela"   
## [33] "Belgium" "Lebanon" "Singapore" "Puerto Rico"   
## [37] "Chile" "Canada"

Art\_of <- Articulos\_final %>% dplyr::filter(paradigm=="of") %>%   
dplyr::filter(!(study\_country %in% c("Other", "Review", "Many", NA)))  
unique(Art\_of$study\_country)

## [1] "Australia" "Caribe" "China" "Cyprus" "Emirates" "France"   
## [7] "Germany" "Ghana" "Greece" "Haiti" "Israel" "Japan"   
## [13] "Mauritius" "Spain" "Sri Lanka" "Taiwan" "Tanzania" "Thailand"   
## [19] "Turkey" "UK" "USA"

Art\_for <- Articulos\_final %>% dplyr::filter(paradigm=="for") %>%   
dplyr::filter(!(study\_country %in% c("Other", "Review", "Many", NA)))  
unique(Art\_for$study\_country)

## [1] "Australia" "Brazil" "Canada" "Chile"   
## [5] "China" "Colombia" "France" "India"   
## [9] "Indonesia" "Ireland" "Israel" "Italy"   
## [13] "Jamaica" "New Zealand" "Portugal" "South Africa"   
## [17] "Sweden" "The Netherlands" "Turkey" "UK"   
## [21] "USA" "Vietnam" "Japan" "Puerto Rico"   
## [25] "Greece"

## 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 at least 60.34% of articles, including 35 countries, from all continents and it has a count from one to 24 publications for each country, with the maximum number of articles presented by the United States. The focus *of the city* is shown at a lower percentage than the previous paradigm. With 20.25% of publications, in 24 countries, and some articles between one and nine, being the maximum number also presented by the United States. Investigations focused on *for the city* showed (19.41%) are also presented in 24 countries. China presents six articles, which is the highest number of papers in a country which addresses this paradigm.

During the years, paradigms *in*, *of*, and *for the cities* have shown substantial differences, not only in the total number of articles published (143, 48, and 46, respectively), 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 was developed 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 only since 1997. The three paradigms showed different publishing tendencies during the years, where in and of the city paradigms seem to be increasing in time, the paradigm for the city would be decreasing after an inflexion point near to the year 2012. Quadratic regressions better illustrate this tendency for articles published during the years considering paradigms. Here, the three paradigms present significant p-values.

Three spatial scales of research had different patterns according to paradigms and, and they are independent of the population of cities where they are developed (Fig. 9). Research classified as under the paradigm *in the city* presented studies on city size, infra-city, and supra-city spatial scale surrounding average population of cities considered in this study. The paradigm *of the city* established research on city size and supra-city spatial scale in urban areas smaller than the average population of cities. The paradigm *for the city* presented also studies city size and supra-city spatial scale below the average of city’s population, however research with infra-city scale were made in urban areas up to 15,000,000 inhabitants.

As expected, evidence suggests that the three paradigms are different according to study subject, disciplinary focus, and study components presented in their articles. On the contrary, the approximation focus of articles is similar among paradigms (Fig. 10). Study subject is presented differently depending on each paradigm. Urban impacts and changes in habitat use are dominant themes in studies under the paradigm in the city. This paradigm also presents an article with subject as human adaptation, shoreline changes, natural disasters, anthropogenic pollution, and city design. As expected, human adaptation and urban impacts are the most prominent themes in studies under the paradigm of the cities. However, this paradigm also presents studies related to habitat use, demographic change, natural disaster, and shoreline changes. Also, human adaptation and city design are the mayor subjects in investigations under the paradigm for the cities. This paradigm had also published about habitat use, shoreline changes, natural disasters, and urban impacts, reflecting the focus on policy and planning implications of these studies.

Study components of research show interesting tendencies where some elements are present in every paradigm. That is the case of the human component, being more important for the paradigm for the city. The paradigm in the city evaluates more articles with abiotic and biotic components (and both at the same time). paradigms of and for the city present mostly articles with the human part. The paradigm in shows a significant proportion of articles examining abiotic and humans, while for the city, shows a bigger percentage of the only human component. Considering the type of analysis of publications, there is a greater number of quantitative analysis in studies in the city. Studies of the city show similar proportions between quantitative and qualitative analysis and studies for the city present a majority of qualitative analysis.

When analysing the whole database of coastal urban ecology articles, only 26 articles present a little connection among citations (Fig. 11). From that, four articles quote two articles from the 201 articles reviewed (Dominick *et al.* 2015; Bolton *et al.* 2017; Branoff 2017; Leclerc and Viard 2018), the rest of the studies only quote one article. In the same way, just two articles are cited twice (Belant 1997; Li *et al.* 2017). Thus, network analysis shows a marginal interaction among articles’ paradigms (Fig. 11). The paradigm *in* quotes mainly *in* articles (as few as 11 from 19), six of, and two for the cities studies. Only one article *of* quotes *of the cities* articles and three (3/4) *in the cities* study. Every article classified as a paradigm for cite paradigm *in the cities*. These results suggest that coastal urban ecology article quotation does not have a strong connection among publications, which is further reinforced when the three paradigms are considered, and they do not show the order of complexity described before.

## Conclusions

In this study, we performed a systematic review of articles published under the concept of coastal urban ecology and assessed tendencies and gaps. Our results seems to demonstrate that even when most of the articles are centred in urban areas with less than 5 million people, research development in coastal urban ecology are more related to countries with large population than growth population rate. On one hand, from the three countries that presented the highest number of articles published (China, USA, and Australia, Fig. 2.C), China is the number one and USA is the third in population (Fig. 2.A). On the other hand, even when African continent presents the highest rates of population growth (Fig. 2. B), only a minimum number of articles are published in this area (only four countries for this continent).

In specific, more than half of the articles correspond to the paradigm *in the cities*, which highlights its focus in ecological research, non-human components, spatial and quantitative analysis (Fig. 10). Most of its topics are related to urban impacts and changes in habitat use. These results are consistent at the moment to check study models presented in publications, where physical and biological aspects prevailed over those centred in people.

As Pickett *et al.* (2016) proposed for urban ecology, the three paradigms present specific characteristics of research and are connected through an incremental complexity which could be seen in the quotation of articles. However, in this review we found a prevalence of ecological research (urban ecology in the city) over other paradigms (of and for), indicating coastal urban ecology does not present an intricate network of quotation (Fig. 11). Moreover, there is lack of connection among authors quotation and even the lack of a network of citation among paradigms may also reflect that coastal urban ecology does not operates quoting itself. Coastal urban ecology citations seems to be based mostly in terrestrial urban ecology. China and Australia are the only two countries that have been studied harmonising the three paradigms in their research (Fig. 7), alluding the presence of some development of research under the pressure or concern for urban and coastal transformations.

## Gaps in coastal urban ecology studies

The fact that only 23.88% of the articles in coastal urban ecology were classified under the paradigm of the city represents an important research gap associated to the lack of social knowledge in a system where man uses space to live, extract subsistence and non-subsistence resources, perform recreational activities, and deposits waste, among others (Weinstein 2009). Because of that, a lack of research in human dimensions represents the loss of an integral part of the ecosystem (McDonnell *et al.* 1993; Rees 1997; Collins *et al.* 2000). For example, in studies on the complexity of the human-wildlife conflict in urban areas (Soulsbury and White 2016), the importance of considering the social factor in the conflict have been declared (Dickman 2010). In these cases, human perceptions can provide important information about differences between what there is and what people can see of urban nature (Lindemann-Matthies *et al.* 2010; Celis-Diez *et al.* 2017) or its value in terms of the well-being provided (Fuller *et al.* 2007; Dallimer *et al.* 2012). Also, knowing people’s perception could mean a tool for conservation and management of resources, for example when considering the availability of participating in new ideas of management or implementation of new environmental policies (Gelcich *et al.* 2005, 2009).

Another gap identified in coastal urban ecology is the fact that most of the research developed in this area is focused in near-shore habitats and inland (Fig. 6), this includes mainly terrestrial environments. The lack of information in coastal-marine urban environments, revealed a lack of integration in a relevant interphase for urban areas (seawater-land configuration and dimensionality). The results can be translated as marine environments in urban areas are not fully recognised as a conservation biology priority generating segregation between urban and marine ecology (Bulleri 2006).

We have been discussing coastal urban ecology is far from “terrestrial” urban ecology development. Even when it has been described the need for studies in marine ecosystems that are also affected by urbanization (Bulleri 2006; Shochat *et al.* 2006). Thus, coastal urban ecology may help to transparent the impacts of urbanization on both terrestrial areas where are settled but also the impacts on the interface of both ecosystems: the shoreline and upon the whole benthic ecosystems. A large portion of ecosystems services are benefiting the coastal communities, but much of these benefits are disregarded or treated as externalities for inland urban areas. Thus, coastal urban ecology research that regard the integration across marine and terrestrial ecosystems, may help to close the loop about the spatial extent at which the basic ecological knowledge, the human dimensions and the development of urban policies and planning must be approached.

## Challenges in coastal urban ecology

Our results provide compelling evidence in how coastal urban ecology has been developed in countries with high level of population. Hence, one of the biggest challenges in coastal urban ecology is to investigate in that countries where the demographic change is occurring rapidly, which is the case of African countries. Given increment in urbanization could be seen as a consequence of population growth, countries where rate population growth is high presents an opportunity of knowledge. This scenario presents the possibility of finding variables with both natural and perturbed settings.

Future research in coastal urban ecology should focus population growth and the consequent city expansion, human dimension studies lack, and the challenge of integrating marine and terrestrial studies to better describe coastal ecosystems. Considering this diversification and interdisciplinary work, sustainable development of coastal cities can be achieve, joining also well-being and biological conservation.

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