A review on coastal urban ecology: Research gaps, challenges and needs

Giorgia Graells[1,2,7*], Nao Nakamura[3], Juan L. Celis-Diez[4], Nelson A. Lagos[5,7], Pablo A. Marquet[1,6], Patricio Pliscoff[1], Stefan Gelcich[1,2,7]

[1]Departamento de Ecología, Facultad de Ciencias Biológicas, Pontificia Universidad Católica de Chile, Santiago, Chile.

[2]Center of Applied Ecology and Sustainability (CAPES), Santiago, Chile.

[3]Australian Research Council Centre of Excellence for Coral Reef Studies, James Cook University, Townsville, Queensland, Australia.

[4] Pontificia Universidad Católica de Valparaíso, Escuela de Agronomía, Casilla 4-D, Quillota, Chile.

[5] Centro de Investigación e Innovación para el Cambio Climático, Facultad de Ciencias, Universidad Santo Tomás, Santiago, Chile.

[6] Instituto de Ecología y Biodiversidad (IEB), Santiago, Chile.

[7] Instituto Milenio en Socio-Ecología Costera (SECOS), Santiago, Chile

*** Correspondence:**
Corresponding Author
gygraell@uc.cl

Keywords: coastal urban ecology, marine urbanization, coastal cities, urban ecology paradigms, coastal urbanization.

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 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* with a focus on the 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 and cities have been constantly growing in number and size, forming large cities. The so-called megacities have reached over 10 million inhabitants (according to the United Nations 2018, presenting 33 settlements). 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 '70s 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 in 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 recent 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 (Arns et al. 2017, Vitousek et al. 2017, Luijendijk et al. 2018, Benveniste et al. 2019).

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 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, using Boolean operators to combine concepts and keywords: ("urban ecology" or "urban environment*") and (coast* or marine). The period of the search included from 1975 until December 2019. We based our search on systematic mapping in order to collate, describe and catalog available evidence relating to the topic, allowing to address open-frame or closed-frame questions (James et al. 2016). 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). Studies were counted just once for each paradigm. 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 examining 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. For each category, articles were counted just once.

City's population data were obtained from the United Nations (2019) compendium. Urban centres classification was modified from the United Nations (2014) and Barragán & 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 descriptive analysis of the network. We did not used topological measurements of the network, but rather describe its directionality. This 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. 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).

4 Results

4.1 Coastal urban ecology tendencies

Coastal urban ecology studies that met selection criteria included a total of 237 articles (Fig. 1) 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 with Barcelona in 1979, however, it was not until 1995 that another study related to the field was published with Punda-Polić et al. (1995). 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% (e.g. Kulkova et al. 2011, Giovene di Girasole 2014, Fu et al. 2018), indexed book chapters 2.11% (e.g. Race et al. 2010, Wong 2011, Juchimiuk & Januszkiewicz 2019), and reviews 2.11% (e.g. Garden et al. 2006, Cohen et al. 2013, Branoff 2017).

General findings 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. Among ecological studies, those where coastal urbanization have modified ecological patterns stand out. For example Way et al. (2004), tracked movement and activity patterns of coyotes in northeastern North America, demonstrating that these mammals used more urbanized areas than natural ones. Other studies have assessed diets and feeding habitats of coastal birds to assess the interplay between natural and anthropogenic factors in determining diversity patterns (Washburn et al. 2013). Social-ecological studies were the second most common disciplinary focus with 24.47% (an average 2.2 publications per year between 2005 and 2009, 4.4 between 2010 and 2014, and 3.8 between 2015 and 2019; Fig 3a). Social-ecological studies include those which focus on biodiversity and natural environment perceptions and human wellbeing. For instance, White et al. (2013) assessed human emotions towards different coastal environments and Burger et al. (2017) assessed human preferences towards protection and restoration. Environmental policy and planning studies have focused on developing guidelines for planning in order to contribute to the sustainability of the urban environment. For instance Alcoforado et al. (2009) identified climatic needs in a coastal city and discussed problems that arise when applying climatic knowledge to urban planning. Disciplinary focus of research showed high number of publications on traditional ecology, centered on how biodiversity patterns are affected by cities. However, despite noticeable exceptions, focus on human dimensions, such as studies which deal with perceptions and well-being associated to urban development and environmental footprint have received less attention. In addition multidisciplinary research on defining and designing solutions, associated to various forms of participatory approaches in order to move towards urban sustainability, are still scarce, showing a gap in knowledge.

Coastal ecology research has mainly considered spatial approaches searching for patterns based on differences in urban morphology. These spatial patterns include land cover and land use. For instance, research based on beach width and coastal slope that determine the most critical physical parameters to create coastal vulnerability maps (Kantamaneni et al. 2019). Study approaches have slowly included temporal dimensions (Fig. 3b). Spatio-temporal studies included articles such as Grossmann (2008) who discusses the consequences of current global technological, organisational and economic developments for a port. Temporal studies included Priestley et al. (2018) who assessed inorganic and organic compounds and their relation to photolysis and Martin et al. (2007) who studied management approaches for a coastal urban pest (White Ibis) along the east coast of Australia. Studies which use experimental approaches through time represent less than 1% of the articles. They included articles such as the study of Leclerc & Viard (2018), who studied how swimming predators influenced the early development of fauna associated with floating pontoons in marinas. A significant higher number of publications considering spatial instead of temporal approaches could generate a static representation of what happens in coastal cities. This is particularly relevant in the face of climate change scenarios, where temporal variability becomes important.

Quantitative studies have dominated the literature during the past 20 years and have focused on ecological approaches. For example Tzortzakaki et al. (2018) studied the effect of the different land-cover types on bird species richness and abundance and concluded that open green spaces are the most significant factor favoring bird diversity in a coastal city in Greece. Qualitative studies represent 20% of the articles. These mainly use a social-ecological approach. Studies use qualitative interviews to assess urban coastal environmental constructs and preferences (Cleland et al. 2015). Other qualitative studies have been used to design green infrastructure in urban cities (Chen et al. 2015). Policy studies such as Guerrero Valdebenito & Alarcon Rodriguez (2018) used qualitative approaches to assess tensions and threats to traditional small-scale artisanal fishers coexisting with larger urbanized systems such as mega infrastructures, ports and cities. Modelling studies which include simulation of urban conditions, have begun to emerge in the past six years (Fig. 3c) to address a wide variety of issues. For example, Stathopoulou & Cartalis (2007) modeled the thermal urban environment and urban heat island phenomenon in mayor urban areas in Greece. Su et al. (2019) used modelling to determine realistic flooding scenarios. Other modelling studies have contributed to assess social-ecological dimensions. Sahal et al. (2013) used macro-simulators and micro-simulators with multi-agent-based modelling to select shelter points and choose evacuation routes for future tsunamis. Song et al. (2016) modeled urban environmental benefits, such as green infrastructure, industrial upgrade, and environmental management, in China, testing social-economic and demographic variables. The use of modelling to inform environmental policies has been approached mainly through mapping and risk assessments. For instance, Storch & Downes (2011) quantified and mapped current and future city-wide flood risks, combining climate change scenarios with urban land use scenarios. A key finding is that qualitative research approaches have been underrepresented. This has important consequences especially when assessing how the general public engage with urbanization and its impacts in coastal zones. Accordingly, there are important gaps of knowledge in this area.

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. For instance, Jartun & Pettersen (2010) collected sediments from urban stormwater runoff and analyzed various contaminants, showing that several active pollution sources are supplying the runoff systems. Studies that focus on habitat use in urban areas are also common. For example, studies have focused on differences in communities between fixed and floating structures (Holloway & Connell 2002) or on abundance and survival rates of charismatic species in highly industrialized bays (Eguchi et al. 2010). Studies which focus on different aspects of city design are less frequent, but they have been increasing in the last 10 years. Some of these studies have developed climatic guidelines for planning and identifying climatic needs in ~~a~~ coastal cities (e.g Alcoforado et al. 2009), others have applied multi-criteria decision analysis to explore local stakeholders' perceptions in terms of priority actions for waterfront development (Papatheochari & Coccossis 2019).

According to study models used (Fig. 4), a significant number of publications focused on physical aspects (48.10%) such as pollutants and risk towards natural hazards (Buggy & Tobin 2008; Dominick et al. 2018). The second most frequent study model was biological, centered on specific species (21.94%). In this group, birds were the most studied (e.g. Kalinowski & Johnson 2010, studying a suburban bird community; Sainz-Borgo et al. 2016, studying the house sparrow; Blight et al. 2019, studying an urban-nesting gull population). Invertebrates were the second most studied group including marine (Galimany et al. 2013; Eddy & Roman 2016); and terrestrial species (Bizzo et al. 2010, Reyes-López & Carpintero 2014). While other marine species such as fishes received less attention, some noticeable examples include the study by Bolton et al. (2017) of fish communities. Studies centered on specific ecosystems (Ehrenfeld 2000, Branoff 2017) or social-eco-technological systems showed less than 10 articles published. Foremost among these are those on eco-cities (e.g.Wong 2011). This evidence indicates that study models have been frequently replicated. The dominance of certain study models has allowed progress in the field on certain issues. But at the same time, there are some fields that have not progressed at all such as those that include organisms like algae or marine microorganism.

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 such as Los Angeles in USA (Barcelona 1979), Osaka in Japan (Yamazaki et al 2007), Tianjin in China (Peng et al. 2011), Bangkok in Thailand (Burnett et al. 2007), and megacities with more than 10 million people such as Shanghai in China (Li et al. 2018), Tokyo in Japan (Krishnan et al. 2019), New York in USA (Washburn et al. 2013), Buenos Aires in Argentina (Cardo et al. 2014). Coastal areas with less than 100,000 inhabitants presented only 10% of articles. These are dominated by articles from the USA (e.g. Kalinowski & Johnson 2010, Wolsko & Marino 2016). There is a clear focus on large cities and important knowledge gaps remain in studying urbanization processes and differences associated to growth of smaller cities and the social-ecological complexities they confront.

Research in coastal urban ecology has focused mostly in near-shore terrestrial environments, presenting more than 68% of articles. These have focused on urban environments (e.g. Parzych et al. 2016), anthropogenic constructions (Günel 2018), green areas (Callaghan et al. 2018) and urban watersheads (Pinheiro & Hokugo 2019). Intertidal areas presented 17.30% of the publications. Some of these focused on coastal defenses (e.g. Jonkman et al. 2013), estuarine and shallow coastal systems (Kuwae et al. 2016), estuarine mullet in an urban harbor (Naidoo et al. 2016) and predation on a threatened coastal seabird (Greenwell et al. 2019). Near-shore coastal benthic habitats accounted for 3.38% and included studies such as those which assess community structure (e.g. Holloway & Connell 2002; Eddy & Roman 2016), impacts of light on communities (Bolton et al. 2017) and spatial distribution patterns (e.g. Heery et al. 2018 for the giant Pacific octopus (*Enteroctopus* *dofleini*). Studies which focus on pelagic environments near the coast account for only 1.69% . These relate mostly to sea water studies such as Zhen et al. 2007 and ocean thermal energy (Wang 2010). Coastal atmosphere showed 8.86% of total articles published (e.g. aerosol: Castro et al. 1999; PM10 pollution episodes: Vicente et al. 2012; atmospheric deposition: Shanquan et al. 2016; and chemical composition of fine-aerosol fraction: Theodosi et al. 2018).

Current research evidence suggests studies in coastal urban systems deal greatly with pollutants and ecological implications, with emerging interests in planning and social interactions and responses. The ways in which these areas interact in time and space and across different city sizes and configurations could provide to be particularly novel research endeavors. Important issues such as the environmental footprint and social-ecological tradeoffs of coastal configurations of few large or a series of smaller cities settled along the coast are some key areas which need further development (Weinstein 2009, Kaniewski et al. 2013, Barragan and Andres, 2015). Ultimately, coastal urban ecology still has important research opportunities in addressing the interactive effects of urban drivers, social-ecological responses and how planning processes accommodate these complex system dynamics.

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 (e.g Way et al. 2004, Eddy & Roman 2016, Maguire & Fulweiler 2019). 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 (e.g. Gasper et al. 2011, Douglas et al. 2012, Burger et al. 2017). Research addressing the *for the city* paradigm represented 19.41% of total articles and came from 25 different countries. China presents six articles (e.g. Li et al. 2011, Peng et al. 2011, Li et al. 2017), which is the highest number of papers in a country which addresses this paradigm. This result indicates that coastal urban ecology is dominated by research with a focus *in the city* and only few countries have attended to develop the three paradigms.

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 (Patz et al. 2004). Before that, the paradigm *in the city* (since the beginning with Barcelona 1979) dominated this research area, with some occurrence of the paradigm *of the city* since 1997 (Belant 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. This could result in an even larger gap between the number of publications focused on each paradigm.

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 social-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 (for example *ecology in the city*: Hosannah et al. 2014; *ecology of the city*: Bulleri 2006; *ecology for the city*: Santos & Freire 2015), followed by spatio-temporal approach (for example *ecology in the city*: Castro et al. 1999; *ecology of the city*: Serre et al. 2010; *ecology for the city*: Storch & Downes

2011). 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 (e.g. Wolsko & Marino 2016, integrated research on disasters and climate change-induced migration with environmental psychology and the psychology of natural disasters), this topic also appears in the paradigm *for the city* in combination with city design, a consequence of the predominant focus on policy and planning implications of these studies. An example of human adaptations can be found in Villagra et al. (2016) who described the 'resilience thinking' approach in urban planning, in order for a coastal city to adapt to extreme natural events such as tsunamis. Also, Conticelli & Tondelli (2018) proposed an urban regeneration of a coastal territory considering the local coastal landscape as a key element for boosting local sustainable growth.

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* cited 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 shortfall in long-term dynamic perspectives in the study of coastal cities. Results demonstrate 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 CO_2 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 by 2017 more than 60% of cities in the world have between 100,000 and 1 million inhabitants (United Nations 2019, data compilation).

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, where marine and terrestrial ecosystems could meet as two isolated systems (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 social-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 understanding 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 (Fig. 8) can undermine urban coastal sustainability. Under Pickett's complexity of paradigms (Pickett et al. 2016), ecology *for the city* should include the knowledge generated by both *ecology in* and *ecology of the city.* In order to understand coastal urban ecological systems, coastal urban ecological paradigms need to build upon literature from each other.

While biophysical and ecological approaches to coastal urban systems are important, urban ecology necessarily operates in a human context. Results highlight the need for coastal cities 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. Developing regional learning platforms to address these dimensions should be a priority. Results of this review also recommend research needs to focus 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. Clear research agendas that include trans-disciplinary collaborations 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 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.

Funding

This work was supported by the National Agency for Research and Development (ANID) Scholarship Program, National graduate scholarship [21171829, 2017], ANID – Millennium Science Initiative Program [Code ICN2019_015], Center of Applied Ecology and Sustainability (CAPES) [ANID PIA/BASAL FB0002] and Fondecyt 1190109.

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 based on a PRISMA flow diagram. Description of the selection process for articles in coastal urban ecology review. After four passes for selection filters, the remaining 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 Pickett´s paradigms *in*, *of*, and *for the cities*.

Figure 8. Network analysis. 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.

References

Abarca-Álvarez, F. J., Campos-Sánchez, F. S., & Reinoso-Bellido, R. (2018). Signs of gentrification usin g Artificial Intelligence: identification through the Dwelling Census. Bitácora Urbano Territorial, 28(2), 103-114.

Abdul-Aziz, O. I., & Ahmed, S. (2019). Evaluating the emergent controls of stream water quality with similitude and dimensionless numbers. Journal of Hydrologic Engineering, 24(5), 04019010.

Aerts, J. C., Botzen, W. W., Emanuel, K., Lin, N. De Moel H., & Michel-Kerjan, E. O. (2014). Evaluating flood resilience strategies for coastal megacities. Science, 344(6183), 473-475.

Alberico, I., Cavuoto, G., Di Fiore, V., Punzo, M., Tarallo, D., Pelosi, N., Ferraro, L., & Marsella, E. (2018). Historical maps and satellite images as tools for shoreline variations and territorial changes assessment: the case study of Volturno Coastal Plain (Southern Italy). Journal of Coastal Conservation, 22(5), 919-937.

Alberti, M. (2005). The effects of urban patterns on ecosystem function. International regional science review, 28(2), 168-192.

Alberti, M. (2008). Advances in urban ecology: integrating humans and ecological processes in urban ecosystems (No. 574.5268 A4). New York: Springer.

Alcoforado, M. J., Andrade, H., Lopes, A., & Vasconcelos, J. (2009). Application of climatic guidelines to urban planning: the example of Lisbon (Portugal). Landscape and urban planning, 90(1-2), 56-65.

Allan, D., Erickson, D., & Fay, J. (1997). The influence of catchment land use on stream integrity across multiple spatial scales. Freshwater biology. 37(1),149-61.

Antrop, M. (2004). Landscape change and the urbanization process in Europe. Landscape and urban planning, 67(1-4), 9-26.

Aria, M., & Cuccurullo, C. (2017). Bibliometrix: An r-tool for comprehensive science mapping analysis. Journal of Informetrics, 11, 959–75.

Arif, A. A. (2017). "Green city Banda Aceh: city planning approach and environmental aspects," in IOP Conference Series: Earth and Environmental Science (Vol. 56, No. 1, p. 012004). IOP Publishing.

Arns, A., Dangendorf, S., Jensen, J., Talke, S., Bender, J., & Pattiaratchi, C. (2017). Sea-level rise induced amplification of coastal protection design heights. Scientific reports, *7*(1), 1-9.

Arruti, A., Fernández-Olmo, I., & Irabien, A. (2011). Regional evaluation of particulate matter composition in an Atlantic coastal area (Cantabria region, northern Spain): Spatial variations in different urban and rural environments. Atmospheric research, 101(1-2), 280-293.

Auguie, B. (2016). GridExtra: Miscellaneous functions for "grid" graphics.

Barcelona, M. J. (1979). Human exposure to chloroform in a coastal urban environment. Journal of Environmental Science & Health Part A, 14(4), 267-283.

Barragán, J. M., & Andrés, M. de. (2015). Analysis and trends of the world's coastal cities and agglomerations. Ocean & Coastal Management, 114, 11–20.

Barthel, S., Folke, C., & Colding, J. (2010). Social–ecological memory in urban gardens—Retaining the capacity for management of ecosystem services. Global Environmental Change, 20(2), 255-265.

Belant, J. L. (1997). Gulls in urban environments: landscape-level management to reduce conflict. Landscape and urban planning, 38(3-4), 245-258.

Benveniste, J., Cazenave, A., Vignudelli, S., Fenoglio-Marc, L., Shah, R., Almar, R., Andersen, O., Birol, F., Bonnefond, P., Bouffard, J., Calafat, F., CArdellach, E., Cipollini, P., Le Cozannet, G., Dufau, C., Fernandes, M. J., Frappart, F., Garrison, J., Gommenginger, C., Han, G., Hoyer, J. L., Kourafalou, V., Leuliette, E., Li, Z., Loisel, H., Madsen, K. S., Marcos, M., Melet, A., Meyssignac, B., Pascual, A., Passaro, M., Ribó, S., Scharroo, R., Song, Y. T., Speich, S., Wilkin, J., Woodworth, P., & Wöppelmann, G.(2019). Requirements for a coastal hazards observing system. Frontiers in Marine Science, 6, 348.

Bergen, S. D., Bolton, S. M., & Fridley, J. L. (2001). Design principles for ecological engineering. Ecological Engineering, 18(2), 201-210.

Bertocci, I., Arenas, F., Cacabelos, E., Martins, G. M., Seabra, M. I., Álvaro, N. V., Fernandes, J. N., Gaião, R., Mamede, N., Mulas, M.,& Neto, A. I. (2017). Nowhere safe? Exploring the influence of urbanization across mainland and insular seashores in continental Portugal and the Azorean Archipelago. Marine pollution bulletin, 114(2), 644-655.

Bizzo, L., Gottschalk, M. S., Toni, D. C. D., & Hofmann, P. R. (2010). Seasonal dynamics of a drosophilid (Diptera) assemblage and its potencial as bioindicator in open environments. Iheringia. Série Zoologia, 100(3), 185-191.

Blair, R. B. (1996). Land use and avian species diversity along an urban gradient. Ecological applications, 6, 506–19.

Blight, L. K., Bertram, D. F., & Kroc, E. (2019). Evaluating UAV-based techniques to census an urban-nesting gull population on Canada's Pacific coast. Journal of Unmanned Vehicle Systems, 7(4), 312-324.

Bolton, D., Mayer-Pinto, M., Clark, G. F., Dafforn, K. A., Brassil, W. A., Becker, A., & Johnston, E. L. (2017). Coastal urban lighting has ecological consequences for multiple trophic levels under the sea. Science of the Total Environment, 576, 1-9.

Bolund, P., & Hunhammar, S. (1999). Ecosystem services in urban areas. Ecological economics, 29(2), 293-301.

Branoff, B. L. (2017). Quantifying the influence of urban land use on mangrove biology and ecology: A meta-analysis. Global ecology and biogeography, 26(11), 1339-1356.

Buggy, C. J., & Tobin, J. M. (2008). Seasonal and spatial distribution of metals in surface sediment of an urban estuary. Environmental Pollution, 155(2), 308-319.

Bugnot, A. B., Hose, G. C., Walsh, C. J., Floerl, O., French, K., Dafforn, K. A., Hanford, ., Lowe, E. C., & Hahs, A. K. (2019). Urban impacts across realms: making the case for inter-realm monitoring and management. Science of the Total Environment, 648, 711-719.

Bulleri, F. (2006). Is it time for urban ecology to include the marine realm? Trends in ecology & evolution, 21, 658–9.

Burger, J., Tsipoura, N., Simnor, A., Pittfield, T., Jeitner, C., Mizrahi, D., ... & Ferguson, L. (2017). Perceptions of Caucasian users about avian resources and beach restoration following hurricane Sandy. Urban ecosystems, 20(2), 363-373.

Burke, L., Kura, Y., Revenga, C., Spalding, M., & Mcallister, D. (2001). Pilot analysis of global ecosystems: coastal ecosystems, World Recourses Institute. Washington, DC, pág, 13.

Burnett, W. C., Wattayakorn, G., Taniguchi, M., Dulaiova, H., Sojisuporn, P., Rungsupa, S., & Ishitobi, T. (2007). Groundwater-derived nutrient inputs to the Upper Gulf of Thailand. *Continental Shelf Research*, *27*(2), 176-190.

Burt, J. A., & Bartholomew, A. (2019). Towards more sustainable coastal development in the Arabian Gulf: Opportunities for ecological engineering in an urbanized seascape. Marine pollution bulletin, 142, 93-102.

Cadenasso, M. L., Pickett, S. T., & Grove, M. J. (2006). Integrative approaches to investigating human-natural systems: the Baltimore ecosystem study. Natures Sciences Sociétés, 14(1), 4-14.

Callaghan, C. T., Major, R. E., Lyons, M. B., Martin, J. M., & Kingsford, R. T. (2018). The effects of local and landscape habitat attributes on bird diversity in urban greenspaces. Ecosphere, 9(7), e02347.

Campbell, M. (2010). An animal geography of avian foraging competition on the Sussex coast of England. Journal of Coastal Research, 26(1 (261)), 44-52.

Capaldo, K. P., Pilinis, C., & Pandis, S. N. (2000). A computationally efficient hybrid approach for dynamic gas/aerosol transfer in air quality models. Atmospheric Environment, 34(21), 3617-3627.

Cardo, M. V., Vezzani, D., Rubio, A., & Carbajo, A. E. (2014). Integrating demographic and meteorological data in urban ecology: a case study of container□breeding mosquitoes in temperate Argentina. *Area*, *46*(1), 18-26.

Castro, L. M., Pio, C. A., Harrison, R. M., & Smith, D. J. T. (1999). Carbonaceous aerosol in urban and rural European atmospheres: estimation of secondary organic carbon concentrations. Atmospheric Environment, 33(17), 2771-2781.

Chabas, A., Fouqueau, A., Attoui, M., Alfaro, S. C., Petitmangin, A., Bouilloux, A., Saheb, M., Coman, A., Lombardo, T., Grand, N., Zapf, P., Berardo, R., Duranton, M., Durand-Jolibois, R., Jerome, M., Pangui, E., Correia, J. J., Guillot, I. & Nowak, S. (2015). Characterisation of CIME, an experimental chamber for simulating interactions between materials of the cultural heritage and the environment. Environmental Science and Pollution Research, 22(23), 19170-19183.

Chace, J. F., & Walsh, J. J. (2006). Urban effects on native avifauna: a review. Landscape and urban planning, 74(1), 46-69.

Chang, L. F., & Huang, S. L. (2015). Assessing urban flooding vulnerability with an emergy approach. Landscape and Urban Planning, 143, 11-24.

Charalambous, K., Bruggeman, A., & Lange, M. A. (2012). Assessing the urban water balance: the Urban Water Flow Model and its application in Cyprus. Water Science and Technology, 66(3), 635-643.

Chauvin, J. P., Glaeser, E., Ma, Y., & Tobio, K. (2017). What is different about urbanization in rich and poor countries? Cities in Brazil, China, India and the United States. Journal of Urban Economics, 98, 17-49.

Chen, Y-C., Pei, L., & Shiau, Y. C. (2015). Application of coastal vegetation to green roofs of residential buildings in Taiwan. Artificial Life and Robotics, 20(1), 86-91.

Chen, Y-C., Yao, C-K., Honjo, T., & Lin, T-P. (2018). The application of a high-density street-level air temperature observation network (hisan): Dynamic variation characteristics of urban heat island in tainan, taiwan. Science of the Total Environment, 626, 555–66.

Chiesura ,A. (2004). The role of urban parks for the sustainable city. Landscape and urban planning, 68(1),129-38.

Childers, D. L., Cadenasso, M. L., Grove, J. M., Marshall, V., McGrath, B., & Pickett, S. T. (2015). An ecology for cities: A transformational nexus of design and ecology to advance climate change resilience and urban sustainability. Sustainability, 7(4), 3774-3791.

Clarkson, T. S., Martin, R. J., Rudolph, J., & Graham, B. W. L. (1996). Benzene and toluene in New Zealand air. Atmospheric Environment, 30(4), 569-577.

Cleland, V., Hughes, C., Thornton, L., Venn, A., Squibb, K., & Ball, K. (2015). A qualitative study of environmental factors important for physical activity in rural adults. PLoS One, 10(11).

Cohen, P., Potchter, O., & Matzarakis, A. (2013). Human thermal perception of Coastal Mediterranean outdoor urban environments. Applied Geography, 37, 1-10.

Cole, M. A., & Neumayer, E. (2004). Examining the impact of demographic factors on air pollution. Population and Environment, 26(1), 5-21.

Collins, J. P., Kinzig, A., Grimm, N. B., Fagan, W. F., Hope, D., Wu, J., & Borer, E. T. (2000). A new urban ecology: modeling human communities as integral parts of ecosystems poses special problems for the development and testing of ecological theory. American scientist, 88(5), 416-425.

Costanza, R., Sklar, F. H., & White, M. L. (1990). Modeling coastal landscape dynamics. BioScience, 40(2), 91-107.

Conticelli, E., & Tondelli, S. (2018). Regenerating with the green: a proposal for the coastal land-scape of Senigallia. Direttore scientifico/Editor-in-Chief, 91.

Creswell, J. W., Hanson, W. E., Clark Plano, V. L., & Morales, A. (2007). Qualitative research designs: Selection and implementation. The counseling psychologist, 35(2), 236-264.

Cui, H., & Yuan, L. (2009). "Study on thermal environmental distribution in coastal city using ASTER data," in 2009 Joint Urban Remote Sensing Event (pp. 1-6). IEEE.

Daily, G. (2003). What are ecosystem services. Global environmental challenges for the twenty-first century: Resources, consumption and sustainable solutions, 227-231.

Dallimer, M., Irvine, K. N., Skinner, A. M., Davies, Z. G., Rouquette, J. R., Maltby, L. L., Warren, P. H., Armsworth, P. R., & Gaston, K. J. (2012). Biodiversity and the feel-good factor: understanding associations between self-reported human well-being and species richness. BioScience, 62(1), 47-55.

Davis, J. C., & Henderson, J. V. (2003). Evidence on the political economy of the urbanization process. Journal of urban economics, 53(1), 98-125.

Decelis, R., & Vella, A. J. (2007). Contamination of outdoor settled dust by butyltins in Malta. Applied Organometallic Chemistry, 21(4), 239-245.

Dodman, D. (2009). Globalization, tourism and local living conditions on Jamaica's north coast. Singapore Journal of Tropical Geography, 30(2), 204-219.

Dominick, D., Wilson, S. R., Paton-Walsh, C., Humphries, R., Guérette, E. A., Keywood, M., Kubistin, D., & Marwick, B. (2018). Characteristics of airborne particle number size distributions in a coastal-urban environment. Atmospheric Environment, 186, 256-265.

Donovan, G. H., & Prestemon, J. P. (2012). The effect of trees on crime in Portland, Oregon. Environment and behavior, 44(1), 3-30.

Donovan, G. H., Butry, D. T., Michael, Y. L., Prestemon, J. P., Liebhold, A. M., Gatziolis, D., & Mao, M. Y. (2013). The relationship between trees and human health: evidence from the spread of the emerald ash borer. American journal of preventive medicine, 44(2), 139-145.

Dorney, J. R., Guntenspergen, G. R., Keough, J. R., & Stearns, F. (1984). Composition and structure of an urban woody plant community. Urban Ecology, 8(1-2), 69-90.

Douglas, E. M., Kirshen, P. H., Paolisso, M., Watson, C., Wiggin, J., Enrici, A., & Ruth, M. (2012). Coastal flooding, climate change and environmental justice: Identifying obstacles and incentives for adaptation in two metropolitan Boston Massachusetts communities. Mitigation and Adaptation Strategies for Global Change, 17(5), 537-562.

Eddy, E. N., & Roman, C. T. (2016). Relationship between epibenthic invertebrate species assemblages and environmental variables in Boston Harbor's intertidal habitat. Northeastern Naturalist, 23(1), 45-66.

Eguchi, T., Seminoff, J. A., LeRoux, R. A., Dutton, P. H., & Dutton, D. L. (2010). Abundance and survival rates of green turtles in an urban environment: coexistence of humans and an endangered species. Marine Biology, 157(8), 1869-1877.

Ehrenfeld, J. G. (2000). Evaluating wetlands within an urban context. Urban Ecosystems, 4(1), 69-85.

Faeth, S. H., Bang, C., & Saari, S. (2011). Urban biodiversity: patterns and mechanisms. Annals of the New York Academy of Sciences, 1223(1), 69-81.

Galimany, E., Rose, J. M., Dixon, M. S., & Wikfors, G. H. (2013). Quantifying feeding behavior of ribbed mussels (Geukensia demissa) in two urban sites (Long Island Sound, USA) with different seston characteristics. *Estuaries and Coasts*, *36*(6), 1265-1273.

Garden, J., McAlpine, C., Peterson, A. N. N., Jones, D., & Possingham, H. (2006). Review of the ecology of Australian urban fauna: a focus on spatially explicit processes. Austral Ecology, 31(2), 126-148.

Gardner, E. A. (2003). Some examples of water recycling in Australian urban environments: a step towards environmental sustainability. Water Science and Technology: Water Supply, 3(4), 21-31.

Giovene di Girasole, E. (2014). "The hinge areas for urban regeneration in seaside cities: the High Line in Manhattan, NYC," in Advanced Engineering Forum (Vol. 11, pp. 102-108). Trans Tech Publications Ltd.

Goh, K. (2019). Urban Waterscapes: The HydroPolitics of Flooding in a Sinking City. International Journal of Urban and Regional Research, 43(2), 250-272.

Greenwell, C. N., Calver, M. C., & Loneragan, N. R. (2019). Cat gets its tern: A case study of predation on a threatened coastal seabird. Animals, 9(7), 445.

Griggs, D., Stafford-Smith, M., Gaffney, O., Rockström, J., Öhman, M. C., Shyamsundar, P., Steffen, W., Glaser, G., Kanie, N., & Noble, I. (2013). Policy: Sustainable development goals for people and planet. Nature, 495(7441), 305.

Grimm, N. B., Grove, J. G., Pickett, S. T., & Redman, C. L. (2000). Integrated approaches to long-term studies of urban ecological systems: Urban ecological systems present multiple challenges to ecologists—pervasive human impact and extreme heterogeneity of cities, and the need to integrate social and ecological approaches, concepts, and theory. BioScience, 50(7), 571-584.

Grimm, N. B., Faeth, S. H., Golubiewski, N. E., Redman, C. L., Wu, J., Bai, X., & Briggs, J. M. (2008). Global change and the ecology of cities. science, 319(5864), 756-760.

Grimm, N. B., Redman, C. L., Boone, C. G., Childers, D. L., Harlan, S. L., & Turner, B. L. (2013). "Viewing the urban socio-ecological system through a sustainability lens: Lessons and prospects from the central Arizona–Phoenix LTER programme," in Long term socio-ecological research (pp. 217-246). Dordrecht: Springer.

Grisafi, F., Oddo, E., Gargano, M. L., Inzerillo, S., Russo, G., & Venturella, G. (2016). Tamarix arborea var. arborea and Tamarix parviflora: two species valued for their adaptability to stress conditions. Acta Biologica Hungarica, 67(1), 42-52.

Groffman, P. M., Law, N. L., Belt, K. T., Band, L. E., & Fisher, G. T. (2004). Nitrogen fluxes and retention in urban watershed ecosystems. Ecosystems, 7(4), 393-403.

Grossmann, I. (2008). Perspectives for Hamburg as a port city in the context of a changing global environment. Geoforum, 39(6), 2062-2072.

Guerrero Valdebenito, R. M., & Alarcon Rodriguez, M. L. (2018). Neoliberalism and socio-spatial transformations in urban coves of the Metropolitan Area of Concepcion. The cases of Caleta Los Bagres and Caleta Cocholgue, Tome. Revista de Urbanismo, 38.

Gumusay, M. U., Koseoglu, G., & Bakirman, T. (2016). An assessment of site suitability for marina construction in Istanbul, Turkey, using GIS and AHP multicriteria decision analysis. Environmental monitoring and assessment, 188(12), 677.

Günel, G. (2018). Air Conditioning the Arabian Peninsula. International Journal of Middle East Studies, 50(3), 573-579.

Heery, E. C., Olsen, A. Y., Feist, B. E., & Sebens, K. P. (2018). Urbanization-related distribution patterns and habitat-use by the marine mesopredator, giant pacific octopus (enteroctopus dofleini). Urban Ecosystems, 21, 707–19.

Henry, L. & Wickham, H. (2017). Purrr: Functional programming tools.

Holloway, M. G., & Connell, S. D. (2002). Why do floating structures create novel habitats for subtidal epibiota?. Marine Ecology Progress Series, 235, 43-52.

Holt, A. R., Mears, M., Maltby, L., & Warren, P. (2015). Understanding spatial patterns in the production of multiple urban ecosystem services. Ecosystem services, 16, 33-46.

Hosannah, N., & Gonzalez, J. E. (2014). Impacts of aerosol particle size distribution and land cover land use on precipitation in a coastal urban environment using a cloud-resolving mesoscale model. Advances in Meteorology, 2014.

Ip, C. C., Li, X. D., Zhang, G., Wai, O. W., & Li, Y. S. (2007). Trace metal distribution in sediments of the Pearl River Estuary and the surrounding coastal area, South China. Environmental Pollution, 147(2), 311-323.

Jacobs, J. C. J. (2011). The Rotterdam approach: connecting water with opportunities. Water Sensitive Cities, 251.

Jartun, M., & Pettersen, A. (2010). Contaminants in urban runoff to Norwegian fjords. Journal of soils and sediments, 10(2), 155-161.

Johansson, E., & Emmanuel, R. (2006). The influence of urban design on outdoor thermal comfort in the hot, humid city of Colombo, Sri Lanka. International journal of biometeorology, 51(2), 119-133.

Jonkman, S. N., Hillen, M. M., Nicholls, R. J., Kanning, W., & van Ledden, M. (2013). Costs of adapting coastal defences to sea-level rise—new estimates and their implications. Journal of Coastal Research, 29(5), 1212-1226.

Juchimiuk, J., & Januszkiewicz, K. (2019). Envisioning infrastructure to reduce disaster's impact to cities during the climate change area being elements of smart cities. In IOP Conference Series: Earth and Environmental Science (Vol. 214, No. 1, p. 012141). IOP Publishing.

Kalinowski, R. S., & Johnson, M. D. (2010). Influence of suburban habitat on a wintering bird community in coastal northern California. *The Condor*, *112*(2), 274-282.

Kaniewski, D., Van Campo, E., Morhange, C., Guiot, J., Zviely, D., Shaked, I., ... & Artzy, M. (2013). Early urban impact on Mediterranean coastal environments. Scientific Reports, 3(1), 1-5.

Kantamaneni, K., Gallagher, A., & Du, X. (2019). Assessing and mapping regional coastal vulnerability for port environments and coastal cities. Journal of coastal conservation, 23(1), 59-70.

Kates, R. W., Clark, W. C., Corell, R., Hall, J. M., Jaeger, C. C., Lowe, I., McCarthy, J. J., Schellnhuber, H. J., Bolin, B., Dickson, N. M., Faucheux, S., Gallopin, G. C., Grübler, A., Huntley, B., Jäger, J. Jodha, N. S., Kasperson, R. E., Mabogunje, A., Matson, P., Mooney, H., Moore III, B., O'Riordan, T., & Svedin, U. (2001). Sustainability science. Science, 292(5517), 641-642.

Krishnan, S., Lin, J., Simanjuntak, J., Hooimeijer, F., Bricker, J., Daniel, M., & Yoshida, Y. (2019). Interdisciplinary Design of Vital Infrastructure to Reduce Flood Risk in Tokyo's Edogawa Ward. Geosciences, 9(8), 357.

Kulkova, M., Chadov, F., & Davidochkina, A. (2011). Radiocarbon in vegetation of coastal zone of Finnish Bay (Russia). Procedia Environmental Sciences, 8, 375-381.

Kumar, T. S., Mahendra, R. S., Nayak, S., Radhakrishnan, K., & Sahu, K. C. (2010). Coastal vulnerability assessment for Orissa State, east coast of India. Journal of Coastal Research, 26(3 (263)), 523-534.

Kuwae, T., Kanda, J., Kubo, A., Nakajima, F., Ogawa, H., Sohma, A., & Suzumura, M. (2016). Blue carbon in human-dominated estuarine and shallow coastal systems. Ambio, 45(3), 290-301.

Leclerc, J. C., & Viard, F. (2018). Habitat formation prevails over predation in influencing fouling communities. Ecology and Evolution, 8, 477–92.

Li, Y., Qiu, J., Zhao, B., Pavao-Zuckerman, M., Bruns, A., Qureshi, S., ... & Li, Y. (2017). Quantifying urban ecological governance: A suite of indices characterizes the ecological planning implications of rapid coastal urbanization. *Ecological Indicators*, *72*, 225-233.

Li, Y., Yang, X., Zhu, X., Mulvihill, P. R., Matthews, H. D., & Sun, X. (2011). Integrating climate change factors into China's development policy: Adaptation strategies and mitigation to environmental change. Ecological Complexity, 8(4), 294-298.

Li, Z., Zhou, C., Yang, X., Chen, X., Meng, F., Lu, C., ... & Qi, W. (2018). Urban landscape extraction and analysis in the mega-city of China's coastal regions using high-resolution satellite imagery: A case of Shanghai, China. International journal of applied earth observation and geoinformation, 72, 140-150.

Lim, H. C., & Sodhi, N. S. (2004). Responses of avian guilds to urbanisation in a tropical city. Landscape and Urban Planning, 66(4), 199-215.

Liu, J., Dietz, T., Carpenter, S. R., Alberti, M., Folke, C., Moran, E., Pell, A. N., Deadman, P., Kratz, T., Lubchenco, J., Ostrom, E., Ouyang, Z., Provencher, W., Redman, C. L., Schneider, S. F., & Taylor W. W. (2007a). Complexity of coupled human and natural systems. Science, 317(5844), 1513-1516.

Liu, J., Dietz, T., Carpenter, S. R., Folke, C., Alberti, M., Redman, C. L., Schneider, S. H., Ostrom, E., Pell, A. N., Lubchenco, J., Taylor, W. W., Ouyang, Z., Deadman, P., Kratz, T.,& Provencher, W. (2007b). Coupled human and natural systems. AMBIO: a journal of the human environment, 36(8), 639-649.

Lopes, A., Lopes, S., Matzarakis, A., & Alcoforado, M. J. (2011). The influence of the summer sea breeze on thermal comfort in funchal (madeira). A contribution to tourism and urban planning. Meteorologische Zeitschrift 20: 553–64.

Luijendijk, A., Hagenaars, G., Ranasinghe, R., Baart, F., Donchyts, G., & Aarninkhof, S. (2018). The state of the world's beaches. *Scientific reports*, *8*(1), 1-11.

Maguire, T. J., & Fulweiler, R. W. (2019). Urban groundwater dissolved silica concentrations are elevated due to vertical composition of historic land-filling. *Science of the Total Environment*, *684*, 89-95.

Marzluff, J. M. (2001). "Worldwide urbanization and its effects on birds," in Avian ecology and conservation in an urbanizing world (pp. 19-47). Boston: Springer.

Marshall, F. E., Banks, K., & Cook, G. S. (2014). Ecosystem indicators for Southeast Florida beaches. Ecological Indicators, 44, 81-91.

Martin, J. M., French, K., & Major, R. E. (2007). The pest status of Australian white ibis (Threskiornis molucca) in urban situations and the effectiveness of egg-oil in reproductive control. Wildlife Research, 34(4), 319-324.

McDonald, R. I., Mansur, A. V., Ascensão, F., Crossman, K., Elmqvist, T., Gonzalez, A., ... & Huang, K. (2019). Research gaps in knowledge of the impact of urban growth on biodiversity. Nature Sustainability, 1-9.

McDonnell, M. J., Pickett, S. T., & Pouyat, R. V. (1993). "The application of the ecological gradient paradigm to the study of urban effects," in Humans as components of ecosystems (pp. 175-189). New York: Springer.

McKinney, M. L. (2006). Urbanization as a major cause of biotic homogenization. Biological conservation, 127, 247–60.

Mejia, J. F., & Morawska, L. (2009). An investigation of nucleation events in a coastal urban environment in the Southern Hemisphere. Atmospheric Chemistry and Physics, 9 (1), 2195-2222.

Mgelwa, A. S., Hu, Y. L., Liu, J. F., Qiu, Q., Liu, Z., & Ngaba, M. J. Y. (2019). Differential patterns of nitrogen and δ15N in soil and foliar along two urbanized rivers in a subtropical coastal city of southern China. Environmental pollution, 244, 907-914.

Mitsch, W. J. (2012). What is ecological engineering?. Ecological Engineering, 45, 5-12.

Morris, R. L., Heery, E. C., Loke, L. H., Lau, E., Strain, E., Airoldi, L., ... & Dong, Y. W. (2019). "H4 Design Options, Implementation Issues and Evaluating Success of Ecologically Engineered Shorelines," in Oceanography and Marine Biology. Taylor & Francis.

Morris, R. L., Boxshall, A., & Swearer, S. E. (2020). Climate-resilient coasts require diverse defence solutions. Nature Climate Change, 1-3.

Musacchio, L. R. (2009). The scientific basis for the design of landscape sustainability: a conceptual framework for translational landscape research and practice of designed landscapes and the six Es of landscape sustainability. Landscape Ecology, 24(8), 993.

Nagendra, H., Bai, X., Brondizio, E. S., & Lwasa, S. (2018). The urban south and the predicament of global sustainability. Nature Sustainability, 1(7), 341-349.

Naidoo, T., Smit, A. J., & Glassom, D. (2016). Plastic ingestion by estuarine mullet Mugil cephalus (Mugilidae) in an urban harbour, KwaZulu-Natal, South Africa. African Journal of Marine Science, 38(1), 145-149.

Noble, R. T., Griffith, J. F., Blackwood, A. D., Fuhrman, J. A., Gregory, J. B., Hernandez, X., ... & Schiff, K. (2006). Multitiered approach using quantitative PCR to track sources of fecal pollution affecting Santa Monica Bay, California. Appl. Environ. Microbiol., 72(2), 1604-1612.

Noyes, J. H., & Progulske, D. R. (Eds.). (1974). A Symposium on Wildlife in an Urbanizing Environment, November 27-29, 1973, Springfield, Massachusetts (No. 28). Cooperative Extension Service, University of Massachusetts.

Nunkoo, R., & Ramkissoon, H. (2010). Small island urban tourism: a residents' perspective. Current Issues in Tourism, 13(1), 37-60.

Ogie, R. I., Adam, C., & Perez, P. (2020). A review of structural approach to flood management in coastal megacities of developing nations: current research and future directions. Journal of Environmental Planning and Management, 63(2), 127-147.

Oliveira, W., e Silva, J. L. S., de Oliveira, M. T. P., Cruz-Neto, O., da Silva, L. A. P., Borges, L. A., ... & Lopes, A. V. (2019). Reduced reproductive success of the endangered tree brazilwood (Paubrasilia echinata, Leguminosae) in urban ecosystem compared to Atlantic forest remnant: lessons for tropical urban ecology. *Urban Forestry & Urban Greening*, *41*, 303-312.

O'Shaughnessy, K. A., Hawkins, S. J., Evans, A. J., Hanley, M. E., Lunt, P., Thompson, R. C., ... & Simmonds, D. (2020). Design catalogue for eco-engineering of coastal artificial structures: a multifunctional approach for stakeholders and end-users. Urban Ecosystems, 23(2), 431-443.

Pacione, M. (2003). Urban environmental quality and human wellbeing—a social geographical perspective. Landscape and urban planning, 65(1-2), 19-30.

Pallarés, S., Gómez, E., Martínez, A., & Jordán, M. M. (2019). The relationship between indoor and outdoor levels of PM10 and its chemical composition at schools in a coastal region in Spain. Heliyon, 5(8), e02270.

Papatheochari, T., & Coccossis, H. (2019). Development of a waterfront regeneration tool to support local decision making in the context of integrated coastal zone management. Ocean & Coastal Management, 169, 284-295.

Parzych, A., Astel, A., Zduńczyk, A., & Surowiec, T. (2016). Evaluation of urban environment pollution based on the accumulation of macro-and trace elements in epiphytic lichens. *Journal of Environmental Science and Health, Part A*, *51*(4), 297-308.

Patel, P., Ghosh, S., Kaginalkar, A., Islam, S., & Karmakar, S. (2019). Performance evaluation of WRF for extreme flood forecasts in a coastal urban environment. Atmospheric research, 223, 39-48.

Paul, M. J., & Meyer, J. L. (2001). Streams in the urban landscape. Annual review of Ecology and Systematics, 32(1), 333-365.

Patz, J. A., Daszak, P., Tabor, G. M., Aguirre, A. A., Pearl, M., Epstein, J., ... & Working Group on Land Use Change Disease Emergence. (2004). Unhealthy landscapes: policy recommendations on land use change and infectious disease emergence. Environmental health perspectives, 112(10), 1092-1098.

Peng, C., Wang, S., Zhang, J., Lim, C. C., & Ooi, L. K. (2011, March). Sustainable In-Situ Water Resource Management Strategies in Water Scarce Urban Environment: A Case Study of Sino-Singapore Tianjin Eco City. In 2011 Asia-Pacific Power and Energy Engineering Conference (pp. 1-4). IEEE.

Peng, F., Wong, M. S., Wan, Y., & Nichol, J. E. (2017). Modeling of urban wind ventilation using high resolution airborne LiDAR data. Computers, Environment and Urban Systems, 64, 81-90.

Perkol-Finkel, S., Hadary, T., Rella, A., Shirazi, R., & Sella, I. (2018). Seascape architecture–incorporating ecological considerations in design of coastal and marine infrastructure. Ecological Engineering, 120, 645-654.

Pickett, S. T., Cadenasso, M. L., Grove, J. M., Groffman, P. M., Band, L. E., Boone, C. G., ... & Law, N. L. (2008). Beyond urban legends: an emerging framework of urban ecology, as illustrated by the Baltimore Ecosystem Study. BioScience, 58(2), 139-150.

Pickett, S. T., Cadenasso, M. L., Childers, D. L., McDonnell, M. J., & Zhou, W. (2016). Evolution and future of urban ecological science: ecology in, of, and for the city. Ecosystem health and Sustainability, 2(7), e01229.

Pinheiro, A. T. K., & Hokugo, A. (2019). Effectiveness of early warning and community cooperation for evacuation preparedness from mega-risk type coastal hazard in childcare centers. International journal of disaster resilience in the built environment.

Pinho, O. S., & Orgaz, M. M. (2000). The urban heat island in a small city in coastal Portugal. International journal of biometeorology, 44(4), 198-203.

Pizarro, R. E. (2008). Sustainable planning for poor communities: urban design studios as a catalyst for development in Colombia. Dialogues in Urban Planning: Towards Sustainable Regions, 175.

Priestley, M., Breton, M. L., Bannan, T. J., Worrall, S. D., Bacak, A., Smedley, A. R., ... & Percival, C. J. (2018). Observations of organic and inorganic chlorinated compounds and their contribution to chlorine radical concentrations in an urban environment in northern Europe during the wintertime. Atmospheric Chemistry and Physics, 18(18), 13481-13493.

Punda-Polić, V., Bradarić, N., Klišmanić-Nuber, Z., Mrljak, V., & Giljanović, M. (1995). Antibodies to spotted fever group rickettsiae in dogs in Croatia. European journal of epidemiology, 11(4), 389-392.

Purvis, K. G., Gramling, J. M., & Murren, C. J. (2015). Assessment of beach access paths on dune vegetation: diversity, abundance, and cover. Journal of Coastal Research, 31(5), 1222-1228.

Pushpawela, B., Jayaratne, R. & Morawska, L. (2018). Differentiating between particle formation and growth events in an urban environment. Atmospheric Chemistry and Physics, 18(15), 11171-11183.

Race, D., Luck, G. W., & Black, R. (2010). "Patterns, drivers and implications of demographic change in rural landscapes." in Demographic change in Australia's rural landscapes (pp. 1-22). Dordrecht: Springer.

Ramalho, C. E., & Hobbs, R. J. (2012). Time for a change: dynamic urban ecology. Trends in ecology & evolution, 27(3), 179-188.

R Core Team (2020). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Redman, C. L., Grove, J. M., & Kuby, L. H. (2004). Integrating social science into the long-term ecological research (LTER) network: social dimensions of ecological change and ecological dimensions of social change. Ecosystems, 7(2), 161-171.

Rees, W. E. (1997). Urban ecosystems: The human dimension. Urban ecosystems, 1, 63–75.

Reyes-López, J., & Carpintero, S. (2014). Comparison of the exotic and native ant communities (Hymenoptera: Formicidae) in urban green areas at inland, coastal and insular sites in Spain. European Journal of Entomology, 111(3), 421.

Robinson, D. (2017). Broom: Convert statistical analysis objects into tidy data frames.

Rosenzweig, B. R., Groffman, P. M., Zarnoch, C. B., Branco, B. F., Hartig, E. K., Fitzpatrick, J., ... & Parris, A. (2018). Nitrogen regulation by natural systems in “unnatural” landscapes: denitrification in ultra-urban coastal ecosystems. Ecosystem Health and Sustainability, 4(9), 205-224.

RStudio Team (2019). RStudio: Integrated Development for R. RStudio, Inc., Boston, MA URL http://www.rstudio.com/.

Sahal, A., Leone, F., & Péroche, M. (2013). Complementary methods to plan pedestrian evacuation of the French Riviera's beaches in case of tsunami threat: graph-and multi-agent-based modelling. Natural Hazards and Earth System Sciences, 13(7), 1735-1743.

Sainz-Borgo, C., Giner, S., González-Carcacía, J. A., Caula, S., Fernández-Ordóñez, J. C., Hernández, C., ... & Rodríguez-Ferraro, A. (2016). Current distribution, habitat use, and breeding records of the house sparrow (Passer domesticus) in Venezuela. Ornitología Neotropical, 27, 267-273.

Sairinen, R., & Kumpulainen, S. (2006). Assessing social impacts in urban waterfront regeneration. Environmental impact assessment review, 26(1), 120-135.

Santos, T., & Freire, S. (2015). Testing the contribution of Worldview-2 improved spectral resolution for extracting vegetation cover in urban environments. Canadian Journal of Remote Sensing, 41(6), 505-514.

Schwartz, M. W., Smith, L. M., & Steel, Z. L. (2013). Conservation investment for rare plants in urban environments. PloS one, 8(12).

Semadeni-Davies, A., Hernebring, C., Svensson, G., & Gustafsson, L. G. (2008). The impacts of climate change and urbanisation on drainage in Helsingborg, Sweden: Combined sewer system. Journal of Hydrology, 350(1-2), 100-113.

Serre, D., Barroca, B., & Diab, Y. (2010). "Urban flood mitigation: Sustainable options," in The Sustainable City VI, Urban Regenerations and Sustainability, 129, 299-309. Southampton: WIT press.

Shanquan, L., Zhang, G., Yang, J., & Nan, J. (2016). Multi-source characteristics of atmospheric deposition in Nanjing, China, as controlled by East Asia monsoons and urban activities. Pedosphere, 26(3), 374-385.

Shepard, E. L., Williamson, C., & Windsor, S. P. (2016). Fine-scale flight strategies of gulls in urban airflows indicate risk and reward in city living. Philosophical Transactions of the Royal Society B: Biological Sciences, 371, 20150394.

Sherbinin, A. D., Carr, D., Cassels, S., & Jiang, L. (2007). Population and environment. Annual Review of Environment and Resources, 32, 345-373.

Shochat, E., Warren, P. S., & Faeth, S. H. (2006). Future directions in urban ecology. Trends in Ecology & Evolution, 21, 661–2.

Smith, A. C., & Munro, U. (2010). Seasonal population dynamics of the Australian White Ibis (*Threskiornis molucca*) in urban environments. Emu, 110(2), 132-136.

Song, X., Chang, K. T., Yang, L., & Scheffran, J. (2016). Change in environmental benefits of urban land use and its drivers in Chinese cities, 2000–2010. International journal of environmental research and public health, 13(6), 535.

Stathopoulou, M., & Cartalis, C. (2007). Daytime urban heat islands from Landsat ETM+ and Corine land cover data: An application to major cities in Greece. *Solar Energy*, *81*(3), 358-368.

Storch, H., & Downes, N. K. (2011). A scenario-based approach to assess Ho Chi Minh City's urban development strategies against the impact of climate change. Cities, 28(6), 517-526.

Su, X., Liu, T., Beheshti, M., & Prigiobbe, V. (2019). Relationship between infiltration, sewer rehabilitation, and groundwater flooding in coastal urban areas. Environmental Science and Pollution Research, 1-11.

Sukopp, H. (1998). "Urban ecology—scientific and practical aspects," in Urban ecology (pp. 3-16). Berlin: Springer.

Surjan, A. K., & Shaw, R. (2008). ‘Eco-city’to ‘disaster-resilient eco-community’: a concerted approach in the coastal city of Puri, India. Sustainability Science, 3(2), 249-265.

Sutton-Grier AE, Wowk K, & Bamford H. 2015. Future of our coasts: The potential for natural and hybrid infrastructure to enhance the resilience of our coastal communities, economies and ecosystems. Environmental Science & Policy, 51, 137-148.

Tait, C. J., Daniels, C. B., & Hill, R. S. (2005). Changes in species assemblages within the Adelaide metropolitan area, Australia, 1836–2002. Ecological Applications, 15(1), 346-359.

Theodosi, C., Tsagkaraki, M., Zarmpas, P., Grivas, G., Liakakou, E., Paraskevopoulou, D., ... & Mihalopoulos, N. (2018). Multi-year chemical composition of the fine-aerosol fraction in Athens, Greece, with emphasis on the contribution of residential heating in wintertime. *Atmospheric Chemistry and Physics*, *18*(19), 14371-14391.

Torresan, S., Critto, A., Dalla Valle, M., Harvey, N., & Marcomini, A. (2008). Assessing coastal vulnerability to climate change: comparing segmentation at global and regional scales. Sustainability Science, 3(1), 45-65.

Tu, W., & Shi, C. (2006). Urban environmental management in Shanghai: achievements, problems, and prospects. Environmental Management, 37(3), 307-321.

Tzortzakaki, O., Kati, V., Kassara, C., Tietze, D. T., & Giokas, S. (2018). Seasonal patterns of urban bird diversity in a Mediterranean coastal city: the positive role of open green spaces. Urban ecosystems, 21(1), 27-39.

Tzoulas, K., Korpela, K., Venn, S., Yli-Pelkonen, V., Kaźmierczak, A., Niemela, J., & James, P. (2007). Promoting ecosystem and human health in urban areas using Green Infrastructure: A literature review. Landscape and urban planning, 81(3), 167-178.

Ulrich, R. S. (1984). View through a window may influence recovery from surgery. Science 224, 420–1.

United Nations. (2017). Concept paper. Partnership dialogue 2: Managing, protecting, conserving and restoring marine and coastal ecosystems.

United Nations. Department of Economics and Social Affairs Population Dynamics. (2014). World urbanization prospects: The 2014 revision. Highlights.

United Nations. Department of Economics and Social Affairs Population Dynamics. (2018). World urbanization prospects: The 2018 revision. Key facts.

United Nations. Department of Economics and Social Affairs Population Dynamics. 2019. World population prospects: Download Files. https://population.un.org/wpp/Download/Standard/CSV/

Van Kamp, I., Leidelmeijer, K., Marsman, G., & De Hollander, A. (2003). Urban environmental quality and human well-being: Towards a conceptual framework and demarcation of concepts; a literature study. Landscape and urban planning, 65(1-2), 5-18.

Vicente, A. B., Sanfeliu, T., & Jordan, M. M. (2012). Assesment of PM10 pollution episodes in a ceramic cluster (NE Spain): Proposal of a new quality index for PM10, As, Cd, Ni and Pb. Journal of Environmental Management, 108, 92-101.

Videla, H. A., & Herrera, L. K. (2017). "A comparative study on biodeterioration and weathering effects in three sites of the Latin American cultural heritage," in Molecular Biology and Cultural Heritage (pp. 253-258). Routledge.

Villagra, P., Herrmann, G., Quintana, C., & Sepúlveda, R. D. (2016). Resilience thinking and urban planning in a coastal environment at risks of tsunamis: the case study of Mehuín, Chile. Revista de Geografía Norte Grande, (64), 63-82.

Vitousek, S., Barnard, P. L., Fletcher, C. H., Frazer, N., Erikson, L., & Storlazzi, C. D. (2017). Doubling of coastal flooding frequency within decades due to sea-level rise. *Scientific reports*, *7*(1), 1-9.

Vye, D., & Rousseaux, F. (2010). Evaluation of urban planning strategies with a versatile urban growth model. The Sustainable City VI: Urban Regeneration and Sustainability, 6, 227.

Walsh, C. J., Roy, A. H., Feminella, J. W., Cottingham, P. D., Groffman, P. M., & Morgan, R. P. (2005). The urban stream syndrome: current knowledge and the search for a cure. Journal of the North American Benthological Society, 24(3), 706-723.

Wang, Z. (2010). Mechanisms of cadmium toxicity to various trophic saltwater organisms. Nova Science Publishers.

Washburn, B. E., Bernhardt, G. E., Kutschbach-Brohl, L., Chipman, R. B., & Francoeur, L. C. (2013). Foraging Ecology of Four Gull Species at a Coastal-Urban Interface: Ecología de Forrajeo de Cuatro Especies de Gaviota en una Interface Costera-Urbana. The Condor, 115(1), 67-76.

Watson, J. (2015). Practical precautions, reasonable responses: How South Australia's planning regime adapts to the coastal impacts of climate change. Environmental and Planning Law Journal, 32, 256-277.

Watson, D., & Adams, M. (2010). Design for flooding: Architecture, landscape, and urban design for resilience to climate change. John wiley & sons.

Way, J. G., Ortega, I. M., & Strauss, E. G. (2004). Movement and activity patterns of eastern coyotes in a coastal, suburban environment. *Northeastern Naturalist*, *11*(3), 237-254.

Weinstein, M. P. (2009). The road ahead: The sustainability transition and coastal research. Estuaries and Coasts, 32, 1044–53.

Whisson, D. A., Weston, M. A., & Shannon, K. (2015). Home range, habitat use and movements by the little raven (Corvus mellori) in a coastal peri-urban landscape. Wildlife research, 42(6), 500-508.

White, M. P., Pahl, S., Ashbullby, K., Herbert, S., & Depledge, M. H. (2013). Feelings of restoration from recent nature visits. Journal of Environmental Psychology, 35, 40-51.

Wickham, H. (2009). Ggplot2: Elegant graphics for data analysis. Springer-Verlag New York.

Wickham, H., & Wickham, M. H. (2017a). Package tidyverse. Easily Install and Load the 'Tidyverse.

Wickham, H. (2017b). stringr: Simple, consistent wrappers for common string operations. R package version, 1(0).

Wickham, H., Francois, R., Henry, L., & Müller, K. (2015). dplyr: A grammar of data manipulation. R package version 0.4, 3.

Williams, C. F., Lloyd, D., Lees, J., Pirog, A., Geroni, G. M., Pastre, J., ... & Porch, A. (2016, May). What the deep sea can tell us about microwaves. In 2016 IEEE MTT-S International Microwave Symposium (IMS) (pp. 1-4). IEEE.

Winzer, L. F., Berthon, K. A., Carnegie, A. J., Pegg, G. S., & Leishman, M. R. (2019). Austropuccinia psidii on the move: survey based insights to its geographical distribution, host species, impacts and management in Australia. Biological Invasions, 21(4), 1215-1225.

Wolch, J. R., Byrne, J., & Newell, J. P. (2014). Urban green space, public health, and environmental justice: The challenge of making cities 'just green enough'. Landscape and urban planning, 125, 234-244.

Wolsko, C., & Marino, E. (2016). Disasters, migrations, and the unintended consequences of urbanization: What's the harm in getting out of harm's way?. Population and Environment, 37(4), 411-428.

Wong, T. C. (2011). "Eco-cities in China: Pearls in the sea of degrading urban environments?," in Eco-city Planning (pp. 131-150). Dordrecht: Springer.

Wu, J. J. (2008). Making the case for landscape ecology an effective approach to urban sustainability. Landscape journal, 27(1), 41-50.

Wu, J. 2014. Urban ecology and sustainability: The state-of-the-science and future directions. Landscape and urban planning, 125, 209-221.

Wu, W. (2007). Coastline evolution monitoring and estimation—a case study in the region of Nouakchott, Mauritania. International Journal of Remote Sensing, 28(24), 5461-5484.

Yamazaki, K., Kitamoto, T., Yariyama, Y., & Sugiura, S. (2007). An analysis of spatial distribution in the exotic slug caterpillar *Parasa lepida* (Cramer)(Lepidoptera: Limacodidae) at an urban coastal site in central Japan. The Pan-Pacific Entomologist, 83(3), 193-199.

Yin, J., Lin, N., & Yu, D. (2016). Coupled modeling of storm surge and coastal inundation: A case study in New York City during Hurricane Sandy. Water Resources Research, 52(11), 8685-8699.

Yu, W., Zhang, Y., Zhou, W., Wang, W., & Tang, R. (2019). Urban expansion in Shenzhen since 1970s: A retrospect of change from a village to a megacity from the space. Physics and Chemistry of the Earth, Parts A/B/C, 110, 21-30.

Zhang, L., Xia, Y. P., Wu, Q., She, L. F., Li, H., & Ruan, T. L. (2014). "Original design and ecological recreation: a comparative analysis of wetland parks in the Yangtse River Delta area," in XXIX International Horticultural Congress on Horticulture: Sustaining Lives, Livelihoods and Landscapes (IHC2014): V 1108 (pp. 241-248).

Zhen, L., Lin, D. M., Shu, H. W., Jiang, S., & Zhu, Y. X. (2007). District cooling and heating with seawater as heat source and sink in Dalian, China. Renewable energy, 32(15), 2603-2616.

Zhou, W., Pickett, S. T., & Cadenasso, M. L. (2017). Shifting concepts of urban spatial heterogeneity and their implications for sustainability. Landscape ecology, 32(1), 15-30.

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.	White *et al.* (2013), Burger *et al.* (2017).
	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), Jonkman *et al.* (2013).
Study approach	Spatial	Focus on landscape, land cover or urban geomorphology changes.	Garden *et al.* (2006), Yamazaki *et al.* (2007).
	Spatiotemporal	Landscape, land cover or urban geomorphology changes, including some changes over time on small	Li *et al.* (2011), Grossmann (2008).

		scale.	
	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 environments 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	Collection and evaluation of measurable data of either social or environmental aspects.	Galimany, *et al.* (2013), Branoff (2017)
	Modelling studies	Mostly computational simulations.	Sahal et al. 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	Pollutants: Pallarés *et al.* (2019).

		elements, land structures, meteorological elements, pollutants, remote sensing data, risk models, seawater, surface deterioration, and water resources.	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, 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).