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Towards a typology for coastal towns and small cities for climate change adaptation planning

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ABSTRACT

The impacts of climate change will manifest differently in urban areas depending upon the individual characteristics and contexts of each settlement. The study of climate adaptation planning for towns and small cities is a relatively under-researched field, there has thus far not been a standard typology for characterising towns and cities located at the coast. A typology can inform stakeholders about the physical hazards a coastal town or small city may be exposed currently and in the future; identify the impact that may have to the local population and the economic, cultural, and environmental assets in the settlement; and identify any barriers or opportunities to plan, develop, and implement adaptation strategies. A typology is presented here that includes 34 parameters that cover physical, economic, environmental and social characteristics. This typology has been used within this Special Issue to obtain information about all 22 case studies of the Special Issue. Future work will concentrate on developing the typology further and analysing the data collected to provide a systematic understanding of some of the data gaps that still exist within the field of adaptation in coastal towns and small cities and allow future research to focus on the aspects that are most needed.

1. Introduction

Urban areas are highly diverse (Solecki et al., 2015) which is primarily driven by their physical, economic, historical, cultural, and social contexts. The impacts of climate change will manifest differently in each urban area depending upon these characteristics, therefore the manner in which adaptation is developed and implemented is also different (Rosenzweig et al., 2018). Typologies have been developed, such as Solecki et al. (2015), Chang et al. (2018), Duffy and Stojanovic (2017), that can be used to facilitate data collection and analysis of urban areas, in order to gain insights into a settlements characteristics. This can then lead to inferences of an urban area's climate change vulnerability, risk, and adaptive capacity that can be employed to develop and plan suitable adaptation.

Climate change adaptation strategies have been developed in larger cities, for example Copenhagen and New York (City of Copenhagen, 2011; City of New York, 2013), to ensure a more resilient future. There have also been global initiatives to support adaptation, such as the 100 Resilient Cities (www.100resilientcities.org), and the C40 Cities (www.c40.org). At the CitiesIPCC Conference held in March 2018 the Global Research and Action Agenda on Cities and Climate Change Science was approved; this aims to support the development of "blueprints and action plans for developing new evidence-based research and knowledge that supports effective climate action strategies in cities" (Cities IPCC, 2018, p.2). There will also be a Special Report on Cities and Climate Change produced by the Intergovernmental Panel on Climate Change (IPCC) in approximately 2023. Despite these efforts, smaller settlements, specifically towns and small cities (less than 100,000 people) have received limited attention.

The lack of focus on smaller settlements is particularly important at the coast, as it is thought that approximately 60% of the global coastal population do not live in large cities (Small and Nicholls, 2003). With coastal hazards such as sea level rise, storm surges, flooding, erosion, and salt-water intrusion likely to be exacerbated due to climate change

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(Masselink and Russell, 2013; Neumann et al., 2015; Vitousek et al., 2017; Werner et al., 2012), it is imperative that urban areas on the coast have the means the adapt. However, small urban areas often have limited information about local climate change impacts, and lack the financial resources to develop appropriate adaptation measures, and the lessons learnt and best practices developed for the larger cities are not necessarily suitable or applicable (Major and Juhola, 2016).

As the study of climate adaptation planning for towns and small cities is a relatively under-researched field, there has thus far not been a typology for characterising towns and cities located at the coast. It is therefore desirable to develop a typology that will provide for more efficient and effective climate change adaptation by assisting with knowledge exchange and creation of adaptation strategies that are relevant to local contexts (Chang et al., 2018). An initial typology was presented in Major et al. (2018).

Throughout this Special Issue a standardised dataset was developed for each of the case study towns and small cities to ensure comparison between cases. Given that the typology is designed to be applicable globally, and data availability is possibly limited in some locations, the data requested for the most part is numerical or a simple descriptive term. The data collected as part of the Special Issue inform complete or partial characterisation of the settlements, i.e. tourist town, and so are referred to as 'the 'Typology' or 'Typology Tables' by the authors within each of the subsequent case study articles.

The typology is subject to future change and development as experience with climate change adaptation in coastal towns and small cities is gained, and reflections from using and developing the typology within this Special Issue are given within this article. Therefore, the aim of this article is to propose an initial data collection approach that could:

a) guide stakeholders about the predominant physical hazards a coastal town or small city may be exposed to currently and in the future;
b) identify the potential key impacts these hazards have on the local population and the economic, cultural, and environmental assets in the settlement; and
c) possibly identify any barriers or opportunities to plan, develop, and implement adaptation strategies.

This article is structured into four sections: this introduction, further discussion of the uses of typologies; the data collected for use within the typology; and finally, the next steps and further research.

1.1. Uses of a typology

There are several important reasons for developing and using a typology of coastal towns and small cities for climate adaptation planning. First, a robust typology allows for the orderly and efficient collection of data on a variety of settlements. This permits the useful accumulation of information on the adaptation of coastal towns and small cities. One example of this is in Major et al. (2018), where a typology helped ensure the comparability of more than 100 case studies of urban climate adaptation. This was a contribution to research, while the longer-term objective of developing and implementing the typology in relation to this Special Issue goes beyond research and towards providing value for adaptation practice.

Second, for a coastal settlement, a typology could be used to link to methods and costs that are appropriate for that settlement. A typology can be an aid to more efficient adaptation that can be used by local planners, engineering firms, or aid agencies. It could also increase adaptation efficiency by helping cities and towns to borrow or adapt methods from towns with similar characteristics.

Finally, the aggregation of information on settlements that is collected by means of the typology, together with supporting information on costs, could in the future help to provide initial global estimates of the challenges of climate adaptation for coastal towns and small cities.

More broadly, the application of the typology can be seen as a response to the challenge of climate change adaptation for coastal towns and small cities identified in Major and Juhola (2016). It is intended to both help identify specific problems, and, going further, to support the development of ways of dealing with them.

1.2. Typology data

Table 1 and 2 show the data that should be collected for each of the case study settlements in order to inform characterisation. These tables include 34 physical, economic, environmental and social characteristics. For each of the element indicators and metrics; sources and the rational for including the element are provided. Henceforth, Tables 1 and 2 of the typology are collectively referred to as the Data Collection Protocol (DCP).

The DCP is divided into two groups. The first group (Typology Table 1) relates to characteristics associated with *coastal hazards* that define the physical potential, and types, of coastal hazards, which is used here to refer to the current and future extents likely to be impacted by such hazards (see Cardona et al. (2012); de la Vega-Leinert and Nicholls (2008); Lavell et al. (2012); Torresan et al. (2008)). The second group (Typology Table 2) relates to *exposure,* which establishes who or what is likely to be impacted by coastal hazards, and *vulnerability,* which characterises the degree of this impact. This is dependent upon institutional, social, economic, cultural, historical, and environmental factors that vary over spatial and temporal scales. Understanding of all of these characteristics supports decisions on adaptation responses.

Fig. 1 summaries the risk framework utilised by the IPCC and highlights where the data presented in the DCP fits within the framework. The knowledge of the local risks initially identified via the DCP can be used to inform the development of adaptation and/or mitigation plans. The DCP is designed to be used within an iterative approach, so that once adaptation and/or mitigation has been implemented the process could be repeated at planned intervals to help ensure settlements have adapted appropriately to current and future risks.

The distinction between the types of characteristics has been made to allow parts of the collected data to be used even when data availability issues prevent all of the data in the DCP obtained. Data related to hazards may be more readily available as they are often measured by national organizations and/or included within global datasets. Conversely, some of the data related to exposure and vulnerability may be less easily obtained, and in some cases may not exist. This is true for countries in the Global North, but especially the Global South. Therefore, the DCP can act both as a way to organize existing data, but also as a potential pathway to target future data collection. By arranging the DCP in this way, we hope to encourage the use of the DCP even within data poor areas, without users feeling obliged that they must have data for all the elements in order to benefit from its use.

To support this, each of the elements within Typology Table 1 has been assigned a temporality, indicating that historic, current, and/or future data related to that element should be collected if possible. In addition, each of the element in Typology Table 2 has been assigned a class depending on whether the element relates to the exposure or vulnerability categories. In some cases, an element has been assigned two classes and it relates to both hazard and susceptibility or exposure and vulnerability. The elements within Table 2 have also been given a sub-class depending whether the element relates to the economic, social, governance or cultural aspects of exposure and vulnerability. These classifications allow the user to select a particular aspect to assess, for example, the future impact of coastal hazards on the cultural assets within a location.

1.3. Characterising settlements

Within the development of the Special Issue, data was collected for each of the case studies. In addition to the entries in the DCP, additional information, and further contextualisation of the case studies were

Table 1
The Data Collection Protocol (DCP) to assess the hazards and susceptibility of a coastal locality. This table defines the physical potential, and types, of climate events, as well as the current and future geographical extents likely to be influenced by such events.

#	Hazard Elements	Potential Indicators or Metrics	Potential Sources	Rationale	Temporality		
					Historic	Current	Future
1	Settlement location	Latitude/longitude; km from present and future shoreline; cm above present and future MSL; island settlement, island size.	Records, satellite, local data, Global Climate Models	Link to regional or local (if available) CC forecasts, assistance agencies' programs		□	
2	Köppen–Geiger climate classification system	Temperature and other data; future change of classification	System, literature	Guide assessment of impacts and possible adaptation methods		□	□
3	Isostatic rebound	cm/year	Literature	Add/subtract from SLR forecasts	□	□	□
4	Subsidence	cm/year	Literature	Add to relative SLR forecasts	□	□	□
5	Local/regional mass density changes	SLR adjustments in cm	From Global Climate Models and literature	Adjust global or large region SLR data	□	□	□
6	Coastal erosion	Presence of coastal erosion mitigation management; degree of historic and future coastal erosion	Satellite, records, literature, local knowledge	To determine if the settlement is located on/near erodible coasts	□	□	□
7	Slopes and angles on or near the shore	Beach: km and slope; Ocean floor: near shore slope	Satellite, records, literature	Suggest/determine nature of impacts and suggest adaptation methods		□	
8	Located in tropical or other storm zone	Geographical location, number of days water temperature above 26 °C	Records, forecasts of changes	Nature and frequency of impacts		□	
9	Inland Rainfall	Present and future intensity and frequency, including potential for drought	Records or local knowledge, GCMs	Need for interior protection and drainage improvements		□	□
10	Inland rivers	Fluvial reach located within the boundaries of the settlement, catchment characteristics e.g. proportion urban/rural, volume increase in upper 3% of flows over time, and capacity of catchment to cope with the high intensity precipitation.	Hydrologic data, literature	Determine whether there is a threat from simultaneous coastal and fluvial flooding	□	□	□
11	Extent and likelihood of coastal and/or fluvial flooding	Number and intensity of storms; future forecasts, past tsunami events	Records, local knowledge, GCMs	Assist in design of adaptation measures	□	□	□
12	Air temperature	Heat wave frequency and severity	Records, local knowledge, GCMs	Determine whether extreme heat may be an issue	□	□	□
13	Ocean/Coastal Parameters	Data on acidity, temperature, currents, pollution, frequency of algal blooms	Records, local knowledge, GCMs	Determine whether changes in coastal waters may impact upon local ecology and/or habitats	□	□	□
14	Habitats	Area and health of local habitats e.g. coral reef, seagrass, mangrove, tundra, sand dune	Records, local knowledge,	Determine if there is changes in habitats that offer key ecosystem services	□	□	□
15	Groundwater salinization	Aquifer size, changes in extraction location, volume, and water quality	Records, local knowledge, literature	Assist in design of adaptation measures	□	□	□
16	Base Rock	Type, km depth and width	Records	Determine physical impacts through salinization		□	
17	Other non-coastal natural hazards	Presence of active volcanoes, susceptible to earthquakes, heatwaves	Records, local knowledge, literature	Assist in design of adaptation measures	□	□	□

Table notes: Based in part on the following sources: Gornitz (2012); Major et al. (2018).

obtained via a narrative. Both the DCPs and the narratives were used by the lead authors on each of the case study chapters to compare and contrast across the case studies. It is unlikely that data is readily available for all 34 parameters requested by the DCP for all of the case study locations. Specific typological classifications are not presented here, as this article is designed to demonstrate the initial process of developing a formal classification of settlement types suitable for international contexts. Within the Special Issue articles, characterisation of the towns or small cities is given, if sufficient data is available to support it. In cases where data availability is more limited, the DCP was completed as much as possible, however, also knowing where data gaps exist is an important finding. The completed data collection tables are referred to as a the "Typology" or "Typology Tables" within each of the case study articles.

1.4. Reflections

The Special Issue proved to be a useful arena in which to test the use and appropriateness of the DCP as a tool for informing adaptation planning and towards a typology of coastal towns and small cities. All 22 cases in the Special Issue used the DCP, however, for some case studies it was not possible for the DCP to be fully completed. Nevertheless, there was sufficient data availability to ensure it was used across a range of physical, economic, and cultural contexts.

Reflecting on this identified a number of elements that were not included in the initial DCP that should be added for future work (and have been considered in part in the cases described in the articles to follow):

- *Tidal range* – important to factor in for storm surges, e.g. for coasts with a large tidal range a storm surge may occur at low tide, which would potentially have minimal impact on flooding;
- *Hinterland characteristics* – important for managed retreat considerations, e.g. whether there is steep land (hills or mountains beyond the beach - this affects whether a community can easily move back.

1.5. Towards a typology

Additional discussion of the typology are included in the final article

Table 2
The Data Collection Protocol (DCP) to assess exposure and vulnerability of a coastal locality. Vulnerability and Exposure focuses on establishing who or what is likely to be impacted by these climate events, and the degree of this impact, which depends upon institutional, social, economic, cultural, historical, and environmental factors.

#	Exposure and Vulnerability Elements	Potential Indicators or Metrics	Potential Sources	Rationale	Class		Sub-class			
					Exposure	Vulnerability	Economic	Social	Governance	Cultural
18	Population	Permanent population, tourist equivalent, peak season population	Records, satellite, local knowledge	Size of adaptation challenge	□			□		
19	Future Population Change	Increasing/decreasing numbers	Records, literature	Whether greater or fewer adaptations needed	□			□		
20	Impact of historic coastal and/or fluvial flooding	Hours/days downtime of key infrastructure, number of buildings impacted, km of roads and other transport facilities impacted	Records, local knowledge	Assist in design of adaptation measures		□	□	□	□	
21	Human Development Index (national)	Index	UNDP	Possible indicator of local capacity		□	□			
22	GNP/capita (probably national)	$US Purchasing Power Parity	World Bank	Possible indicator of local capacity		□	□			
23	Proportion of national population that is coastal	% population within selected distances from coast and within selected heights above MSL	Records, satellite, literature	To determine whether coastal adaptation is/will be high on the national agenda		□		□	□	
24	Governance	Type	National and local records	Aid in determining adaptive capacity		□			□	
25	Relationships to larger governmental entities	Larger entities to which it is related or of which the settlement is a part	National and regional records	Measure of joint capacity to adapt		□			□	
26	Relationships to international entities	UN, national aid agencies, NGO	National, local and NGO records	Measure of capacity to adapt		□			□	
27	Built Infrastructure	Number and location of buildings, transport infrastructure, key assets e. g. wastewater treatment plants, water abstraction, airports	Records, literature	Ascertain the potential assets that are exposed	□		□			
28	Natural Capital	Changes in ecosystem services, e.g. loss of coastal defence due to mangrove loss, loss of local biodiversity, e.g. reducing fish stocks, loss of key plant species, loss of income from agriculture/fishing	Records, satellite, literature, National, local and NGO records	Determine if changes in habitats and/or biodiversity may impact the local wellbeing and/or economy	□		□			□
29	Available geographic/GIS data	Housing, population, elevation	Records, literature	Assist in planning	□	□			□	
30	Minority status	Ethnic group, religion, indigenous, with population numbers	National, local and NGO records	Measure of need to adapt: aid design of adaptation measures		□		□		
31	Historical areas	Area (ha), buildings	National, local and NGO records	A measure of benefits from protection	□		□	□		□
32	Environmental areas	Area (ha), type	National, local and NGO records	A measure of benefits from protection	□		□	□		□
33	Cultural areas	Area (ha), type, cultural value impacts e.g. cultural connection to place and history	National, local and NGO records	A measure of benefits from protection	□		□	□		□
34	Tourism areas	Area (ha), type	National, local and NGO records	Economic measure of benefits from protection	□		□	□		□

Table notes: Based in part on the following sources: Gornitz (2012); Major et al. (2018).

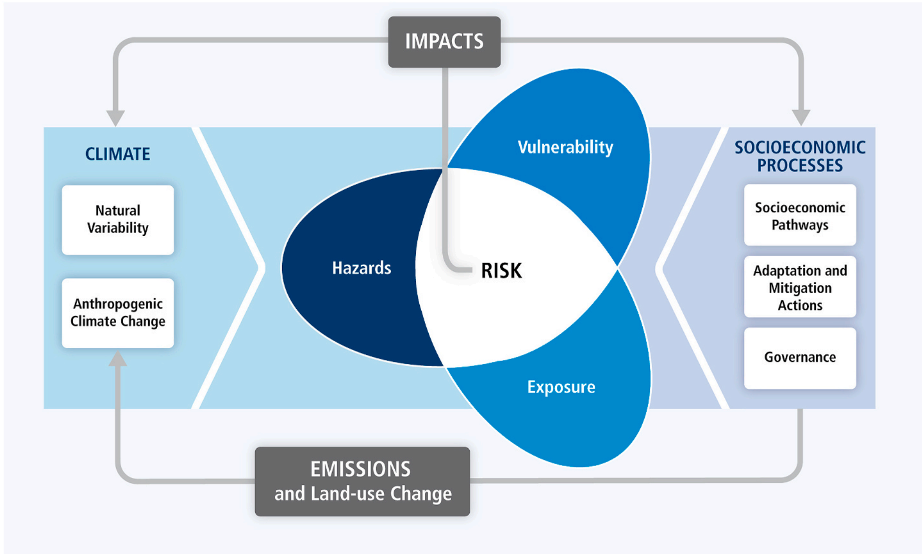

Fig. 1. The relationship between climate change and risk as utilised by the IPCC. The hazard component of risk is the focus on the DCP in Table 1, whereas Table 2 focuses on the exposure and vulnerability components. Adapted from Oppenheimer et al. (2014).

in the Special Issue. These include considerations of the extent to which different elements of the typology have been included by the case study authors, difficulties of developing some information at the local level, and strengthening the DCP. Further research and investigation into these and development of the typology is planned.

For example, in order to move toward a more comprehensive typology that can be used more widely in adaptation planning, the typology should be evaluated to see if it is effective and efficient in representing the essential characteristics of settlements for adaptation guidance. This evaluation should be done with the aim of developing a typology that is both useful and has a long shelf life. One element of this evaluation is the present application of the typology to the case studies for the Special Issue. This begins to provide information on, among other things: review the utility of the characteristics, indicators and metrics and sources proposed; help to determine to what extent the required information is available; and indicate gaps that may arise between wealthier and poorer settlements. This should help, for example, in establishing who or what is likely to be impacted by climate events, and the extent of these impacts, which depends upon institutional, social, economic, cultural, historical and environmental factors that vary over spatial and temporal scales. Understanding such characteristics supports decisions on adaptation responses. Further, it will be important to evaluate how the typology can be used in different decision frameworks (e.g. national, international, local) for which different elements of the typology may be relatively important for identifying settlements of interest and how to provide adaptation assistance for them.

Beyond and as a result in part of the Special Issue, detailed field level evaluations could be conducted for settlements in the US, Denmark, Australia and elsewhere that have been chosen as case studies to be included in the Special Issue. Furthermore, surveys and interviews with local government staff in other coastal communities can be conducted to identify bottom-up adaptation issues and barriers to successful adaptation. Further evaluations can be undertaken to determine: 1) whether it appears feasible to group types of settlements for better large-scale planning using at least some of the data and characteristics identified via the typology; and 2) if matrices of characteristics vs. adaptation types and costs can be realistically developed. Adjustments can then be made as required to adapt to data availability and usefulness.

2. Conclusions

The DCP presented here and developed as part of this Special Issue has already provided insights into the cases analysed in the articles by allowing characterisation of the case study settlements. The DCP itself requires an iterative process and will continue to develop as the typological characterisation is applied to more cases. Consequently, the authors encourage its application by other researchers to help identify areas for improvement. Future work will also concentrate on analysing the data that was and was not included within the data collected for each of the case studies, as well as data sources. This will provide a systematic understanding of the data gaps that still exist within the field of adaptation in coastal towns and small cities and allow future research to focus on the aspects that are most needed to fully realise the ambition of a comprehensive typology of coastal towns and small cities.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

Cardona, O.-D., van Aalst, M.K., Birkmann, J., Fordham, M., McGregor, G., Perez, R., Pulwarty, R.S., Schipper, E.L.F., Sinh, B.T., Décamps, H., Keim, M., Davis, I., Ebi, K. L., Lavell, A., Mechler, R., Murray, V., Pelling, M., Pohl, J., Smith, A.-O., Thomalla, F., 2012. Determinants of risk: exposure and vulnerability. In: Field, C.B., Barros, V., Stocker, T.F., Dahe, Q. (Eds.), Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. Cambridge University Press, Cambridge, pp. 65–108. https://doi.org/10.1017/CBO9781139177245.005.

Chang, S.E., Yip, J.Z.K., Conger, T., Oulahen, G., Marteleira, M., 2018. Community vulnerability to coastal hazards: Developing a typology for disaster risk reduction. Appl. Geogr. 91, 81–88. https://doi.org/10.1016/j.apgeog.2017.12.017.

Cities IPCC, 2018. Global Research and Action Agenda on Cities and Climate Change Science [WWW document]. https://citiesipcc.org/wp-content/uploads/2018/09/Research-Agenda-Aug-10_Final_Long-version.pdf. accessed 2.19.19.

City of Copenhagen, 2011. Copenhagen Climate Adaptation Plan.

City of New York, 2013. A Stronger More Resilient New-York 445.
de la Vega-Leinert, A.C., Nicholls, R.J., 2008. Potential implications of sea-level rise for great britain. J. Coast Res. 2008, 342. https://doi.org/10.2112/07A-0008.1.
Duffy, P., Stojanovic, T., 2017. The potential for Assemblage thinking in population geography: assembling population, space, and place. Popul. Space Place, e2097. https://doi.org/10.1002/psp.2097.
Gornitz, V., 2012. Rising Seas: Past, Present, Future. Columbia University Press, New York, NY, USA.
Lavell, A., Oppenheimer, M., Diop, C., Hess, J., Lempert, R., Li, J., Muir-Wood, R., Myeong, S., Moser, S., Takeuchi, K., Cardona, O.-D., Hallegatte, S., Lemos, M., Little, C., Lotsch, A., Weber, E., 2012. Climate change: new dimensions in disaster risk, exposure, vulnerability, and resilience. In: Field, C.B., Barros, V., Stocker, T.F., Dahe, Q. (Eds.), Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. Cambridge University Press, Cambridge, pp. 25–64. https://doi.org/10.1017/CBO9781139177245.004.
Major, D.C., Ali Ibrahim, S., Driscoll, P., Lehmann, M., Debucquoy, W., 2018. Annex 3: case study docking station: overview and methods. In: Rosenweig, C., Solecki, W., Romer-Lankao, P., Mehotra, S., Dhakal, S., Ali Ibrahim, S. (Eds.), Climate Change and Cities: Second Assessment Report of the Urban Climate Change Research Network (ARC3.2). Cambridge University Press, pp. 629–636.
Major, D.C., Juhola, S., 2016. Guidance for climate change adaptation in small coastal towns and cities: a new challenge. J. Urban Plann. Dev. 142, 02516001 https://doi.org/10.1061/(ASCE)UP.1943-5444.0000356.
Masselink, G., Russell, P., 2013. Impacts of climate change on coastal erosion. MCCIP Sci. Rev. 71, 86. https://doi.org/10.14465/2013.arc09.071-086.
Neumann, B., Vafeidis, A.T., Zimmermann, J., Nicholls, R.J., 2015. Correction: future coastal population growth and exposure to sea-level rise and coastal flooding - a global assessment. PloS One 10, e0131375. https://doi.org/10.1371/journal.pone.0131375.
Oppenheimer, M., Campos, M., Warren, R., Birkmann, J., Luber, G., O'Neill, B., Takahashi, K., 2014. Climate Change 2014 Impacts, Adaptation, and Vulnerability, Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge. https://doi.org/10.1017/CBO9781107415379.
Rosenzweig, C., Solecki, W., Romero-Lankao, P., Mehrotra, S., Dhakal, S., Bowman, T., Ibrahim, S.A., 2018. Climate change and cities: second assessment Report of the urban climate change research network. In: Climate Change and Cities. Cambridge University Press. https://doi.org/10.1017/9781316563878.007 xvii–xlii.
Small, C., Nicholls, R.J., 2003. A global analysis of human settlement in coastal zones. J. Coast Res. 19, 584–599.
Solecki, W., Seto, K.C., Balk, D., Bigio, A., Boone, C.G., Creutzig, F., Fragkias, M., Lwasa, S., Marcotullio, P., Romero-Lankao, P., Zwickel, T., 2015. A conceptual framework for an urban areas typology to integrate climate change mitigation and adaptation. Urban Clim 14, 116–137. https://doi.org/10.1016/j.uclim.2015.07.001.
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. Sustain. Sci. 3, 45–65. https://doi.org/10.1007/s11625-008-0045-1.
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. Sci. Rep. 7, 1399. https://doi.org/10.1038/s41598-017-01362-7.
Werner, A.D., Ward, J.D., Morgan, L.K., Simmons, C.T., Robinson, N.I., Teubner, M.D., 2012. Vulnerability indicators of sea water intrusion. Ground Water 50, 48–58. https://doi.org/10.1111/j.1745-6584.2011.00817.x.