CCP2

Cities and Settlements by the Sea

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This cross-chapter paper should be cited as:

Glavovic, B.C., R. Dawson, W. Chow, M. Garschagen, M. Haasnoot, C. Singh, and A. Thomas, 2022: Cross-Chapter Paper 2: Cities and Settlements by the Sea. In: *Climate Change 2022: Impacts, Adaptation and Vulnerability.* Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 2163–2194, doi:10.1017/9781009325844.019.

Table of Contents

Frequently Asked Questions

Executive Summary

Cities and settlements (C&S) by the sea are on the frontline of climate change—they face climate-compounded risks that are amongst the highest, but are a key source of innovation in climate resilient development (*high confidence*[1]) {Sections 6.1, 6.2; Chapter 7; Box 15.2; Cross-Chapter Box COVID in Chapter 7; Cross-Chapter Box SLR in Chapter 3; CCP2.2; SMCCP2.1}.

Much of the world's population, economic activities and critical infrastructure are concentrated near the sea (*high confidence*), with nearly 11% of the global population, or 896 million people, already living on low-lying coasts directly exposed to interacting climatic and non-climatic coastal hazards (*very high confidence*). Low-lying cities and settlements (C&S) by the sea are experiencing adverse climate impacts that are superimposed on extensive and accelerating anthropogenic coastal change (*very high confidence*). Depending on coastal C&S characteristics, continuing existing patterns of coastal development will worsen exposure and vulnerability (*high confidence*). With accelerating sea level rise (SLR) and worsening climate-driven risks in a warming world, prospects for achieving the Sustainable Development Goals (SDGs) and charting climate resilient development (CRD) pathways are dismal (*high confidence*). However, coastal C&S are also the source of SDG and CRD solutions, because they are centres of innovation with long histories of place-based livelihoods, many of which are globally connected through maritime trade and exchange (*medium confidence*) {CCP2.1, CCP2.2 CCP2.3, CCP2.4; SMCCP2.1; Chapters 16, 18}.

Regardless of climate and socioeconomic scenarios, many C&S face severe disruption to coastal ecosystems and livelihoods by 2050—extending to all C&S by 2100 and beyond—caused by compound and cascading risks, including submergence of some low-lying island states (*very high confidence*) {CCP2.1; CCP2.2; SROCC SPM, Chapter 4; 6.2}.

There is *high confidence* that projected climate risks will increase with (i) exposure to climate- and ocean-driven hazards manifest at the coast, such as heat waves, droughts, pluvial floods and impacts due to SLR, tropical cyclones, marine and land heatwaves, and ocean acidification; (ii) with increasing vulnerability driven by inequity and (iii) increasing exposure driven by urban growth in at-risk locations. Compounded and cascading climate risks, such as to coastal C&S infrastructure and supply chain networks, are also expected to increase. These risks are acute for C&S on subsiding and/or low-lying small islands, the Arctic, and open, estuarine and deltaic coasts (*high confidence*). By 2050, more than a billion people located in low-lying C&S will be at risk from coast-specific climate hazards, influenced by coastal geomorphology, geographical location and adaptation action (*high confidence*). Between USD 7 and 14 trillion of coastal infrastructure assets will be exposed by 2100, depending on warming levels and socioeconomic development trajectories (*medium confidence*). Historically rare extreme sea level events will occur annually by 2100, with some atolls being uninhabitable by 2050. The coastal flood risk will rapidly increase during coming decades, possibly by 2–3 orders of magnitude by 2100 in the absence of effective adaptation and mitigation, with severe impacts on coast-dependent livelihoods and socioecological systems (*high confidence*). Impacts reach far beyond C&S; for example damage to ports severely compromising global supply chains and maritime trade, with local–global geopolitical and economic ramifications. Global investment costs to accommodate port growth and adapt to SLR will amount to USD 223–768 billion before 2050, presenting opportunities for C&S by the sea to build climate resilience (*medium evidence*, *high agreement*). Severely accelerated SLR resulting from rapid continental ice mass loss would bring impacts forward by decades, and adaptation would need to occur much faster and on a much greater scale than ever performed in the past (*medium confidence*) {Table SMCCP2.1; CCP2.1; CCP2.2; Cross-Chapter Box SLR in Chapter 3; Chapter 4; Sections 6.2.7}.

A mix of interventions is necessary to manage coastal risks and build resilience over time. An adaptation-pathways approach sets out near-term 'low-regret' actions that align with societal goals, facilitates implementation of a locally appropriate sequence of interventions in the face of uncertain climate and development futures, and enables necessary transformation (*high confidence*) {CCP2.3; Cross-Chapter Box DEEP in Chapter 17, Cross-Chapter Box SLR in Chapter 3}.

A mix of infrastructural, nature-based, institutional and sociocultural interventions are needed to reduce the multifaceted risk facing C&S, including vulnerability-reducing measures, avoidance (i.e., disincentivising developments in high-risk areas), hard and soft protection, accommodation, advance (i.e., building up and out to sea) and retreat (i.e., landward movement of people and development) (*very high confidence*). Depending on the C&S archetype, technical limits for hard protection may be reached beyond 2100 under high-emission scenarios, with socioeconomic and governance barriers reached before then (*medium confidence*). However, hard protection can set up lock-in of assets and people to risks and, in some cases, may reach limits—due to technical and financial constraints—by 2100 or sooner depending on the scenario, local SLR effects and community tolerance thresholds (*medium confidence*). Where sufficient space and adequate habitats are available, nature-based solutions can help to reduce coastal hazard risks and provide other benefits, but biophysical limits may be reached before end-century (*medium confidence*). Accommodation is easier, faster and cheaper to implement than hard protection, but limits may be reached by 2100, or sooner in some settings. An adaptation-pathways planning approach demonstrates how the solution space can expand or shrink depending on the type and timing of adaptation interventions. As SLR is relentless on human timescales, the solution space will shrink without adoption of an adaptation-pathways planning approach (*high confidence*). Due to long implementation lead times and the need to avoid maladaptive lock-in, particularly in localities facing rapid SLR and climate-compounded risk, adaptation will be more successful if timely action is taken accounting for long-term (committed) SLR, and

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[1] In this report, the following summary terms are used to describe the available evidence: *limited*, *medium* or *robust*; and for the degree of agreement: *low*, *medium* or *high*. A level of confidence is expressed using five qualifiers: *very low*, *low*, *medium*, *high* and *very high*. The terms expressing evidence, agreement and confidence are typeset in italics (e.g., *medium confidence*, also *medium to high confidence*, *robust evidence*, *low agreement*). For a given evidence and agreement statement, different confidence levels can be assigned, but increasing levels of evidence and degrees of agreement are correlated with increasing confidence.

if this is underpinned by sustained and ambitious mitigation to slow greenhouse gas emission rates (*high confidence*) { CCP1.3.1.2; CCP2.3; CCP2.4; Cross-Chapter Box SLR in Chapter 3}.

Individual and collective choices founded on public-centred values and norms, as well as pro-social behaviour, help to foster climate-resilient coastal development in C&S (*high confidence*) {CCP2.4.1}.

The effectiveness of different approaches (e.g., awareness and education, market-based and legal strategies) is mediated by how well they address contextual and psychosocial factors influencing adaptation choices in coastal C&S (*medium confidence*). Adaptation options accounting for risk perceptions and aligning with public values tend to be more socioculturally acceptable, and consequently facilitate pro-social behavioural change {CCP2.4.1}.

Locally appropriate institutional capabilities, including regulatory provisions and finances dedicated to maintaining healthy coastal socioecological systems, build adaptive capacity in C&S by the sea (*high confidence*) {CCP2.4}.

Implementing integrated multi-level coastal zone governance, pre-emptive planning, enabling behavioural change and alignment of financial resources with a wide set of values will provide C&S with greater flexibility to open up the solution space to adapt to climate change (*high confidence*). Insufficient financial resources are a key constraint for coastal adaptation, particularly in the Global South (*high confidence*). Engaging the private sector in coastal adaptation action with a range of financial tools is crucial to address the coastal adaptation funding gap (*high confidence*). Considering the full range of economic and non-economic values will improve adaptation effectiveness and equity across C&S archetypes (*high confidence*). Aligning adaptation in C&S with socioeconomic development, infrastructure maintenance and COVID-19 recovery investments will provide additional co-benefits. Urgency is also driven by the need to avoid lock-in to new and additional risks, for example to avoid C&S sprawl into fragile ecosystems and the most exposed coastal localities {CCP2.3; CCP2.4.2; CCP2.4.4}.

Realising global aspirations for CRD depends on the extent to which coastal C&S institutionalise key enabling conditions and chart place-based adaptation pathways to close the coastal adaptation gap, and on the extent to which they take urgent action to mitigate greenhouse gas emissions (*medium confidence*) {CCP2.4; Table CCP2.1}.

Extensive adaptation planning has been undertaken since the IPCC Fifth Assessment Report (AR5), but there has not been widespread effective implementation, thus giving rise to a 'coastal adaptation gap' (*high confidence*). To date, most interventions have been reactive and often rely on protective works alone (*high confidence*). The effectiveness of alternative interventions differs among C&S archetypes, while their feasibility is influenced by geomorphology and socioeconomic conditions as well as cultural, political and institutional considerations (*very high confidence*). Mismatches between adaptation needs and patterns of physical development are commonplace in many coastal C&S, with particularly adverse impacts on poor and marginalised communities in the Global North and Global South (*high confidence*). Overcoming this gap is key to transitioning towards CRD (*medium confidence*). Under higher warming levels and higher SLR, increasingly dichotomous coastal futures will become more entrenched (*medium confidence*), with stark differences between more urbanised, resource-rich coastal C&S dependent on hard protection, and more rural, resource-poor C&S facing displacement and migration {CCP2.3; CCP2.4, Chapter 18}.

Coastal adaptation innovators adopt more flexible, anticipatory and integrative strategies, combining technical and non-technical interventions that account for uncertainties and facilitate effective resolution of conflicting interests and worldviews (*limited evidence*, *high agreement*). Moreover, a core set of critical enablers is foundational for C&S to chart CRD pathways. These include building and strengthening governance capabilities to tackle complex problems; taking a long-term perspective in making short-term decisions; enabling more effective coordination across scales, sectors and policy domains; reducing injustice, inequity, and social vulnerability; and unlocking the productive potential of coastal conflict while strengthening local democracy (*medium evidence*, *high agreement*) {Table CCP2.1, Table CCP2.2; CCP2.3; CCP2.4; Chapters 17, 18; Cross-Chapter Box DEEP in Chapter 17}.

C&S play a pivotal role in global aspirations to implement the Paris Agreement, advance the SDGs and foster CRD. Progress towards these ends depends on the extent to which C&S mobilise urgent and transformational changes to institutionalise enabling conditions, close the coastal adaptation gap by addressing the drivers and root causes of exposure and vulnerability to climate-compounded coastal hazard risks, and drastically reduce greenhouse gas emissions (*medium confidence*) {CCP2.4; Chapter 18}

CCP2.1 Context of Cities and Settlements by the Sea

CCP2.1.1 Introduction and Context

This cross-chapter paper examines the distinctive roles played by C&S by the sea in vulnerability and coastal hazard risk reduction, adaptation, resilience and sustainability in a changing climate. The paper builds upon evidence from AR5 (Wong et al., 2014), the Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC; Magnan et al., 2019; Oppenheimer et al., 2019) and draws material from across WGII AR6 (especially Chapters 3, 6, 9–15). It differs from the SLR-focused analysis of urban areas in SROCC (Section 4.3) through a more integrated assessment that distinguishes between archetypal coastal C&S (Section CCP2.1.2), sectoral risks to C&S by the sea (Section CCP2.2), responses to address these risks (Section CCP2.3) and enabling conditions and lessons learned (Section CCP2.4).

We define C&S as concentrated human habitation centres, whether small or large, rural or urban (Section 6.1.3). We highlight the unique exposure and vulnerability of coastal C&S resulting from rapid urbanisation at the narrow land–sea interface, and a high concentration of economic activity and at-risk people, many with long-standing cultural ties to the coast and dependence on coastal ecosystems that are prone to climate change impacts (*high confidence*; He and Silliman, 2019; Lau et al., 2019; Oppenheimer et al., 2019; Sterzel et al., 2020).

Presently, the coastal C&S population exposure to ocean-driven impacts from SLR and other climate-driven impacts is considerable by any measure (Buddemeier et al., 2008; Barragán and de Andrés, 2015; Kay and Alder, 2017; Haasnoot et al., 2019; McMichael et al., 2020; Sterzel et al., 2020). In 2020, almost 11% of the global population—896 million people—resided in C&S within the low-elevation coastal zone (LECZ; coastal areas below 10 m of elevation above sea level that are hydrologically connected to the sea; Haasnoot et al., 2021b), a figure which will potentially increase beyond 1 billion by 2050 (Oppenheimer et al., 2019). Infrastructural and economic assets worth USD 6,500–11,000 billion are also exposed in the 1-in-100-year floodplain for C&S of all sizes (Neumann et al., 2015; Muis et al., 2016; Brown et al., 2018; Andrew et al., 2019; Kulp and Strauss, 2019; Kirezci et al., 2020; Thomas et al., 2020; Haasnoot et al., 2021b; Hooijer and Vernimmen, 2021).

Further, coastal cities located at higher elevations (e.g., São Paulo, Brazil) or distantly located inland along tidally influenced rivers (e.g., the Recife Metropolitan Region, Brazil) also have populations and infrastructure exposed to climate impacts. As such, the inclusion of C&S beyond the LECZ is warranted when assessing climate impacts and associated exposure, vulnerabilities and risks. The coastal zone includes some of the world's largest, most densely populated megacities, as well as the fastest-growing urban areas. However, vast coastal areas are sparsely populated, with populations in these regions concentrated in smaller C&S, including along subsiding shorelines and in deltas (Nicholls and Small, 2002; McGranahan et al., 2007; Merkens et al., 2018; Edmonds et al., 2020; Nicholls et al., 2021). From this wider perspective, climate change impacts on the coast directly or indirectly affect a large portion of the global population, economic activity and associated critical infrastructure. Some estimates suggest that 23–37% of the global population lives within 100 km of the shoreline (Nicholls and Small, 2002; Shi and Singh, 2003; Christopher Small and Joel E. Cohen, 2004; McMichael et al., 2020).

C&S by the sea are thus on the frontline of action to adapt to climate change, mitigate greenhouse gas emissions and chart CRD pathways for several distinct reasons. First, home to a concentrated (and growing) portion of the world's population, many coastal C&S are simultaneously exposed and vulnerable to climate-compounded hazards as well as being centres of creativity and innovation (Glavovic, 2013; Crescenzi and Rodríguez-Pose, 2017; Druzhinin et al., 2021; Mariano et al., 2021; Storbjörk and Hjerpe, 2021). Second, people in C&S by the sea rely on coastal ecosystems, many of which are highly sensitive to climate change impacts that compound non-climatic risks and increase the precarity of coastal livelihoods (Lu et al., 2018; He and Silliman, 2019; Thrush et al., 2021). Third, coastal C&S are linked together through a network of ports and harbours that underpin global trade and exchange, but which are prone to climate change impacts, especially SLR, with significant implications for global CRD prospects (Becker et al., 2018; Christodoulou et al., 2019; Walsh et al., 2019; Hanson and Nicholls, 2020). For these reasons, this paper assesses responses, enabling conditions and lessons learned for addressing climate change in C&S by the sea.

CCP2

CCP2.1.2 Urbanisation in Coastal Systems: Coastal City and Settlement Archetypes

This assessment uses an archetype framework categorizing coastal C&S according to geomorphological characteristics, urban growth, economic resources and inequalities (Figure CCP2.1). Three broadly defined coastal settlement geomorphologies are used in each row: open coasts (a coast with sediment without river mouths) and two transitional coastal zones with river mouths, distinguishing between estuaries (a wetland receiving sediment from both fluvial and marine sources, which is affected by tide, wave and river processes) and deltas (a wetland where fluvial sediment is supplied and deposited more rapidly than it can be redistributed by basin processes such as waves and tides; Bhattacharya, 1978; Barragán and de Andrés, 2015; Kay and Alder, 2017; Haasnoot et al., 2019; Sterzel et al., 2020). Small island C&S are not singled out in this typology, because their coastlines often include the geomorphic features listed above, or require a different adaptation approach at larger spatial scales (Haasnoot et al., 2019). Several coastal C&S have a combination of two typologies, for example, Maputo-Matola, Mozambique and Mumbai, India, having both open and transitional riverine coasts, and can be classed as mixed. We also acknowledge that several coastal C&S may have areas sited in mountainous topography that abruptly rises from the coast (e.g., along the Mediterranean), but generally these cities have narrow, densely populated coastlines exhibiting these three archetypal categories (Blackburn et al., 2019). Arctic settlements are addressed separately in this cross-chapter paper.

Coastal C&S within these geomorphological categories are further distinguished according to higher or lower rates of urban growth and inequality, which can be estimated through population growth

Archetypal C&S affected by ocean, terrestrial, geological, atmospheric and hydrological hazards driven by climate change

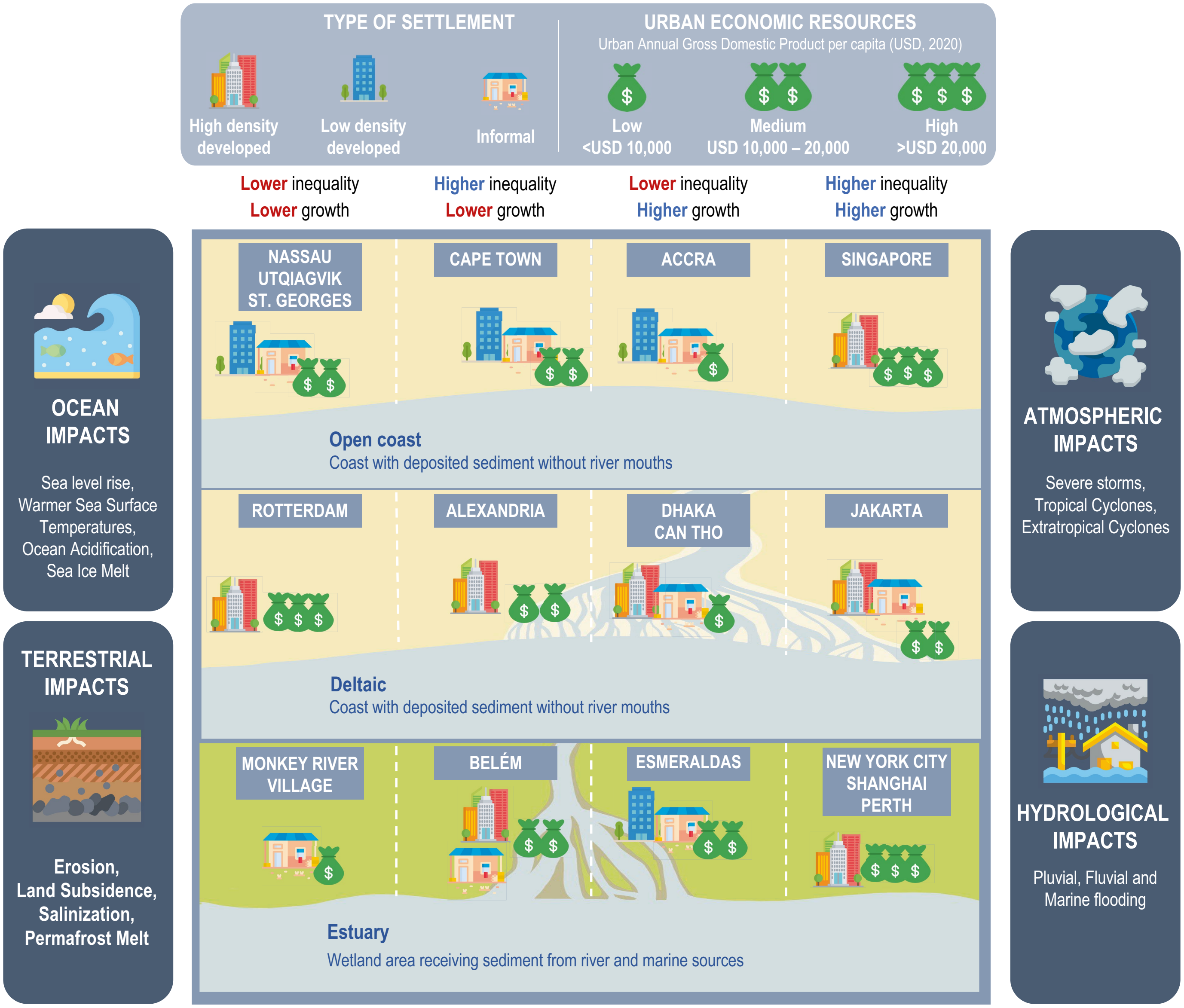

Figure CCP2.1 | Archetypal cities and settlements (C&S) affected by ocean, terrestrial, geological, atmospheric and hydrological hazards driven by climate change. Coastal C&S are grouped by physical geomorphology along estuarine, deltaic or open coasts (Barragán and de Andrés, 2015; Kay and Alder, 2017; Haasnoot et al., 2019). C&S are also classified according to relative inequality (e.g., urban Gini coefficient or poverty rates) and growth rates (e.g., recent population growth and increasing density of urban form or built-up areas over the past decade; OECD, 2018; CEIC, 2021; OECD, 2020). Settlement types (e.g., informal, low-density or high-density developments) and economic resources (e.g., urban per capita gross domestic product) are also reflected in their respective categories. The bottom map shows location, 2020 population size and geomorphological types.

from national census data or areal extent of urban development (CEIC, 2021), as well as by relative urban inequalities estimated by Gini coefficient data and urban–rural poverty rates (OECD, 2018; OECD, 2020). Combining geomorphological and socioeconomic data accounts for urban–rural interconnections and differences, with levels of capital generation, diversity of economic functions and human development indices having previously been used to discern cultural, economic, administrative and political differences between cities and their hinterland (Blackburn et al., 2019; Rocle et al., 2020). For instance, the ecological, cultural and economic footprint of tertiary sectors, for example, coastal tourism associated with the Australian Great Barrier Reef, stretches far beyond the nearest onshore settlement of Cairns (Bohnet and Pert, 2010; Brodie and Pearson, 2016).

Some caveats are warranted. First, locating a specific city or settlement in a particular archetype does not account for future reclassification due to growth or shifts in development trajectories. Second, significant socioeconomic, political and governance variations exist within many C&S, such as impoverished informal settlements alongside wealthy neighbourhoods in cities like Cape Town and São Paulo (also see Table SMCCP2.1). Third, this archetype framework does not explicitly reveal important interconnections between coastal C&S and their hinterlands, or between particular C&S through maritime trade or other economic, sociocultural and geopolitical interdependencies. Notwithstanding these caveats, these archetypes reveal differentiated physical impacts and socioeconomic conditions, as well as the variable challenges and opportunities arising when addressing climate change impacts and projected risk, which, depending on coastal type, C&S size and resource availability, help to inform efforts to adapt and chart CRD for each archetype (Sánchez-Arcilla et al., 2016; Rocle et al., 2020; Sterzel et al., 2020).

CCP2.2 Climate Change Risks to Cities and Settlements by the Sea

Coastal C&S are at the forefront of climate risk (FAQ CCP2.1). The dynamic interaction between ocean and climate drivers and varied coastal geographies influences the character of coastal risks, including many that are unique to C&S by the sea. The interaction of coastal hazards with exposure and vulnerability is differentiated by coastal archetypes, leading to distinct climate change-compounded risks and associated responses (Figure CCP2.2; Section 1.3.1.2; Simpson et al., 2021).

Overall, interactions between climatic and non-climatic drivers of coastal change are increasing the frequency and intensity of many coastal hazards, with settlement archetypes and the wider coastal zone subject to escalating risk (*high confidence*; Figure CCP2.2; Table SMCCP2.1 for examples of selected coastal C&S). Risks can vary markedly between different archetypes: C&S sited on deltaic and estuarine coasts face additional risks of pluvial flooding compared to open coasts, while greater vulnerabilities arise in coastal settlements with higher inequalities.

Risks to C&S by the sea were extensively covered in SROCC (Oppenheimer et al., 2019) and also in Chapters 3, 6 and regional chapters; in this paper, specific risks to livelihoods, activities, the built environment and ecosystems are assessed in detail in Supplementary Material SMCCP2.1. The ocean and climate impact drivers influencing these risks are assessed in WGI (Ranasinghe et al., 2021), which include extreme heat, pluvial floods from increasing rainfall intensity, coastal erosion and coastal flood driven by increasing SLR, and tropical cyclone storm surges (*high confidence*). Further, Arctic coastal settlements are particularly exposed to climate change due to sea ice retreat as well as from permafrost melt (*high confidence*).

Without adaptation, risks to land and people in coastal C&S from pluvial and coastal flooding will *very likely*[2] increase substantially by 2100 and *likely* beyond as a result of SLR, with significant impacts even under RCP2.6 (Neumann et al., 2015; Muis et al., 2016; Brown et al., 2018; Nicholls et al., 2018; Kulp and Strauss, 2019; Oppenheimer et al., 2019; Kirezci et al., 2020; Haasnoot et al., 2021b). Across these studies, by 2100, 158–510 million people and USD 7,919–12,739 billion assets under RCP4.5, and 176–880 million people and USD 8,813–14,178 billion assets under RCP8.5 will be within the 1-in-100-year floodplain (*very high confidence*). There is *medium confidence* that accelerated SLR will increase shoreline erosion globally, although biophysical feedbacks will allow many coastlines to maintain relatively stable morphology if room exists to accommodate mangroves in estuarine and deltaic coasts and beach movement along open coasts (Kench et al., 2015; McLean and Kench, 2015; Perkins et al., 2015; Richards and Friess, 2016; CCC, 2017; Duncan et al., 2018; Luijendijk et al., 2018; Mentaschi et al., 2018; Schuerch et al., 2018; Ghosh et al., 2019; Masselink et al., 2020; Toimil et al., 2020; Vousdoukas et al., 2020b). Limiting emissions to RCP2.6 (corresponding to a mean post-industrial global temperature increase of 1.5–2°C) significantly reduces future SLR risks (Hinkel et al., 2014; Brown et al., 2018; Nicholls et al., 2018; Schinko et al., 2020). For example, by 2100, the population at risk of permanent submergence increases by 26% under RCP2.6 compared with 53% under RCP8.5 (median values from Kulp and Strauss, 2019).

There is *high confidence* regarding regionally differentiated but considerable global sectoral impacts in coastal C&S arising from

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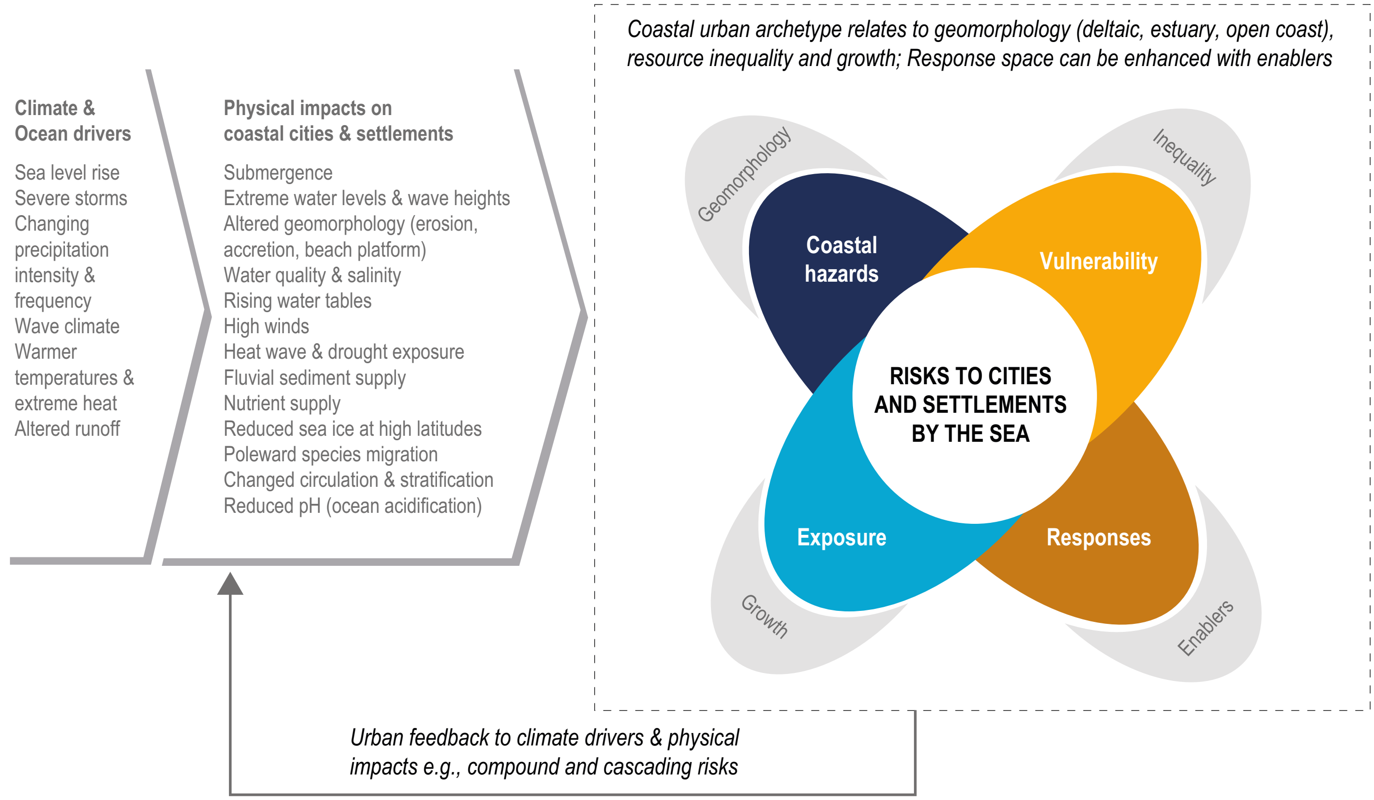
[2] In this report, the following terms have been used to indicate the assessed likelihood of an outcome or a result: *virtually certain* 99–100% probability, *very likely* 90–100%, *likely* 66–100%, *about as likely as not* 33–66%, *unlikely* 0–33%, *very unlikely* 0–10% and *exceptionally unlikely* 0–1%. Additional terms (*extremely likely* 95–100%, *more likely than not* >50–100% and *extremely unlikely* 0–5%) may also be used when appropriate. Assessed likelihood is typeset in italics (e.g., *very likely*). This report also uses the term '*likely* range' to indicate that the assessed likelihood of an outcome lies within the 17–83% probability range.



Schematic of how climate- and ocean-drivers (from WGI Chapter 12.4.10.2) and consequential physical impacts on coastal C&S influence risks assessed in (CCP2.2; Figure based on Simpson et al. (2021) and Section 1.3.1.2).

Figure CCP2.2 | Schematic of how climate and ocean drivers (from WGI Chapter 12.4.10.2 (Ranasinghe et al., 2021)) and consequential physical impacts on coastal cities and settlements (C&S) influence risks assessed in (Section CCP2.2; figure based on Simpson et al., 2021, and Section 1.3.1.2). These risks to C&S by the sea are shaped and mediated by adaptation interventions aimed at reducing vulnerability and exposure to coastal hazards given settlement archetypes, as well as by expanding the space for responses to risk via the enabling conditions assessed in Section CCP2.4. Note that exposure to coastal hazards is controlled chiefly by underlying coastal C&S geomorphology and changes in coastal hazards and urban growth, including population and infrastructure growth. Vulnerability is controlled, for example, by socioeconomic development and inequality, and responses that shape the risks assessed in Section CCP2.3 can be enhanced by enabling conditions, including behavioural change, conducive finance and prudent governance.

exposure to hazards. Tangible impacts include damage, loss of life and loss of livelihoods, especially fisheries and tourism (Tessler et al., 2015; Avelino et al., 2018; Hoegh-Guldberg et al., 2018; Seekamp et al., 2019; Arabadzhyan et al., 2020); negative impacts on health and wellbeing, especially under extreme events (McIver et al., 2016; Bakkensen and Mendelsohn, 2019; Bindoff et al., 2019; Pugatch, 2019); and involuntary displacement and migration (Hauer, 2017; Davis et al., 2018; Neef et al., 2018; Boas et al., 2019; McLeman et al., 2021). Intangible impacts include psychological impacts due to extreme events such as heatwaves, flooding, droughts and tropical cyclones; heightened inequality in coastal archetypes with systematic gender/ethnicity/structural vulnerabilities; and loss of things of personal or cultural value and sense of place or connection, including an existential risk of the demise of nations due to submergence (Allison and Bassett, 2015; Barnett, 2017; Schmutter et al., 2017; Weir et al., 2017; Farbotko et al., 2020; Hauer et al., 2020; Hoffmann et al., 2020; Bell et al., 2021). Impacts extend beyond the coastal zone, for example disruption to ports and supply chains, with major geopolitical and economic ramifications from the C&S to the global scale (*very high confidence*; Becker et al., 2018; Camus et al., 2019; Christodoulou et al., 2019; Walsh et al., 2019; Hanson and Nicholls, 2020; Yang and Ge, 2020; Izaguirre et al., 2021; León-Mateos et al., 2021; Ribeiro et al., 2021).

Many coastal C&S have densely built physical infrastructure and assets that are exposed and vulnerable to climate change-compounded coastal hazards. There is *high confidence* that SLR, land subsidence, poorly regulated coastal development and the rise of asset values are major drivers of future risk in all coastal archetypes and, without adaptation, built environment risks—especially in archetypes with high exposure due to rapid growth—are expected to rise considerably in this century across all RCPs (Koks et al., 2019; Magnan et al., 2019; Oppenheimer et al., 2019; Abadie et al., 2020; Nicholls et al., 2021). Archetypes with more informal settlements are often disproportionally exposed to coastal risks (Roy et al., 2016; Hallegatte et al., 2017; Bangalore et al., 2019).

There is *high confidence* that loss of coastal ecosystem services will increase risks to all coastal C&S archetypes that include reduced

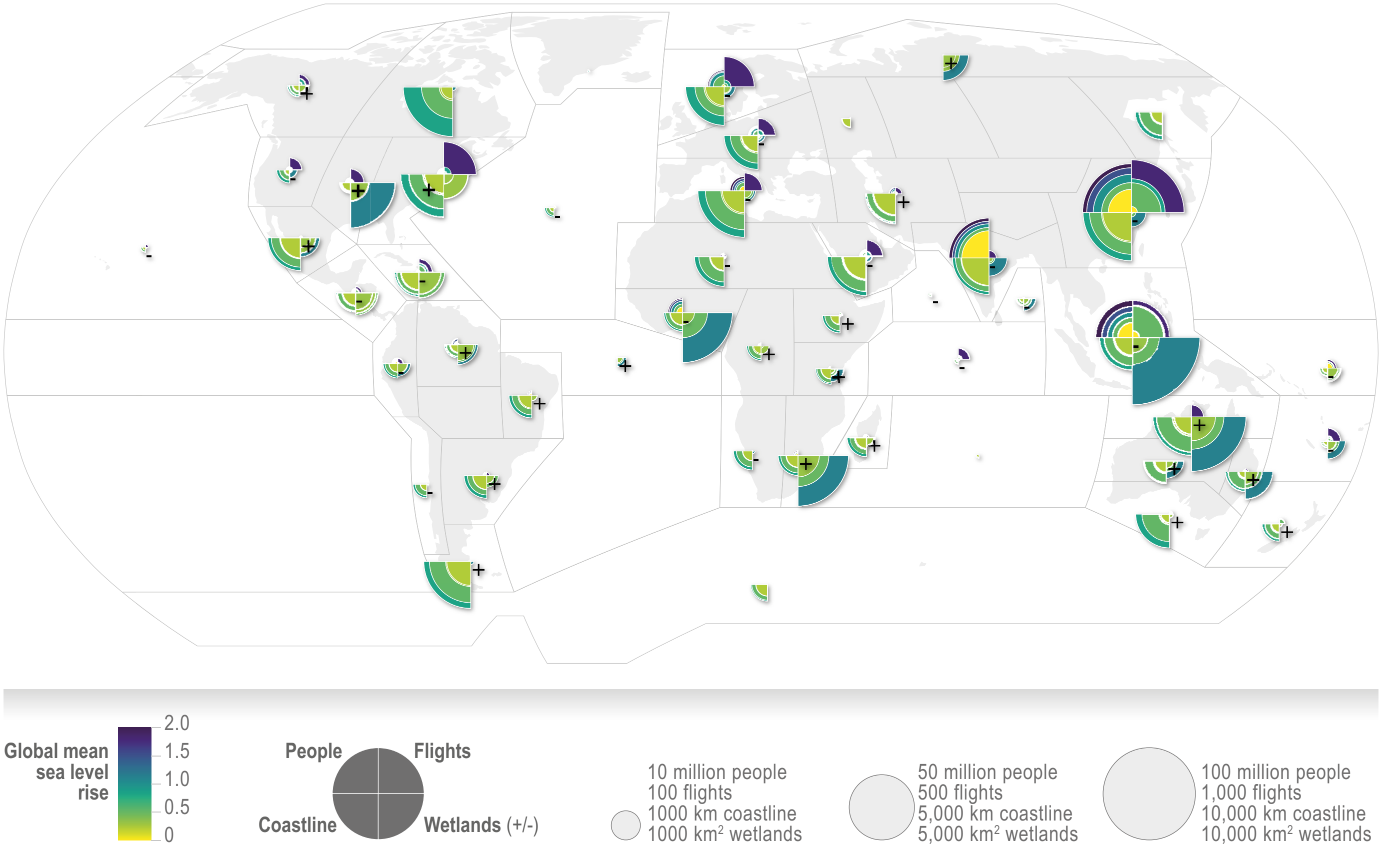


Figure CCP2.3 | Map of coastal cities and settlements' risks according to IPCC regions, showing risks to people (number of people at risk from a 100-year coastal flood event; Haasnoot et al., 2021b), risks of loss of coastal land (length of coast with more than 100 m retreat; Vousdoukas et al., 2020b), risks to the built environment (airports at risk indicated by expected annual number of flights disrupted by coastal flooding (Yesudian and Dawson, 2021) and risk to wetlands (± indicates positive or negative area change; Schuerch et al., 2018). Risks are reported against global mean sea level rise relative to 2020, depending on data availability.

provisioning of materials and food (e.g., wood, fishery habitat; Kok et al., 2021), amelioration of coastal hazards (e.g., attenuation of storm surges, waves and containing erosion) (Section 2.3.2.3; Godfroy et al., 2019; Schoutens et al., 2019; Zhu et al., 2020b), climate change mitigation (through carbon sequestration; Macreadie et al., 2017; Rovai et al., 2018; Ward, 2020), water quality regulation (nutrient, pollutant and sediment retention and cycling; Wilson et al., 2018; Zhao et al., 2018) and recreation and tourism (Pueyo-Ros et al., 2018).

Most studies of coastal C&S focus on adaptation to a single or limited set of risks, but there is *high confidence* that compound and cascading risks significantly alter C&S risk profiles (Nicholls et al., 2015; Estrada et al., 2017; Edmonds et al., 2020; Eilander et al., 2020; Yin et al., 2020; Ghanbari et al., 2021). Extreme events can lead to cascading infrastructure failures that cause damage and economic losses well beyond the coastal zone (Haraguchi and Kim, 2016; Kishore et al., 2018; Rey et al., 2019; So et al., 2019), and have forced evacuation of C&S and small islands (Look et al., 2019; Thomas and Benjamin, 2020). These risks are exacerbated by non-climatic drivers, for example compound and cascading impacts arising from exposure to tropical cyclones and COVID-19 that threaten population health and hamper pandemic responses (Salas et al., 2020; Shultz et al., 2020a; Shultz et al., 2020b). There is emerging evidence (*low confidence*) from individual coastal C&S and regional case studies (e.g., in Europe, Australia and the US) to illustrate the increasing influence of compound risks on vulnerability due to accelerating climate change (Wahl et al., 2015; Xu et al., 2019; Kirezci et al., 2020).

Figure CCP2.3 shows that ocean-driven coastal risks to people, land and infrastructure in East and Southeast Asia are highest compared to other regions, even for low levels of projected SLR. However, risks facing coastal C&S are high across the globe, especially under higher SLR projections (*high confidence*). Without adaptation, the population at risk of a 100-year coastal flood increases by ~20% if the global mean sea level rises by 0.15 m relative to current levels; this at-risk population doubles at a rise of 0.75 m in mean sea level and triples at 1.4 m. Simultaneously, coastal C&S are projected to experience shoreline retreat, with coastlines having more than 100 m of retreat increasing by ~165% if current mean sea levels rise between 0.23 and 0.53 m. Ocean-driven flooding in coastal C&S is also projected to disrupt flights by up to three orders of magnitude per year in selected coastal C&S as mean sea level increases. Typically, larger risks correspond to archetypes associated with higher inequality and high growth rates, especially in deltas, leading to larger vulnerability and exposure, respectively, under higher warming levels.

CCP2.3 Adaptation in Cities and Settlements by the Sea

CCP2.3.1 Introduction

This section extends SROCC Chapter 4 (Oppenheimer et al., 2019), which focused on SLR, and draws from Chapters 6 and 9–15 to cover all C&S archetypes. Adaptation interventions span psychosocial (e.g., awareness raising), economic (e.g., insurance), physical (e.g., retreat), technical (e.g., sea walls) and natural dimensions (e.g., wetland restoration; Nicholls et al., 2015). Adaptation strategies for coastal C&S are typically classified in terms of protect, accommodate, advance and retreat, which are used below.

Some coastal cities have adapted to meters of SLR in the past, indicating that adaptation is feasible (Esteban et al., 2020a), but future adaptation options are influenced by variations in projected socioeconomic conditions and rates of SLR (Cross-Chapter Box SLR in Chapter 3). To date, interventions are typically implemented reactively in response to extreme events (*high confidence*), but leading adaptors are increasingly proactive (*medium confidence*; Araos et al., 2016; Dulal, 2019; Dedekorkut-Howes et al., 2020) and those that move from previously rigid to more adaptive and flexible solutions, using an adaptation-pathways approach that keeps options open in the face of uncertainty, have improved climate risk management (*high confidence*; Sections 9.9.4; 10.5; 11.7; 12.5.5; 13.2; 14.7; 15.5; Cross-Chapter Box DEEP in Chapter 17; Walker et al., 2013; Marchau et al., 2019).

The effectiveness of different strategies and interventions is mediated by physical coastal features for hard adaptation measures and by the scope and depth of soft adaptation measures, for example by the coverage and extent of social safety nets for the urban poor (Section 6.3). Their feasibility is also shaped by socioeconomic, cultural, political and institutional factors, for example social acceptance of measures (Section CCP2.2, SMCCP2.2.4). Together, response effectiveness and feasibility shape the solution space for mediating risks (Section 1.3.1.2; Figure CCP2.3; Simpson et al., 2021), which is achieved chiefly through governance interventions, for example laws and regulations (Haasnoot et al., 2020). Access to financial resources expands the solution space, most notably for some resource-rich coastal archetypes (Section CCP2.4.2; Table SMCCP2.1; Sections 3.6; 14.7), but rapid population growth and unfolding climate-driven impacts can increase risks (Haasnoot et al., 2021a), especially for small island and poorer C&S (*high confidence*; Section 15.3; Magnan and Duvat, 2020).

CCP2.3.2 Protection of Coastal Cities and Settlements

CCP2.3.2.1 Hard Engineering Measures

Hard engineering protective measures are commonly used to reduce coastal flooding and to drain or store excess water from intense precipitation. Many coastal cities, in particular densely populated and high-resource archetypes, have planned and are planning to continue a protection-based strategy, comprising, for example, breakwaters, sea walls and/or dikes, which could be raised or complemented with large barriers, or with 'super-levees' enabling construction on top of them (*high confidence*; Table SMCCP2.1; Takagi et al., 2016; Haasnoot et al., 2019; Hall et al., 2019; Esteban et al., 2020b).

Protection is effective in the short- to medium-term for many coastal cities, and can be cost effective in the 21st century (Section CCP2.4.2), but residual risk remains because protection can fail. Even under RCP8.5, technical limits to hard protection may only be reached after 2100 in many regions, but socioeconomic and institutional barriers may be reached before then (Hinkel et al., 2018). With progressive SLR, protection eventually becomes unaffordable and impractical (Strauss et al., 2021). Combining hard engineering measures with nature-based solutions, spatial planning and early warning systems can help to contain residual risk (Du et al., 2020). Protective works do not prevent salinisation and higher groundwater levels (Alves et al., 2020), and can lead to loss of coastal habitat (Cross-Chapter Box SLR in Chapter 3; Achete et al., 2017; Cooper et al., 2020). Hard protective measures also create long-term path dependency as they last for decades and attract new development, locking in impact and exposure as C&S grow, with the expectation of ongoing protection (Chapter 3; Di Baldassarre et al., 2015; Gibbs, 2016; Griggs and Patsch, 2019; Siders, 2019a).

CCP2.3.2.2 Soft Engineering and Sediment-Based Measures

Sediment-based interventions, for example beach nourishment, aim to limit coastal erosion and flood risk and have become a widely applied strategy, especially in open-coast archetypal C&S. This is in part because there is less impact on adjacent beaches and coastal ecology and also lower construction and maintenance costs compared to hard protection (*high confidence*; Parkinson and Ogurcak, 2018). In addition, it is considered a flexible strategy under more rapid SLR conditions (Kabat et al., 2009; Stive et al., 2013) and can be applied in the form of a mega-nourishment strategy, wherein natural currents distribute sand along the coast (Stive et al., 2013; de Schipper et al., 2021). However, there are limits to this strategy due to environmental impacts, costs and the availability of potential and permitted sand reserves, which may be unable to keep up with higher rates of SLR (Parkinson and Ogurcak, 2018; Haasnoot et al., 2019; Harris et al., 2021; Staudt et al., 2021). Simultaneously, other socioeconomic needs (e.g., damming rivers or for building and transport infrastructure) may compete for sand as a limited resource (Torres et al., 2017; Bendixen et al., 2019). Regional and global governance provisions (e.g., spatial reservations for sand mining, international frameworks for distribution) could improve long-term feasibility (Torres et al., 2017; Parkinson and Ogurcak, 2018; Bendixen et al., 2019; Haasnoot et al., 2019).

CCP2.3.2.3 Nature-Based Measures

Nature-based measures, such as retaining mangroves and marshes, have been successful in reducing deaths and damage due to storm surges (*medium evidence, high agreement*; Das and Vincent, 2009; Saleh and Weinstein, 2016; Narayan et al., 2017; Triyanti et al., 2017; Hochard et al., 2019; del Valle et al., 2020), and reportedly provide USD 23.2 billion yr–1 in storm protection services across the USA (Saleh and Weinstein, 2016). They are also a cost-effective strategy (*medium confidence*) that provides C&S with additional co-benefits through ecosystem services (*high confidence*; Cross-Chapter Box NATURAL in Chapter 2; Section 2.2.4; Narayan et al., 2016; Depietri and McPhearson, 2017; Morris et al., 2018; Reguero et al., 2018; Chausson et al., 2020; Du et al., 2020; NIES and ISME, 2020; Reguero et al., 2020; Sudmeier-Rieux et al., 2021).

Nature-based measures can reduce inland propagation of extreme sea levels (high tides, storm surges; *high agreement*; Godfroy et al., 2019; James et al., 2020; Zhu et al., 2020b), with vertical reduction in water levels ranging from 5 to 50 cm/km behind large mangroves and marshes (Stark et al., 2015; Van Coppenolle and Temmerman, 2020). They also attenuate wind-driven waves and reduce shoreline erosion (*high agreement*), and this can be by as much as 90% over stretches of 10–100 m for dense mangrove and marsh vegetation (*medium evidence*; Li et al., 2014; Möller et al., 2014; Vuik et al., 2016; Vuik et al., 2018; Godfroy et al., 2019; Zhu et al., 2020a) and up to 40% for dunes (Feagin et al., 2019). Coral reefs on average reduce wave energy by 97% (Ferrario et al., 2014). Seagrass meadows attenuate wind waves to a lesser extent, and are only effective in water <0.2 m deep (Ondiviela et al., 2014; Narayan et al., 2016; Morris et al., 2019).

Within limits, coastal ecosystems can respond to RSL through sediment accretion and lateral inland movement (Kirwan et al., 2016; Schuerch et al., 2018). Nature-based measures have the greatest potential in coastal deltas and estuaries, where human populations are exposed, but large ecosystems, like mangroves and marshes, can be conserved and restored (Menéndez et al., 2020; Van Coppenolle and Temmerman, 2020). Their feasibility depends on physical, ecological, institutional and socioeconomic conditions that are typically locality dependent (Temmerman and Kirwan, 2015; Arkema et al., 2017); space may not be available in certain places (e.g., intensive urbanization on the shoreline), or these measures may conflict with other human demands for scarce land (Tian et al., 2016). Successful nature-based measures require site-specific knowledge and science-based design, pilot monitoring and adaptive upscaling (Evans et al., 2017; Nesshöver et al., 2017), as well as a more rigorous understanding of long-term performance, maintenance and costs (Kumar et al., 2021).

Nature-based measures are increasingly implemented in combination with hard protection measures (Hu et al., 2019; Schoonees et al., 2019; Morris et al., 2020; Oanh et al., 2020). They can reduce dike failure and increase design life where sediment accretion allows wetlands to respond to SLR (Jongman, 2018; Vuik et al., 2019; Zhu et al., 2020a). There is *high agreement* that a hybrid strategy combining hard and soft protection strategies is more effective and less costly under many circumstances, and there is *limited evidence* that technical limits will be encountered with such a strategy for low-lying C&S built on soft or permeable soil or with high exposure to monsoons and river discharges (Spalding et al., 2014; Sutton-Grier et al., 2015; Pontee et al., 2016; Morris et al., 2018; Reguero et al., 2018; Du et al., 2020; Morris et al., 2020; Seddon et al., 2020; Waryszak et al., 2021).

CCP2.3.3 Accommodation of the Built Environment

The most effective solution for limiting the growth of climate risks in C&S by the sea is to avoid new development in coastal locations prone to major flooding and/or SLR impacts (*very high confidence*; Cross-Chapter Box SLR in Chapter 3; Oppenheimer et al., 2019; Doberstein et al., 2019). For existing C&S, accommodation includes biophysical and institutional responses to reduce exposure and/or vulnerability of coastal residents, human activities, ecosystems and the built environment, enabling continued habitation of coastal C&S (Oppenheimer et al., 2019). Next to hard protection, accommodation is the most widely used adaptation strategy across all archetypes to date (*high confidence*; Sayers et al., 2015; Olazabal et al., 2019; Le, 2020). Measures include elevation or flood proofing of houses and other infrastructure (Garschagen, 2015; Aerts et al., 2018; Buchori et al., 2018; Jamero et al., 2018; Tamura et al., 2019), spatial planning (e.g., Duy et al., 2018), amphibious building designs (Nilubon et al., 2016), increasing water storage and/or drainage capacity within C&S (Chan et al., 2018), early warning systems and disaster responses (Hissel et al., 2014) and slum upgrading (Jain et al., 2017; Olthuis et al., 2020).

Raising land, or individual buildings, can avert flooding and be accomplished artificially or by nature-based interventions through river diversion and control in estuarine and deltaic archetypes (Nittrouer et al., 2012; Auerbach et al., 2015; Day et al., 2016; Sánchez-Arcilla et al., 2016; Hiatt et al., 2019; Cornwall, 2021). Nature-based land elevation is limited by sediment supply and can address SLR rates of up to 10 mm yr–1 (Kleinhans et al., 2010; Kirwan et al., 2016; IPCC, 2019). It also assumes that existing land-use patterns permit land raising (e.g., in rural or newly developed areas; Scussolini et al., 2017). Artificial land raising can achieve significant elevations and be implemented over a large spatial scale (Esteban et al., 2015; Esteban et al., 2019). Raising land can be cost beneficial for small areas or where lower safety levels are satisfactory, but protection is usually more economical for larger areas, although both strategies are often combined (Lendering et al., 2020).

Accommodation measures can be very effective for current conditions and small changes in SLR (Laurice Jamero et al., 2017; Scussolini et al., 2017; Oppenheimer et al., 2019; Du et al., 2020; Haasnoot et al., 2021a), and buy time to prepare for more significant changes in sea level and other climate-compounded coastal hazards. However, limits to this strategy occur comparatively soon in some locations, possibly requiring protection in the medium term and retreat in the long run and beyond 2100, particularly in scenarios of dramatic SLR (Oppenheimer et al., 2019). For the foreseeable future, accommodation can play an important role in combination with protective measures to form hybrid interventions, with higher effectiveness than either approach in isolation (Du et al., 2020). Accommodation can play an increasingly important role where hard protection is neither technically nor financially viable, but detailed studies about expected trends of accommodation are lacking (Oppenheimer et al., 2019).

CCP2.3.4 Advance

An advance strategy creates new land by building seaward, which can reduce risk for the hinterland and the newly elevated land, either by land reclamation through landfilling or polderisation through planting of vegetation to support natural land accretion (Wang et al., 2014; Sengupta et al., 2018). Advance has occurred in all archetypes (*high confidence*), from open coasts (e.g., Singapore) and small atolls (e.g., Hulhumalé in the Maldives; Hinkel et al., 2018; Brown et al., 2020), to cities on estuaries (e.g., Rotterdam) and deltas (e.g., Shanghai Sengupta et al., 2020), and mountainous coasts (e.g., Hong Kong SAR, China). Earth observations show that between 14,000 and 33,700 km^2 of land has been gained in coastal areas over the past 30 years, the dominant drivers being urban development and activities like fish farming (Donchyts et al., 2016; Zhang et al., 2017; Mentaschi et al., 2018). Advancing seawards through large floating structures may be a viable option in the future (Wang et al., 2019; Setiadi et al., 2020; Wang and Wang, 2020) but is at an experimental stage, and, so far, only applied in calm water within a city as part of an accommodate strategy (Scussolini et al., 2017; Penning-Rowsell, 2020; Storbjörk and Hjerpe, 2021).

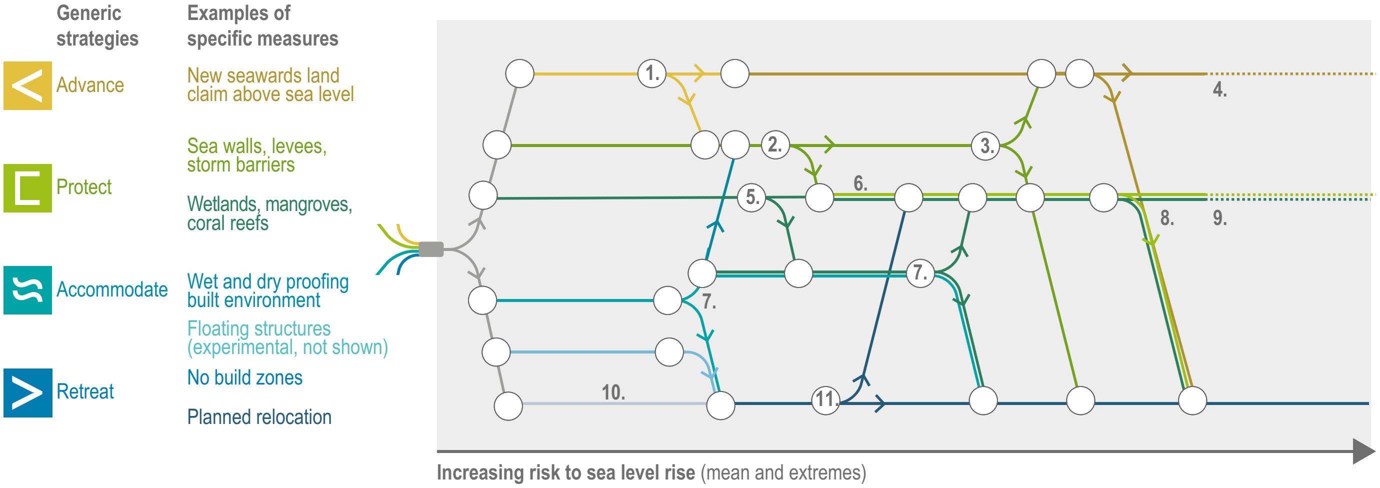
Advance is seen as an attractive option to adapt to SLR in growing cities that are already densely populated and have limited available land for safe development, with a moderate to high adaptive capacity. But advance can have significant negative impacts on coastal ecosystems and livelihoods, requires substantial financial and material resources and time to build, and may be subject to land subsidence (Jeuken et al., 2014; Garschagen et al., 2018; Brown et al., 2019; NYCEDC, 2019; Oppenheimer et al., 2019; Sengupta et al., 2020; Bendixen et al., 2021).

CCP2.3.5 Retreat

Retreat is a strategy to reduce exposure and eventually risks facing coastal C&S by moving people, assets and activities out of coastal hazard zones (Oppenheimer et al., 2019). This includes adaptive migration, involuntary displacement and planned relocation of population and assets from the coast (Section 7.2.6; Cross-Chapter Box CB-MIGRATE in Chapter 7).

Solution space for coastal cities and settlements by the sea

(a) Generic adaptation pathways for coastal cities and settlements to sea level rise



1. Successful pilot, lack of development space triggers advance, or protect due to lack of support, time or finance.
2. Preference for nature-based solutions.
3. Unaffordable, salinisation, pumping limit, lack of support.
4. Unaffordable, pumping limit, lack of time, support, knowledge, material.
5. Warming, limited space, human pressures, frequent flooding require additional measures.
6. Hybrid strategy.
7. Frequent flooding, flooding creates access problems.
8. Warming, limited space, human pressures, frequent flooding.
9. Unaffordable, salinisation, pumping limit, lack of support.
10. Long lead time to align with social goals and ensure just outcomes.
11. Lack of acceptance and equity triggers shift.

(b) Illustrative pathways for some coastal archetypes

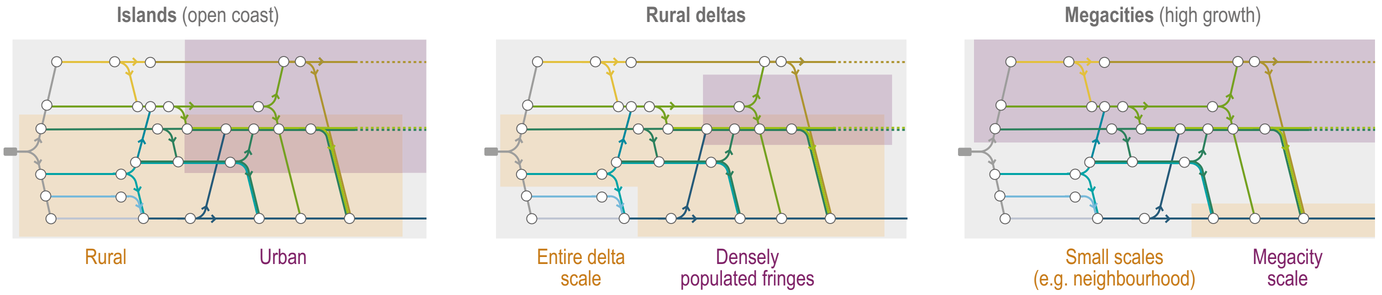


Figure CCP2.4 | Generic adaptation pathways for coastal cities and settlements (a) and the typical solution space, with illustrative pathways for three coastal archetypes (b). As risk increases under rising sea levels, solutions need to be combined or sequenced in order to contain risk. Pathways involve different trade-offs. Based on Tables SMCCP2.1–2.3; Chapters 11 and 13; Magnan and Duvat (2020); Lawrence et al. (2020); Haasnoot et al. (2019). Depending on local conditions, archetype and risk tolerance, alternative pathways are needed and possible to contain risk. Dashed lines indicate uncertainty in the pathway (a); dashed and plain borders are used for illustrating various local situations within each archetype (b).

Planned relocation in coastal C&S with high hazard exposure and climate impacts is already occurring and has been increasing in frequency (*medium confidence*; Hino et al., 2017; Mortreux et al., 2018), with some small islands purchasing land in other countries to facilitate movement (Klepp, 2018). In the Arctic, the pressure to relocate away from the coast is expected to rise given the interacting effects of permafrost thaw and coastal erosion. Native villages in Alaska are already relocating (Ristroph, 2017; Ristroph, 2019). Involuntary resettlement may be a secondary effect of large-scale hard coastal protection projects, or inner-city river and canal regulation. In Jakarta, for example, a new giant seawall project involves resettling coastal households along large parts of the coastline (Garschagen et al., 2018).

Increased migration is to be expected across different climate scenarios, but there is *limited evidence* and *medium agreement* about the scale of climate-induced migration at the coast (Oppenheimer et al., 2019; Chapter 16, RKR on peace). Planned relocation is expected to rise in C&S in response to SLR and other coastal hazards (*high agreement*, *medium evidence*; Siders et al., 2019). Relocation has predominantly been reactive to date, but increased attention is being given to pre-emptive resettlement and the potential pathways and necessary governance, finance and institutional arrangements to support this strategy (Ramm et al., 2018; Lawrence et al., 2020; Haasnoot et al., 2021a). There is *limited evidence* about the costs of planned relocation and retreat more generally (Oppenheimer et al., 2019).

Retreat can effectively reduce exposure of urban residents to coastal hazards and provide opportunity for re-establishment of ecosystem services (*very high confidence*; Song et al., 2018; Carey, 2020; Hindsley and Yoskowitz, 2020; Lincke et al., 2020; Lincke and Hinkel, 2021). But there is *high confidence* that it can sever cultural ties to the coast (Reimann et al., 2018) and lead to negative and inequitable socioeconomic effects for resettled communities if not planned and implemented in ways that are inclusive and just and address cultural, place-attachment and livelihood considerations (Ajibade, 2019; Adger et al., 2020; Carey, 2020; Jain et al., 2021; Johnson et al., 2021), as well as the rights and practices of Indigenous People (Nakashima et al., 2018; Ristroph, 2019; Mohamed Shaffril et al., 2020). If planned well ahead and aligned with social goals, pathways to managed retreat can achieve positive outcomes and provide opportunities for transformation of coastal C&S (Haasnoot et al., 2021a; Mach and Siders, 2021). There is *medium confidence* that the availability of suitable and affordable land as well as appropriate financing is a major bottleneck for planned relocation (Alexander et al., 2012; Ong et al., 2016; Hino et al., 2017; Fisher and Goodliffe, 2019; Hanna et al., 2019; Buser, 2020; Doberstein et al., 2020), particularly in very dense mega-urban areas (Ajibade, 2019) and crowded small islands (Neise and Revilla Diez, 2019; Weber et al., 2019; Kool et al., 2020; Lincke et al., 2020).

CCP2.3.6 Adaptation Pathways

No single adaptation intervention comprehensively addresses coastal risks and enables CRD. An adaptation-pathways approach can facilitate long-term thinking, foresee maladaptive consequences and lock-ins, and address dynamic risk in the face of relentless and potentially high SLR; it can also frame adaptation as a series of manageable steps over time (Cross-Chapter Box DEEP in Chapter 17; Figure CCP2.4; Haasnoot et al., 2019). A portfolio of hard, soft and nature-based interventions can be used to implement strategies to protect, accommodate, retreat and advance, individually or in combination.

The strategy and the portfolio of interventions can be adjusted in response to new information about SLR and other climate risks according to economic, environmental, social, institutional, technical or other objectives. In cases of rapid SLR, it may be necessary to implement a short-term protection strategy to buy time to implement more transformative and enduring strategies (*high confidence*; Du et al., 2020; Lawrence et al., 2020; Morris et al., 2020; Haasnoot et al., 2021a). There is *high agreement* that combining and sequencing adaptation interventions can reduce risk over time (Du et al., 2020; Morris et al., 2020). Phasing interventions can help to spread costs and minimise regret (de Ruig et al., 2019), provided options are kept open to adjust to changing conditions (Buurman and Babovic, 2016; Haasnoot et al., 2019; Hall et al., 2019).

Many megacities plan to continue a protection strategy (Table SMCCP2.1). This becomes increasingly costly, institutionally challenging and requires space, possibly facilitated through local relocation. There is *high agreement* that many C&S are locked-in to a self-reinforcing pathway: coastal defences have a long lifetime and attract people and assets that require further protection (Gralepois et al., 2016; Bubeck et al., 2017; Welch et al., 2017; Di Baldassarre et al., 2018; Jongman, 2018). Transitioning to alternative pathways may involve major transfer and sunk costs (e.g., Gralepois et al., 2016), but these may prove to be less costly in the long term. Because of considerable inertia in the built form of cities, such transitions have a greater chance of success and alignment with societal goals if embedded early into C&S planning and development processes that enable transformational change and CRD (Sections 6.4.8; 11.7; 13.11; Box 18.1; Ürge-Vorsatz et al., 2018; Siders 2019b).

In islands, hybrid options of nature-based (where space and environmental conditions allow) and protection measures (on wealthy, already densely populated islands) could reduce risk for low SLR in the next few decades (Section 15.5). Where feasible, retreat is a compelling option to reduce risk (Figure CCP2.4). With higher rates and levels of SLR in the medium to long term, financial, governance and material barriers may differentiate resource-rich and more rural islands, leading to a dichotomy between which islands retreat or can rely on protection for a period of time.

CCP2.4 Enabling Conditions and Lessons Learned

Here we distil enabling conditions and lessons learned from C&S archetypes adapting to coastal risk (Table SMCCP2.1; Table SMCCP2.2; Sections 6.4; 9.9.4; 10.5; 10.6; 11.7; 11.8; 12.5.5; 13.6.2; 14.7.2; 15.6).

CCP2.4.1 Enabling Behavioural Change

Changing behaviours and practices are a critical enabler of adaptation in coastal C&S. Behavioural enablers include using economic, informational, sociocultural and psychological incentives to motivate adaptation actions (van Valkengoed and Steg, 2019; Gibbs, 2020), for example leveraging Indigenous knowledge and local knowledge (IKLK) and religious beliefs to incentivise adaptation (Hiwasaki et al., 2014; Ford et al., 2015), implementing subsidies/bans to incentivise sustainable aquaculture (Condie et al., 2014; Krause et al., 2020), providing localised flood warnings and forecasts to inform individual risk perceptions and risk management (Bruine de Bruin et al., 2014; Gibbs, 2020) or incentivise risk insurance (Bradt, 2019).

There is *high evidence* with *medium agreement* that public attitudes and perceptions of climate risks significantly influence individual adaptation behaviour across all coastal archetypes (Bradt, 2019; Buchanan et al., 2019; Javeline et al., 2019). Information on climate risks and impacts (e.g., flood warnings, SLR projections) strongly shapes public perceptions of climate risks. It is most effective at incentivising and enabling adaptation behaviour if provided on meaningful spatial and temporal scales, with guidance about how to interpret the information (*medium evidence*, *high agreement*; Gibbs, 2020; Cools et al., 2016). Further, there is *medium evidence*, *high agreement* that integrating climate information with existing knowledge systems, such as local norms and beliefs and IKLK, is critical to improve public acceptability and develop context-specific solutions (Ford et al., 2015).

A second key enabler of coastal adaptation behaviour is self-efficacy or belief in one's capacity to undertake adaptation. There is *medium evidence*, *high agreement* that high risk perception is in itself insufficient to motivate people to undertake adaptation (Fox-Rogers et al., 2016; Roder et al., 2019; Gibbs, 2020) and needs to be supplemented with supportive policy and financial provisions to enable adaptation (Fox-Rogers et al., 2016).

Third, there is *medium evidence* on how trust in state-led, planned adaptation measures can hinder or enable individual adaptation (van Valkengoed and Steg, 2019; Schneider et al., 2020). As an enabler, trust in early warnings can mitigate flood risk by incentivising evacuation (Binh et al., 2020) and high trust can help overcome uncertainty attached to projected climate impacts and/or adaptation decisions (Frederiksen, 2014). As a barrier, low trust can disincentivise adaptation, for example willingness to pay for flood insurance (Roder et al., 2019) or public support for managed retreat (Hanna et al., 2020). Paradoxically, high trust in existing adaptation measures can reduce people's perceived need for ongoing adaptation (e.g., levees potentially reducing individual flood-proofing actions). Adaptation decisions also manifest 'single-action bias', with modest cost-adaptation actions in the present disincentivising further adaptation (Buchanan et al., 2019).

Several tools to incentivise adaptation behaviour are being tested around the world. For example, nudges and boosts[3] are being experimented with to shape individual risk beliefs and the demand for flood insurance (Bradt, 2019); ordinances are being used to ban, authorise or limit certain activities (Herrick, 2018); subsidies and financial support are being used to incentivise adaptation such as subsidised beach nourishment (McNamara et al., 2015); and zoning restrictions and building codes restrict or guide climate-resilient infrastructural development (Schneider et al., 2020). Overall, the literature affirms that behavioural interventions are more readily taken up if they are aligned with cultural practices, norms and beliefs; are on temporal scales within peoples' planning horizons; and if they build upon relationships of trust and legitimacy (Donner and Webber, 2014; Herrick, 2018; Schneider et al., 2020).

CCP2.4.2 Finance

Lack of financial resources is a key constraint affecting all coastal archetypes (*high confidence*; Table SMCCP2.2). Adaptation to coastal hazards is costly: the global costs of protecting coastal areas with levees (annual investment and maintenance costs) are estimated at USD 12–71 billion for 2100 with SLR up to 1.2 m (Hinkel et al., 2014). Broadly speaking, it is cost effective to contain coastal hazard risk in the short to medium term in densely populated wealthy localities by using protective works, but such measures are unaffordable in dispersed poorer coastal C&S (Lincke and Hinkel, 2018).

Archetypes with high adaptive capacity may currently have financial resources to meet adaptation needs, but such funding may be unsustainable in the long term. In Catalonia, while public funds are currently used to finance beach nourishment, these costs will increase with SLR and it is unclear whether public finance will remain a feasible source (Hinkel et al., 2018). Even in relatively richer municipalities, financing adaptation is constrained by other urban priorities (Bisaro and Hinkel, 2018). In Europe, shifting responsibilities from national governments to transnational and local actors has resulted in reduced national budgets for coastal adaptation investment and increased pressure on local authorities to raise public funds for adaptation without alienating electoral bases (Bisaro and Hinkel, 2018).

Locations in the Global South have limited public budgets allocated to coastal adaptation and may rely on international donor aid (Donner et al., 2016; Araos et al., 2017). Such aid is often inconsistent and short term, which limits long-term maintenance of the knowledge, equipment and infrastructure needed to sustain adaptation measures beyond initial funding periods (Weiler et al., 2018; Thomas et al., 2020), with resultant negative consequences in places as different as Kiribati (Donner and Webber, 2014) and Bangladesh (Hinkel et al., 2018). Donor-funded adaptation programs aimed at promoting behavioural change, for example through coastal planning or new decision-making systems, require enduring training and institutional capacity, which is difficult to upkeep after aid is depleted. Donor funding is often project based and there are few avenues available to fund the additional permanent and long-term staff needed to bolster climate change institutions. Without funding to support additional staff, existing institutions often lack the human capacity and resources needed for coastal adaptation (Ziervogel and Parnell, 2014).

C&S in the Global South also face financial challenges in addressing loss and damage due to climate-induced slow-onset and extreme events. Financial support to address both quantifiable damages and non-economic losses through measures such as climate-resilient

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[3] Nudges are interventions or conditions that steer people towards better choices while retaining freedom of choice. Boosts improve decision-making by creating new competencies or improving existing ones.

reconstruction after extreme weather events as well as national and local-level emergency contingency funds are lacking, which has been an issue of contention in international policy arenas (Bahinipati et al., 2017; Wewerinke-Singh and Salili, 2020; Martyr-Koller et al., 2021).

While coastal adaptation has largely been viewed as the responsibility of governments, private finance is increasingly recognised as necessary to help close the coastal adaptation funding gap (Ware and Banhalmi-Zakar, 2020). Financial arrangements for coastal adaptation measures that align public-actor and private-investor interests are suitable for a range of budgets, from USD 10,000 to 100 million (Bisaro and Hinkel, 2018). Private equity instruments that involve real estate development companies have already been successfully implemented and are most effective in urban areas with high-value real estate development (Chiang and Ling, 2017). Public–private partnership equity instruments that engage construction and real estate developers have been successful for small- to medium-scale infrastructural projects. While public–private partnership bonds and public bonds have the potential to align public actors and private investors, such instruments require de-risking of coastal adaptation through enabling economic policy instruments, such as concessional loans (Bisaro and Hinkel, 2018).

Explicitly identifying the benefits, or goods and services, that are provided by coastal adaptation is critical to supplement limited government funds and engage a broader set of financial tools and actors (Woodruff et al., 2020). Matching goods and services provided by particular adaptation strategies to specific beneficiaries helps to identify the range of fair and equitable financial tools. In the Netherlands, public fundings through state, regional and local entities have independent tax revenue systems to provide the funding needed to maintain flooding infrastructure (Hinkel et al., 2018).

Given the high costs of coastal adaptation, benefit-to-cost ratios (BCR) are often used to determine the value of investing in adaptation. BCR are high for urbanised coastal areas with high concentrations of assets (13% of the world's coastline), covering 90% of the global coastal floodplain population and 96% of assets in the global coastal floodplain (Lincke and Hinkel, 2018). A global assessment shows a BCR for investing in flood protection of up to ~120 (Tiggeloven et al., 2020). For Europe, at least 83% of flood damages could be avoided by elevating dikes along ~23–32% of Europe's coastline and BCR vary from 8.3 to 14.9, with higher ratios for higher concentration pathways (Section 13.2; Vousdoukas et al., 2020a). Globally, 40% of damages can be reduced with levees of 1 m and costs lower than avoided damage (Tamura et al., 2019). For a mix of expensive storm surge barriers, nature-based solutions and flood-proofing measures for New York City, Aerts et al. (2014) found BCRs <1 for the current situation, but >2 for a SLR scenario of +1 m.

However, BCR values may be low and adaptation investment may not be financially viable for small coastal settlements, less densely populated poorer coasts or isolated communities *(medium confidence).* Considering BCRs of protection and coastal migration across a range of SLR and Shared Socioeconomic Pathways (SSP) scenarios for the 21st century, a higher BCR was found for protection of only 3% of the global coastline protecting 78% of the coastal population and 92% of global coastal floodplain assets, while for the remaining coasts, coastal migration was estimated to be optimal in terms of economic costs (Lincke and Hinkel, 2021). Considering coastal migration as part of the solution space could lower global costs in investment and maintenance for SLR protection by a factor of 2–4 in the 21st century, but would result in large land losses and high levels of migration for South and Southeast Asia in particular, and in relative terms, small island nations would suffer most. The need to consider place attachment, community relationships, livelihoods and the spiritual and cultural significance of settlements limits the application of BCR as a tool for coastal adaptation decisions in these contexts (Thomas and Benjamin, 2020). Moreover, there is limited knowledge on trade-offs, including BCR, of alternative adaptation options and pathways at a global to regional scale, in particular over the long term (beyond 2100).

Even where BCR is high, finance may be inaccessible, as it is challenging to convert the long-term benefits of adaptation into the revenue streams that may be needed to initially finance adaptation investments (Hinkel et al., 2018). For example, in Ho Chi Minh City, Vietnam, despite high BCR, high costs of flood protection (USD 1.4–2.6 billion) have prevented such adaptation measures from being implemented (Hinkel et al., 2018; Cao et al., 2021). Moreover, drawing from places as distinct as small communities in Fiji (Neef et al., 2018) and Belize (Karlsson and Hovelsrud, 2015), and megacities like New York City and Shanghai (Oppenheimer et al., 2019), BCR provides only a limited view and consideration of feasibility, effectiveness, efficiency, equity, culture, politics and power, and attachment to place has a greater chance of fostering CRD (*high confidence*).

CCP2.4.3 Governance

An array of climatic and non-climatic perils (Le Cozannet et al., 2017) present coastal communities and their governing authorities with immense governance and institutional challenges that will become progressively more difficult as sea level rises (*high confidence*; Wallace, 2017; Leal Filho et al., 2018; Oppenheimer et al., 2019). Yet a study of public provisions for coastal adaptation in 136 of the largest coastal port–urban agglomerations across 68 countries found no policy implementation in 50% of the cases; in 85% of cases, adaptation actions are not framed by current impacts or future risks, and formal efforts are recent and concentrated in more developed settings (Olazabal et al., 2019; Olazabal and Ruiz De Gopegui, 2021), thus underscoring a persistent coastal adaptation gap. Translating these challenges into enabling governance conditions is difficult, but instructive lessons are being learned and are summarised (from Table SMCCP2.4) for archetypal C&S in Tables CCP2.1 and 2.2.

We start with a synopsis of governance settings within which coastal adaptation and CRD choices are made, and spotlight factors hindering and enabling translation of adaptation into practice. Then, building upon and extending the SROCC analysis of enablers and lessons learned in responding to SLR (Oppenheimer et al., 2019), we assess key governance challenges, related enablers and lessons learned (Tables CCP2.1, Section CCP2.2).

Governance arrangements and practices are embedded in the sociopolitical and institutional fabric of coastal C&S. Consequently,

Table CCP2.1 | Governance challenges and critical enablers for addressing coastal hazard risk in C&S

Key governance challenges	Critical enablers for C&S to address coastal hazard risk
Complexity: climate change compounds non-climatic hazard risks facing coastal C&S in interconnected, dynamic and emergent ways for which there are no simple solutions.	Draw on **multiple knowledge systems** to co-design and co-produce more acceptable, effective and enduring responses.
	Build **governance capacity** to tackle complex problems.
Time horizon and uncertainty: The future is uncertain, but climate change will continue for generations and cannot be addressed by short-term (e.g., 1–10 years) responses alone.	Adopt a **long-term view** but take action now. **Keep options open** to adjust responses as climate risk escalates and circumstances change.
	Avoid new development commitments in exposed locations. Enable managed retreat in most at-risk locations by **anticipatory actions**, e.g., secure funds, legal provisions for buy-outs, resettlement, etc.
Cross-scale and cross-domain coordination: Decisions bound by jurisdictional and sectoral boundaries fail to address linkages within and between coastal ecosystems and C&S facing interconnected climate change-compounded impacts and risk.	Develop networks and linkages within and between different governance scales and levels and across policy domains and sectors, to improve **coordination**, build trust and legitimise decisions.
	Build **shared understanding** and enable locally appropriate responses through experimentation, innovation and social learning.
Equity and social vulnerability: Climate change compounds everyday inequity and vulnerability in coastal C&S, making it difficult to disentangle and address social drivers and root causes of risk.	Recognise political realities and **prioritise vulnerability**, justice and equity concerns to enable just, impactful and enduring outcomes.
	Strengthen **community capabilities** to respond to coastal hazard risk, using external assistance and government support if necessary.
Social conflict: Coastal C&S will be the focal point of contending views about appropriate climate responses, and face the challenge of avoiding destructive conflict and realising its productive potential.	Design and facilitate **tailor-made participation processes**, involving stakeholders early and consistently from negotiating responses to implementation.
	Create **safe arenas of engagement** for inclusive, informed and meaningful deliberation and collaborative problem-solving.

barriers and enablers for adapting to climate change at the coast and charting pathways for CRD reflect more general constraints and opportunities (*high confidence*; Meerow, 2017; Rocle and Salles, 2018; Rosendo et al., 2018; Di Giulio et al., 2019; Hölscher et al., 2019; Van Assche et al., 2020; Williams et al., 2020). Local-level action is often constrained: 231 cities in the USA report weak leadership, lack of funding and staffing, and low political will (Fu, 2020). A meta-analysis of coastal municipal planning documents in Australia shows that few localities have moved beyond risk assessment (Bradley et al., 2015). Coastal C&S tend to prefer strategies that protect and accommodate existing coastline assets in the sense of a 'fix and forget' approach (Gibbs, 2015), rather than enduring proactive adaptation (Cooper and Pile, 2014).

Many C&S, especially in the Global South, already face high exposure to coastal risks and development constraints associated with poverty and socioeconomic inequality, lack of transparent resource allocation mechanisms and low political will (*high confidence*; Di Giulio et al., 2019; Nagy et al., 2019; Pasquini, 2020; Lehmann et al., 2021). Research from across South America notes inadequate regulatory frameworks, missing data and information, widespread coastal ecosystem degradation and complex interactions between natural disasters and civil conflict (Villamizar et al., 2017; Nagy et al., 2019). Coastal climate risks in the Global South are often compounded by ongoing land-use management conflicts and other pressures including informal land uses, unregulated and/or inadequate infrastructure/building development, public health priorities such as combating Dengue fever, inadequate income diversification, low education levels and political marginalization of communities historically not represented in the urban development process (Barbi and Ferreira, 2014; Salik et al., 2015; Cabral et al., 2017; Goh, 2019). There are also entrenched socioeconomic inequalities leading to the maldistribution of adaptation actions and benefits in the Global North (Gould and Lewis, 2018; Keenan et al., 2018; Ranganathan and Bratman, 2019; Yumagulova, 2020; Long et al., 2021).

To address the myriad governance challenges attributed to low awareness, low skills, scalar mismatches, and high socioeconomic inequality and coastal vulnerability, post-AR5 research highlights enablers of more innovative approaches to bridge capacity, policy and financial deficits (Reiblich et al., 2019), and facilitate more proactive implementation of coastal adaptation actions (Table SMCCP2.2; Fu, 2020). A survey of NGOs, state and local government across Alaska, Florida and Maryland in the USA found that perceived risk, uncertainty and trust in support for climate adaptation varied across two stages of adaptation, that is between support for the development of plans and willingness to allocate human and financial resources to implement plans (Kettle and Dow, 2016). To bridge this gap, Cinner et al. (2018) suggest the need to build capacity across five domains: the assets that people can draw upon in times of need; the flexibility to change strategies and interventions; the ability to organise and act collectively; learning to recognise and respond to change (especially as important thresholds are approached); and the agency to determine whether to change or not, and to then take prudent action.

Effective and accountable local leadership can help to mobilise capacities, resources and climate awareness within coastal C&S. Strong leadership is associated with agenda-setting authorities and the ability to navigate complex institutional interests towards more strategic planning efforts (*high confidence*; Ferguson et al., 2013; Anguelovski et al., 2014; Chu et al., 2017; Valdivieso and Andersson, 2018; Fink, 2019; Ndebele-Murisa et al., 2020). Policy leadership can positively influence the motivation and initiative of municipal officers (Lassa and Nugraha, 2014; Wijaya et al., 2020), whilst local leadership

Table CCP2.2 | Lessons learned from efforts to address coastal hazard risk

Lessons to address governance challenges and unlock enablers	Archetypal C&S initiatives, constraints aside
Complexity: multiple knowledge systems – Reveal dynamic complexity drawing on multiple sources of locally relevant evidence. – Use and integrate local, Indigenous and scientific knowledge. – Include marginalised voices and knowledge of vulnerable groups, women, young people, etc. – Build shared understanding through storytelling. – Bridge gaps between science, policy and practice by experimenting with novel approaches and working across organisational, sectoral and institutional boundaries.	**Seychelles (0.1 million; open coast):** Science–policy–local knowledge partnerships to co-produce usable information for decision-making. **Dhaka, Bangladesh (21 million; delta):** Climate change is national priority. Partnering with the Netherlands to develop long-term data plans. **Jakarta, Indonesia (10.8 million; delta):** Community-based efforts to foster mutual assistance and self-organisation. **Utqiagvik (formerly Barrow) Alaska, USA (0.04 million; Arctic, open coast):** Using local knowledge and historical precedent of transformative change to integrate local and scientific knowledge.
Complexity: governance capacity – Joined-up visionary leadership is key, e.g., cabinet- and C&S-level commitments to long-term implementation. – Translate political will into substantial dedicated budgets to build government capacity to tackle complex problems. – Use flexible approaches to build resilience, e.g., independent agency alongside traditional administrative bodies. – Counter deadlocks due to short-term priorities and vested interests with long-term perspectives, considering plausible scenarios and incentivising novel solutions. – Translate national requirements into local action with enabling provisions for tailored local policy and practice. – Tackle emergent problems by setting up enduring monitoring and lesson-learning processes. – Governance arrangements reconcile competing interests in an inclusive, timely and legitimate manner. – Make visible and reflect on underlying reasons for policy actions/inaction, including values, attitudes and taken-for-granted habits influencing problem-solving capability.	**Singapore (5.6 million; open coast):** Integrated approach across ministries committing to long-term adaptation (and mitigation goals) by 2030. **Rotterdam, the Netherlands (0.65 million; delta):** Delta Programme, supported by law, administrative arrangements and a €1 bill. pa budget to 2029. **Florianopolis, Santa Catarina Island, Brazil (1.2 million; mixed):** Building knowledge hub via public–private–civil society partnerships. **Nassau, Bahamas (0.275 million; open coast, small island):** Identifying responsibilities, accessing funding and preparing adaptation plans drawing on evidence-based studies. **Shanghai (27 million; estuary), China:** Contain risk by combining long-term planning, political will, national and municipal provisions, and technical capability. **Can Tho City, Vietnam (0.4 million; delta):** Engage international donors and research community.
Time horizon and uncertainty: long-term view – Establish national policies and guidance with a long-term view (e.g., 100 years) that enable action now. – Develop shared medium- (10–50 years) to long-term vision (100+ years). – Use an adaptation-pathways approach to make short-term decisions consistent with long-term goals. – Meaningfully involve stakeholders, e.g., involve representatives in decision-making. – Address power imbalances and human development needs, e.g., in goal setting and process design. – Reconcile divergent perspectives through tailored responses.	**Napier (0.07 million), Hawkes Bay (0.18 million; open coast), New Zealand:** National law compels local authorities to take a 100-year perspective; 2100 Strategy accounts for dynamic complexity and uncertain future through adaptation pathways. **Shanghai, China (27 million; estuary):** Plans up to 2100, strong national and municipal focus on climate change, and access to technical expertise. **Dhaka, Bangladesh (21 million; delta):** Long-term adaptation plans through to 2100.
Time horizon and uncertainty: avoidance and anticipatory action – Avoid development in exposed localities using spatial plans. – Use window of opportunity created by extreme events. – Prepare pre-event plans and tailor risk reduction and resilience building post disaster. – Reveal political pressures and opposition that hamper efforts to address intolerable risk and unacceptable impacts.	**Rotterdam, the Netherlands (0.65 million; delta):** Delta Programme promotes 'living with water', allowing and managing urban flooding. **Napier (0.07 million), Hawkes Bay, New Zealand (0.18 million, open coast):** Regulatory provisions discourage new development in high-risk locations; strategy sequences adaptation interventions. **Florianopolis, Santa Catarina Island, Brazil (1.2 million; mixed):** Research reveals unregulated ad hoc development in at-risk locations preventing effective adaptation.
Cross-scale and cross-domain coordination: coordination – Collaborative projects involve state and non-state actors. – Multi-lateral agreements, e.g., between neighbouring countries, coastal regions and C&S. – Connect people, organisations and communities through boundary-spanning organizations. – Leadership by central actors with capable teams is key. – Mobilise the capabilities of communities and non-state actors. – Address policy inconsistencies and clarify roles and responsibilities. – Secure national and regional resources to support local efforts. – Use measures to promote interaction, deliberation and coordination to manage spill-over effects. – Strengthen linkages between formal (e.g., regulatory) and informal (e.g., traditions and rituals) institutions, e.g., through information sharing. – Use spatial coordination mechanisms, e.g., land-use planning, to translate national and regional provisions into local competencies.	**Seychelles (0.1 million; open coast, small island):** Cross-sectoral and institutional collaboration to improve use of limited financial resources; community-based and ecosystem-based adaptation to bridge adaptation and mitigation and improve coordination. **Florianopolis, Santa Catarina Island, Brazil (1.2 million; mixed):** Effective local climate action hampered by governance constraints and weak federal leadership. **Cape Town, South Africa (4.6 million; mixed):** Multi-level climate governance advanced at local-provincial level, but political turf battles hamper national–provincial–local progress.

Lessons to address governance challenges and unlock enablers	Archetypal C&S initiatives, constraints aside
Cross-scale and cross-domain coordination: shared understanding – Prioritise social learning and shared understanding, e.g., information accessible to all, irrespective of education, language, etc. – Account for local history, culture and politics through engagement, experimentation and innovation. – Generate socioeconomic, livelihood and climate development co-benefits. – Leverage national and trans-national community and local authority networks.	**Cape Town, South Africa (4.6 million; mixed):** Capable local leaders collaborate with researchers in municipality-initiated community-based adaptation. Translating plans into action challenging given 'everyday' vulnerability exacerbated by climate change impacts. **New York City, USA (23.5 million; mixed):** State and city government work with communities to build adaptive capacity and resilience; drawing on technical capabilities but many challenges.
Equity and social vulnerability: address vulnerability – Expose drivers and root causes of injustice, structural inequity and vulnerability. – Link human development concerns, risk reduction, resilience and adaptation. – Raise awareness and public support for actions that are just and equitable. – Understand discriminatory drivers (e.g., on racial grounds) of coastal land-use patterns and risk. – Address barriers facing marginalised groups. – Use inclusive planning, decision-making and implementation processes that give voice to vulnerable people.	**Cape Town, South Africa (4.6 million; mixed):** Adaptation framed by apartheid legacy; focus on reducing vulnerability, public safety and securing critical infrastructure and community assets. **Maputo-Matola, Mozambique (3 million; mixed):** Livelihood opportunities compromised by ecological degradation compelling community DIY coping in face of severe poverty and vulnerability, weak governance and institutional capacity, and reliance on donors. **New York City, USA (23.5 million; estuary):** Hurricane Sandy (2012) focused attention on climate risk and the plight of exposed and vulnerable people, and sparked adaptation action.
Equity and social vulnerability: community capabilities – Raise vulnerability and risk awareness and understanding; build community capability and leverage external support by working with professionals, academics, local NGOs, journalists and activists. – Secure rights of vulnerable groups through court action where necessary. – Integrate traditional community responses with local government efforts. – Ensure gender equity, e.g., representation on planning and decision-making bodies.	**Monkey River Village, Belize (200 people; estuary):** Remote indigenous community; capacity to tackle erosion enabled by interventions by researchers, journalists and local NGOs to secure media and political attention after hurricane damage. **Accra, Ghana (2.5 million; delta):** Household adaptation mediated by local government flood-mitigation efforts; need better early warning and maintenance of local stormwater to prevent flooding. **Lagos, Nigeria (14 million; open coast):** Building adaptive capacity to overcome 'everyday' vulnerability and poverty severely challenging.
Social conflict: tailor-made participation – Create opportunities for integrative and inclusive solutions. – Use conflict-resolution mechanisms. – Appoint independent facilitators/mediators and involve officials as 'bureaucratic activists' to improve inclusivity and iterative and reflexive engagement. – Align informal participatory processes with statutory processes and government practices. – Sustain engagement by securing resources for local use and aligning activities with political and bureaucratic cycles. – Involve historically disadvantaged and socially vulnerable groups, e.g., accessible meeting locations/venues, local languages and culturally appropriate meeting protocols. – Involve local leaders who will champion adaptation and help mainstream findings to be integrated into C&S decision-making. – Inclusive processes help address conflict and drivers of vulnerability and promote just adaptation	**Napier (0.07 million), Hawkes Bay, New Zealand (0.18 million, open coast):** Collaboration between local authorities and Indigenous People (Māori) involving stakeholders led to co-designed long-term strategy with implementation commitment. **Manila, Philippines (14 million; open coast):** Metro-wide planning and infrastructure provisions that foster climate justice and resilience explored, with community-based actions.
Social conflict: safe arenas of engagement – Use flexible and enabling processes based in local institutions that are robust and fair, supported by governing authorities. – Attend to local social dynamics and reduce elite domination. – Use local and Indigenous knowledge and science. – Use institutional improvisation to address local concerns. – Use trusted independent facilitators. – Incentivise participation by disadvantaged groups. – Focus on improving risk literacy, optimism and capacity for joint problem-solving. – Use joint, collaborative activities to facilitate public dialogue, and secure institutional support for action. – Enable ongoing deliberation and social learning. – Make continual adjustments as circumstances change, e.g., build shared understanding about locally relevant thresholds beyond which alternative courses of action need to be actioned.	**Napier (0.07 million), Hawkes Bay, New Zealand (0.18 million, open coast):** Active involvement of local communities, Indigenous People (Māori) and research community to co-produce fit-for-purpose long-term coastal hazard risk strategy. **Rotterdam, the Netherlands (0.65 mill.; delta):** Delta Programme institutionalised multi-level adaptation governance with strong accountability mechanisms. **Greater London, UK (8.9 mill.; estuary):** Long-term provisions for at-risk Thames Estuary including major protective works, embedded in Greater London Spatial Development Plan and London Climate Change Partnership, championed by strategic leadership and supported by the public and strong technical capability.

is needed integrate coastal management, disaster management and climate adaptation mandates (Rosendo et al., 2018).

Inclusive decision-making arrangements can enable participation, local ownership, and further equity in crafting coastal adaptation plans and policies (Chu et al., 2016). Inclusion of diverse stakeholders can help improve awareness of adaptation needs; help to bridge existing social inequalities in decision-making about adaption needs, options and outcomes; close the gap between formal and informal institutions and engage indigenous forms of decision-making, which often associate climate risks with livelihood, housing and employment stressors (Ziervogel et al., 2016; Fayombo, 2020). For example, research from Pacific island states (Nunn et al., 2017) and coastal Arctic zones (Romero Manrique et al., 2018) highlights the need to engage with indigenous environmental knowledge. Case studies from Indonesia, the Philippines and Timor-Leste show that Indigenous knowledge and local knowledge and customary laws can support environmental awareness, strengthen social cohesion and help communities to better respond to climate impacts (Hiwasaki et al., 2015). Research from coastal Cambodia shows that inclusive governance arrangements can target empowerment of the most vulnerable groups to facilitate better adaptation behaviour and mainstream adaption knowledge through both formal and informal education at the community level (Ung et al., 2016).

The law is key to governing climate risks in C&S, including regulating exposure to coastal hazards; facilitating accountable decision-making; funding arrangements, liabilities and resolving disputes; and also for securing human rights (*high confidence*; Setzer and Vanhala, 2019; Averill, 2020). However, it has limits and can be both an adaptation enabler and barrier (Green et al., 2015; Cosens et al., 2017; Craig et al., 2017; DeCaro et al., 2017). Contemporary legal practice has not enabled effective adaptation in part because SLR affects compensable property rights that are secured by the law, and which generally trump concerns about public safety, resilience and sustainability (Reiblich et al., 2019). Private property rights can be used as both a sword and a shield to privilege dominant interests by undermining land use policies, plans and implementation efforts intended to promote integrated coastal management and risk reduction (O'Donnell et al., 2019; Reiblich et al., 2019). Climate change litigation has proliferated over the past decade (Setzer and Vanhala, 2019), addressing, among other things, failures to prepare for or adapt to climate change, and to secure human rights (Peel and Osofsky, 2018). Reflexive and adaptive law that accounts for the distinctive features of coastal hazard risk and associated governance imperatives builds coastal C&S adaptive capacity and resilience (*high confidence*; Garmestani and Benson, 2013; Cosens et al., 2017; DeCaro et al., 2017). Procedural justice, due process and use of substantive standards instead of rules provide legal stability and enable adaptation (Craig et al., 2017). Coastal adaptation efforts are ultimately implemented through C&S actions that are enabled or constrained by prevailing legislative, executive and judicial provisions and practices, which differ significantly across jurisdictions (He, 2018). In practice, the 'coastal lawscape' is made up of interconnected cultural normative, political and legal systems that need to be understood holistically to enable coastal adaptation in C&S (O'Donnell, 2021).

Tables CCP2.1 and CCP2.2 summarise key insights about key governance challenges facing archetypal coastal C&S around the world as well as associated critical enablers and lessons learned to address climate change-compounded coastal hazard risk (based on synthesis of Table SMCCP2.3).

In sum, prospects for addressing climate risk in archetypal coastal C&S around the world depend on the extent to which societal choices—and associated governance processes and practices—address the drivers and root causes of exposure and social vulnerability (*very high confidence*). Coastal C&S are more able to address these challenges when authorities work with local communities and vulnerable groups in particular, and with stakeholders from the local to national levels and beyond, to chart adaptation pathways that enable sustained reduction in the exposure and vulnerability of those most at risk *(very high confidence*; Cross-Chapter Box SLR in Chapter 3; Magnan et al., 2019; Oppenheimer et al., 2019). Unlocking potential enablers for locally appropriate and effective adaptation is difficult because many drivers and root causes of coastal risk are historically and institutionally embedded *(high confidence*; Thomas et al., 2019). Charting credible, salient and legitimate adaptation pathways is consequently a struggle in reconciling divergent worldviews, values and interests (Sovacool, 2018; Mendenhall et al., 2020; Bowden et al., 2021a; Bowden et al., 2021b). Unlocking the productive potential of conflict is foundational for transitioning towards pathways that foster CRD *(high confidence*; Abrahams and Carr, 2017; Harris et al., 2018; Sharifi, 2020). But this can be especially challenging for low-lying coastal C&S characterised by degraded coastal ecosystems susceptible to climate change impacts as well as pronounced inequity and governance constraints *(high confidence*; Esteban et al., 2017; Jones et al., 2020).

CCP2.4.4 Enabling Climate Resilient Development for Cities and Settlements by the Sea

The above critical enablers and lessons learned from around the world establish a strong foundation for charting pathways for CRD in coastal C&S. These pathways will necessarily vary in different C&S, and synergies and commonalities within different coastal archetypes can be leveraged. Pivotal is recognition of the narrow window of time remaining to translate embryonic risk assessment and adaptation planning into concerted implementation efforts. C&S by the sea could be the centres of innovation that lead the way to advancing SDGs through to 2030 and CRD beyond this decade (see Section 2.1.1).

This cross-chapter paper shows that a range of adaptation solutions, hard and soft protection, nature-based measures, accommodate, advance, retreat and behavioural change will need to be implemented as an integrated and sequenced portfolio of responses if coastal C&S are to contain the adverse risks of climate change (*high confidence*). The effectiveness and feasibility of any intervention—at any given moment—to reduce a particular climate-compounded coastal hazard risk or combination of risks depend upon the settlement archetype, including its geomorphological, cultural, economic, technical, institutional and political features, as well as on its historical development trajectory. Coastal C&S will benefit from developing flexible adaptation pathways—sequences of adaptation strategies and intervention options—to navigate a dynamic solution space that changes in response to climate and other drivers of change, and is also shaped by human development choices and socioeconomic, technological and institutional change.

There is no silver bullet or panacea. But developing locally appropriate yet flexible pathways for CRD will help coastal communities to address escalating risks and uncertainty (Cross-Chapter Box DEEP in Chapter 17). Effective pathways are based on robust integrated information about dynamic coastal hazard risk and plausible interventions. However, their successful implementation requires multi-scale governance arrangements and practices able to bridge different administrative and sectoral capacities in the coastal zone; effective and accountable leadership; and inclusive decision-making arrangements to enable participation, manage conflicts and trade-offs, engender local ownership, and promote equity and justice in coastal adaptation plans and policies. Further, the feasibility of adaptation strategies and interventions, especially those entailing changing behaviours and practices, is increased by recognising and incorporating peoples' values and beliefs and Indigenous and local knowledge systems, as well as the voices of women and vulnerable groups.

Coastal C&S are on the frontline of observed climate change impacts and future risk (*high confidence*). Difficult choices will be made as climate- and ocean-driven extremes become more frequent. In the next few decades, many coastal regions and C&S will have the opportunity to take actions to avoid and reduce risk, through incremental as well as more transformative interventions. Under higher levels of global warming, decisions will need to be made faster or respond to higher levels of SLR (*high confidence*; Cross-Chapter Box SLR in Chapter 3). This is particularly challenging in coastal C&S characterised by the inertia and path dependency of development choices, with long lead times for adaptation planning and implementation, and the long design life and societal impact of many interventions. Given the risks assessed in coastal C&S, the scale of climate impacts globally will depend to a large extent on whether coastal settlements develop and implement pre-emptive and flexible adaptation pathways, and whether a significant and timely reduction in greenhouse gas emissions is achieved in C&S and globally *(high confidence)*.

Frequently Asked Questions

FAQ CCP2.1 | Why are coastal cities and settlements by the sea especially at risk in a changing climate, and which cities are most at risk?

Coastal cities and settlements (C&S) by the sea face a much greater risk than comparable inland C&S because they concentrate a large proportion of the global population and economic activity, whilst being exposed and vulnerable to a range of climate- and ocean-compounded hazard risks driven by climate change. Coastal C&S range from small settlements along waterways and estuaries, to small island states with maritime populations and/or beaches and atolls that are major tourist attractions, large cities that are major transport and financial hubs in coastal deltas, to megacities and even megaregions with several coastal megacities.

The concentration of people, economic activity and infrastructure dynamically interacts with coast-specific hazards to magnify the exposure of these C&S to climate risks. While large inland cities and coastal settlements can be exposed to climate-driven hazards, such as urban heat islands and air pollution, the latter are also subject to distinctive ocean-driven hazards, such as sea level rise (SLR), exposure to tropical cyclones and storm surges, flooding from extreme tides and land subsidence from decreased sediment deposition along coastal deltas and estuaries. With climate change increasing, the intensity and frequency of hazards under all future warming levels and thus the risks to lives, livelihoods and property are especially acute in C&S by the sea.

Coastal cities are diverse in shape, size, growth patterns and trajectories, and in terms of access to cultural, financial and ecosystem resources and services. Along deltaic and estuarine archetypes, cities most vulnerable to a changing climate have relatively high levels of poverty and inequality in terms of access to resources and ecosystem services, with large populations and dense built environments translating into higher exposure to coastal climate risks.

These climate risks at the coast can also be magnified by compounding and cascading effects due to non-climate drivers directly affecting vulnerable peri- and ex-urban areas inland. These risks include disruption to transport supply chains and energy infrastructure from airports and power plants sited along the coastline, as occurred in New York City, USA, during Hurricane Sandy in 2012. The impacts can be felt around the world through globalised economic and geopolitical linkages, for example through maritime trade and port linkages.

For open coasts, settlements on low-lying small island states and the Arctic are especially vulnerable to climate change, and SLR impacts in particular, well before 2100. While the economic risks may not compare to the scale of those faced in coastal megacities with high per capita GDP, the existential risks to some nations and an array of distinctive livelihoods, cultural heritage and ways of life in these settlements are great, even with modest SLR.

Frequently Asked Questions

FAQ CCP2.2 | What actions can be taken by coastal cities and settlements to reduce climate change risk?

Sea level rise (SLR) responds to climate change over long timeframes and will continue even after successful mitigation. However, rapid global mitigation of greenhouse gases significantly reduces risks to coastal cities and settlements (C&S), and, crucially, buys time for adaptation.

Appropriate actions to reduce climate change risks in coastal C&S depend on the scale and speed of coastal change interacting with unfolding local circumstances, reflecting the hazards, exposure, vulnerability and response to risks.

'Hard' protection, like dikes and seawalls, can reduce the risk of flooding for several metres of SLR in some coastal C&S. These are most cost effective for densely populated cities and some islands, but may be unaffordable for poorer regions. Although these measures reduce the likelihood of coastal flooding, residual risk remains, and hard protection typically has negative consequences for natural systems. In low-lying protected coastal zones, draining river and excess water will increasingly be hampered, eventually requiring pumping or transferring to alternative strategies.

Whereas structures can disrupt natural beach morphology processes, sediment-based protection replenishes beaches. These have lower impact on adjacent beaches and coastal ecology and lower costs for construction and maintenance compared to hard structures. Another form of 'soft' protection involves establishing, rehabilitating and preserving coastal ecosystems, like marshes, mangroves, seagrass, coral reefs and dunes, providing 'soft' protection against storm surges, reducing coastal erosion and offering additional benefits including food, materials and carbon sequestration. However, these are less effective where there is limited space in the coastal zone, limited sediment supply and under higher rates of SLR.

Coastal settlements can 'avoid' new flood and erosion risks by preventing development in areas exposed to current and future coastal hazards. Where development already exists, settlements can 'accommodate' climate change impacts through, among other things, land-use zoning, raising ground or buildings above storm surge levels, installing flood-proofing measures within and outside properties, and early warning systems. Improving the capacity of urban drainage, incorporating nature-based solutions within urban areas and managing land upstream of settlements to reduce runoff from the hinterland reduces the risk of compound flood events. More radically, land can also be reclaimed from the sea, which offers opportunities for further development but has impacts on the natural system and wider implications for the trajectory of development.

Coastal risks and impacts such as floods, loss of fisheries or tourism, or salinization of groundwater require people to change behaviour to adapt, such as diversifying livelihoods or moving away from low-lying areas. Currently, most of these practices are reactive and help people adjust to/cope with current impacts. While a critical part of coastal adaptation, changing behaviour can be enabled by supportive policies and financial structures aligned with sociocultural values and worldviews.

Where risks are very high or resources are insufficient to manage risks, submergence or erosion of coastal C&S will be inevitable, requiring 'retreat' from the coastline. This is the outlook for millions of people in the coming decades, including those living in river deltas, Arctic communities, small islands and low-lying small settlements in poor and wealthy nations. Whilst the impacts of retreat on communities can be devastating, the prospect of many C&S and even whole nations being permanently inundated in the coming centuries underscores the imperative for urgent action.

Crucial to making choices about how to mitigate greenhouse gas emissions and adapt to climate change in coastal C&S is to establish institutions and governance practices supporting climate resilient development—a mix and sequence of mitigation and adaptation actions—that are fair, just and inclusive as well as technically and economically effective across successive generations.

Frequently Asked Questions

FAQ CCP2.3 | Considering the wide-ranging and interconnected climate and development challenges coastal cities and settlements face, how can more climate resilient development pathways be enabled?

Coastal cities and settlements (C&S) are on the frontline of the climate change challenge. They are the interface of three interconnected realities. First, they are critical nodes of global trade, economic activity and coast-dependent livelihoods, all of which are highly and increasingly exposed to climate- and ocean-driven hazards (FAQ CCP2.1). Second, coastal C&S are also sites where some of the most pressing development challenges are at play (e.g., trade-offs between expanding critical built infrastructure while protecting coastal ecosystems, high economic growth coupled with high inequality in some coastal megacities). Third, coastal C&S are also centres of innovation and creativity, thus presenting a tremendous opportunity for climate action through a range of infrastructural, nature-based, institutional and behavioural solutions (FAQ CCP2.2). Given these three realities of high climate change risks, rapid but contested and unequal development trajectories, and high potential for innovative climate action, C&S are key to charting pathways for climate resilient development (CRD).

Three key levers can enable pathways that are climate resilient and meet goals of inclusive, sustainable development. One key enabler involves flexible, proactive, and transparent governance systems, built on a bedrock of accountable local leadership, evidence-based decision-making—even under uncertainty—and inclusive institutions that consider different stakeholder voices and knowledge systems. Another key enabler is acknowledging the sociocultural and psychological barriers to climate action and incentivising people to change to lifestyles and behaviours that are pro-climate and aligned with community-oriented values and norms. In practice, coastal C&S are experimenting with different strategies to change practices and behaviours, such as using subsidies and zoning policies, tax rebates and public awareness campaigns to promote individual and collective action. Finally, enabling CRD needs dedicated short- and long-term financing to reorient current trajectories of unsustainable and unequal development towards climate mitigation and adaptation action that reduces current and predicted losses and damages, especially in highly vulnerable coasts such as the small island states, the Arctic and low-lying C&S. Currently, adaptation finance is concentrated in coastal megacities and tends to be deployed for risk-proofing high-value waterfront properties or key infrastructures. Addressing these financial imbalances (globally, regionally and sub-nationally) remains a critical barrier to inclusive climate resilient coastal development.

Notwithstanding the many interconnected challenges faced, from more frequent and intense extreme events to the COVID-19 pandemic, many coastal C&S are experimenting with ways to pivot towards CRD. Critical enablers have been identified and lesson learned, which, if translated into practice, will enhance the prospects for advancing the SDGs and charting pathways for CRD that are appropriate to local contexts and foster human well-being and planetary health.

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