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Differentiated trajectories of ecosystem-based adaptation for urban coastal defence in the Asian-Pacific region: A biodiversity–climate–society nexus perspective

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ABSTRACT

Many coastal cities already experience severe climate change impacts and are in urgent need of an immediate shift toward transformative adaptation. Ecosystem-based adaptation (EbA) measures for coastal defence have garnered increasing attention as a more sustainable and cost-effective approach to foster climate-resilient development in coastal areas. This study explores the current priorities, processes, and progress of EbA implementation for coastal defence in Asia Pacific cities. It uses the Biodiversity – Climate – Society (BCS) nexus lens popularised in the first joint report by the Intergovernmental Panel on Climate Change (IPCC) and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). Utilising case studies from Singapore, China, and Vietnam, we evaluate the current stage and status of EbA implementation and examine interacting outcomes, feedback loops, leverage points, and tipping points within the BCS nexus. The insights drawn here from multiple cities in Asia Pacific can offer insights that could be useful to similar coastal areas in other parts of the world as well as decision-makers and stakeholders within the broader climate change community.

1. Introduction

Coastal cities worldwide experience escalating threats from climate change through sea level rise and increases in the severity and frequency of climate-related natural hazards (IPCC, 2021). Predictions for the year 2100 suggest a global mean sea level increase between 0.43m (likely range: 0.26–0.53m) and 0.84m (likely range: 0.61–1.1m) under the Representative Concentration Pathway scenarios 2.6 and 8.5, respectively (IPCC et al., 2019). Such severe future changes could threaten coastal cities and their populations, since some of the most exposed urban communities to climate change are located in lowland hazard-prone areas (Abadie et al., 2020).

Many of the coastal areas that are highly vulnerable to climate change are located in the Asian-Pacific region (APR) (Hashim and Hashim, 2014). For example, several coastal cities in the APR are extremely susceptible to accelerated climate change and experience at the same time fast-paced urbanisation and economic growth (Marcotullio et al., 2014). This has been emphasised, for example, on the aftermath of extreme weather events such as Typhoon Haiyan in central Manila in 2013 that caused 6300 fatalities (Pacific Disaster Center, 2013), and Typhoon Saomai in 2006 that displaced 1.7 million people and caused USD 1.4 billion in economic losses in China, including in cities such as Fujian, Wenzhou, and Zhejiang (Elliott et al., 2015).

Many coastal cities in the region are adopting measures to mitigate and adapt to climate change, aiming to achieve a sustainable and climate-resilient development. At the same time, coastal cities in the region (and more broadly) are engines of economic growth and innovation and thus have the potential to shape climate change adaptation in their respective national contexts in transformative ways. However, traditionally, urban adaptation has relied heavily on engineered hard structures such as dykes, breakwaters, and embankments (André et al., 2016). Such structures do not adapt well to changing climates, and will likely face serious challenges in the coming decades (Morris et al., 2020).

In recent years, there has been a growing acknowledgement of ecosystem-based adaptation (EbA) approaches to climate change (Temmerman et al., 2013). EbA refers to the strategic utilisation of biodiversity and ecosystems within an overarching climate change

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adaptation strategy, aimed at enabling local communities to cope with climate change (CBD, 2009). Coastal ecosystems such as wetlands, mangroves, grasslands, coral reefs, and kelp beds can act as natural buffer zones, reducing disaster risks on vulnerable coastal communities and mitigating carbon emissions (Spalding et al., 2014), thereby offering an alternative to hard structures (Sudmeier-Rieux et al., 2021). Using coastal ecosystems for climate adaptation can be sometimes more cost-effective and offer higher ecological and social (co)-benefits to local communities (Narayan et al., 2016).

The above imply that EbAs can have significant potential for climate change adaptation, possibly offering multiple benefits at the nexus of biodiversity, climate and society.[1] Arguably, urban transitions that integrate EbAs into urban adaptation strategies can contribute to sustainable and climate-resilient development, which aligns well with the vision of several relevant global initiatives such as Resilient Cities, Regenerative Cities, and Biophilic Cities, among others (Pedersen Zari et al., 2022).

However, there is also a growing realisation that current adaptation efforts often ignore the dynamic feedback loops and nexus interactions in this interface of biodiversity–climate–society (BCS) (Pascual et al., 2022). Arguably, understanding the integration of EbAs for coastal defences through BCS nexus lens can generate valuable insights for urban adaptation efforts. However, there are two major knowledge and practice gaps. First, there is little literature examining EbA implementation through a BCS nexus lens, resulting in our limited understanding of how these nexus interactions unfold and the factors that influence them. Second, more broadly, there is notably scarce empirical research about the implementation of EbAs for urban adaptation in the APR, and particularly in developing parts of the region. Since EbA, as the concept, is generally rooted in Euro-American settings (Herbeck and Siriwardane-de Zoysa, 2022a), scholars have pointed to the comparatively little literature from other parts of the world (for some exceptions see Marcotullio et al., 2014; Giffin et al., 2021). This has created major knowledge gaps about the implementation status of EbAs, particularly in the Global South.

This paper aims at addressing the aforementioned gaps by unravelling how EbAs have been implemented in different coastal urban contexts of the APR. We adopt a BCS lens to critically and comparatively synthesise diverse types of information from three coastal cities in the APR, namely Singapore, Xiamen (China), and Danang (Vietnam). These cities collectively provide a good cross-section within the region in terms of (a) types of climatic hazards and vulnerability, (b) EbAs implementation for coastal protection, and (c) demographic and socioeconomic circumstances.

2. Methodology

2.1. Theoretical framework and key concepts

An important starting point is to appreciate the different approaches to coastal defence and adaptation. Coastal defence structures can be broadly differentiated into 'hard', 'hybrid', 'soft', and 'natural' measures (Huynh et al., 2024). 'Hard' measures include grey infrastructure such as breakwaters, dykes, dams, groins, and levees that are engineered and constructed to protect coastal communities from natural disasters (André et al., 2016). 'Natural' measures refer to coastal habitats that can be formally protected/conserved (or not) and act as buffers against natural hazards (Spalding et al., 2014). 'Soft' measures entail the restoration, rehabilitation, or afforestation of degraded coastal habitats or the creation of entirely new coastal habitats that provide disaster protection functions similar to those of non-degraded natural habitats (Morris et al., 2018). 'Hybrid' measures combine restored or natural habitats with grey infrastructure such as dikes in front of mangroves, rock sills with oyster reefs, or ecological engineering structures (Morris et al., 2018). 'Natural', 'soft', and 'hybrid' measures collectively fall under the umbrella terms of 'ecosystem-based adaptations' (EbAs) or 'nature-based solutions' (NbS),[2] or 'building with nature' (Huynh et al., 2024; Morris et al., 2018). These measures essentially utilise nature to enhance coastal protection, while promoting climate change adaptation and mitigation (Morris et al., 2020).

This study uses the Biodiversity–Climate–Society (BCS) nexus framework (highlighted in the first joint IPCC–IPBES report) to understand the integration of EbAs into coastal defence (Pörtner et al., 2021). The central point of this framework is that biodiversity, climate, and society are profoundly intertwined, and rather than perceiving them as separate pillars, it emphasises the dynamic and causal relationships that can help identify co-benefits, trade-offs, and co-detriments among them (see Fig. 1).

The BCS nexus includes several interacting sub-systems (for more details, see (Pörtner et al., 2021)). In summary, the biophysical components involve the interacting processes related to biodiversity and its supporting ecosystems (B) and related to climate systems (C). These include the current state of biodiversity, changes in ecological health, changes in the provision of ecosystem services, drivers of changes, carbon removal and storage, and the tolerance and adaptation limits of ecosystems (Pörtner et al., 2021). The society (S) subsystems involve human social dimensions such as quality of life, human wellbeing, justice, human values and norms, governance, institutions and regulations (Pörtner et al., 2021). The society (S) dimensions shape and are shaped by the B-C interactions.

As mentioned above, all the components and subsystems in the BCS nexus are interlinked. Actions that influence the BCS nexus can lead to three types of outcomes: co-benefits, trade-offs, and co-detriments (Pörtner et al., 2021). Co-benefits occur when the actions lead to positive outcomes in all BCS nexus components. Trade-offs occur when actions lead to positive outcome for one BCS nexus component but undermines the outcomes of others. Co-detriments occur when actions lead to negative outcomes for multiple BCS nexus components. However, we must point to the complexity of the interactions in the BCS nexus, particularly related to non-linearity and feedback loops (Pörtner et al., 2021). For example, a certain policy measure can yield positive outcomes up to a certain threshold but have negative outcomes beyond a certain point (or vice versa). BCS nexus interactions may encompass synergistic or saturating functions, cascades, feedback loops, and off-stage effects (i.e. impacts that are spatially and temporally distant, diffuse, or delayed) (Pascual et al., 2022).

'Tipping points' is another important concept within the BCS nexus

[1] The concept of biodiversity – climate - society (BCS) nexus has been gaining attention recently in both academic literature and global climate assessment reports. The first joint workshop between the Intergovernmental Panel on Climate Change (IPCC) and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) emphasised the importance of exploring the interconnected interactions among biodiversity, climate, and society to efficiently optimise mutual benefits and minimise negative outcomes (Pörtner et al., 2021).

[2] Ecosystem-Based Adaptations (EbAs) and Nature-Based Solutions (NbS) have overlapping principles but differ in scope and emphasis. Both approaches leverage ecosystems to tackle environmental challenges, yet they are understood differently in global frameworks. EbA, as defined by the Convention on Biological Diversity (CBD), focuses on using biodiversity and ecosystem services to help communities adapt to the impacts of climate change (CBD, 2009). In contrast, NbS, as defined by the International Union for Conservation of Nature (IUCN) and endorsed by the UN Environment Assembly, involves protecting, managing, and restoring ecosystems to address a wide range of societal challenges, while benefiting both biodiversity and human well-being (Cohen-Shacham et al., 2022). While EbA centres on climate change adaptation, can NbS target a broader set of challenges beyond just climate impacts, including among other food security, water security, or social and economic development (Cohen-Shacham et al., 2022).

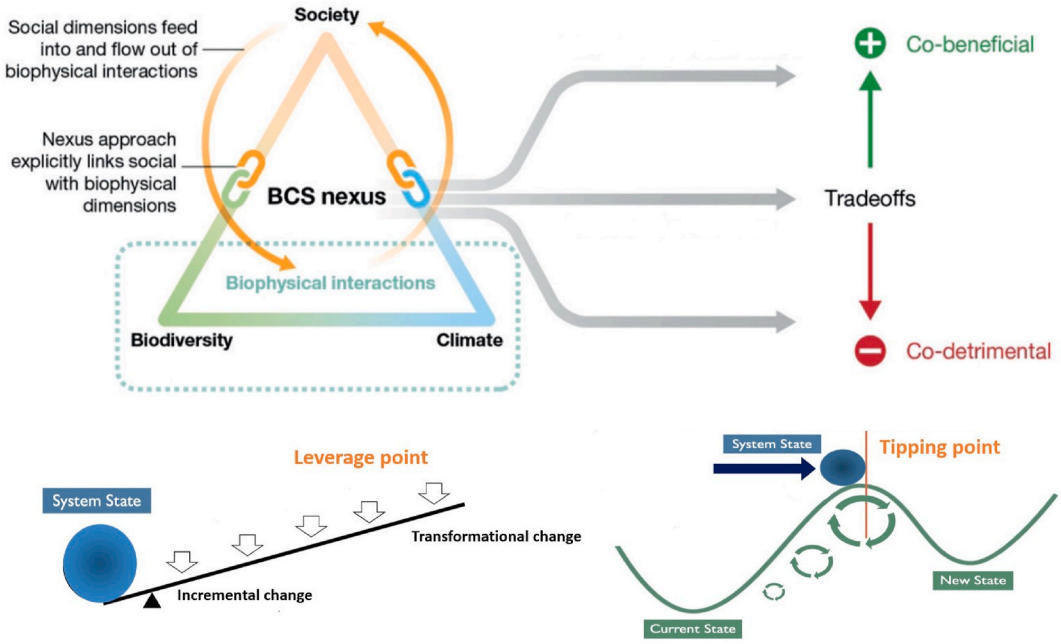

Fig. 1. Schematic representation of the conceptual framework. The triangle indicates the components of the Biodiversity–Climate–Society (BCS) nexus. The interacting outcomes include co-benefits, trade-offs, and co-detriments. Within the BCS nexus, leverage points indicate places where targeted interventions can induce systemic changes in system behaviour. Tipping points refer to points where the system undergoes an irreversible shift and enters a new state. The conceptual framework was informed from (Ives et al., 2018; Pörtner et al., 2021).

framework, which denote pivotal moments where the system undergoes a critical and potentially irreversible shift to a different equilibrium state (Dakos et al., 2019). Tipping points can be understood from both biophysical and social perspectives (Pascual et al., 2022). Regarding the former, biophysical tipping points can be certain anthropogenic drivers that could cause impacts surpassing biophysical thresholds, causing the B-C space to shift into a new state from which recovery may be difficult (Dakos et al., 2019). Regarding the latter, social tipping points are situations characterised by significant and sudden changes within the social system that are capable of initiating transformative shifts in the other components of the BCS nexus (Pascual et al., 2022). In essence, the dynamics of social tipping points involve the diffusion of norms,

Table 1
Main characteristics of study cities.

	Singapore	Xiamen	Da Nang
Population in 2022 (residents)	5.64 million	4.27 million	1.2 million
Population increased since 2000 (%)	141	208	211
Area ($km^{2)}$	725.7	1701	1283.4
Coastline length (km)	228	265	92
Climate	Tropical monsoon climate	Monsoonal humid subtropical climate	Tropical monsoon climate
Temperature range (°C)	24–32	10–32	19–33
Annual rainfall (mm)	2113.3	1300	2576
Economic output in 2022 (USD/capita)	82,867	21,913	4110
Economic output increase since 2000 (%)	347	409	1334
Main industries	- Manufacturing of electronics and machinery - Financial services - Tourism	- Manufacturing of electronics and machinery - Tourism - Logistics	- High-tech manufacturing - Tourism
Human Development Index (score)	0.939 (in 2021)	0.768 (national index, in 2021)	0.703 (national index, in 2021)
Extreme weather events	- Extreme rainfalls - Dry spells - Strong winds	- Typhoons - Droughts - Heatwaves - Rainstorms	- Typhoons - Droughts - Heatwaves - Rainstorms
Climatic vulnerability	- Coastal erosions - Flooding - Increase in extreme weather events - Urban heat	- Typhoons - Coastal erosions - Flooding - Increase in extreme weather events	- Typhoons - Coastal erosion - Flooding - Increase in extreme weather events
Types of EbAs	Hybrid EbAs using advanced techniques	Hard structures and soft EbAs	Hard structures and natural EbAs
Maturity of EbA implementation	Mature EbAs implementation with evidence of risk reduction. EbAs integration at the same priority as hard measures.	Ongoing implementation of EbAs for coastal defence.	Early planning of EbAs for coastal defence. Coastal defence heavily depends on hard structures.

opinions, behaviours, and actions across social networks in ways that are challenging to halt or reverse (Pörtner et al., 2021). Tipping points could lead to both positive and negative shifts to the entire system.

Another central, but rather understudied concept within the BCS nexus literature, is 'leverage points'. These denote strategic loci within a complex system before triggering a 'tipping point' where targeted interventions can induce systemic changes in system behaviour (Ives et al., 2018). While the notion of 'leverage points' has gained some prominence in policies aiming to reconnect people with nature (Huynh et al., 2022; Ives et al., 2018), its application within the context of climate change and the BCS nexus remains relatively limited. In this framework, leverage points are crucial areas where small, well-directed actions can induce significant changes across biodiversity, climate, and society, making their identification essential for developing effective policies and actions that drive positive system-wide changes and facilitate tipping points.

2.2. Study cities

As both the BCS nexus and EbAs concepts originate from Euro-American contexts, exploring coastal cities in other regions, such as the APR, could provide valuable insights for advancing coastal adaptation. This paper examines EbA implementation in coastal defence across three APR cities: Singapore, Xiamen (China), and Da Nang (Vietnam), which, as detailed in Table 1, have (a) diverse vulnerabilities to climate change, (b) varying experiences with EbA, and (c) different demographic and socioeconomic conditions.

Singapore is a city state in the southern tip of the Malay Peninsula, covering 725.7 km^2 and a population of 5.64 million (2022) (Department of Statistics Singapore, 2022). It is one of the most prosperous cities in the world and ranked highest in the 2020 World Bank Human Capital Index (World Bank, 2023). Located near the equator, Singapore has a tropical climate with high rainfall, temperatures, and humidity year-round. It is warming at twice the global average rate, with a 1 °C increase since 1950 (Global Center on Adaptation, 2019). As a low-lying island, Singapore is facing challenges such as coastal erosion and flooding due to sea level rise, increased extreme weather events, and urban heat (Cui et al., 2021).

Xiamen, located on China's southeast coast facing the Taiwan Strait, covers 1701 km^2 and has a population of 4.27 million (2023). Declared as a Special Economic Zone in 1980, Xiamen has experienced rapid economic growth and urbanisation. As a low-lying coastal city, 16 % of its land is below 10 m (Xu et al., 2021a). The city has a monsoonal humid subtropical climate and frequently faces typhoons from the Western-North Pacific. The strongest recorded typhoon, Meranti, hit Xiamen in September 2019, causing USD 1.6 billion in damages, including over 650,000 fallen trees and more than 800 collapsed houses (Fang, 2016; Zhang and Li, 2019).

Danang, located in central Vietnam, covers 1283.4 km^2 with nearly 92 km of coastline and has a population of 1.2 million (Danang Provincial Statistical Office, 2019). The city has experienced rapid urbanisation and beachfront tourism development over the past 20 years. With five of its eight districts adjacent to the sea, its coastlines are crucial for economic growth and socio-cultural value (People's Committee of Danang City, 2001). Danang faces significant climate risks, including projected temperature increases of 1.9–4.0 °C and sea level rise of 53–75 cm by 2100 (WorldBank, 2013). Recent years have seen worsening coastal erosion, floods, and typhoons, leading to considerable social and economic losses.

In summary, Singapore adopts more hybrid EbAs measure and is characterised by high economic development and low social vulnerability level. Xiamen (China) is implementing soft measures (e.g. restoration and rehabilitation) and is characterised by a medium level of economic capability and social vulnerability. Finally, Danang (Vietnam) prioritises natural measures (e.g. conservation and protection) and is characterised by relatively low economic capability and high-to-medium social vulnerability levels.

2.3. Data collection and analysis

In this study, we use a BCS nexus lens to conduct a comparative analysis about the priorities, processes, and ongoing progress of integrating EbAs for coastal defences and climate change adaptation in Singapore, Xiamen, and Danang. We critically synthesise diverse types of information to identify the different nexus outcomes of EbA for coastal defence (e.g. co-benefits, trade-offs, co-detriments), as well as possible tipping points and leverage points.

We relied on secondary information collected through an extensive literature review that covered relevant policy documents, academic literature, and grey literature for each city. First, we searched and reviewed policies and related documents on climate change adaptation, coastal defence and development, and EbA implementation in each city to understand the underlying regulatory frameworks and institutional approaches. Second, we gathered from academic journal articles empirical insights about the theoretical foundations and priorities, drivers, processes, progress, and outcomes of EbAs implementation in each city. Third, we reviewed grey literature, such as non-peer-reviewed reports and documents from non-governmental organisations and international agencies, particularly in relation to the implementation, challenges and opportunities of EbA for coastal protection in each city.

We complemented information from the literature review with insights gained from field visits in each city, and particularly through direct observation of the current EbA projects and informal dialogues with local stakeholders. These visits provided a deeper understanding of the on-the-ground realities, contextual factors, and the current EbA implementation progress, acting as a reality check for the information collected through the literature review.

We synthesised this information in three consistent tables in the Results section (section 3.1-3.3) that indicated for each study city the BCS nexus outcomes (i.e. co-benefits, trade-offs, co-detriments), feedback loops, leverage points, and tipping points of EbAs. We then critically extracted in the Discussion key commonalities, differences, and patterns across the case cities related to EbA implementation for coastal defence.

3. Results

3.1. Singapore: the garden by the bay

The term 'ecosystem-based adaptations' have gained significant attention in Singapore for the last ten years. The vision of greening the city as an urban solution could trace back many decades in Singapore's history, starting with the Garden city Vision in the 1960s (Cui et al., 2021). Singapore's green coverage increased from 35 % to 50 % between 1986 and 2010, despite the rapid urbanisation rate and population growth (Pedersen Zari et al., 2022).

Particularly for coastal defence, Singapore has demonstrated successful adoption of a wide range of hybrid EbAs which use advanced engineering methods to optimise nature's capacity (see Fig. 2). Construction of seawalls and stone embankments covered 70–80 % of Singaporean coastlines in 2011 and well-integrated with EbAs (Gordon et al., 2015). In 2006, a new programme called Active, Beautiful, Clean Waters (ABC Waters) was launched to build the city with enhanced resilience and improved flood management, all while utilising natural solutions for water purification (Infopedia, 2019). In combating sea level rise, in 2019, Singapore first announced its coastal defence plan to implement EbAs along with solutions relying on conventional engineering such as land reclamation and seawalls (Mohan, 2021). For example, mangroves, which account for 1.1 % of Singapore's land area, have been recognised as important for coastal defence and actively restored through multiple soft projects engaged with multiple stakeholders such as Restored Ubin Mangrove Initiatives in Pulau Ubin and

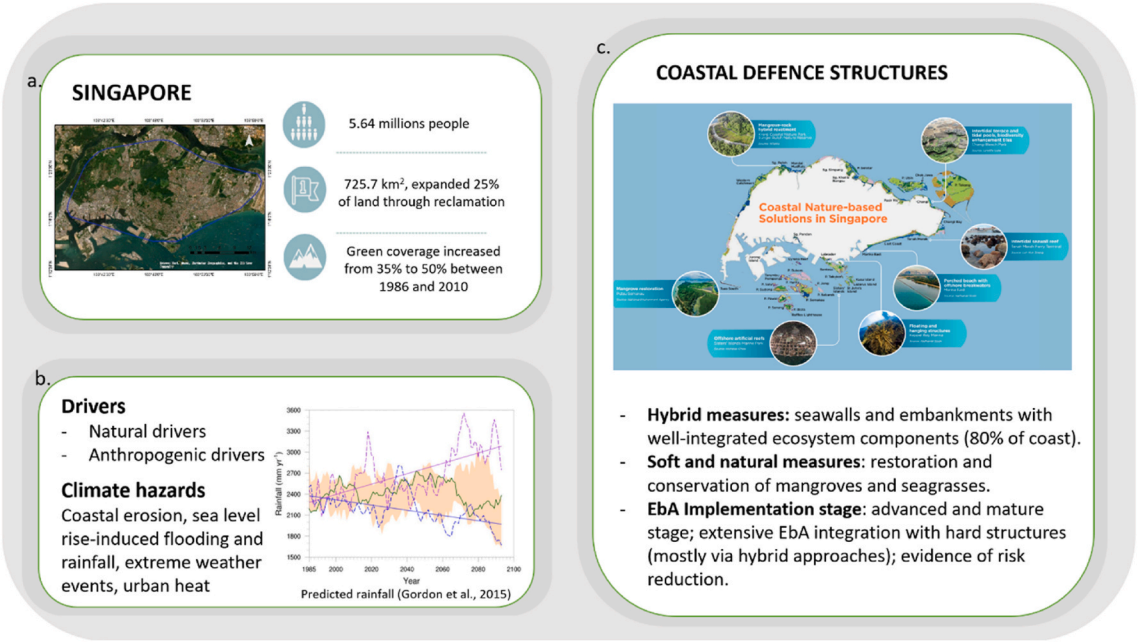

Fig. 2. Geographic location, climatic risks and coastal defence measures in Singapore. Panel (a) general statistics and map. Panel (b) drivers and climate hazards (inset figure adopted from Gordon et al., 2015). Panel (c) current coastal defence measures (inset picture adopted from Centre for Liveable Cities, 2022).

Restoration of Mangrove Biodiversity in Pulau Tekong (Tan and Fogarty, 2021).

The coastline greening initiatives in Singapore show that the implementation of hybrid and soft EbAs has been at a mature phase. The EbA strategies in Singapore convey a message that living in harmony with nature is possible and futuristic in the urban context (Cui et al., 2021). Co-benefits are found in the BCS nexus. Various risk reduction evidence in Singapore has shown that EbAs which pursue the 'biodiversity' component can simultaneously increase the 'climate' component (see Table 2). Implementing EbAs for coastal defence in Singapore promote healthy ecosystems, increasing carbon storage and resilience to climate risks in terms of flooding mitigation, shoreline stabilisation and urban heat reduction. In addition, greening the city which integrates natural landscapes also fulfils multiple urban demands and promote the 'wellbeing' of citizens (Fink, 2016). Apart from regulating, provisioning, and supporting services from EbAs, cultural services also contribute significantly to enhancing the quality of life such as mental health, physical health, personal growth, place attachment, and spirituality (Tan et al., 2021; Thiagarajah et al., 2015). Large-scale EbA projects also present opportunities for business investment and technological innovation.

Interestingly, co-benefits and trade-off in Singapore demonstrate a more complicated dynamic along the time and spatial scale rather than solely being mutually reinforcing. Short-term trade-offs may emerge, but they can transform into co-benefits over an extended timeframe. For instance, the proximity of protected mangroves in Pulau Ubin and Pulau Tekong to the city centre may momentarily diminish the recreational advantages for urban residents. However, with effective resource management and improved accessibility, these areas can yield long-term ecological benefits, serving the interests of all stakeholders. Immediate positive ecological outcomes arise from the ecosystem restoration, although the positive climate risk reduction and mitigation effects are slightly delayed as time is required for the newly planted trees to mature to provide full benefits. The outcomes of EbA projects are also contingent on spatial scale, with large-scale hybrid coastal defence projects which include land reclamation potentially generating co-benefits in Singapore but possibly leading to environmental trade-offs for neighbouring countries (Ananthalakshmi, 2015).

When looking at the system as a whole, the implementation of EbAs for coastal defence in Singapore generates more co-benefits than trade-offs in all BCS component, representing a transformative progress in urban adaptation. Positive feedback loops enhance all subsystems. The benefits people get from the B-C subsystem to their 'society' (S) subsystem strengthens the connections between humans and nature, as many Singaporean people support the green image of their country (Teo, 2004). This further reinforces a positive feedback loop in which higher wellbeing/social component leads to better stewardship and engagement with nature, allowing room for more innovations and the development of more green solutions, and consequently promoting 'biodiversity-climate' subsystems and 'society' subsystems of the city.

We identified several leverage points in the system that when targeting can contribute to promoting co-benefit outcomes and uplifting the system. First is the capacity building and inclusive engagement from multiple sectors (Lee et al., 2020). The government promotes collaboration and participation in an early, sustained, inclusive, and active manner (Lee et al., 2020). Since its Independence, the Singaporean government has shown their willingness to engage the public, demonstrate commitments to long-term benefits, and tailor outreach to private and academic sectors along the planning phases (Tortajada and Joshi, 2013). Capacity building and education are prioritised to promote the knowledge and skills of the involved stakeholders (Tortajada and Joshi, 2013). Second, effective value-framed and place-based communications reveal as a success criterion for BCS system. Communication of EbAs in Singapore has been framed in a way that highlights the quality of life and wellbeing benefits from nature, emphasises mutual attachment to nature and place, and fosters a sense of altruism in the community (Kong and Yeoh, 1996). The third is the multifunctional and equitable benefits that EbA projects bring to the country. Nature-based solutions and EbAs in Singapore not only function for coastal protection but more importantly provide multiple co-benefits to wellbeing such as aesthetics, leisure, urban lifestyle, restored cultural elements, and spirituality (Tan et al., 2021; Tortajada and Joshi, 2013). Through landscape planning, the benefits from nature are relatively equitably redistributed in the community.

It is worth noting that a complicated dynamic in relation to EbA implementation in Singapore stems from the tension between the two approaches: creating carefully curated and human-centred green spaces in the city on the one hand, and promoting more biodiverse, native

Table 2
Biodiversity – climate – society nexus interaction outcomes from EbAs implementation for coastal defence in Singapore.

EbA measures	BCS nexus components	Description
Hybrid measures - Integrated coastal management zones: seawalls and embankments integrated with ecosystem components - Land reclamation with hard and hybrid eco-engineering components - ABC Waters programme for flood control and waterway rehabilitation **Soft and Natural measures** - Restoration and conservation of mangroves along the Northwest coast (Pulau Seletar, Sungei Khatib Bongsu, Pasir Ris) and northeastern islands (Pulau Ubin, Pulau Tekong) - Restoration and conservation of seagrass on Eastern coast (Changi, East Coast, Pasir Ris) - Restoration and conservation of coral reef in southwestern islands - Restoration of sandflats, mudflats and coastal forests - Protection and conservation of marine habitats and coastal forests	**Co-benefits**	**Biodiversity (+):** EbA projects conserve or restore coastal habitats or modify artificial coastlines/structures, providing habitat for biodiversity **Climate (+):** EbA projects increase carbon storage capacity through vegetation, and reduce climate risks through wave attenuation, shoreline erosion prevention, flooding mitigation, and urban heat reduction. **Society (+):** EbA projects provide opportunities for innovation and technical development.
	Trade-offs	**Society (−):** EbA projects improve human well-being for some actors (e.g. through aesthetic value, recreational and educational opportunities) and reduce it for others (e.g. through preventing use of forest products in protected areas). **Biodiversity (−):** Large hybrid EbA projects are associated with extensive land reclamation, causing damages to the ocean and creating tension with neighbouring countries **Biodiversity (−):** Large hybrid EbA projects that rely on highly curated green spaces may lack the ecological complexity and diversity of native ecosystems
	Leverage points	- Capacity building - Inclusive engagement from multiple sectors - Education and awareness raising - Value-framed and place-based communication - Early and forward-thinking master plan - Multi-functionality - Equity
	Tipping points	- High potential for positive social tipping points via raising awareness and enhancing stewardship. - High potential for positive transformative changes (i.e. infrastructural, institutional and societal)
	Feedback loops	**Positive**: ↑biodiversity → ↑ society → ↑ human-nature relationship → ↑ innovation and development of EbAs → ↑ climate and biodiversity

Note: Definitions of BCS nexus elements are included in Section 3.1.

ecosystems on the other hand. Singapore's greening strategies have been often criticised as prioritising human design and aesthetic appeal, creating well-maintained environments that resonate with the public's vision of nature, over green spaces that prioritise biodiversity conservation and greenery metrics (Chiu-Shee, 2022; Tan et al., 2013). Although both types can offer adaptation benefits, the latter tend to align better with a robust EbA framework. In this sense, although many of the innovative hybrid EbA projects outlined above successfully deliver multiple co-benefits within the BCS nexus such as the ABC Water programme with enhanced resilience and improved flood management (see above), there is ongoing discussion about whether these projects could further conserve and enhance biodiversity, as the plant species they have integrated tend to differ from native biodiversity (Chiu-Shee, 2022). As large-scale hybrid EbA projects are increasingly implemented in the city, the full spectrum of their co-benefits and trade-offs may only become clear over time.

3.2. Xiamen: mangrove restoration in a Special Economic Zone

Located in a Special Economic Zone, Xiamen's coast has been experiencing intensive land reclamation to comply with development (Xu et al., 2021b). Large reclamation activities destroyed marine ecosystems growing on the coastline. Natural mangrove areas, which covered about 320 ha in the 1960s, dwindled to just 21 ha by 2005 due to reclamation for agriculture, aquaculture, and infrastructure (HU, 2016; Lin et al., 2005). This loss of mangroves is believed to weaken urban resilience to increasingly severe typhoon events as the climate warms (Fang, 2016).

Construction of seawalls was the main effort in the Xiamen City to combat typhoon and storm surge in the past decades. However, some constructed seawalls have led to poor water exchange, tidal volume reduction, and silt accumulation for years (Xue and Dong, 2010), which accelerated the deterioration of the coastal environment. In 1997, Xiamen started Integrated Coastal Management (ICM), which aimed to achieve sustainable development and economic growth through enhancing the health of the coastal environment and ecosystems (Su and Peng, 2021). The implementation of ICM includes opening the old seawalls (i.e. Gaoji and Jixing seawalls and Zhongzhai seawall) and starting coastal ecological restoration, including mangrove plantations. It has been a lesson that Xiamen was hit by a rarely strong typhoon in 1958, which came with fierce storm surge that almost engulfed the entire coastal area. While in the Longhai district next to Xiamen, the farmland and houses were mildly damaged due to the protection by dense mangrove forests. Recognising the critical role of mangroves in coastal protection, Xiamen began planting and restoring mangroves (soft measures) on accessible mudflats in the 1990s. In September 2020, the Ministry of Natural Resources launched a Special Action Plan aiming to restore 18,800 ha of mangroves in China by 2025 (State Council of the People's Republic of China, 2020). This legislation highlights the ongoing challenge for Xiamen to advance mangrove restoration and integrate EbAs into its coastal defence strategy (see Fig. 3).

Integrating EbAs into coastal defence in Xiamen through soft approaches yields significant co-benefits across the BCS nexus (see Table 3). Mangrove restoration improves ecological outcomes, mitigates climate risks through storm surge attenuation and carbon storage, and offers various ecosystem services to local residents. For example, the Xiatanwei sea area, once a dump site, has transformed into Xiatanwei Mangrove Park, featuring 85 ha of restored mangroves. This park exemplifies successful coastal ecological restoration and disaster mitigation in China. It also attracts many local and international visitors, boosting nature-based tourism and the local economy. The restored mangroves enhance urban vegetation and carbon mitigation, benefiting human health and quality of life. Additionally, social factors, influenced by economic and governance drivers, shape the B-C outcomes, creating a positive feedback loop that enhances the BCS nexus.

However, there are also trade-offs in the BCS nexus regarding the implementation of EbAs in Xiamen (Table 3). The restoration of mangrove has negative impact on the livelihoods of aquaculture farmers. Despite the fact that the expansion of aquaculture ponds has caused dramatic decrease in mangrove extent, the removal of aquaculture would significantly affect the livelihood of aquaculture farmers. Immediate trade-offs are conflicts in the use of coastal resources between different stakeholders in the areas that needs to be restored. Long-term trade-offs are social and environmental inequity as the results of unequal tourism-driven income gaps among community members and

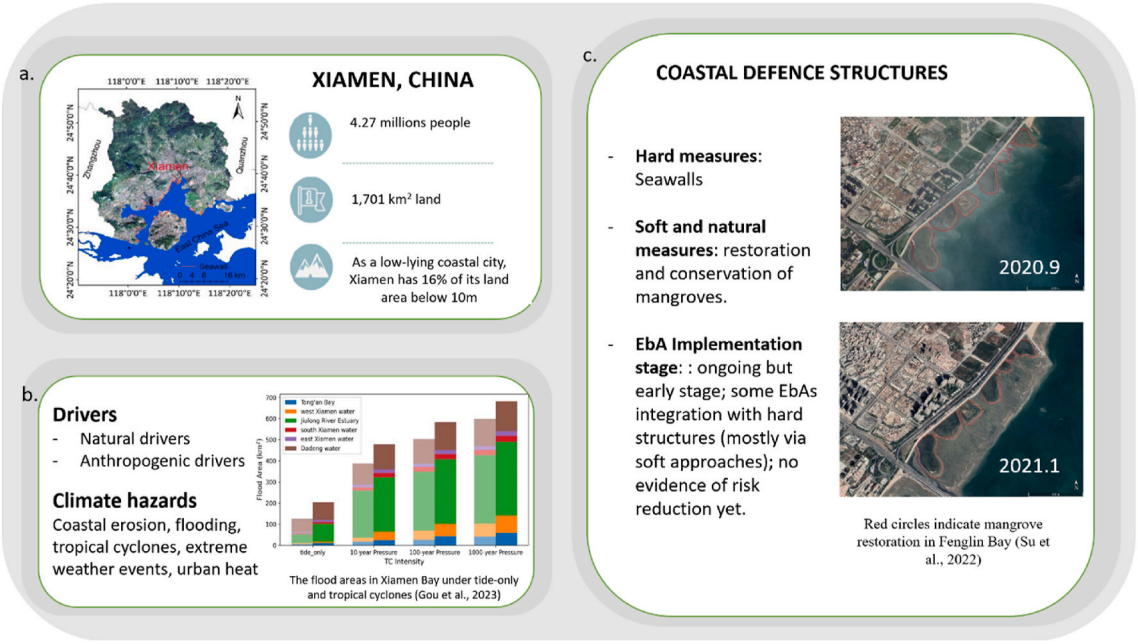

Fig. 3. Geographic location, climatic risks and coastal defence measures in Xiamen City. Panel (a) general statistics and map. Panel (b) drivers and climate hazards (inset figure adopted from Guo et al., 2023). Panel (c) current coastal defence measures (inset pictures adopted from Su and Peng, 2021).

inequitable access to forests and natural resources.

Several leverage points can be identified that significantly determine the outcomes in the BCS nexus in Xiamen. First, capacity building plays an indispensable role. Since the Xiamen was selected as the demonstration city of ICM, trainings have been provided for local officials and decision makers to learn how to cope with rapid socio-economic and environmental changes in Xiamen, as well as how to manage emerging conflict of interests in the coastal zone (Qiu et al., 2021). Second, the mechanism for integration of science into decision-making, which was established as one of the efforts of Xiamen's ICM, found the basis to inform the trajectories toward long-term sustainability. This science-management integration improved landscape use planning through Marine Functional Zoning to solve use-use and use-environment conflict (Fang et al., 2021), as well as increased success rate of mangrove restoration. Third, understanding the multifunctionality of ecosystem is another key driver for the successful project of Xiatanwei Wetland Park. Mangroves were not only restored for defending typhoon but were planted in a unique shape that provide aesthetic value, tourism and recreation, sense of place, cultural education. The booming of the tourism in the park also facilitates the uprising local tourism industry which increase the income of residents. However, despite the co-benefits, trade-off exists which can be attributed to the lack of community participation in the design, implementation and monitoring of mangrove restoration projects. Especially the future restoration would rely mainly on returning aquaculture ponds to forest and wetland (Paulson Institute, 2019), which will hamper the livelihood of aquaculture farmers. Community involvement can be the answer of this tricky issue of how to ensure livelihoods while protecting and restoring mangroves (Lingyu, 2022). Overall, when looking at the current BCS system in Xiamen, there are potential but currently limited opportunities for positive social tipping points. Given the priority and progress of integrating EbAs into coastal defence in Xiamen, it is unlikely to foster deeper transformational urban changes.

3.3. Danang: ecosystem conservation in an intensive tourism area

Danang city faces severe climate risks including sea level rise, intensified typhoons, coastal floods, erosion, and saline intrusion (Huynh and Stringer, 2018). The city's coastal protection primarily relies on hard structures, such as dykes, groins, and embankments, along with a city-wide water drainage system. Breakwaters and ports are constructed and also serve as storm surge protection. However, flooding occurred quite often after heavy rains and typhoons, resulting in severe damage to assets and people in the city.

The city has great natural resources, which have been significantly degraded during the past decades due to heavy economic activities and rapid urbanisation. Coral reefs and seagrasses are present along the North and South of Son Tra Peninsula and on the northern coasts of Danang Bay (ICM, 2010). Son Tra Peninsula is also home to diverse wetlands and forests, which are important for biodiversity and disaster risk reduction (People's Committee of Danang City, 2001). In response to ecosystem degradation and climate change, the city has taken natural and soft approach to protect and restore coral reefs and seagrasses at the north of the city (see Fig. 4). Since 2008, Da Nang government declared 2591 ha of Son Tra Peninsula as a strictly protected zones and 1884 ha as ecological rehabilitation zones (GreenViet, 2023). From 2010, the city has strictly protected near-shore ecosystems and carried out the restoration of coral reefs and seagrasses as part of the integrated coastal zone management initiatives.

The integration of EbA into coastal defence strategies within the city is still in its early stages, exposing various co-benefits, trade-offs, and co-detriments within the BCS nexus. Initially, conservation and protection of marine ecosystems have been prioritised in Son Tra peninsula with the aims to simultaneously promote all components of the BCS nexus (see Table 4). The original policy objectives aimed to establish integrative marine protected areas, fostering healthy ecosystems, and providing multiple ecosystem services for the local community, all while addressing climate change challenges (Nguyen, 2011). The city underscores the co-benefits of preserved marine areas for fisheries and eco-tourism. However, despite the multi-faceted goals of the EbA initiative, its current implementation reveals a predominantly inconsistent approach. Specifically, 1056 ha of the protected forests in Son Tra Peninsula are also used for eco-tourism (VNA, 2022). Hotels and resorts have been built in the protected areas and 68 projects have been found without legal permissions for construction (Vo, 2022). The construction activities in these protected zones has resulted in ecological damage, coastal erosion, and a decline in water quality (Hue and Thanh, 2020). While the government has effectively imposed a ban on further

Table 3
Biodiversity – climate – society nexus interaction outcomes from EbAs implementation for coastal defence in Xiamen city.

EbA measures	BCS nexus component	Description
Soft and natural measures - Special Action Plan for Mangrove Protection and Restoration: restoring 18,000 ha of mangroves from 2020 to 2025. - Xiatanwei Mangrove Park for disaster mitigation, ecological restoration and recreation	**Co-benefits**	**Biodiversity (+):** EbA projects conserve and restore mangroves and mudflats, providing habitat for biodiversity and sustaining fisheries. **Climate (+)**: EbA projects increase carbon storage capacity through vegetation, and reduce climate risks through wave attenuation, shoreline erosion prevention, flooding mitigation, and protection from storm and typhoon damages. **Society (+)**: EbA projects improve human well-being (e.g. through aesthetic value, recreational and educational opportunities)
	Trade-offs	**Society (−)**: EbA projects provide economic opportunities to some actors (e.g. through tourism, fisheries, forest products) but compromise them for others (e.g. through aquaculture ponds removal for mangrove restoration). **Society (−)**: EbA projects create conflicts related to the access and use of coastal resources between different stakeholders **Society (−)**: EbA projects can create long-term social inequity through inequitable access to forests and tourism income.
	Leverage points	- Capacity building - Science-management integration - Multi-functionality - Public acceptance
	Tipping points	- Potential but currently limited opportunities for positive social tipping points due to competing interests between different stakeholders
	Feedback loops	**Positive:** ↑biodiversity → ↑ society → ↑ human-nature relationship → ↑ effectiveness of restoration → ↑ climate risk reduction and biodiversity **Negative:** ↑ social conflicts and inequity → ↓ local participation in EbAs → ↓ effectiveness of EbAs → ↓ climate risk reduction and biodiversity

Note: Definitions of BCS nexus elements are included in Section 3.1.

construction on the peninsula, effective restoration of ecosystems remains a challenge, especially in balancing environmental preservation with the economic benefits derived from these protected areas (Le, 2022). Up to 42 % of the coral reef area has disappeared in the past 10 years even though conservation and restoration efforts have been in place (GreenViet, 2023). Furthermore, the restoration initiatives exhibit limited involvement from local residents. Conflicts arise due to altered resource provisioning, issues related to resource access, and inappropriate land tenure and investment policies.

Additionally, trade-offs and co-detriments may exhibit synergistic effects, potentially creating feedback loops. In other words, negative impacts on biodiversity, climate, and social subsystems can reinforce each other, leading to a cycle of challenges. In areas where co-detriments have emerged within restoration projects, ecosystems may experience degradation, which can weaken the connection between people and nature and reduce environmental stewardship. This could result in less effective natural resource management, further contributing to biodiversity loss. Policies intended to achieve win-win outcomes for biodiversity and climate relations may inadvertently trigger negative bio-physical tipping points, potentially leading to shifts toward less productive EbAs for coastal defence in the city.

The prioritisation of short-term economic opportunities and the general lack of forward-thinking planning can be perceived as leverage points for the trade-offs and co-detriments of EbAs in the city. Although the government and citizens have shown appreciation in nature, as indicated by a recent municipal decision (Ủy Ban Nhân Dân Thành Phố Đà Nẵ;ng, 2019), economic pressures, particularly from the tourism sector, may have led to decisions that favour immediate economic benefits over long-term ecological gains (Le and Tran, 2013). Consequently, this situation has likely led to compromises that undermine the effectiveness of ecosystem restoration efforts as part of EbAs. Furthermore, this absence of long-term planning in decision-making processes may hinder the full realisation of the long-term benefits that EbAs can offer, as these benefits are not immediate. As a result, the city faces difficulties in fully leveraging the potential of EbAs. Importantly, it is not clear whether this short-term focus will remain, and whether (and how) it will impede the effective implementation of EbAs in the future.

4. Discussion

4.1. Differentiated trajectories of EbAs integration into coastal defence

Many coastal cities in the APR are characterised by rapid urbanisation and economic development, but at the same time heightened vulnerability to climate risks. A comparative understanding of their adaptation trajectories can offer interesting insights about coastal protection in the face of accelerated climate change (Herbeck and Siriwardane-de Zoysa, 2022b). Here we used the Biodiversity-Climate-Society (BCS) nexus lens to delve deeper into how EbAs have been integrated in three coastal cities in the APR, each characterised by different geographical features, climate risks, economic capabilities, policy priorities, and social contexts (Table 1).

A starting point of this research is the recognition that hard measures for coastal defence that rely on conventional grey infrastructure alone would likely be neither sustainable nor adaptable (Morris et al., 2020). This implies that the incorporation of EbA measures seems to be becoming inevitable for climate change adaptation and sustainable urban development (Ives et al., 2018). However, is this process of EbA integration homogeneous, or are there marked differences between urban contexts?

Our results highlight that there are indeed very different trajectories in the study cities in terms of priorities, processes, progress and ultimately preferred EbA measures for coastal defence (Table 5). Although all three cities have integrated EbA measures, this has been at varying degrees and always as a secondary option to hard measures.

Notably, in terms of EbA types, cities with lower economic capabilities such as Da Nang and Xiamen have gravitated towards soft and natural measures. Xiamen is currently in the process of establishing and expanding soft EbAs (through ecosystem restoration) alongside traditional hard measures (Table 3). Conversely, Danang has prioritised up to this point hard measures such as dikes and embankments complemented by natural measures linked with past and ongoing ecosystem restoration and conservation efforts (Table 4). What is important to note here is that in both cities, the EbAs are associated more with biodiversity conservation and restoration efforts, rather than long-term climate adaptation planning for coastal protection. In this sense, the integration of EbAs in these two cities seems to be closer to an offshoot of efforts to conserve ecosystems or reverse ecosystem degradation along the coastlines. In contrast, Singapore has capitalised on its high economic capabilities and

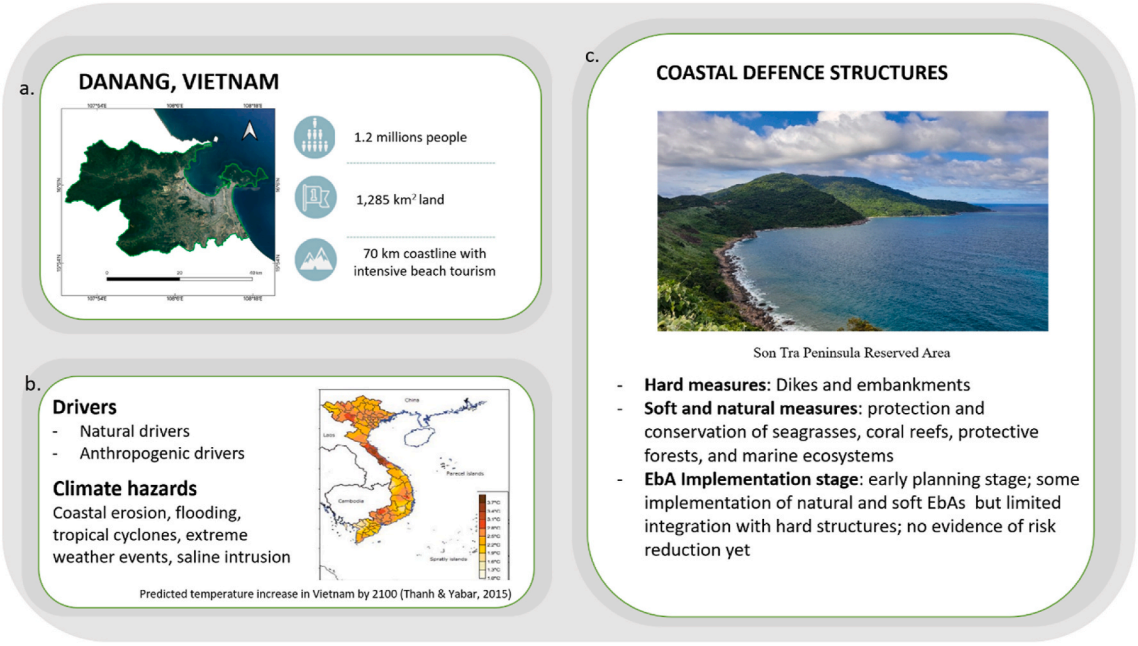

Fig. 4. Geographic location, climate risks and coastal defence measures in Da Nang city, Vietnam. Panel (a) general statistics and map. Panel (b) drivers and climate hazards (inset figure adopted from Thanh and Yabar, 2015). Panel (c) current coastal defence measures.

used advanced technology to harness ecosystem benefits to create novel hybrid measures for coastal defence (Table 2). These hybrid measures arguably originate from more conscious and long-term adaptation planning that sees EbAs as important options for coastal defence.

Such disparities among in cities with different economic capacities resonate with previous literature on EbAs (Morris et al., 2018; Tiwari et al., 2022). For example, while there is an expanding literature from hybrid EbA projects in affluent cities in the United States and Europe (Moraes et al., 2022; Sutton-Grier et al., 2015), such examples are much rarer from other parts of the worlds (and especially developing countries). This higher adoption of EbAs in developed cities has also been identified in the broader green infrastructure literature (Andersson et al., 2015; Haaland and van den Bosch, 2015). Conversely, reviews of NbS projects in East Asia and South East Asia shows a big proportion of projects designed for short-term environmental solutions to rapid urban development and landscape change (Lechner et al., 2020; Wolff et al., 2023).

More critically, the observed differentiation in the adoption and implementation of EbAs in the study cities also reflects different 'mindset' in urban planning, especially in relation to climate change. Arguably, the more advanced state of EbA implementation in Singapore reflects the proactive planning mindset in the city, where coastal defences are seen as a part of the broader urban infrastructure, with human wellbeing, environmental sustainability, and climate risk mitigation being broader policy objectives. However, in Xiamen and Da Nang, these recognitions are much less mature, with the planning for coastal defence and adaptation heavily relying on assessments of past and current hazard events and conditions. In contrast to Singapore, there is arguably a notable absence of a comprehensive consideration of anticipated future climate risks in their coastal adaptation planning, let alone the strategic integration of EbAs that considers the future exposure of ecosystems, populations at risk, infrastructure, and capacity. This lack of forward planning in Danang and Xiamen resonates with other parts of the world. Various prior literature emphasises the limited consideration of future risks and exposure trends in national adaptation plans around the globe (Berrang-Ford et al., 2021; Wannewitz et al., 2024). Nevertheless, we heighten the significance of this observation, considering the substantial impacts and the complex dynamic between climate change and urban sphere.

While Singapore provides a compelling example of successful EbA implementation, its case is nevertheless shaped by unique conditions, including a centralised government, extensive control over coastal areas, and a high capacity for resource mobilisation (Han, 2018; Ooi, 1994). These factors allow Singapore to pursue ambitious, large-scale EbA strategies that would be challenging to replicate in regions with different governance regimes and resource availability. However, we must keep in mind that while the centralised governance enables the efficient coordination of projects, there are strong societal preferences for orderly, well-maintained green spaces that align with the government's urban greening vision. This human-centred design approach aligns with Singapore's broader cultural and political context, where aesthetic appeal and public approval significantly influence policy decisions. However, these conditions have also raised some concerns about the overall effectiveness for biodiversity conservation (Chiu-Shee, 2022; Sini, 2020). While these conditions and approaches offer significant short-term co-benefits, they also present opportunities for continuous learning and adaptation, ensuring that long-term biodiversity goals and ecosystem resilience to future climate challenges are met (Table 2). Understanding these distinctive political and societal factors is crucial for assessing the feasibility of replicating Singapore's approach to EbA elsewhere.

4.2. Towards transformative urban governance shifts for implementing EbAs

The rapid onset of climate change coupled with the high (but often unforeseen) climate risks requires urgent and transformative shifts in urban governance for climate change adaptation (Berrang-Ford et al., 2021; Elmqvist et al., 2019). This is particularly pertinent for the design and implementation of EbAs (or NbS more broadly), as they are relatively new concepts in some urban contexts. Many cities have pre-existing policies and governance frameworks that might not be automatically amendable to this concept (Hölscher et al., 2023).

To facilitate transformative urban governance for climate change adaptation, there is a need for paradigm shifts. These shifts should entail moving away from conventional and fragmented approaches to urban governance, towards more holistic and systemic strategies that account for the complex interdependencies between biodiversity, climate, and

Table 4
Biodiversity – climate – society nexus interaction outcomes from EbAs implementation for coastal defence in Danang city (Vietnam).

EbAs measures	BCS nexus component	Description
Soft and natural measures - Conservation and restoration of coral reefs and seagrasses in the Sơn Trà Nature Reserve aim to reduce coastal risks and promote eco-tourism – 2591 ha of the Sơn Trà Peninsula designated as strictly protected zones since 2008, including 1056 ha for eco-tourism. – 1884 ha of the Sơn Trà Peninsula allocated for ecological rehabilitation,	**Co-benefits**	**Biodiversity (+):** EbA projects conserve and restore coral reefs, seagrasses and protective forests, providing habitat for biodiversity and sustaining fisheries. **Climate (+):** EbAs projects in areas with good restoration increase carbon storage capacity in vegetation, and reduce climate risks through wave attenuation, shoreline erosion prevention, and protection from storms and typhoons
	Trade-offs	**Society (−):** EbA projects improve human well-being for some actors (e.g. through aesthetic value, recreational and educational opportunities) and reduce it for others (e.g. through preventing use of forest products in protected areas). **Society (−)** EbA projects can create conflicts related to the access and use of coastal resources between local communities and international hotel investors (e.g. by blocking access to local communities and only allowing it to tourists)
	Co-detriments	**Biodiversity (−):** EbA projects in areas with inadequate tourism development result in ecosystem degradation. **Climate (−):** EbA projects in areas with inadequate tourism development result in coastal erosion due to heavy construction for tourism facilities. **Society (−):** EbA projects can create long-term social inequity through inequitable access to forests and tourism income.
	Leverage points	- Capacity building - Equity - Forward thinking planning - Political interests and prioritisation - Public participation
	Tipping point	- Moderate potential for negative biophysical tipping points in some areas due to sudden degradation of ecosystem. - Few opportunities for positive social tipping points due to competing interests among stakeholders.
	Feedback loops	**Positive**: ↑biodiversity → ↑ society → ↑ human-nature relationship → ↑ effectiveness of restoration → ↑ climate risk reduction and biodiversity **Negative**: ↑ social conflicts and inequity → ↓ local participation in EbAs → ↓ effectiveness of EbAs → ↓ climate risk reduction and biodiversity

Note: Definitions of BCS nexus elements are included in Section 3.1.

society (Pascual et al., 2022). Understanding the prerequisites for this governance transformation is key, thus in our analysis, we identified leverage points that can facilitate the emergence of positive tipping points while preventing negative ones (Pörtner et al., 2021). However, we must also acknowledge that we strongly believe there are no individual silver-bullet approaches fit for all urban contexts. Recognising and strategically utilising context specific realities and opportunities would be critical for fostering the conditions necessary for transformative urban governance shifts for climate change adaptation.

By activating positive tipping points, EbAs can fully realise their adaptation potential through maximising co-benefits and minimising trade-offs within the BCS nexus. This is evident in the case of Singapore, where community engagement, environmental stewardship, and EbA-related norms have helped increase public awareness and support for coastal greening initiatives. Once a social tipping point gains momentum, transformative changes can proliferate rapidly (Pascual et al., 2022) as observed in various other contexts (e.g. the rapid and wide uptake of electric vehicles in Norway) (Lenton et al., 2019). This demonstrates how leveraging social tipping points can drive large-scale shifts in climate actions.

However, it is crucial to avoid the assumption that EbA strategies always activate positive tipping points or that it is possible to achieve positive tipping points in the same way across different contexts (Pascual et al., 2022). In fact, negative tipping points can sometimes emerge, as observed in Da Nang where the inadequate eco-tourism development as part of EbAs could possibly lead to negative ecological tipping points. This underscores the importance of careful planning and effective implementation through continuous monitoring and evaluation to ensure that EbA interventions deliver the desired outcomes and not inadvertently cause harm to ecosystems.

The critical question that arises in this context is what policy and governance interventions could activate positive tipping points for this transformation, while precluding or diminishing negative tipping points. Based on our comparative analysis, we argue that activating positive tipping points requires the comprehensive understanding of the system dynamics and a strategic design of leverage points, where small changes can create favourable conditions for deep, transformative changes. Again, the three case studies have shown that such leverage points can be very context-specific, both in their type, activation mechanism, and outcomes. Some of the identified leverage points include capacity building, inclusivity, value-framed and place-based communication, multi-functionality, science-management integration, equity, forward-thinking planning, and public acceptance and participation (Tables 2–5). Some of the useful policy and practice interventions observed in these case studies were: (a) creating multi-stakeholder platforms for deliberation and co-creation of knowledge, (b) developing and implementing participatory governance structures, (c) ensuring access to adequate funding, (d) fostering forward and long-term planning rather than immediate benefits, and (e) promoting education and capacity-building programs that raise awareness and build support for EbAs. Additionally, incentivising cross-disciplinary collaborations between scientists, policymakers, and practitioners can further enhance the integration of science into management and policy frameworks, ensuring that solutions are evidence-based and contextually relevant. Moreover, policies should seek to prioritise inclusivity by considering the needs of marginalised groups and incorporating equity-focused objectives into planning and implementation.

All of the above essentially underscore the importance of a holistic and comprehensive governance approach for transformative climate adaptation. This approach should be reflexive and adaptive, continuously learning from past experiences, integrating new knowledge, and understand the evolving dynamics to address emerging challenges and opportunities (Hölscher and Frantzeskaki, 2020).

Table 5
Synthesis of main finding.

Study city	Singapore	Xiamen, China	Danang city, Vietnam
Targeted hazards	Sea-level rise, urban heat island, floods	Sea level rise, storms, floods	Sea level rise, floods, typhoons
Social vulnerability	Low	Medium	High to medium
Coastal defence measures	Hybrid EbAs with advanced techniques	Hard structures with soft and natural EbAs	Mainly hard structures with few natural and soft EbAs
EbA ecosystem type	Newly created blue and green systems, restored mangroves	Restored mangroves	Protected marine areas, restored coral reefs, seagrasses, and protective forests
EbA implementation stage	Mature EbA implementation with evidence of risk reduction. EbAs have been integrated with the same priority as hard measures.	Ongoing EbA implementation for coastal defence.	Early EbA planning for coastal defence.
Nexus outcomes	- Well-designed hybrid coastal defence projects deliver co-benefits for ecological restoration, carbon storage, risk reduction, and human wellbeing - Few trade-offs occur between stakeholders regarding the use of forest products in protected areas.	- Well-designed mangrove restoration projects provide co-benefits for coastal defence, tourism/recreation and ecological restoration. - Trade-offs occur between restoration and local livelihoods.	- Protected zones provide co-benefits to ecological restoration, and disaster risk reduction. - Trade-offs occur between stakeholders regarding the use of forest products in protected areas. - Co-detriments in areas with inadequate eco-tourism planning could lead to ecological degradation, coastal erosion and resource use conflicts.
Leverage points	Capacity building, inclusivity, value-framed and place-based communication, multi-functionality.	Capacity building, science-management integration, multi-functionality, public acceptance and participation.	Equity, forward-thinking planning, and public acceptance and participation
Tipping points	High potential for positive social tipping points (increase environmental stewardship, public support and engagement, social norms regarding EbA implementation).	Moderate (but currently limited) potential for positive social tipping points.	Moderate potential for negative biophysical tipping points (degradation of coral reefs and marine ecosystem). Few opportunities for positive social tipping points
Overall status of EbA implementation	Potential for transformative progress	Incremental progress	Incremental progress

5. Conclusion

Climate change poses significant threats to coastal cities across the world through sea-level rise, increased climate variability, and more frequent and severe droughts, floods, and storms. Traditional approaches to coastal defences have relied on conventional hard measures. However, it has been argued that in many contexts such measures are unsustainable and unable to keep pace with climate change, but ecosystem-based adaptation (EbA) can be a more sustainable and cost-effective approach to coastal defence. In this study, we used a Biodiversity–Climate-Society nexus approach to comparatively discuss the progress and lessons learned from the current implementation of EbAs in three coastal cities, Singapore, Xiamen, and Danang. As these cities have different vulnerabilities to climate change, varying experiences with EbA, and different demographic and socioeconomic conditions, their comparative analysis can offer insights on the current progress of EbAs in the region.

We find that the implementation of EbAs, whether on a small or large scale, does not follow a one-size-fits-all approach that can be universally applied with guaranteed success. It is essential to acknowledge the unique ecological, social, and economic contexts of different coastal regions. The inherent complexity of coastal environments necessitates a bespoke and nuanced approach to EbAs. This approach recognises that strategies effective in one location may not translate seamlessly to another, as evidenced by the very diverse and unique co-benefits, trade-offs and co-detrimental effects observed in EbA projects in Singapore, Danang, and Xiamen. Therefore, the path to transformative coastal adaptation lies in embracing the complexity and diversity of the system, and in tailoring EbA strategies accordingly.

Policy and governance interventions should seek to activate positive tipping points, while precluding or diminishing negative tipping points. In order to activate effectively such positive tipping points, we must have a deep understanding of the prevailing urban dynamics and a strategic design of leverage points, where small changes can create favourable conditions for deep, transformative changes. Our comparative analysis has shown that such leverage points can be very context-specific, both in their type, activation mechanism, and outcomes.

CRediT authorship contribution statement

Lam Thi Mai Huynh: Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Jie Su:** Writing – review & editing, Writing – original draft, Visualization, Validation. **Alexandros Gasparatos:** Writing – review & editing, Supervision, Methodology, Conceptualization.

Declaration of competing interest

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

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Data availability

No data was used for the research described in the article.

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