Natural Portrait: Ecological Processes and Patterns of Metropolitan Areas in the Guangdong-Hong Kong-Macao Greater Bay Area

WANG An, MA Xiangming, LI Kehong, LÜ Shuheng

Abstract: The natural environment influences human society through the medium of "productive forces." In the Anthropocene — an era marked by a dramatic surge in human productivity alongside immense environmental challenges — territorial spatial planning must not only embody the mechanisms of ecological processes, but also respond to the spatial transformations brought about by new production relations involving natural elements. To address the limited attention to natural dynamic evolution and urban-rural interactive processes in current territorial spatial evaluation methods such as the "Double Evaluation," this study proposes a "Natural Portrait" approach as a complementary perspective for territorial spatial cognition. From a "process-driven" perspective, the method deconstructs the historical formation of natural landform patterns, identifies key geographical units, and predicts future evolutionary trends. From a "pattern-response" perspective, it examines the adaptation and transformation of natural landforms under human processes such as urban construction and agricultural production, contributing to an understanding of integrated natural-urban-rural territorial spatial patterns. Through empirical studies of the Guangzhou, Shenzhen, and Western Pearl River Delta metropolitan areas in the Guangdong-Hong Kong-Macao Greater Bay Area (GBA), the research identifies three distinct ecological processes — alluvial deposition, marine deposition, and island-intercepted flotation deposition — each of which has shaped markedly different landform types: concentric plains, headland coastal zones, and circular sand flats. In response to these ecological processes, the three metropolitan areas have developed different territorial spatial patterns — concentric, clustered, and cellular — which continue to evolve toward estuary extension, finger-like expansion, and integrated mosaic development. This method has effectively complemented the existing territorial spatial planning technology chain by enhancing "process cognition" and "unit deconstruction," thereby supporting the development of spatial structures with improved spatiotemporal continuity and more coherent human-land interaction units.

Keywords: natural portrait; ecological processes; Guangdong-Hong Kong-Macao Greater Bay Area; metropolitan area

1 Introduction

The relationship between humanity and the land has long been characterized by the co-emergence and dynamic interplay of the natural environment and human society [1]. From Montesquieu's assertion that "climate influence is the most powerful of all influences" to Plekhanov's proposition that "the geographical environment directly influences the development of productive forces," the understanding of how geography shapes human civilization has gradually evolved from "abstract determinism" — providing the material basis for human emergence, survival, development, and decline — to "specific influence theory," which holds that within specific spatiotemporal contexts, the geographical environment generally serves only to accelerate or decelerate development [2]. It has been recognized that the natural environment does not act directly but rather indirectly influences production relations and culture through the medium of "productive forces" [3]. Projected onto territorial space, this manifests as the evolving relationship between nature and cities as mediated by changes in productive forces. In the agricultural era, cities were embedded within nature, and the natural environment was understood through the experiential framework of Fengshui geomancy — the four disciplines of "dragon (mountain), water, sand (peripheral hills), and lair (city or tomb)" — connected by the concept of "qi" [4]. In the industrial era, cities pursued the standardization of nature, which became an ordered landscape extended through road networks and drainage systems. Now, in the Anthropocene, human influence has arguably surpassed natural forces, yet society simultaneously faces enormous environmental challenges. Cities are turning toward breaking down zoning boundaries to restore natural continuity, viewing nature as the provider of provisioning, regulating, cultural, and supporting ecosystem services. Throughout this process, territorial spatial planning must not only deeply understand the operating mechanisms of ecological processes but also fully account for the spatial transformation demands arising from new production relations, including those involving natural elements [5-6].

Territorial space is a complex mosaic coupling natural ecosystems with urban-rural construction systems. Ecological processes continuously drive territorial spatial evolution, while urban-rural construction activities simultaneously adapt to and transform the territorial landscape. At present, the primary approach to territorial spatial cognition — the "Double Evaluation" (assessment of resource and environmental carrying capacity, and assessment of territorial spatial development suitability) — generates quantitative evaluations through comprehensive assessment of resource endowments and environmental conditions, following the logic of "carrying capacity determines scale, suitability determines spatial arrangement." This approach has played an important role in guiding the rational layout of various territorial spatial elements [7]. However, when confronted with territorial space as a dynamic mosaic, two shortcomings remain: first, the separation of spatiotemporal evolutionary drivers from present-day patterns. Existing analyses of urban-rural spatial patterns tend to focus on static, single-temporal spatial characteristics, with limited consideration of dynamic mechanisms. Research extending to the intrinsic, dynamic surface processes remains scarce, hindering the revelation of the holistic logic behind the formation of landscape-urban-rural patterns. Second, the separation of natural ecosystem processes from urban-rural construction processes. Human activities have permeated all natural ecological resources and profoundly influenced natural processes; studying them in isolation neglects the trade-offs and synergies between natural and anthropogenic processes [8].

"Profile" is a method of understanding complex phenomena, emphasizing not the proportional scaling down of reality but rather purposeful simplification — organizing parts in relation to one another through selective reduction, exclusion, or even addition of elements [9]. In the 1960s, Kevin Lynch, from the perspective of social psychology, proposed the concept of "city image," measuring urban visual quality through citizens' mental images. Subsequently, scholars [10-11] extended this profiling approach to social domains such as urban economics and culture, exploring analytical paths including industrial portraits and user profiles. However, research specifically addressing territorial space remains limited. Therefore, this study proposes the "Natural Portrait" approach as a pathway for territorial spatial cognition, deconstructing the mechanisms of natural ecosystem evolution and urban-rural construction responses from a process-driven perspective, identifying natural geographical units that bear critical ecological functions and translating them into elements of the urban pattern. This produces a "natural portrait" linked by ecological processes, carried by geographical units, and reflecting both ecological evolutionary patterns and urban land-use configurations. Compared with the "Double Evaluation," which identifies important ecological spaces at the "grid" level through multi-layer overlay of current conditions, the "Natural Portrait" methodologically supplements the pathway of identifying critical ecological spaces based on driving forces from inside out, and spatially outputs a pattern with "geographical units" as carriers representing both ecological functions and urban land-use modes. This provides an effective complement to existing territorial spatial cognition approaches and can robustly support multi-disciplinary collaboration in territorial spatial planning.

2 Study Area and Technical Approach

2.1Study Area

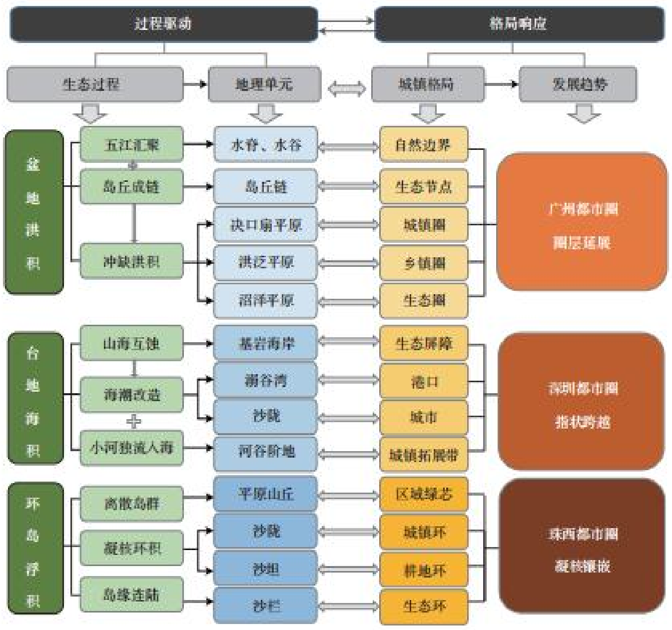
The "metropolitan area" is a spatial assemblage of urban groups composed of a core city and its surrounding areas with close socioeconomic linkages [12-13], representing a complete unit for the coupling of natural ecosystems and urban-rural construction systems at the regional scale [14]. The perspective of metropolitan-area-based regional coordinated development imposes new requirements on existing spatial organizational frameworks, necessitating corresponding changes in the spatial patterns, ecological functions, and urban coupling relationships of the natural environment [15]. The Guangdong-Hong Kong-Macao Greater Bay Area is both a geomorphologically diverse region featuring major mountains, rivers, and seas [16] and a complex human-land region with high levels of urbanization [17]. According to the Coordinated Guidelines for Territorial Spatial Planning of Metropolitan Areas in Guangdong Province, the Guangzhou Metropolitan Area, the Shenzhen Metropolitan Area, and the Western Pearl River Delta Metropolitan Area are all located within the Greater Bay Area [18] (Fig. 1). These three areas share the same regional development background yet each exhibits distinctive natural endowments and urban patterns [19-20], making them an ideal setting for natural portrait research.

Fig.1 Location of the three metropolitan areas in the Guangdong-Hong Kong-Macao Greater Bay Area

2.2Technical Approach

Ecological processes such as geological and hydrological dynamics continuously influence geomorphic evolution, while urban-rural construction, in adapting to geomorphic change, also subjectively transforms natural patterns. To better deconstruct this ongoing interaction, this study draws on the "process-driven — pattern-response" technical framework from landscape ecology research on process coupling and spatial integration [21], constructing a territorial spatial cognition pathway based on the "Natural Portrait." In the 'process-driven' dimension, the method examines the mechanisms by which specific ecological processes, such as river confluence and sediment deposition, drive the evolution of natural landforms, identifying geographical units that carry critical ecological functions, including water ridges, water troughs, and chains of island hills. In the "pattern-response" dimension, it further examines the role these geographical units play in shaping urban patterns, mapping them onto elements of the urban-rural construction system such as natural boundaries, ecological nodes, and urban circles, and then integrates the direction of natural evolution with urban development needs to assess overall trends in the evolution of the urban-rural pattern. See Fig. 2.

Fig.2 The analytical framework of the research



3 Three Depositional Landforms Driven by Ecological Processes in the Greater Bay Area

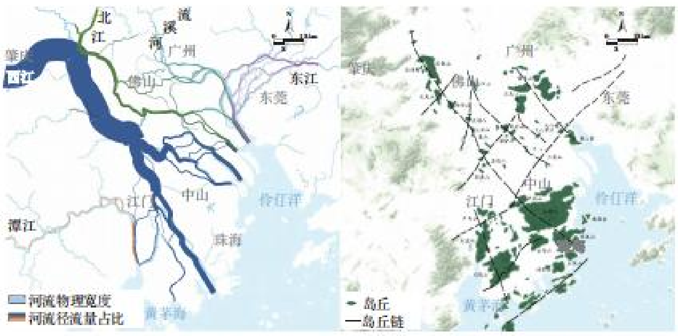
In the sediment deposition process of the Guangdong-Hong Kong-Macao Greater Bay Area, three distinct natural forces — river, sea, and mountain — drive differentiated depositional processes, forming distinct geographical units and shaping three fundamentally different ecological endowments across the Bay Area.

3.1 Basin Alluvial Deposition: Concentric Plains Formed by Major River Breach Through Island Hill Chains

The primary ecological process in the Guangzhou-Foshan area is the alluvial deposition of major rivers including the West River and North River. Where rivers converge and pass through multiple chains of island hills, sediment interception and deposition create a concentric landform composed of water ridges, water troughs, island hill chains, crevasse splay plains, floodplains, and marsh plains — characterized by abundant water and sediment and a broad hinterland.

Five-river confluence. The Pearl River Delta is the only composite delta among China's major river basins. Unlike the Yangtze River, which flows into the sea as a single channel, it is formed by the confluence of five major rivers — the West River, North River, East River, Tan River, and Liuxi River — in a plain region, creating a complex river network of over 300 distributary channels that discharge into the sea through eight estuary gates. Within its complex dynamic mechanisms and geomorphic forms, "water ridges" and "water troughs" play a critical role [22]. The physical width of a river channel is not proportional to its runoff volume (Fig. 3). The West River, North River, and East River have the largest runoff volumes — 222 billion m³, 41 billion m³, and 22 billion m³ respectively — accounting for over 94% of the Bay Area's total runoff, yet their channels are not the widest, with average widths of approximately 500 m. In contrast, the Liuxi River and Tan River, which account for only about 1.7% of total runoff, have estuary widths exceeding 2 km. Therefore, the high-volume West River, North River, and East River are "squeezed" into relatively narrow channels, forming "water ridges" with relatively high water levels, while the lower-volume Liuxi River and Tan River flow through wider channels, forming "water troughs" with relatively low water surface levels. Since water flows downhill, the tributaries within the Pearl River network continuously branch and converge as they flow from "water ridges" to "water troughs," developing the seemingly intricate yet orderly functioning plain water network of the Pearl River Delta.

Fig.3 River network runoff and the chains of island hills in the Bay Area



(a) 湾区河网径流量 (b) 岛丘链布局

Island hills forming chains. The Guangdong “multi”-shaped fault zone extends into the Pearl River Delta plain, giving rise to over 160 island hill protrusions, which appear as hills, terraces, and residual hills with elevations generally ranging from 100 to 300 meters. These were once islands but have become isolated hills embedded in the plain as sediment accumulated [23]. Constrained by geological folding, these island hills are distributed in a checkerboard pattern, forming 7 lateral and 8 longitudinal "island hill chains" (Fig. 3). Although individual island hills are small, the aligned chains exert a significant influence on the plain's geomorphology. Longitudinally, they constrain the main channels of the East River, West River, and North River, reducing channel migration. Laterally, they intercept river sediment, forcing the water system to bifurcate and form river networks.

Breach-and-deposit formation. As the West River and North River — functioning as "water ridges" — converge toward the main Pearl River channel at the Liuxi River–Lingdingyang estuary, they encounter island hill chains. The river either erodes through gaps or bifurcates to pass, causing flow velocity to decrease, sediment-carrying capacity to weaken, and deposition to occur. From the first island hill chain at Kundu Mountain, the Guangzhou Metropolitan Area has four east-west island hill chains running from north to south: "Baiyun Mountain–Xiqiao Mountain," "Daifu Mountain–Yuanshan Mountain," and "Wugui Mountain–Huangshanlu Mountain." Each island hill chain acts as a threshold, intercepting sediment and depositing its own sub-delta unit, ultimately forming a composite delta composed of multiple sub-deltas. During the deposition of each sub-delta, materials are layered by weight and particle size, forming concentric plains. The heaviest gravel deposits first, forming the crevasse splay plain at the highest elevation; lighter silt travels farther, forming the middle-zone floodplain; and the outermost zone is the marsh plain, at the lowest elevation with the weakest hydrodynamic energy. Thus, the Guangzhou Metropolitan Area, as water flows from ridges to troughs, encounters four layers of island hill chains and deposits four layers of progressively lower-elevation landforms — "island hill chain — crevasse splay plain — floodplain — marsh plain" (Fig. 4).

3.2 Marine Terrace Deposition: Headland-Bay Coastal Zone Formed by Tidal Erosion of Hills

Unlike the Guangzhou Metropolitan Area dominated by major rivers, the Shenzhen Metropolitan Area is shaped by the direct interaction of mountains and sea. Through coastal deposition and small-river erosion-transport processes, a headland-bay coastline has formed, composed of bedrock coast, drowned valley bays (rias), sand ridges, and river valley terraces. Although the proportion of flat land is small, it possesses excellent harbor conditions.

Mutual erosion of mountains and sea. The Lianhua Mountain range, originating in eastern Guangdong, splits into northern and southern branches at Tieluzhang. The northern branch — "Eweishan Mountain–Baoshan Mountain–Yinping Mountain" — forms the main boundary between Dongguan and Shenzhen and serves as Shenzhen's ecological barrier. The southern branch — "Tanglang Mountain–Wutong Mountain–Tiantou Mountain" — directly meets the sea, forming a jagged bedrock coastline with alternating bays and headlands. Under tidal boring, the harder granite is selected into protruding headlands, while softer portions are scoured and reworked into recessed bays, forming nested drowned valley bays. Meanwhile, the north-south mountain ranges of Damao Mountain and Qiniang Mountain divide Shenzhen's coastline into three major bays — Shenzhen Bay, Dapeng Bay, and Daya Bay — which, with their steep slopes, deep water, calm waves, and minimal sand, provide ideal sites for port development.

Coastal deposition. As sediment transported by upstream rivers or mountain erosion reaches the coast: one portion is reworked by tidal currents and longshore drift into narrow sand spits, such as Dachan Bay, where the spit gradually extends, enclosing the inner bay to form a lagoon, which eventually silts up to become a coastal plain. Another portion is transported vertically inland by sea winds and storm surges, blocked by hills to form sand dikes. Multiple sand dikes accumulate into sand ridges, evolving into rare coastal plain areas that constitute Shenzhen's primary zones suitable for urban construction.

Independent small rivers entering the sea. Blocked by the Lianhua Mountain range, the East River diverges from the Shenzhen Metropolitan Area, entering the sea via the Shiziyang estuary north of Dalingshan. Consequently, the water systems within the Shenzhen Metropolitan Area are predominantly small rivers originating locally, including the Hanxi River, Shima River, and Danshui River. Rivers developing in mountainous and hilly terrain initially incise downward, forming V-shaped channels. Subsequently, lateral erosion strengthens through concave-bank erosion and convex-bank deposition, forming wide and deep river valley terraces — the primary corridors for roads and water pipelines between Shenzhen and Dongguan. These local rivers, due to their relatively small runoff volumes, typically do not bifurcate but flow independently into rivers or the sea. See Fig. 4.

Fig.4 Map of geomorphic depositional patterns in metropolitan areas in the Guangdong-Hong KongMacao Greater Bay Area

3.3 Island Flotation Deposition: Circular Sand Flats Formed by Island-Intercepted Sediment

Unlike the progressive alluvial deposition of the Guangzhou-Foshan Metropolitan Area and the marine deposition of the Shenzhen Metropolitan Area, the Zhuhai–Zhongshan area on the western side of the Pearl River estuary experiences a discrete flotation deposition process, where islands dominate the formation of a nucleated landform composed of rocky islands, sand dikes, sand flats, and sand bars.

Discrete island groups. The mountains and hills of the Wugui Mountain and Huangyang Mountain areas in Zhongshan and Zhuhai, located in the lower reaches of the West River, are farthest from the sediment source and developed latest. The evolution of the coastline reveals that these were originally relatively isolated islands.

Nucleated circular deposition. Sediment washed down by the West River encounters islands that intercept the flow, reducing velocity and causing sand ridges and sand flats to form in rings around each island, each accumulating circularly with the island as its nucleus. As deposition continues, these rings expand outward in sequence: the sand dikes closest to the island are highest and hardest, followed by sand flats with gradually decreasing elevation and particle size but increasing organic content, and finally outer sand bars.

4 Three Metropolitan Spatial Patterns Responding to Natural Landforms

The three sediment deposition processes have significantly influenced regional landforms, and the metropolitan areas, through adapting to and transforming these landforms, have formed three distinctive urban patterns and development trajectories [24-25].

4.1 Guangzhou-Foshan Metropolitan Area — Concentric Extension Under Breach Alluvial Deposition

4.1.1 Urban Pattern: Multi-Concentric Layout of "City–Farmland–Water Bay"

As discussed above, in the process of island hill chains intercepting river sediment to form the concentric landform of "crevasse splay plain — floodplain — marsh plain," different natural units play distinct roles in the metropolitan spatial pattern. The "island hill chains" are critical for sediment deposition and water system stabilization, and also play an important role in regulating the urban microclimate of the plain areas. They therefore serve as the nearest mountain-forest barriers to the city, such as Baiyun Mountain, Xiqiao Mountain, and Daifu Mountain. The "crevasse splay plain" immediately adjacent to the island hill chains, composed of the largest, hardest gravel particles at the highest elevation and relatively poor soil, is suitable for urban construction. Accordingly, the four layers of crevasse splay plains in the Guangzhou Metropolitan Area support four concentric urban belts: Sanshui–Huadu, Yuexiu–Haizhu–Liwan–Nanhai–Chancheng, Panyu–Shunde, and Nansha–Zhongshan urban area. Beyond the crevasse splay plain, the "floodplain" has softer texture and higher organic content, suitable for village-building and cultivation, such as the Sangyuanwei embankment area at the foot of Xiqiao Mountain and the Wanqingsha area of Nansha. Finally, the outermost "marsh plain" is the zone richest in water systems and highest in ecological value, such as Shiwan Wetland and Nansha Wetland; place names like "Shawan" (sand bay) and "Shiwan" (stone bay) also reflect the geomorphology of the former marsh plain. Overall, the seemingly interlocking urban-rural pattern of Guangzhou-Foshan can be deconstructed into four concentric layers of "crevasse splay plain — floodplain — marsh plain," each carrying a repeating spatial structure of "city — farmland — water bay" (Fig. 4). Water ridges and water troughs, as the areas of greatest water volume or widest channels, serve as the region's important water sources, primary navigation channels, and natural boundaries of the metropolitan area (Fig. 5).

Fig.5 Spatial patterns of three metropolitan areas in the Guangdong-Hong Kong-Macao

Greater Bay Area

4.1.2Development Trend: Estuary Extension in Response to Rapid Deposition

The alluvial deposition process has brought the Guangzhou-Foshan Metropolitan Area fertile soil and abundant freshwater, supporting its development as a historical prefecture-type city, and also providing ample space for future metropolitan expansion. Under the strong impetus of the Guangzhou-Foshan core, the metropolitan area continues to expand concentrically [26]. Between concentric layers, the contiguous agricultural areas of Baiyun Mountain–East River–Shiziyang–North River form the natural boundary of the Guangzhou Metropolitan Area's core zone, while the contiguous agricultural areas of Wangzi Mountain–Fenghuang Mountain–Zeng River–West River form the natural boundary of the metropolitan area's urbanized zone. Compared with the old city's siting at the basin core backed by mountains and facing water, development nodes are mostly 布局 at island hill chains and river confluences, such as Guangzhou South Railway Station–Sanlongwan Pilot Zone. The rural farmland between concentric layers serves as resilient space for flood absorption. However, the rapid sediment deposition — a "sea into mulberry fields" transformation — also dynamically affects the navigation capacity of the metropolitan area's ports and channels. According to observations, the Nansha coastline in Guangzhou extends seaward by approximately 100 m per year. To reduce the impact of sediment on ports, Guangzhou has continuously extended its port eastward and southward along the Pearl River, expanding the urban framework: the sea port has progressively migrated from Baietan to Huangpu to Nansha, and the lateral shipping routes connecting the West River and the main Pearl River channel have gradually shifted southward from Baini River (Qin-Han dynasties) to Lubao Creek (Tang-Song dynasties), Xinan Creek (Ming dynasty), Foshan Waterway (Qing dynasty), and finally the Dongping Waterway in the contemporary era.

4.2 Shenzhen Metropolitan Area — Finger-Like Expansion Under Marine Terrace Deposition

4.2.1 Urban Structure: Clustered City of "Ports" + "Corridors"

The drowned valley bays with deep, calm water provide ideal locations for port construction. With the establishment of the Shenzhen Special Economic Zone and the initiation of the "front shop, back factory" cooperative model with Hong Kong, major port areas including Shekou, Mawan, Chiwan, and Yantian were successively developed at the heads of Shenzhen Bay and Dapeng Bay, and port checkpoints such as Shekou and Luohu developed around these port areas. As the checkpoints further developed and cross-district connectivity needs increased, east-west trunk roads such as Shennan Avenue, Binhai Avenue, and Beihuan Expressway were constructed atop the sturdy, elevated sand ridges. As the construction space on the coastal plain gradually saturated, urban construction began to expand northward, developing roads such as G107 and G205 along the north-south river valley terraces of the Shima River and Danshui River, and nurturing five new cities including Dayun and Pinghu. Interspersed among these, the hilly areas constitute the region's primary ecological barriers, including Dalingshan, Eweishan, Baoshan, Tanglang Mountain, and Wutong Mountain (Fig. 5).

4.2.2 Development Trend: Finger-Like Expansion Seeking Spatial Hinterland

Marine terrace deposition has brought Shenzhen excellent deep-water harbors, but also the challenge of limited urban development space. Flat land accounts for only 20%–30% of Shenzhen's territorial area, while hills and ridges occupy 70%–80%, and over 40% of the area is designated within ecological redlines. In 2010, Shenzhen crossed the southern branch of the Lianhua Mountains to integrate the areas inside and outside the special zone border. Now, in the metropolitan era, Shenzhen is further breaking through the northern branch of the Lianhua Mountains to strengthen connections with Dongguan. Since the small rivers originating from local hills flow toward the most vulnerable parts of the mountain system, and through accumulated incision and lateral cutting form river valley terraces, these valleys become viable corridors for building urban green corridors, transportation corridors, and industrial expansion corridors cutting through the mountain system. This has produced the Shenzhen Metropolitan Area's distinctive pattern of finger-like corridor radiation outward [27-28]. For example, leveraging the excellent valley of the Shima River, combined with the Guangzhou-Kowloon Railway and the Dongguan-Shenzhen Highway, and overlaid with the planned Changlong Intercity Railway and Shenzhen Metro Line 22, a composite corridor has been formed, linking development platforms including Dongguan's Tangxia and Songshan Lake.

4.3 Western Pearl River Delta Metropolitan Area: Nuclear Mosaic Under Island Flotation Deposition

4.3.1 Urban Pattern: Nucleated Cluster of "Green Core–Encircled Polders"

In the process of island-surrounding deposition, mountains provided local residents with freshwater sources and shelter from storm surges, serving as vital ecological barriers. Even after the plains eventually merged into continuous expanses, the spatial logic of living and farming around the mountains has not changed, and the plain hills have evolved into shared regional green cores conserved by different cities. Additionally, the sand dikes and sand ridges formed by island-surrounding deposition, being elevated and firm, serve as priority sites for urban construction. As deposition extends outward from the sand ridges, the sand flats gradually decrease in elevation and particle size while organic content increases, and through polder enclosure, they form valuable farmland protected from tidal influence. The outermost sand bars serve as regional resilience zones for flood storage and storm surge defense. Thus, the urban structure presents a pattern of "regional green core — urban ring — farmland ring — ecological belt" forming encircled clusters (Fig. 5).

4.3.2 Development Trend: Holistic Mosaic Centered on Regional Green Space

The Western Pearl River Delta Metropolitan Area, built through island-nucleated flotation deposition, appears spatially continuous, yet the original urban framework of self-development around mountain barriers remains strongly influential. The metropolitan area emphasizes the flow of elements among different regions to achieve overall gains. On the basis of originally separated urban distributions, the protection and utilization of shared ecological space to forge a consensus on shared development has become a near-term priority [29]. For example, the establishment of the Wugui Mountain Nature Reserve, and the development of platforms such as Zhongshan Science City and Xiangshan New City around the mountain, has formed a ring-mountain industrial belt.

5 Conclusions and Discussion

Taking the Guangzhou, Shenzhen, and Western Pearl River Delta metropolitan areas in the Guangdong-Hong Kong-Macao Greater Bay Area as examples, this study examines how different ecological processes drive differentiated depositional landforms under varying natural settings, and how the urban-rural system adopts differentiated response strategies, forming distinctly different urban structures and development trajectories (Table 1):

Tab.1 Summary of spatial expansion models of the three metropolitan areas in the Guangdong-Hong KongMacao Greater Bay Area

都市圈	沉积方式	关键地理单元	自然地理特征	空间演变需求
广州	盆地洪积：大江冲缺岛丘链沉积的圈层平原	水脊—岛丘链—决口扇平原—洪泛平原—沼泽平原—水谷	腹地大、淡水丰富、口门淤积快	延展型演变：顺应快速沉积，调整框架
深圳	台地海积：海潮冲蚀丘陵的岬湾海岸带	基岩海岸—溺谷湾—沙陇—河谷阶地	港湾优良，岸线连绵，山体阻隔，腹地小	跨越型演变：跨越山体，争取腹地，由海湾到盆地
珠西	离岛浮积：岛屿拦截泥沙的环形沙坦	岩岛—沙堤—沙坦—沙栏	竖向河道强直，山体高大，斑块破碎	镶嵌型演变：强化联通，由"凝核"到"镶嵌"

① The Guangzhou Metropolitan Area, located upstream of the Bay Area's trumpet-shaped estuary, is dominated by the alluvial deposition process of major rivers including the North River and West River. Abundant sediment, intercepted by multiple island hill chains, deposits in layers to form multi-level landforms of "crevasse splay plain — floodplain — marsh plain." Correspondingly, a multi-concentric urban pattern of "city — farmland — ecology" has formed, with the Guangzhou prefecture developing at the basin center as a regional political, cultural, and economic hub. Under the metropolitan framework, the area continues to expand concentrically driven by the strong Guangzhou-Foshan core, with water ridges and troughs serving as the primary natural boundaries and progressively deposited farmland serving as inter-cluster separators. Meanwhile, to accommodate the rapid deposition of water and sediment, the metropolitan area must continuously adjust shipping routes and channel layouts to maintain its function as a river-sea transshipment hub.

② The Shenzhen Metropolitan Area, located on the eastern shore downstream of the Bay Area's trumpet-shaped estuary, is affected by the Coriolis force which diverts sediment away, causing mountains to directly meet the sea. Tidal erosion of the mountains forms a headland-bay coastline with alternating bays and headlands — limited in flat land but rich in excellent harbors. The city first developed port areas at bay heads, gradually forming a clustered urban structure of "ports + corridors." Under the metropolitan framework, the core area seeks stronger connections with peripheral platforms, crossing mountains along river valleys in a finger-like expansion pattern.

③ The Western Pearl River Delta Metropolitan Area, located on the western shore of the Bay Area's trumpet-shaped estuary, was originally composed of small mountain masses that existed as islands. These islands intercepted sediment and accumulated individually in rings, gradually developing into a nucleated mosaic landform through mutual compression. Under the metropolitan framework, relatively separated clusters seek strong cooperation, with regional collaboration centered on shared ecological space as the near-term priority.

Table 1 Summary of spatial expansion models of the three metropolitan areas in the Guangdong-Hong Kong-Macao Greater Bay Area

Metropolitan Area	Deposition Mode	Key Geographical Units	Natural Geographical Characteristics	Spatial Evolution Trend
Guangzhou	Basin alluvial deposition: concentric plains formed by major river breach through island hill chains	Water ridge — island hill chain — crevasse splay plain — floodplain — marsh plain — water trough	Broad hinterland, abundant freshwater, rapid estuary siltation	Extension-type evolution: adapting to rapid deposition, adjusting framework
Shenzhen	Marine terrace deposition: headland-bay coastal zone formed by tidal erosion of hills	Bedrock coast — drowned valley bay — sand ridge — river valley terrace	Excellent harbors, continuous coastline, mountain barriers, limited hinterland	Finger-like expansion: crossing mountains, gaining hinterland, from bays to basins
Western PRD	Island flotation deposition: circular sand flats formed by island-intercepted	Rocky island — sand dike — sand flat — sand bar	Steep vertical channels, tall mountains, fragmented patches	Mosaic-type evolution: strengthening connectivity, from "nucleus" to "mosaic"

	sediment			

This study has constructed a "Natural Portrait" pathway for territorial spatial cognition, supplementing two critical links — "process cognition" and "unit deconstruction" — within the "evaluation — zoning — regulation" territorial spatial planning technology chain, along both temporal and spatial dimensions, supporting the construction of spatial structures with greater spatiotemporal continuity and more coherent human-land interaction management units:

① Temporally, "process cognition" constructs a dynamic territorial spatial pattern. Building on the static zoning of the "Double Evaluation," the "Natural Portrait" emphasizes identifying horizontal processes such as geological formation, water-sediment deposition, and agricultural production from a driving-force perspective, identifying interrelated causal spaces, constructing a "process-flow" spatial pattern, and understanding evolutionary trends to support development direction assessments.

② Spatially, "unit deconstruction" provides a more comprehensive and organic management vehicle. The "Double Evaluation," using "grid cells" as units, derives high-medium-low suitability zones through "thousand-layer cake" overlay and further clusters to delineate three categories of space, causing a certain degree of territorial functional separation and spatial structural fragmentation. The "Natural Portrait" emphasizes using "geographical units" —spaces with complete functions and clear boundaries — as vehicles to carry ecological processes and social activities, and through multi-scale sequential deconstruction, connect management zoning, regulatory planning units, and restoration areas, supporting integrated territorial spatial planning.

Future research can be enriched and deepened in the following directions: ① Bidirectional natural-anthropogenic driving-response mechanisms. This study emphasizes the coupling of natural and anthropogenic processes, but primarily takes nature as the driving force to deduce urban-rural adaptation and transformation, treating nature as the independent variable and urban-rural patterns as the dependent variable. However, as noted above, the natural environment influences human society through the medium of "productive forces," which are in turn affected by culture, politics, and contingent events. Therefore, it is necessary to supplement anthropogenic driving processes, identify new demands on spatial organization arising from new production relations, and correspondingly regulate adaptation to the natural environment. ② Linking the "process-driven — pattern-response mechanism" with "monitoring — early warning systems." The current analysis of process flow and spatial evolution is primarily qualitative mechanism-based deduction, lacking quantitative monitoring and prediction. This creates shortcomings for medium- and small-scale planning decisions and timely spatial assessment. Integration with territorial spatial planning monitoring networks and early warning systems would facilitate dynamic monitoring and adaptive planning.

References

[1] WU Chuanjun. Theoretical study on man-land areal system and its regulation [J]. Journal of Yunnan Normal University, 2008, 40(2): 1-3.

[2] GE Jianxiong. Comprehensively and correctly understanding the influence of geographical environment on history and culture [J]. Fudan Journal (Social Sciences Edition), 1992(6): 51-

55.
[3] BAO Qingde, YUE Xinlu. Geographical environment: reflection on determinism and exploration of influence theory [J]. Journal of Nanjing Forestry University (Humanities and Social Sciences Edition), 2024, 24(5): 26-40.
[4] SHEN Qiming. Dialectical interpretation of the Ming dynasty Fengshui compendium "Essential Knowledge of Geography for Human Beings" [D]. Tianjin: Tianjin University, 2018.
[5] FU Bojie, ZHAO Wenwu, CHEN Liding. Progress and prospect of geo-ecological process research [J]. Acta Geographica Sinica, 2006(11): 1123-1131.
[6] LIU Yansui. Modern man-land relationship and man-land system science [J]. Scientia Geographica Sinica, 2020, 40(8): 1221-1234.
[7] JIA Kejing, HE Hongfei, ZHANG Hui, et al. Optimization of territorial spatial pattern based on "Double Evaluation" [J]. China Land Science, 2020, 34(5): 43-51.
[8] ZHANG Yang. "Double Evaluation": scientific leap in spatial planning decision-making — review of "Theory and Practice of Double Evaluation for Territorial Spatial Planning" by YUE Wenze [J]. China Land Science, 2024, 38(5): 125-130.
[9] LYNCH K. The Image of the City [M]. FANG Yiping, HE Xiaojun, trans. Beijing: Huaxia Publishing House, 2001.
[10] YE Guanghui, XU Tong. Research on dynamic urban portrait based on evolutionary analysis [J]. Data Analysis and Knowledge Discovery, 2020, 4(9): 100-110.
[11] ZHENG Degao, LIN Chenhui, WU Hao, et al. Spatialization research and digital portrait technology framework for sustainable urban development [J]. Urban Planning Forum, 2023(6): 32-39.
[12] SHEN Mingrui, WANG Ziqing, CUI Gonghao. Metropolitan areas in China: theoretical origins and planning practice [J]. Urban Planning Forum, 2023(2): 57-66.
[13] ZHANG Yishuai, ZHAO Min. Spatial delineation, characteristic analysis and classification of metropolitan areas in China [J]. Urban Planning Forum, 2023(2): 67-76.
[14] XI Guangliang, ZHEN Feng, FANG Chuanglin, et al. Optimization and coordinated development of territorial space in metropolitan areas from the perspective of flow-form integration [J]. Acta Geographica Sinica, 2025, 80(2): 272-287.
[15] ZHANG Li, GAO Runyi. Repositioning and role analysis of metropolitan area planning [J]. Urban Planning Forum, 2025(4): 26-32.
[16] FANG Yu, SUN Wenyong, CAI Shuyao, et al. Research on urban group inspection and evaluation method for high-quality development: a case study of the Guangdong-Hong Kong-Macao Greater Bay Area [J]. Urban Planning Forum, 2022(Suppl.1): 2-9.
[17] MA Xiangming, CHEN Yang, LI Zhifeng. History, characteristics and prospects of urban agglomeration planning in the Guangdong-Hong Kong-Macao Greater Bay Area [J]. Urban Planning Forum, 2019(6): 15-24.
[18] LAI Shulin, HE Haoyu, ZHANG Yingfeng, et al. Research on high-quality development strategies of five metropolitan areas in Guangdong Province based on core city driving forces [J]. Urban Observation, 2024(4): 115-127.
[19] CHEN Yang, MA Xiangming, JIA Weibin. Generation and evolution of major city relationships in the Guangdong-Hong Kong-Macao Greater Bay Area from the perspective of civilizational interaction [J]. Tropical Geography, 2023, 43(12): 2321-2331.
[20] ZHANG Yishuai, ZHAO Min, WANG Qixuan, et al. Research on the "Greater Bay Area" development from the dual perspectives of "place space" and "flow space": a case study of

the Guangdong-Hong Kong-Macao Greater Bay Area [J]. Urban Planning Forum, 2018(4): 24-33.
[21] PENG Jian, LÜ Danna, DONG Jianquan, et al. Process coupling and spatial integration: landscape ecology cognition of territorial ecological restoration [J]. Journal of Natural Resources, 2020, 35(1): 3-13.
[22] WU Yuwen. Overview of river channel changes in the West River system in historical times [J]. Tropical Geomorphology, 1981, 2(2): 82-86.
[23] HUANG Zhenguo. Formation, Development and Evolution of the Pearl River Delta [M]. Beijing: Science Popularization Press, 1982.
[24] LI Zhifeng, YAO Danyan, HUANG Yongxian, et al. Spatial organization models of metropolitan areas in the Guangdong-Hong Kong-Macao Greater Bay Area from an urban-regional perspective [J]. Planners, 2022, 38(5): 128-133.
[25] FANG Yu, SHI Aihua, SUN Wenyong, et al. Multi-dimensional spatial characteristics and integrated development strategies of the Guangdong-Hong Kong-Macao Greater Bay Area [J]. Urban Planning Forum, 2022(4): 78-86.
[26] ZHU Yuyu, ZHANG Shangwu, HUANG Jianzhong. Innovation in territorial spatial planning practice of metropolitan areas facing cross-regional governance [J]. Urban Planning Forum, 2025(4): 19-25.
[27] CHEN Hongsheng, DENG Shuhan, LI Zheng. Metropolitan spatial structure based on the "core-periphery" perspective: cases of Guangzhou and Shenzhen metropolitan areas [J]. Resources Science, 2025, 47(2): 254-267.
[28] ZHAN Wei, YUAN Qifeng, LU Junwen. Transformation of the "Pearl River Model": the structural process of national spatialization in the Guangdong-Hong Kong-Macao Greater Bay Area [J]. Urban Planning Forum, 2025(1): 46-54.
[29] XUE Meihui. Industrial innovation in development-oriented metropolitan areas: real foundation, constraining factors and policy suggestions — a case study of the Western Pearl River Delta Metropolitan Area in Guangdong Province [J]. Global Science, Technology and Economy Outlook, 2023, 38(10): 41-50.
AI 辅助翻译