

Ecological Niche Analysis and Optimization Strategies for Higher Education in the Guangdong-Hong Kong-Macao Greater Bay Area

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Abstract. The Guangdong-Hong Kong-Macao Greater Bay Area (GBA) is a dynamic economic region with a burgeoning higher education sector. This study conducts an ecological niche analysis to scrutinize the higher education ecosystem's challenges and proposes optimization strategies. By employing a mathematical model with key indicators, we calculate the ecological niche values for educational institutions across the GBA, identifying imbalances and niche overlaps. The study recommends strategies such as resource sharing, open cooperation, and industry-education integration to enhance the quality and distinctiveness of higher education in the GBA.

Keywords: Greater Bay Area, Higher Education, Educational Ecology, Ecological Niche, Optimization Strategies

1. Introduction

The Guangdong-Hong Kong-Macao Greater Bay Area (GBA) is rapidly emerging as a global epicenter for economic growth and technological innovation. As a testament to its burgeoning status, the GBA boasts a vibrant higher education sector that is integral to nurturing talent and propelling regional development. The GBA's strategic geographical position, coupled with its robust economic policies, has set the stage for the region to become a leading hub for innovation and high-quality development (Chan et al., 2021).

The advancement of the GBA's higher education ecosystem is not merely an academic pursuit but a fundamental driver of the region's economic vitality. The region's higher education institutions are at the vanguard of knowledge generation and dissemination, playing a pivotal role in the GBA's ambition to become an international education and innovation nexus (Tang & Cheng, 2019). However, the rapid expansion and diversification of these institutions have introduced challenges concerning resource allocation, niche differentiation, and the strategic optimization of educational offerings (Liu & Li, 2022).

This study addresses the pressing need for a strategic and systematic approach to analyze and optimize the GBA's higher education landscape. By employing an ecological niche analysis, we aim to elucidate the unique roles, functions, and interactions of higher education institutions within their socio-economic milieu (Zhu, 2018). This approach is particularly pertinent in the GBA, where the 'one country, two systems' framework presents a multifaceted educational landscape that demands nuanced understanding and strategic planning (Li et al., 2021).

The research objectives of this study are designed to contribute to regional educational policy discourse and support the GBA's developmental aspirations. We intend to:

- (1) Conduct a comprehensive niche analysis of higher education institutions across the GBA.
- (2) Identify areas of imbalance and overlap within the current educational ecosystem.
- (3) Propose evidence-based strategies that foster resource sharing, open cooperation, and industry-education integration.

The significance of this study is twofold: it offers actionable insights into the optimization of the GBA's higher education ecosystem and contributes to the regional educational policy discourse. By examining the ecological niche of higher education, this research provides a novel perspective on how institutions can be strategically optimized to enhance the quality and distinctiveness of education, thereby underpinning the GBA's vision as a preeminent talent and innovation hub (Fan, 2019).

This introduction lays the foundation for a detailed exploration of the GBA's higher education landscape, providing a novel perspective on the role of ecological niche analysis in shaping the future of education in this dynamic economic region.

2. Literature Review

This section provides a critical review of the existing literature on the development and optimization of higher education ecosystems, particularly within the context of the Guangdong-Hong Kong-Macao Greater Bay Area (GBA). The review is structured to first examine the theoretical underpinnings of educational ecology and niche theory, followed by an analysis of empirical studies that have explored the higher education landscape in the GBA and similar regional contexts.

2.1. Theoretical Framework

The concept of educational ecology, introduced by Craming in 1976, offers a lens through which to view higher education institutions as part of an interactive system with their environment (Fan Guorui, 2000). Niche theory, as applied to education, helps to understand the role and function of these institutions within the social system (Chase, J. M., 2003). The literature emphasizes the importance of this theoretical approach in analyzing educational systems and their evolution (Li Jianguo, 2006).

2.2. Empirical Studies

A review of empirical studies reveals a growing body of work that has begun to explore the higher education ecosystem in the GBA. Xie et al. (Xie Ailei, 2019) discuss the integration and development of higher education in the region, highlighting the unique challenges and opportunities presented by the GBA's geographical and administrative diversity. Song and Liu (Song Jia, 2019) provide a policy review of Hong Kong's efforts to create world-class universities, underscoring the significance of quality assurance and internationalization (Zhou, 2019).

2.3. Application of Niche Theory

Few studies have directly applied niche theory to the analysis of higher education in the GBA. However, the work of Zhu (Zhu Binwei, 1997) on the niche ecostate-ecorole theory provides a foundation for understanding the competitive and cooperative dynamics among higher education institutions. This study aims to fill this gap by employing a niche analysis to examine the GBA's higher education ecosystem.

2.4. Gaps and Contributions

Despite the valuable insights provided by existing literature, there remains a need for a focused examination of the GBA's higher education landscape through the lens of ecological niche theory. This review identifies the lack of comprehensive strategies for optimizing the educational ecosystem in the GBA and highlights the potential contributions of the present study to addressing this gap.

3. Research Method

The GBA has superior geographical conditions, adjacent to the two major administrative regions of Hong Kong and Macau, and surrounding the nine major cities of the Pearl River Delta in Guangzhou and Shenzhen. It is not only a deep integration area of the Pearl River Delta region and the Hong Kong Macao Special Administrative Regions, but also the intersection of the "Silk Road Economic Belt" and the "21st Century Maritime Silk Road". (Xie Ailei, 2019) The development of higher education in Guangdong, Hong Kong, and Macao has its own characteristics, and the basic strength of each region cannot be underestimated. The GBA has abundant high-quality resources, distinctive educational characteristics, and significant knowledge spillover effects in higher education. The three integral regions of Guangdong, Hong Kong, and Macao have collaboratively driven forward high-quality economic progress in the Greater Bay Area. Approaching the distribution of higher education resources in the GBA through the lens of educational ecology necessitates the establishment of a "synergistic overall balance" framework that prioritizes systematic organization, dynamic adaptability, and interactive collaboration. Achieving this balance demands close partnership between governmental bodies and higher education institutions to foster a conducive educational environment, consistently refine resource allocation strategies, and promote harmonious growth within the higher education sector.

3.1. The Scale of Higher Education in 9 Cities in Guangdong Is Huge

On September 30, 2023, a total of 3,072 higher education institutions nationwide were found on the portal website of the Ministry of Education. Among them, there are 2,820 ordinary higher education institutions, including 1,275 undergraduate colleges and 1,545 vocational (vocational) colleges, and 252 adult higher education institutions. The above data does not include higher education institutions in the Hong Kong, Macao, and Taiwan regions.

As a major province in higher education, Guangdong Province boasts a substantial higher education system, comprising 162 ordinary institutions—the second-highest count in the nation after Jiangsu Province, which has 168. These institutions include 69 undergraduate colleges, 93 vocational and technical colleges, as well as 14 adult higher education providers. Notably, within the nine major cities

of the Bay Area in Guangdong, there are 131 ordinary colleges and universities, constituting an impressive 80.9% of the province's total higher education institutions. The specific distribution is detailed in "Table 1".

Table 1 Distribution of Higher Education Institutions in 9 Cities in the GBA

Prefecture/city	Undergraduate (Public)	Undergraduate (Private)	Cooperative education	Higher Vocational Education (Public)	Higher Vocational Education (Private)	Total
Guangzhou	22	15	1	32	14	84
Shenzhen	4	0	2	1	1	8
Zhuhai	0	3	1	1	2	7
Foshan	1	1	0	2	2	6
Huizhou	1	0	0	3	1	5
Dongguan	1	2	0	1	3	7
Zhongshan	0	1	0	2	0	3
Jiangmen	1	0	0	3	1	5
Zhaoqing	1	2	0	1	2	6

3.2. Hong Kong Has a Strong Foundation in Higher Education

Hong Kong has made its higher education more modern and diverse with its high-quality, diverse, and flexible access to education, as well as its educational characteristics that combine China and the West. Currently, there are 11 higher education institutions and 5 vocational schools in Hong Kong, as shown in "Table 2".

Table 2 Distribution of Higher Education Institutions in Hong Kong

Ordinary higher education institutions (11)	Junior colleges (5)
The University of Hong Kong, The Chinese University of Hong Kong, The Hong Kong University of Science and Technology	Heung To College of Professional Studies
Hong Kong Baptist University, The Hong Kong Polytechnic University	Hong Kong School of Commerce
City University of Hong Kong, Lingnan University, The Hong Kong Institute of Education	Hong Kong Academy of Fine Arts
The Open University of Hong Kong, Hong Kong Shue Yan University	Hong Kong Professional Putonghua School
Hang Seng University of Hong Kong	Hong Kong Music Institute

Hong Kong's colleges and universities enjoy a sterling reputation for their academic excellence and teaching proficiency. In the 2022 QS World University Rankings, several Hong Kong institutions featured prominently, with the University of Hong Kong, Hong Kong University of Science and Technology, The Chinese University of Hong Kong, City University of Hong Kong, and The Hong Kong Polytechnic University all securing spots within the global top 100. Additionally, Hong Kong Baptist University and Lingnan University both made it to the top 500. Notably, the University of Hong Kong occupied an impressive 21st position.

Among these esteemed institutions, the University of Hong Kong, Hong Kong University of Science and Technology, and The Chinese University of Hong Kong stand out as global leaders, attracting the finest resources for higher education development and nurturing innovative, high-caliber talents. The Hong Kong Polytechnic University and City University of Hong Kong are highly regarded for their expertise in applied talent cultivation. Meanwhile, Hong Kong Baptist University and Lingnan University emphasize a liberal arts education, fostering a well-rounded educational experience. Multiple universities have a clear positioning and jointly establish a higher education system with clear categories and reasonable structure by developing core areas with their own advantages. (Song Jia, 2019)

3.3. Macao's Higher Education Demonstrates Inclusivity

Modern higher education in Macao is thriving. At present, there are a total of 10 higher education institutions in Macao, including 4 public institutions and 6 private institutions. Among them, there are universities that combine comprehensive teaching and research, as well as multi-disciplinary polytechnics that focus on applied teaching, or specialized colleges that focus on cultivating tourism exhibition talents, gambling industry professionals, professional nursing personnel, and senior management talents, as shown in "Table 3".

Table 3 Distribution of Higher Education Institutions in Macao

Public universities (4)	Private universities (6)
University of Macau	Asia International Open University
Macao Polytechnic University	City University of Macau
Macao Institute for Tourism Studies	University of Saint Joseph
Macao Institute for Security Forces	Kiang Wu Nursing College Of Macau
	Macao University of Science and Technology
	Macao Institute of Management

Data source: Compiled based on the official website of higher education institutions in Macao.

With the swift advancement of Macao's society and economy,, Macao is gradually integrating with the mainland. Taking the construction of the "Hengqin Campus of the University of Macau" as an opportunity, it has expanded its educational space and alleviated the difficulties caused by land resource scarcity. Simultaneously, Macao maintains its positioning as "a tourism center, a business service platform, and a cultural exchange base," (Zhang Hongfeng, 2019) with Chinese culture serving as the mainstay while embracing diverse cultures from across the globe. It fosters close cooperation with the mainland while continuously engaging with the international community, thereby strengthening its role as a bridge between China and the world.

3.4. Analysis of the Characteristics of Higher Education in the GBA

The distribution of higher education in the GBA exhibits characteristics of diversity, competitiveness, synergy, and openness. From the perspective of the layout of higher education resources, there are still problems such as insufficient supply of top education, lack of innovation ability (Smith, 2020), and insufficient allocation of innovation resources in the Bay Area. It is necessary to learn from and learn from international advanced education models, deepen the education system and reform the talent cultivation mechanism, carry out a "precise layout" of higher education, and promote the high-quality development of education and talent cultivation.

(1) Diversity: The types of colleges and universities in the Greater Bay Area are diverse, including research-oriented universities, applied universities, vocational and technical colleges, independent colleges, etc., meeting the choices of students at different levels and needs.

(2) Competitiveness: There is competition among colleges and universities in the Greater Bay Area, and high-quality educational resources and achievements can flow and be shared among colleges and universities, promoting the development and progress of universities.

(3) Synergy: The colleges and universities in the Greater Bay Area have formed a cooperation model with government support and complementary advantages. This cooperation model is conducive to the coordinated development of universities and also promotes the overall level of higher education in the Greater Bay Area.

(4) Openness: Colleges and universities in the Greater Bay Area actively introduce internationally renowned universities and characteristic colleges, promote the construction of world-class universities and disciplines, and accelerate and expand the opening up level of Guangdong's higher education to the outside world.

3.5. Definition of Higher Education Niche in the GBA

The GBA stands out as one of the most vigorously developing economic hubs in China (Lee, 2021). The "Outline of the Development Plan for the GBA" emphasizes the need to enhance educational collaboration, aiming to establish an educational and talent hub. To achieve this, the plan encourages cooperation among higher education institutions in Guangdong, Hong Kong, and Macao in running schools, jointly developing strong academic disciplines, and utilizing the platform provided by the Guangdong-Hong Kong-Macao University Alliance. Additionally, the initiative strives to construct an international education exemplar zone, showcasing best practices in educational cooperation and talent cultivation. The nine cities and two districts in the Greater Bay Area each have educational resource endowments in terms of higher education scale, level, type, and characteristics, highlighting the competitiveness and complementarity of educational resources. From the perspective of educational ecology, there are distinct educational niches within the Bay Area.

3.6. Concepts Related to Ecological Theory

Ecology is the science that studies the interaction between organisms and their environment, typically conducted at four levels: individual, population, community, and ecosystem (Li Jianguo, 2019).

(1) For individuals, the researchers' perspective mainly projects on the changes and reactions of organisms to the environment, the mechanism of environmental factors acting on the organism, and the changes in the organism caused by environmental factors.

(2) A population is a complex composed of individuals of the same species residing in the same region. Researchers are concerned about the population's response to the environment, and the research perspective mainly projects on the fluctuations in population size caused by environmental changes and their impact on population spatial distribution.

(3) A community is a mixture of different populations within a given area, and researchers focus on the composition and structure of the community. The research perspective projects the mechanism between environmental changes and changes in community composition and structure.

(4) An ecosystem is a complex of biological communities and non biological environments in a certain space, and researchers are interested in the energy flow between the ecosystem and the environment, as well as the circulation of food webs and nutrients.

(5) Niche refers to the specific temporal, spatial, and kinetic positions of a species in an ecosystem and community that are associated with other species, meaning that different species occupy different positions of environmental resources in the same area.(Chase, J. M., 2003)

3.7.Definition of the Ecological Niche of Higher Education in the GBA

American educator Craming first proposed the concept of "educational ecology" in "Public Education" in 1976. Education ecology is an emerging discipline that links education and its ecological environment, and studies their interrelationships and mechanisms.(Fan Guorui, 2000)The main content of higher education niche research is the function and role of the higher education system in the social system. Based on the above theories, the principles and methods of educational niche can be applied to analyze the external environment of higher education in the GBA, including issues such as educational levels, overlapping educational types, and regional distribution.

The higher education landscape in the Guangdong-Hong Kong-Macao Greater Bay Area (GBA) is a multifaceted educational ecosystem, wherein the educational niche plays a pivotal role in shaping and influencing the overall system. Through the lens of educational ecology theory, the higher education niche within the GBA is defined by its unique temporal, spatial, and functional positioning within the broader social system of the Bay Area. This positioning encompasses not only the physical and temporal dimensions but also the functional roles and responsibilities of higher education institutions within the region.The higher education communities of 9 cities and two districts in the Greater Bay Area have specific locations, and each higher education community presents a competitive and cooperative state through the influence of internal and various external factors in the system.

3.8.Analysis of Higher Education Niche in 9 Cities of Guangdong Province

The high-quality development of Guangdong's social economy increasingly demands higher education talents, which have the characteristic of "dual core attraction" for high-level talents. Through local cultivation and talent introduction, high-level talents required for industrial upgrading are attracted. The "14th Five-Year Plan for the Development of Education in Guangdong Province"(Guangdong, 2022)proposes the goal of "building a high-quality education system, accelerating the modernization of education, and building a strong province in education". The rapid economic and social development of 9 cities in Guangdong within the Greater Bay Area urgently requires an increase in the supply of higher education talent training. In 2022, the total GDP of the nine mainland cities in the GBA exceeded 10.46 trillion yuan. Among them, the regional gross domestic product of Guangzhou, Shenzhen, Foshan, and Dongguan exceeded 1 trillion yuan, with Shenzhen having the highest regional gross domestic product, reaching 3,238,768 billion yuan, followed by Guangzhou's 288,390 billion yuan, indicating that Guangzhou and Shenzhen are still the main driving force for regional economic growth. In terms of total population, as of 2020, the total population of 9 cities in Dawan District reached 78,014,335, an increase of 38.86% compared to the past 10 years.

3.9. Analysis of the Ecological Niche of Higher Education in the Hong Kong Special Administrative Region

The Hong Kong Special Administrative Region has a total population of 7.4742 million, with a per capita GDP of approximately HKD 384,800 in 2022. Entering 2023, Hong Kong's economy is gradually recovering, and there is a strong demand for high-end talents. In order to attract high-tech talents and industry talents to enhance the competitiveness of Hong Kong's industry, the government has launched multiple excellent talent entry plans, including the "Hong Kong Talent Program" and "Technology Talent Entry Program". Hong Kong's higher education has learned from the British university

governance model in terms of educational philosophy, mechanism construction, quality assurance, integration of teaching and research, and teacher development, and has a distinctive higher education system. Hong Kong's higher education has formed a high-quality and multi-level higher education environment. Five universities, including the University of Hong Kong, the Hong Kong University of Science and Technology, and the Chinese University of Hong Kong, etc., have a high level of internationalization in their education.

3.10. Analysis of the Ecological Niche of Higher Education in the Macao Special Administrative Region

The Macao Special Administrative Region has a total area of 33.3 km² and a population of 683,200 people. In September 2023, the public consultation period of the first comprehensive industrial development plan of the Macao Special Administrative Region, the "Moderate Diversified Economic Development Plan of the Macao Special Administrative Region (2024-2028)", came to an end. This plan proposes specific development goals, main tasks, and key projects for moderately diversified economic development from 2024 to 2028, in order to guide social investment direction and gradually increase the proportion of the four major industries. Under the new development pattern, Macao actively aligns with the national "14th Five-Year Plan" development strategy, develops traditional Chinese medicine manufacturing, characteristic finance, and high-tech industries, proposes a talent cultivation policy of "cultivating and attracting talents simultaneously", breaks through the bottleneck of talent resources in new industries, and assists in the moderate and diversified development of Macao's economy. The development of modern higher education in Macao has only lasted for over 30 years. In the early stages, due to the limited number of higher education institutions, the courses and academic scope provided were also relatively limited. But with the gradual increase of universities and the demand for different professional knowledge in society, the curriculum categories have become increasingly diverse. In recent years, the quality of colleges and universities in Macau has been continuously improving, and their rankings have risen in multiple world university rankings and subject rankings (Zhu Binwei, 2021). Among them, the University of Macau and the Macau University of Science and Technology rank in the top 201-250 globally, while the "Hospitality and Leisure Management" discipline at the Macau Institute for Tourism Studies has risen to 10th globally and 1st in Asia. The discipline and university influence indicators of multiple Macao colleges and universities have entered the global ranking of 200.

3.11. Empirical Study on the Ecological Niche of Higher Education in the GBA

In summary, the GBA boasts a total of 160 ordinary colleges and universities, comprising 90 public and 70 private institutions. In terms of the quantity of higher education institutions, Guangzhou, Hong Kong, and Macao have emerged as the pivotal hubs for higher learning in the region. The GBA is abundant in higher education resources, with each of the three regions—Guangdong, Hong Kong, and Macao—exhibiting unique developments and characteristics in their respective higher education landscapes. The article further empirically analyzes the competitiveness of higher education in the GBA through a theoretical model of the ecological niche situation of higher education in the region.

3.12. Establishing a Niche Situation Model for Higher Education

The niche "situation" theory encompasses the relative positioning and function of organisms within their environment (Zhu Chunquan, 1997). Herein, the term "state" denotes the condition exhibited by a species through energetic enrichment, manifesting in factors like population size, individual count, and resource occupation. Meanwhile, "circumstance" pertains to the surroundings inhabited by a species and the external forces impinging upon it. Within the context of the Guangdong-Hong Kong-Macao Greater Bay Area (GBA), the ecological niche of higher education in its constituent cities embodies two fundamental elements: the "state" and "circumstance" of each city's higher education progress.

More precisely, the "state" in the GBA's higher education ecosystem represents the educational resources, the tally of higher education institutions, and the student population that underpin the survival and advancement of higher education in each city. Conversely, the "circumstance" specifically alludes to the regional economic development level, geographical expanse, population density, and the impact or preeminence of higher education on the prevailing environment within the GBA.

(1) Establishing an indicator system for ecological niche "ecostate" and "ecorole"

Based on the above analysis, this article selects the following data points as the calculation indicators for the "ecostate" and "ecorole" of the higher education ecosystem in the GBA. The calculation indicators of "ecostate" include ordinary higher education institutions (institutions), students (individuals) on campus, and full-time teachers (individuals); The calculation indicators of "ecorole" include per capita financial investment in education (yuan), per capita gross domestic product (yuan), and per capita land area (m²).

(2) Establishing a mathematical model of niche "ecostate" and "ecorole"

The "ecostate" and "ecorole" of higher education in the GBA interact and influence each other. "Ecstate" is the result of long-term accumulation of "ecorole", and "ecorole" is manifested in "ecstate" and promotes the accumulation of "ecstate". Therefore, the mathematical model for establishing the ecological niche of higher education in the GBA is as follows:

$$N_i = \frac{\beta_i(S_i + A_i P_i)}{\sum_{j=1}^n \beta_j(S_j + A_j P_j)} \quad (1)$$

Among them, $i, j=1, 2, \dots, n$; Here, n represents the number of cities in the GBA, i.e. $n=11$;

N_i represents the higher education niche of city i ;

S_i is the ecstate of city i , P_i is the ecorole of city i , S_j is the ecstate of city j , and P_j is the ecorole of city j ;

A_i and A_j is the dimensional conversion coefficient, and $S_j + A_j P_j$ is called the absolute niche;

(3) Determining the weight β_i Define F_{ij} as the proportion of indicator value y_{ij} (after data standardization), then: $F_{ij} = \frac{y_{ij}}{\sum_{j=1}^n y_{ij}}$;

If y_{ij} is the entropy value of y_{ij} indicators, then: $E_{ij} = -K \sum_{j=1}^n F_{ij} * \ln F_{ij}$ (where $K=1/\ln(n)$, $K>0$, $0 \leq E_{ij} \leq 1$), the weight $W_{ij} = (1 - E_{ij}) / \sum_{j=1}^n E_{ij}$ of each indicator; Construct a weighted vector $W=(W_1, W_2, \dots, W_n)$ T , which is the value of β_i .

4. Research Result

The authors collect relevant indicators based on the established "situation" model and corresponding indicator system of higher education ecological niche in the GBA.

(1) All indicators are sourced from the statistical yearbooks of various cities in the Greater Bay Area from 2022 to 2023, as shown in "Table 4".

Table 4 Index system for evaluating the ecological niche of higher education in the GBA

Greater Bay Area city	Niche "ecostate" indicators			Niche "ecorole" indicators		
	Ordinary higher education institutions (institutions)	On campus students (number of people)	Full time teacher (number of people)	Per capita financial investment in education (yuan)	Per capita Gross Domestic Product (yuan)	Per capita land area (m ²)
Guangzhou	84	1307144	71202	298.07	13350.43	396.71

Shenzhen	8	145181	8426	482.48	15691.59	113.28
Zhuhai	7	143778	6811	450.95	14214.32	708.87
Foshan	6	153207	5924	181.24	11363.27	398.97
Huizhou	5	22007	1545	213.14	6969.86	1873.37
Dongguan	7	135279	7828	193.53	9205.04	234.66
Zhongshan	3	56183	3123	187.7	7112.44	402.53
Jiangmen	5	55980	3392	181.3	6662.96	1978.92
Zhaoqing	6	168182	6230	190.75	5615.02	3617.1
Hong Kong	16	99719	19509	1089.12	30703.84	148.39
Macao	10	36107	2598	1548.34	24585.97	48.16

Note: The data for higher education institutions in Hong Kong and Macao is sourced from statistics from the Ministry of Education and indirectly calculated based on relevant online reports. The remaining data comes from the "Guangdong Provincial Statistical Yearbook" and the statistical yearbooks of various cities (2021, 2022, 2023).

(2) Based on the mathematical model of niche situation, the data in Table 4 was processed using EXCEL tools to calculate the higher education niche of 9 cities and 2 districts in the GBA.

Step 1 is to use the [0, 1] normalization method to perform dimensionless processing on the data in "Table 4". The processed data is shown in "Table 5".

Table 5 Data Standardization Processing

Greater Bay Area city	Ordinary higher education institutions (institutions)	On campus students (number of people)	Full time teacher (number of people)	Per capita financial investment in education (yuan)	Per capita Gross Domestic Product (yuan)	Per capita land area (m ²)
Guangzhou	1	1	1	0.085458269	0.308320997	0.097662051
Shenzhen	0.061728395	0.095845034	0.098784042	0.220349645	0.401635868	0.018246314
Zhuhai	0.049382716	0.094753322	0.075599007	0.197286226	0.342754263	0.185127797
Foshan	0.037037037	0.102090283	0.062865182	0	0.229115997	0.098295292
Huizhou	0.024691358	0	0	0.023334065	0.054001743	0.511415154
Dongguan	0.049382716	0.088140019	0.090199119	0.008989832	0.143092421	0.052256412
Zhongshan	0	0.026593274	0.022653861	0.004725331	0.059684752	0.099292787
Jiangmen	0.024691358	0.026435314	0.026515641	4.38885E-05	0.041769202	0.540989762
Zhaoqing	0.037037037	0.113742737	0.067258136	0.006956331	0	1
Hong Kong	0.160493827	0.060469818	0.257892243	0.664091873	1	0.028083969
Macao	0.086419753	0.010971593	0.01511693	1	0.756151545	0

Step 2 is to use the method of data translation to process the data in "Table 4" (adding 0.0001 to each data) to increase the generalization ability of the sample data and avoid data imbalance. The

processed data is shown in "Table 6".

Table 6 Data Translation Processing

Greater Bay Area city	Ordinary higher education institutions (institutions)	On campus students (number of people)	Full time teacher (number of people)	Per capita financial investment in education (yuan)	Per capita Gross Domestic Product (yuan)	Per capita land area (m ²)
Guangzhou	1.0001	1.0001	1.0001	0.085558269	0.308420997	0.097762051
Shenzhen	0.061828395	0.095945034	0.098884042	0.220449645	0.401735868	0.018346314
Zhuhai	0.049482716	0.094853322	0.075699007	0.197386226	0.342854263	0.185227797
Foshan	0.037137037	0.102190283	0.062965182	0.0001	0.229215997	0.098395292
Huizhou	0.024791358	0.0001	0.0001	0.023434065	0.054101743	0.511515154
Dongguan	0.049482716	0.088240019	0.090299119	0.009089832	0.143192421	0.052356412
Zhongshan	0.0001	0.026693274	0.022753861	0.004825331	0.059784752	0.099392787
Jiangmen	0.024791358	0.026535314	0.026615641	0.000143889	0.041869202	0.541089762
Zhaoqing	0.037137037	0.113842737	0.067358136	0.007056331	0.0001	1.0001
Hong Kong	0.160593827	0.060569818	0.257992243	0.664191873	1.0001	0.028183969
Macao	0.086519753	0.011071593	0.01521693	1.0001	0.756251545	0.0001

Step 3 is to calculate F_{ij} based on the data in "Table 6", as shown in "Table 7".

Table 7 Calculation Results of F_{ij}

Greater Bay Area city	Ordinary higher education institutions (institutions)	On campus students (number of people)	Full time teacher (number of people)	Per capita financial investment in education (yuan)	Per capita Gross Domestic Product (yuan)	Per capita land area (m ²)
Guangzhou	0.652822045	0.617291802	0.582135751	0.03867328	0.092407275	0.037137011
Shenzhen	0.040358903	0.059220161	0.05755818	0.099645668	0.120365725	0.006969241
Zhuhai	0.032300178	0.058546323	0.044062692	0.089220749	0.102723967	0.07036275
Foshan	0.024241452	0.063074916	0.036650619	4.52011E-05	0.068676341	0.037377562
Huizhou	0.016182727	6.1723E-05	5.82078E-05	0.010592455	0.016209644	0.194309999
Dongguan	0.032300178	0.054464394	0.052561089	0.004108704	0.042902466	0.019888706
Zhongshan	6.52757E-05	0.016475891	0.013244512	0.002181103	0.017912354	0.037756481
Jiangmen	0.016182727	0.016378394	0.015492367	6.50392E-05	0.012544603	0.205544548
Zhaoqing	0.024241452	0.070267162	0.039207659	0.003189539	2.99614E-05	0.379909429
Hong Kong	0.104828708	0.037385513	0.150171491	0.300222044	0.299644048	0.010706285
Macao	0.056476354	0.00683372	0.008857433	0.452056217	0.226583616	3.79871E-05

Step 4 is to calculate the K , E_{ij} , and weight W_{ij} based on the data in "Table 7", as shown in "Table 8".

Table 8 Calculation Results of K , E_{ij} , and the Weight W_{ij}

K	-0.417032391					
E_{ij}	0.560024898	0.601882852	0.612558657	0.581706219	0.800424575	0.720760607
$1-E_{ij}$	0.439975102	0.398117148	0.387441343	0.418293781	0.199575425	0.279239393
W_{ij}	0.207277092	0.187557352	0.182527863	0.197062785	0.09402217	0.131552738

Step 5 is to use the linear weighting method based on the calculation results in "Table 8", to obtain the absolute ecological niche of 9 cities and 2 districts in the GBA, as shown in "Table 9".

Table 9 Absolute Niche of Higher Education in Cities in the GBA

Greater Bay Area city	Absolute niche
Guangzhou	0.636039671
Shenzhen	0.132387906
Zhuhai	0.137264854
Foshan	0.072772358
Huizhou	0.082071654
Dongguan	0.065330962
Zhongshan	0.02872784
Jiangmen	0.090020498
Zhaoqing	0.174210272
Hong Kong	0.32026526
Macao	0.290887693

Step 6 is to compare the data in "Table 5" above and calculate the ecological niche results of higher education in various cities in the GBA, and visualize them, as shown in "Figure 1".

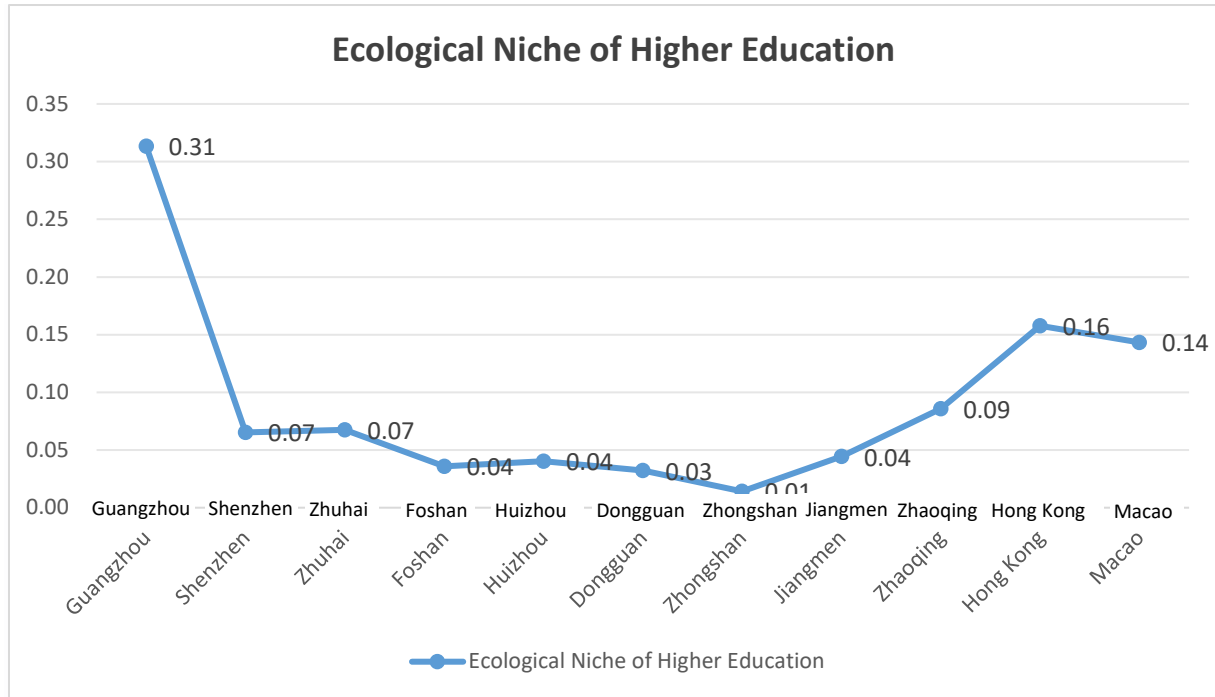


Figure 1. Ecological Niche of Higher Education in 9 Cities and 2 Districts of GBA

According to the principle of ecological niche, the larger the value of ecological niche, the greater the role it plays in the entire ecosystem, and its own development is more representative. By performing a simple sorting transformation on the data in "Figure 1", it can be seen that:

(1) The ecological niche values of higher education institutions in Guangzhou, Hong Kong, and Macao surpass 0.1, collectively commanding the premier resources of higher education within the GBA. These institutions play a pivotal and influential role in shaping the higher education ecosystem of the region, leading the way in innovation, research, and educational excellence. Especially with Guangzhou as the core, higher education resources are abundant, and the distribution of higher education levels is relatively balanced. It has gathered many potential colleges and universities as backing forces, while powerful universities and research institutes play a pivotal role,

(2) The ecological values of higher education in Zhaoqing, Shenzhen, and Zhuhai are 0.09, 0.07, and 0.07, respectively. These three cities belong to the second tier of higher education in the GBA, and have significant development space in higher education. Shenzhen and Zhuhai are both national economic zones. In recent years, with the adjustment and optimization of their industrial structures, there have been many active technology enterprise incubators. The GBA not only has more flexible operational space brought about by the "one country, two systems" policy, but also has three legal systems and three sets of diversity guarantees for higher education systems. The potential demand for higher education is gradually becoming prominent and growing. The unique characteristics of Hong Kong, Zhuhai Macao, and Shenzhen also make the GBA an emerging highland of higher education with both opportunities and challenges.

(3) The ecological digits of higher education in Foshan, Huizhou, Dongguan, Zhongshan, and Jiangmen are all less than 0.05, making them the third tier of higher education in the GBA. The above five cities have relatively few higher education resources, and most of them are public vocational colleges. The quantity of undergraduate and higher-level education institutions is limited, and the absence of key provincial undergraduate colleges and universities is notable. Additionally, the institutions within this realm exhibit a considerable degree of similarity in terms of their educational ideologies, educational types, and academic programs. This homogeneity gives rise to a situation of

"uniformity" and poses challenges related to niche overlap in the educational ecosystem(Zhu Dequan, 2023).

5. Discussion and Implications

From the perspective of educational ecology, the optimization of the layout of higher education in the GBA should consider more matching the industrial spatial layout of the Greater Bay Area, to construct a higher education functional zone that serves the high-tech industry, financial industry, and advanced manufacturing industry. On this basis, it is necessary to leverage the "agglomeration radiation" effect of higher education in central cities to form regional higher education centers while driving the development of surrounding cities. When laying out higher education in the Greater Bay Area, special attention should be paid to closely linking it with the leading industries, emerging industries, and development strategies of various industries in the Greater Bay Area. At the same time, attention should be paid to the overall layout of higher education in the Greater Bay Area, forming complementary advantages and staggered development.

5.1.Enhancing the matching degree of higher education in the Greater Bay Area with industrial layout

To enhance the educational and innovative capabilities of the eastern bank of the Pearl River, where major cities like Guangzhou, Shenzhen, and Hong Kong are located, it is imperative to establish a top-tier university cluster. This cluster should focus on bolstering the development of innovative universities and creating a higher education functional area that caters to the high-tech and financial industries. This approach will foster a robust innovation ecosystem and drive economic growth. Meanwhile, cities situated on the western bank of the Pearl River should align their educational strategies with the prevalent manufacturing industry layout. They should prioritize the establishment of application-oriented undergraduate and vocational colleges, with an emphasis on modern industrial education. By pursuing an integrated approach to industry and education, and leveraging the combined strengths of industry, universities, and research institutions, these cities can cultivate a higher education functional area that serves the advanced manufacturing sector and provides skilled talent support. This collaborative effort will not only enhance the quality of education but also contribute to the overall economic development of the region. The higher education clusters on both sides of the the Pearl River River go hand in hand and complement each other's advantages, so as to promote the matching between the layout of higher education and the industrial layout structure as a whole, and promote the benign interaction and coordinated development of higher education and regional economy in the Greater Bay Area.

5.2.Utilizing the "agglomeration - radiation" effect of the Greater Bay Area higher education centers

To fully harness the potential of the four prominent higher education centers in the Greater Bay Area—comprising Guangzhou, Shenzhen, Hong Kong, and Macau—it is essential to capitalize on their abundant high-quality resources. By leveraging the "agglomeration-radiation" effect, a comprehensive spatial layout for higher education can be established in the central cities, extending its reach to surrounding areas and ensuring comprehensive coverage. Concurrently, bolstering policy support and funding for neighboring cities is crucial. This can be achieved by fostering cooperation and exchange between central and non-central universities through various means such as collaborative education programs, joint research centers and laboratories, and the establishment of innovation and entrepreneurship platforms. Such initiatives will not only enhance the quality of higher education but also stimulate its development in the surrounding regions, contributing to the overall growth and progress of the Greater Bay Area.

5.3. Establishing an organizational mechanism that adapts to the layout structure of higher education in the Greater Bay Area

Due to the differences in concepts among the three regions and the lack of established mechanisms for connection and docking, colleges and universities at all levels are still in a state of "gathering but not grouping, and developing independently". Therefore, it is necessary to establish an organizational mechanism that adapts to the layout structure of higher education in the Greater Bay Area. For example, relying on the established Guangdong Hong Kong Macao University Alliance, a new professional alliance is formed within the framework of the alliance to create the "Guangdong-Hong Kong-Macao One Hour Academic Circle". It is also necessary to provide policy support and funding guarantee, construct a physical strategic alliance organization for colleges and universities, establish a comprehensive management committee, formulate clear and feasible alliance school cooperation plans and projects, and be responsible for their implementation. Benchmark the construction standards of "double first class" in local areas and connect them with existing higher education policies and systems in various regions (such as the "striving for first class, remedying shortcomings, and strengthening characteristics" plan in Guangdong's higher education), and establish strategic alliances at different levels of colleges and universities, such as the "First Class University Alliance", "High Level University Alliance", and "Characteristic University Alliance". In addition, through the cooperation of Guangdong, Hong Kong, and Macao universities in running schools and jointly building research institutes, there will be a necessity to promote the extension of high-quality (Hou Changlin, 2023) educational resources and research and development work in Hong Kong and Macao in the mainland, transform scientific and technological achievements into the mainland, better integrate and serve the overall development of local areas and the construction of the Greater Bay Area, and expand the development space of higher education in Hong Kong and Macao and inject new momentum into higher levels at the same time.

5.4. Optimizing the hierarchical structure of higher education in the Greater Bay Area

There is a necessity to improve the level and level of talent cultivation in the Greater Bay Area, vigorously develop graduate education, and focus on cultivating academic graduate students with strong innovation awareness and research ability, as well as professional graduate students with strong application ability and professional skills that meet the economic, social, and industrial production needs of the Greater Bay Area. There is also a necessity to optimize the disciplinary structure that is suitable for the industrial structure of the Greater Bay Area. With the transformation and upgrading of industries, the traditional industries in the Greater Bay Area are gradually extending towards advanced manufacturing, product research and development, modern service industries, and other high-end value chains, greatly increasing the demand for high-end talents. Colleges and universities in the Greater Bay Area must align their academic programs with the region's pillar and strategic emerging industries. This alignment should focus on strengthening the development of unique and emerging disciplines while establishing majors in areas like electronic information, petrochemicals, artificial intelligence, finance, and trade. By doing so, these institutions can better serve the advanced manufacturing and modern service sectors within the Greater Bay Area, ensuring that their curriculum and research efforts are tailored to meet the evolving needs of these key economic drivers; At the same time, schools can reduce some majors that are not suitable for the industrial structure, have low employment rates, and have high repeatability, in order to build a disciplinary structure that is suitable for the industrial structure of the Greater Bay Area, cultivate professional talents that meet the needs of industrial upgrading, and enhance the contribution ability of higher education to industrial upgrading. They can build a modern higher education system in the Greater Bay Area that is "layered and interconnected". The optimization of the hierarchical structure of higher education also depends on the construction of the modern higher education system. On the one hand, it is necessary to vertically connect vocational education at all levels in the Greater Bay Area, establish a higher vocational education system of "vocational undergraduate professional master professional doctoral", and highlight vocational skills and practical application abilities in talent cultivation; On the other hand, it is also necessary to horizontally integrate vocational

education and general education, build a flexible transfer and promotion mechanism between the two systems of "vocational education", and strengthen communication and connection between different levels of higher education.

6. Conclusion

This study offers a comprehensive ecological niche analysis of the higher education landscape within the Guangdong-Hong Kong-Macao Greater Bay Area (GBA). Our findings underscore the dynamic interplay between the region's higher education institutions and their socio-economic environment, highlighting the need for a strategic approach to optimize this ecosystem.

Through the application of a mathematical model, we have identified key imbalances and niche overlaps within the GBA's higher education sector. Our analysis reveals that while the GBA boasts a vibrant higher education landscape, there remains a pressing need for targeted strategies to enhance resource sharing, open cooperation, and industry-education integration.

The proposed optimization strategies aim to address these challenges by promoting a more cohesive and competitive educational environment. By aligning the GBA's higher education system with its economic and social objectives, we can foster a talent pool that is well-equipped to contribute to the region's growth and development.

Our research contributes to the body of knowledge on educational planning and policy-making in the GBA, providing actionable insights for stakeholders involved in shaping the future of higher education in the region. The study also calls for continued research and monitoring of the implementation of the proposed strategies to ensure their effectiveness and impact.

The conclusions drawn from this study are supported by a robust theoretical framework and empirical evidence, positioning it as a valuable resource for future academic and policy-oriented discourse on higher education optimization.

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