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Transportation Accessibility Evaluation of Educational Institutions Conducting Field Environmental Education Activities in Ecological Protection Areas: A Case Study of Zhuhai City

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Abstract: With the development of society, an increasing number of educational institutions have adopted field environmental education activities rather than classroom education. Field education can not only enhance students' environmental awareness but also enable them to fully understand environmental protection knowledge. Ecological protection areas are important bases for educational institutions to organize students to implement field environmental education. Focusing on Zhuhai City, this study explored spatial relationships between educational institutions and ecological protection zones using Kernel density estimation, the two-step floating catchment area method, and Thiessen polygons. Specific actions included measuring transportation accessibility and dividing the service scopes of ecological protection zones to provide field environmental education for educational institutions. These actions provided a helpful reference for educational institutions to conduct field environmental education activities effectively. The results showed the following: (1) Schools in Zhuhai City were mainly located in subdistricts and presented a spatial layout of "one primary and two secondary." Students were mainly concentrated in villages and towns and presented a spatial layout of "one core and two centers." Ecological protection zones were scattered in the township area; their spatial relationships with educational institutions were scattered. Meanwhile, their spatial relationship with the number of students was relatively concentrated. (2) In terms of the accessibility of educational institutions to ecological protection zones, the educational institutions in the northeast of Xiangzhou District and the middle of Doumen District had higher accessibility, while the educational institutions in the middle and south of Zhuhai City had lower accessibility, and the educational institutions in the middle of Xiangzhou District had the lowest accessibility. (3) Based on accessibility, the service scopes of field environmental education activities in ecological protection zones were divided into 15 blocks. Here, the educational institutions located in Xiangzhou District, the western part of Jinwan District, and western, middle, and eastern parts of Doumen District had relatively strong spatial dispersions with the ecological protection zones within their blocks, while the educational institutions located in the central and eastern parts of Jinwan District and northern and southern parts of Doumen District had relatively weak spatial dispersions with the ecological protection zones within their blocks.

Keywords: educational institutions; ecological protection zones; environmental education; accessibility; Zhuhai City

Citation: Zhou, C.; Zhang, D.; He, X. Transportation Accessibility Evaluation of Educational Institutions Conducting Field Environmental Education Activities in Ecological Protection Areas: A Case Study of Zhuhai City. *Sustainability* **2021**, *13*, 9392. https://doi.org/10.3390/su13169392

Academic Editors: Dina Mateus, Alexandros Stefanakis and Henrique Pinho

Received: 11 July 2021
Accepted: 19 August 2021
Published: 21 August 2021

1. Introduction

In the 1970s, foreign countries researched field environmental education in communities and marine regions. Their findings revealed that field environmental education by educational institutions is of great significance for protecting the ecological environment [1,2]. Thus, they introduced detailed field environmental courses. In China, the national economy has shifted from a stage of high-speed growth to high-quality development. Meanwhile, a prominent social contradiction is found in the growing public need for better living standards against unbalanced and inadequate development conditions. The people's need for an ecologically sufficient environment has also become an important aspect of this contradiction. This makes it particularly important for educational institutions to regularly conduct field environmental education activities in ecological protection zones. Environmental education is a social education practice activity; at the core of this is the relationship between humans and their environments. Institutions must work to solve environmental problems while aiming for sustainable development, which entails efforts to improve environmental awareness and effective participation among residents. Environmental education is conducive to the sustainable development of ecological protection. It can also improve the quality of human settlement environments and enhancing well-being among its residents [3].

Research on environmental education can be traced to the late 20th century [4]. A relatively mature research system has been established since. The current literature mainly includes studies aimed at the following: (1) Evaluations of environmental education include the effectiveness of enhancing environmental protection awareness among local residents and tourists. These issues have been evaluated based on tourists' visitations to wild animal habitats (e.g., dolphins, fruit bats, and crocodiles) and the introduction of relevant environmental protection knowledge [5–7]. Some studies have focused on the history of environmental education, future strategic positioning, and sustainable development [8–10]; (2) Investigations of how environmental education affects the behaviors of residents. For example, scholars have focused on high school and college students in Hungary to investigate the impacts of environmental education on consumption behaviors and daily environmental protection activities [11]. Others have targeted the influences of environmental education on the forest ecological protection behaviors of Ugandan residents in both the short-term and long-term contexts [12]. A structural equation model was used to explore the influences of environmental education on the behaviors of different cultural groups when recycling water resources [13]. Data obtained via questionnaire surveys have been used to determine whether it is effective for students to provide environmental education to their families [14,15]. Another study targeted 233 settlements in the pine forest region of the northeastern United States to explore the influences of environmental education on wildfires initiated by humans [16]; (3) The fusion of environmental education with other disciplines includes the enhanced integration of environmental education with natural science and management to improve the human ability to solve basic environmental problems [17,18]; (4) Carrying out environmental education based on different perspectives and media. Environmental education has been studied from the perspective of scale, a geographical factor [19]. A previous study investigated waste disposal among Indonesian children through 3R (reduce, reuse, recycle) activities [20]. Environmental education has also been conducted via the Internet, thus providing a convenient way to increase knowledge [21,22]. A 3D model has been applied to create an interactive virtual natural environment, thereby improving cognitive levels among students of environmental education [23]; (5) Establishing a research framework and perspective for environmental education includes the common development of education. For example, protected areas and ecotourism in Costa Rica have been promoted by establishing a sustainable development framework for environmental education [24]. An environmental education framework has also been constructed to ensure the harmonious development of an ecological society through local ecological services, thus improving happiness among residents [25]. Researchers have also examined how social structures affect the development and positioning of environmental education, especially in the socialist and capitalist contexts [26]; (6) Identity construction for environmental education teachers. From the high school geography perspective, research has elaborated on the important functions of teachers when providing environmental education [27].

The literature on environmental education primarily consists of studies targeted at the evaluation of environmental protection, behavioral impacts, interdisciplinary integration, teaching methods, the research framework and perspective, and other theoretical dimensions [28–30]. However, the research on field environmental education is relatively weak [31,32]. While the spatial study of educational institutions is mainly characterized by relevant spatial distribution characteristics, few spatial accessibility evaluations have focused on educational institutions that conduct field research activities [33–38].

Zhuhai City is located in the ecological core value area of the Guangdong-Hong Kong-Macao Greater Bay Area, which is rich in natural vegetation. Protected areas account for 27.1% of the total land area, with a forest coverage rate of 35.9%. There are also endangered species, including the Chinese white dolphin. Taken together, these qualities make the area an important ecological protection node on the west side of the Pearl River. The organic combination of environmental education and field investigation allows students to personally experience problems in the surrounding environment. In turn, this promotes a deeper understanding of how important it is to ensure that such areas remain protected. We created the following hypotheses: (1) The field environmental education resources vary according to the educational institution and student density. (2) The spatial representation of educational institutions varies according to their regional position. (3) The dispersions among educational institutions vary according to the region. Using Zhuhai City as a broad research area, this study implemented the kernel density estimation method, two-step floating catchment area method, and Thiessen polygons to explore the spatial accessibility of educational institutions to ecological protection zones. Here, the primary goal was to encourage and facilitate educational institutions in Zhuhai City to conduct robust field environmental education, expand the scope of field environmental education to cover the student population, provide useful references for the rational allocation of the service scope of ecological protection zones, and improve the efficiency of field environmental education activities [39,40].

2. Materials and Methods

2.1. Overview of the Study Area

Zhuhai City is located in the south-central section of Guangdong Province; it has Hong Kong and Shenzhen across the sea to the east, Macao to the south (Hengqin New District is further south, across the river), Jiangmen City to the west, and Zhongshan City to the north. With eight national first-class ports, it is the city with the largest marine area, the largest number of islands, and the longest coastline in the Pearl River Delta. In fact, it is known as the “city of hundreds of islands” (Figure 1). In addition to receiving the China Ecological Civilization Award, Zhuhai has been awarded several prestigious titles, including National Garden City, National Health City, National Ecological Demonstration Area, Top Ten Charming Cities in China, Top Ten Livable Cities in China, Excellent Tourism City in China, Most Happy City in China, and National Forest City.

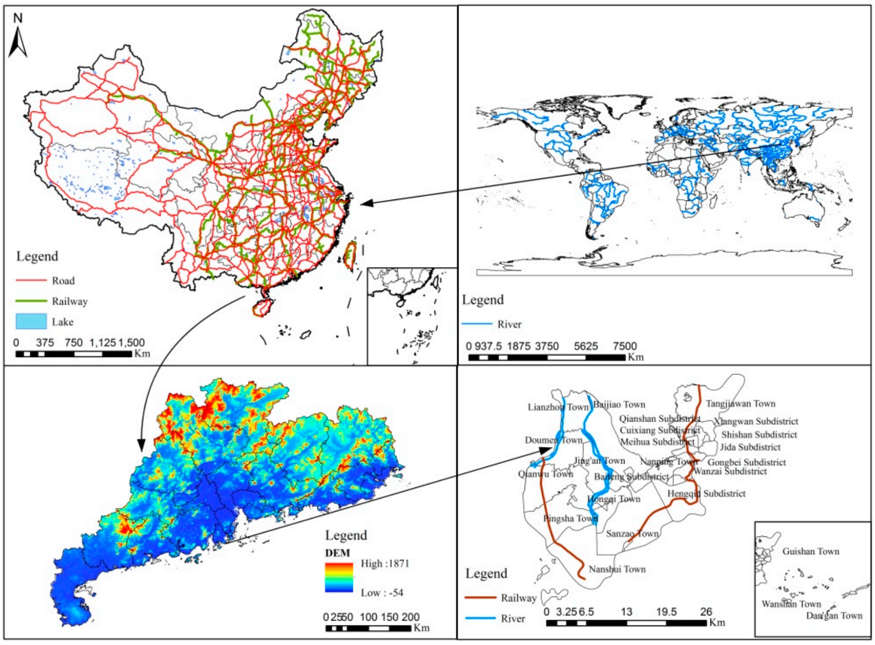

Figure 1. The location of the study area.

2.2. Data Source

This study used data pertaining to five main categories. First, data from schools of all levels in Zhuhai was included. Schools in Zhuhai mainly comprise 10 institutions of higher education (higher vocational colleges), 26 mixed high schools (18 nine-year schools, 4 complete high schools, and 4 twelve-year schools), 18 senior high schools (vocational high schools), 42 junior high schools (secondary technical schools), 127 primary schools, 335 kindergartens, 4 technical schools, and 2 special education schools. Among them, the universities and higher vocational colleges belong to higher education. The mixed high school refers to: a) primary and junior high schools implementing integrated education (nine-year schools), b) junior and senior high schools implementing integrated education (complete high schools), and c) primary, junior, and senior high schools implementing integrated education (twelve-year schools). Vocational high schools mean senior high schools that combine a general education with a vocational education. Secondary technical schools mean junior high schools that combine general with vocational education. Technical schools mean vocational schools with the main goal of developing skilled talents. Special education schools refer to compulsory education institutions implemented explicitly for children and adolescents with disabilities. Basic school information included the name of the school; operation category; organizational structure; educational level; construction area; physical area; and the number of classes, students, teaching staff, and full-time teachers. These data were derived from the 2020 municipal teaching facilities statistics. Second, data on ecological protection zones, which mainly comprised their names and areas, were used in the study. Third, traffic network data as taken from the traffic network map of Baidu (2020) were also included. Fourth, geospatial coordinate data were used. This mainly included the latitude and longitude coordinates of all schools and ecological protection zones as taken from the Baidu map coordinate pickup system (http://aqsc.shmh.gov.cn/gis/getpoint.htm) (accessed on 20 August 2021) (Figure 2). Fifth, other basic data that comprised administrative division data and DEM elevation data were also included in the study. These were obtained from the Resources and Environment Science and Data Center of the Chinese Academy of Sciences (http://www.resdc.cn/data.aspx?DATAID=333) (accessed on 20 August 2021) (Table 1).

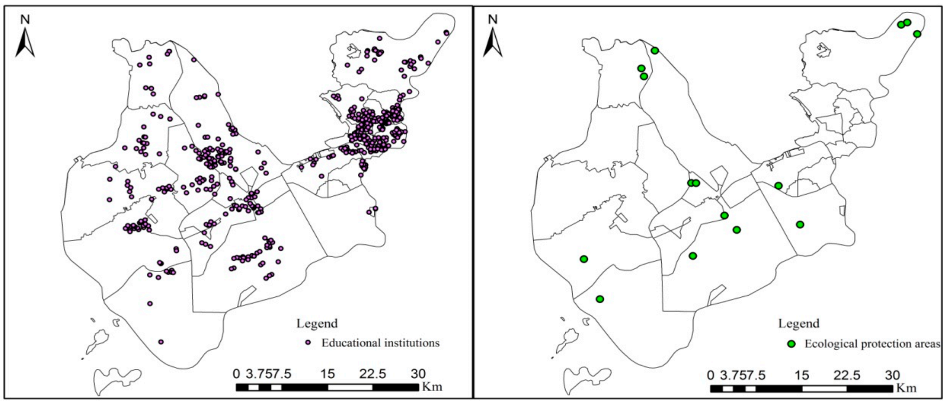

Figure 2. Sample points of educational institutions and ecological protection areas in Zhuhai City.

Table 1. Data sources and descriptions.

Data Category	Data Description	Data Type	Data Source
School data	Number of students, educational level, floor area, etc.	Panel data	Educational facilities statistics
Ecological protection zone data	Ecological protection zone name and area	Panel data	Statistical report on ecological protection zones
Traffic network data	Highways and railways	Vector data	Baidu map
Spatial coordinate data	Latitude and longitude coordinates of schools and ecological protection zones	Vector data	Baidu map coordinate pickup system
Administrative division data	Administrative boundary	Vector data	Resources and Environment Science and Data Center of the Chinese Academy of Sciences
DEM elevation data	Topographic elevation	Raster data	Resources and Environment Science and Data Center of the Chinese Academy of Sciences

2.3. Research Methods

2.3.1. Kernel Density Estimation

As the collection of the geographic coordinates of the schools resulted in a large amount of point data, a kernel density algorithm was used to demonstrate the spatial distribution and agglomeration of the schools as follows. Let x_1, x_2, …, and x_n be a sample drawn from a population with a distribution density function *f*, where *f(x)* symbolizes the estimated value of *f* at a given point *x*, which can be calculated using the Parzen-Rosenblatt window method.

$$f\left(x\right)=\frac{1}{nh}\sum_{i=1}^{n}k\left(\frac{x-x_i}{h}\right), \tag{1}$$

where *k* is the kernel function, *h* indicates the bandwidth and $h > 0$, *n* represents the number of samples, and $(x- x_i)$ represents the distance from the estimated point *x* to the sample x_i.

ArcGIS10.2 software was used to conduct a spatial visualization analysis of the agglomeration characteristics of educational institutions and their students in Zhuhai City.

2.3.2. Two-Step Floating Catchment Area Method

The two-step floating catchment area method was first proposed by Radke and Mu in 2000 [41]. It is a special type of gravity model that overcomes the defects of the early floating catchment area method. Based on both the demand and supply points, two steps are taken to calculate the accessibility to ecological protection zones, as implied by the name [42]. The calculation steps are as follows:

In the first step, all demand points are searched (*c*) within the distance threshold (d_0) from the supply point *j*. Then, the supply-demand ratio R_j is calculated:

$$\mathrm{R}_j = \frac{S_j}{\sum_{r=1,2,3,4} \sum_{k \in D_r} P_c}, \quad (2)$$

where D_r is the distance from demand point *c* to supply point *j*, P_c is the demand for spatial resources of the ecological protection zone at point *c*, and S_j is the total supply at supply point *j*.

In the second step, the supply point (*j*) within the threshold range (d_0) is searched from each demand point *i*. Then, the supply-demand ratios (R_j) of all the supply points are added to obtain the A^F_i of demand point *i*:

$$A_i^F = \sum_{r=1,2,3,4} \sum_{j \in D_r} R_j, \quad (3)$$

where D_r is the distance from the demand point *k* to the supply point *j*, and R_j is the supply-demand ratio of the supply point *j* within the range of the demand point *i*. A larger A^F_i indicates better accessibility and vice versa.

2.3.3. Thiessen Polygons

In Thiessen polygons, the center of gravity relates to all neighboring sampling points, restricting it to triangles, and the vertical bisection method is used to divide the calculation units. According to the ecological space nodes in the calculation area, several non-nested triangles were connected by taking the ecological protection zone as a vertex; the formed triangles were converted to acute-angle triangles as far as possible. Then, the center of gravity for each triangle was calculated (the intersection of the three perpendicular bisectors of the triangle). Using the center of gravity of these triangles, the calculation area was divided into several school units to ensure that there was an ecological protection zone demonstration base near the center of each school unit. The calculation formula is as follows:

$$\overline{P} = \frac{1}{A} \sum_{i=1}^{n} p_i a_i, \quad (4)$$

where a_i is the area of the *i-th* Thiessen polygon (i.e., the *i-th* computational unit); *pi* is the amount of the *i-th* Thiessen polygon, *i=1, 2, …, n*; *n* is the number of Thiessen polygons in the region; and *A* is the area of the region.

3. Results

3.1. Spatial Layout of Teaching Institutions and Students with Ecological Protection Zones

This study employed the kernel density analysis method. As shown in Figure 3, there were some differences in the spatial distribution characteristics of educational institutions and their student numbers in Zhuhai. Educational institutions in Zhuhai are mainly concentrated in the main urban area of Xiangzhou District and show the structural spatial characteristic of "one primary and two secondary." "One primary" (59509–74385) refers to Cuixiang Subdistrict and Qianshan Subdistrict, both of which are high-value districts with a high density of educational institutions in Zhuhai City. The spatial characteristics of the density values show that they extend to the "southwest-northeast" direction with the density polar nucleus at the center and decrease in layers moving outward. "Two secondary" (44632–59508) refers to Gongbei Subdistrict and Baijiao Town, which are in the second-highest value area of educational institution density in Zhuhai. In addition, educational institutions in Wanzai Subdistrict, Baiteng Subdistrict, Tangjiawan Town, Jingan Town, Pingsha Town, Sanzao Town, and Qianwu Town are gathered along a small spatial scale. Compared with educational institutions, the spatial agglomeration characteristics of students in educational institutions in Zhuhai are more significant; they are mainly concentrated in the north of Xiangzhou District, showing the structural spatial characteristics of "one core and two centers." "One core" (103346298–129182872) refers to Tangjiawan Town, which is a high-value area in student density among the educational institutions in Zhuhai City; the spatial characteristics of the density values are shown as concentric circles, with an outward decline from the density polar nucleus at the center. "Two centers" (77509724–103346297) refer to Hongqi Town and Sanzao Town, which are the second-highest value areas in student density among the educational institutions in Zhuhai. In addition, student density was characterized by small-scale spatial agglomeration among the educational institutions in Xiangwan Subdistrict, Cuixiang Subdistrict, Shishan Subdistrict, Jida Subdistrict, Gongbei Subdistrict, and Baijiao Town.

The natural discontinuity method in ArcGIS was used to divide the total Zhuhai ecological protection zone into five categories, including a large ecological protection zone (73.75 km^2–460.00 km^2), a relatively large ecological protection zone (10.01 km^2–73.74 km^2), a medium-sized ecological protection zone (3.63 km^2–10.00 km^2), a relatively small ecological protection zone (1.23 km^2–3.62 km^2), and a small ecological protection zone (0.13 km^2–1.22 km^2) (Figure 4). There were relatively few large-scale ecological protection zones; the main distribution area was Tangjiawan Town in the northeast of Xiangzhou District of Zhuhai City. The medium-sized ecological protection zones were relatively concentrated, mainly being found in the middle of Zhuhai City (i.e., the area adjacent to Jingan Town and Baiteng Subdistrict). The relatively small ecological protection zones were mainly located in the southern area of Zhuhai City, including Pingsha Town, Sanzao Town, and Hengqin Town. With regard to spatial layout, the small ecological protection zones were relatively scattered; they were mainly distributed in Lianzhou Town, Baijiao Town, Nanshui Town, Sanzao Town, Hongqi Town, Nanping Town, and Tangjiawan Town.

As for spatial relationships, there were no layouts for ecological protection zones near the areas with the highest (59509–74385) or the second-highest (44632–59508) densities of educational institutions. For field environmental education, there were relatively few resources. However, there were some zones near the high-value area with high student density, including a large-scale ecological protection zone (Pearl River Estuary China White Dolphin National Nature Reserve), a relatively large ecological protection zone (Qi'ao-Dangan Island Provincial Nature Reserve), and a relatively small ecological protection zone (Qi'ao Mangrove Wetland Park). The low-density area also had nearby zones, including two medium-sized ecological protection zones (Huang Yang River Wetland Park and Huafa Water County Provincial Wetland Park) and a relatively small ecological protection zone (Jinhu Wetland Park), all of which offered relatively rich resources for field environmental education.

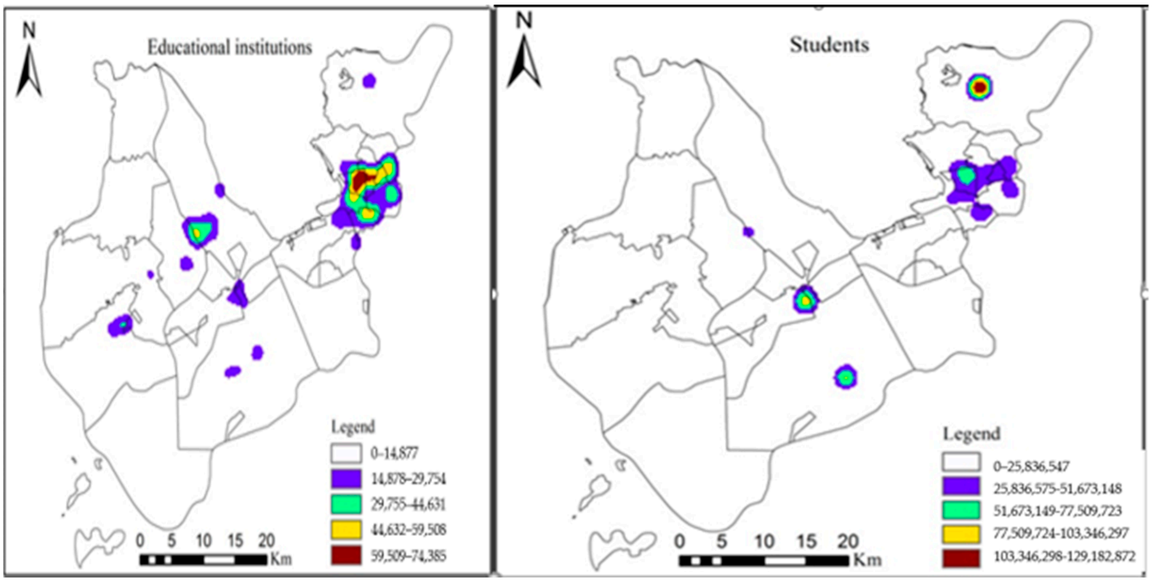

Figure 3. A distribution density map of educational institutions and students in Zhuhai City.

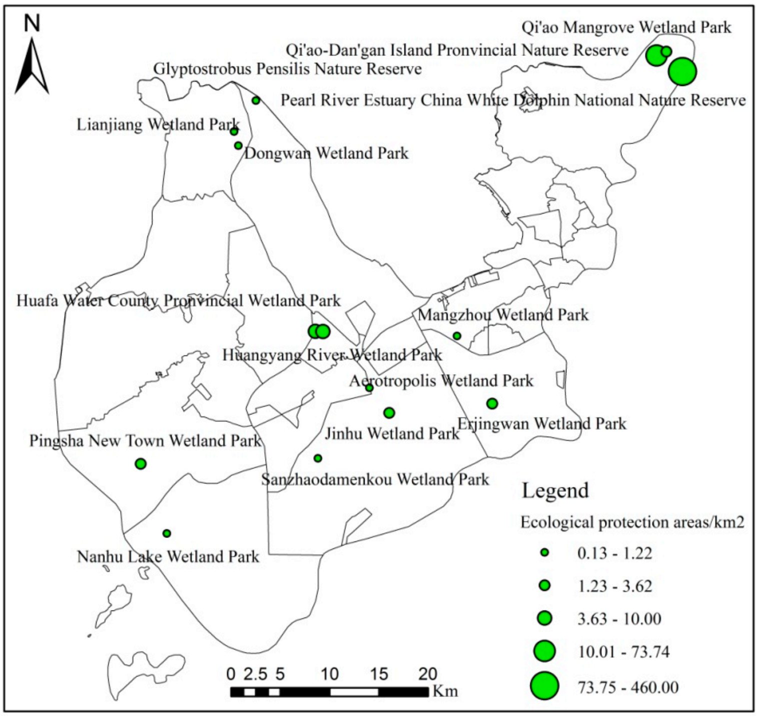

Figure 4. The distribution of ecological protection areas in Zhuhai City.

3.2. Accessibility of Educational Institutions to Ecological Protection Zones

In terms of hierarchy and specialization, educational institutions in Zhuhai are divided into higher education institutions (higher vocational colleges), mixed high schools (nine-year schools, complete high schools, and twelve-year schools), senior high schools (vocational high schools), junior high schools (secondary technical schools), primary schools, kindergartens, and special skill schools (technical schools and special education schools). Using the Jenks natural breaks classification in ArcGIS, the accessibility of educational institutions to ecological protection zones was classified into five levels. As shown in Figure 5, kindergartens and primary schools in Zhuhai have the same spatial accessibility to environmental education bases and overall accessibility to educational institutions in the ecological protection zone. Among these areas, Xiangwan Subdistrict, Cuixiang Subdistrict, Hengqin Subdistrict, and educational institutions in eastern Tangjiawan Town had the highest accessibility (0.718–1.136) to environmental education bases in the ecological protection zone; this was followed by Doumen Town, Jing'an Town, the eastern section of Qianwu Town, the southern section of Lianzhou Town, and northern and southwestern sections of Baijiao Town (0.295–0.717). Educational institutions in Baiteng Subdistrict, Nanshui Town, the middle section of Sanzao Town, the western area of Tangjiawan Town, and the eastern and southern areas of Baijiao Town had average accessibility (0.200–0.294) to environmental education bases in the ecological protection zone. Meanwhile, those in the western area of Hongqi Town, the eastern area of Pingsha Town, and the western area Sanzao Town had poor accessibility (0.100–0.190) to environmental education bases in the ecological protection zone. Finally, the poorest levels of access (0–0.090) to environmental education bases in the ecological protection zone were found for educational institutions in Qianshan Subdistrict, Shishan Subdistrict, Jida Subdistrict, Meihua Subdistrict, Gongbei Subdistrict, Wanzai Subdistrict, northern Pingsha Town, central Qianwu Town, eastern Hongqi Town, and northern Sanzao Town.

In terms of the accessibility of junior high schools (secondary technical schools) in Zhuhai to environmental education bases in ecological protection zones, those with the highest levels (0.718–0.938) were mainly concentrated in Xiangwan Subdistrict and the eastern area of Tangjiawan Town. Those with high accessibility (0.295–0.717) were mainly concentrated in Doumen Town, Jing'an Town, Lianzhou Town, the eastern section of Qianwu Town, and northern and southwestern parts of Baijiao Town. Next, those with general accessibility (0.172–0.294) were mainly concentrated in the western area of Tangjiawan Town, while those with poor accessibility (0.020–0.171) were mainly concentrated in Baiteng Subdistrict, Nanshui Town, and the middle section of Sanzao Town. Finally, those with the poorest accessibility (0–0.019) were mainly concentrated in Shishan Subdistrict, Jida Subdistrict, Gongbei Subdistrict, Wanzai Subdistrict, Meihua Subdistrict, Pingsha Town, the middle section of Qianwu Town, the eastern section of Hongqi Town, and the western section of Sanzao Town.

In terms of the accessibility of mixed high schools (nine-year schools, complete high schools, and twelve-year schools) in Zhuhai to environmental education bases in ecological protection zones, those with the highest levels of accessibility (0.718–0.938) were mainly concentrated in the eastern area of Tangjiawan Town. Those with high accessibility (0.295–0.717) were mainly concentrated in Doumen Town, Jing'an Town, Qianwu Town, and Baijiao Town. Those with general accessibility (0.160–0.294) were primarily concentrated in the western area of Tangjiawan Town, while those with poor accessibility (0.020–0.159) were mainly concentrated in the eastern section of Sanzao Town. Finally, those with the poorest accessibility (0–0.019) were mainly concentrated in Cuixiang Subdistrict, Shishan Subdistrict, Jida Subdistrict, Gongbei Subdistrict, Wanzai Subdistrict, Meihua Subdistrict, Nanping Subdistrict, and the western section of Sanzao Town.

In terms of the accessibility of senior high schools (vocational high schools) in Zhuhai to environmental education bases in ecological protection zones, those with the highest levels of accessibility (0.718–0.938) were mainly concentrated in Xiangwan Subdistrict and Tangjiawan Town. Those with high accessibility (0.172–0.717) were mainly concentrated in Doumen Town and Jing'an Town. Next, those with general accessibility (0.010–0.171) were mainly concentrated in Baijiao Town, while those with poor accessibility (0.005–0.09) were mainly concentrated in Sanzao Town. Finally, those with the poorest accessibility (0–0.004) were mainly concentrated in Cuixiang Subdistrict, Qianshan Subdistrict, Meihua Subdistrict, and Pingsha Town.

In terms of the accessibility of higher education institutions (higher vocational colleges) in Zhuhai to environmental education bases in ecological protection zones, those with the highest (0.295–0.938) and high levels of accessibility (0.160–0.294) were mainly concentrated in Xiangwan Subdistrict and Tangjiawan Town. Next, those with general accessibility (0.010–0.159) and poor accessibility (0.005–0.009) were mainly concentrated in Sanzao Town and Hongqi Town. Finally, those with the poorest accessibility (0–0.004) were mainly concentrated in Meihua Subdistrict.

In terms of the accessibility of special skill schools (technical schools and special education schools) in Zhuhai to environmental education bases in ecological protection zones, those with the highest (0.295–0.638) and high levels (0.060–0.294) of accessibility were mainly concentrated in Jing'an Town and Tangjiawan Town. Next, those with poor accessibility (0.020–0.030) were mainly concentrated in Jida Subdistrict, Meihua Subdistrict, and Nanping Town. Finally, those with the poorest accessibility (0–0.010) were mainly concentrated in Qianwu Town.

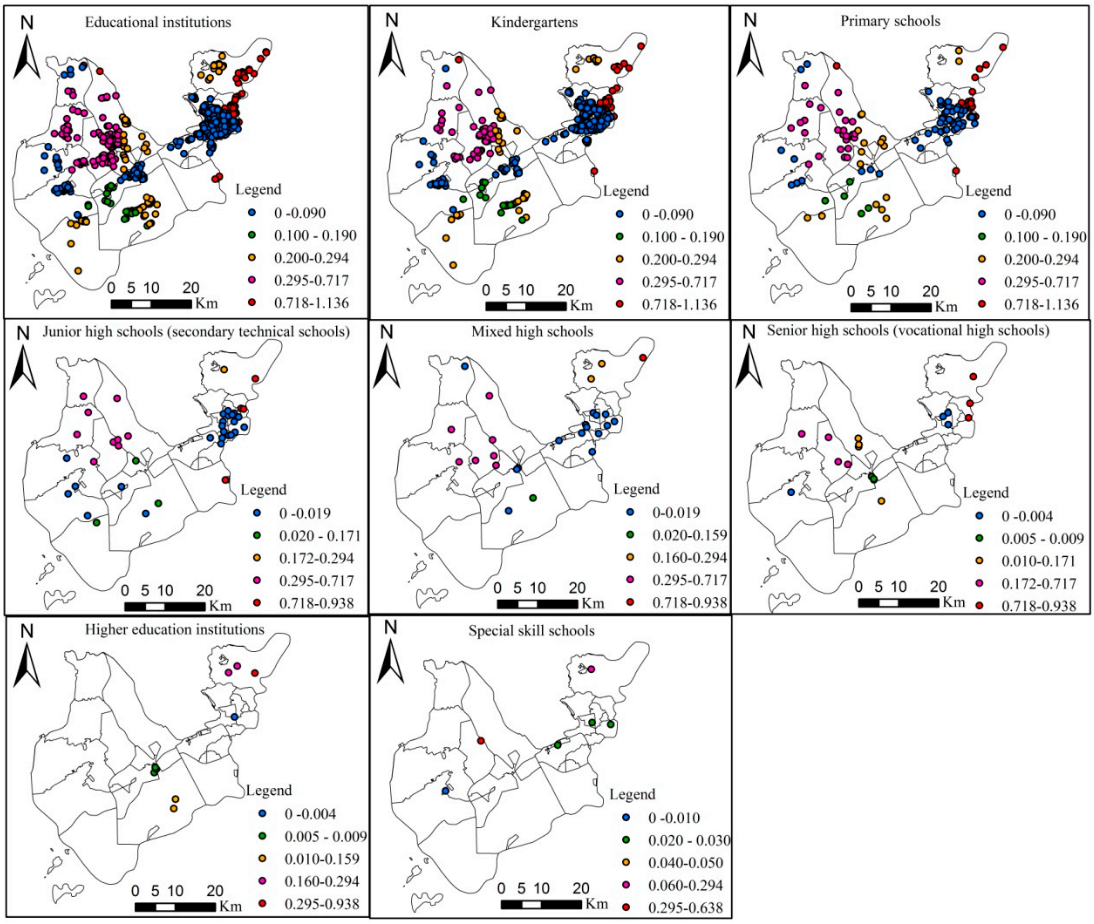

Figure 5. Spatial layout of accessibility to ecological protection zones based on the level of educational institutions.

3.3. Division of Service Scope for Environmental Education in Ecological Protection Zones

Using Thiessen polygons, the field environmental education service scopes of the 15 ecological protection zones in Zhuhai City can be divided into 15 blocks (Table 2). As shown in Figure 6, those with larger areas of environmental education services mainly included block 1, block 4, block 11, block 12, block 13, block 14, and block 15, while those with smaller areas of environmental education service mainly include block 2, block 3, block 5, block 6, block 7, block 8, block 9, and block 10.

As for the service scope of ecological protection zones for regional environmental education, block 9, block 10, and block 11 mainly provided field environmental education services for educational institutions in the north of Doumen District, block 6 and block 12 mainly provided these services for educational institutions in the south of Doumen District, block 13 and block 15 mainly provided these services for educational institutions in the western of Jinwan District and southwest of Doumen District, block 14 mainly provided these services for educational institutions in the middle of Jinwan District, block 7 and block 8 mainly provided these services for educational institutions in the eastern of Jinwan District, block 5 mainly provided these services for educational institutions in Hengqin New District, block 4 mainly provided these services for educational institutions in the middle and south of Xiangzhou District, and block 1 and block 3 mainly provided these services for educational institutions in the north of Xiangzhou District.

Due to its small size, proximity to blocks 1 and 3, and the absence of teaching facilities within its service area, block 2 did not provide field environmental services to educational institutions. In terms of the spatial relationships between educational institutions and ecological protection zones in different blocks, those between institutions in block 1, block 3, block 4, block 5, block 11, block 13, and block 15 were relatively scattered. By contrast, educational institutions in block 7, block 8, block 9, block 10, and block 14 showed relatively concentrated spatial relationships with their respective ecological protection zones.

Table 2. The field environmental education service scopes of ecological protection zones.

Code of Block	Name of Block
Block 1	Qi'ao-Dangan Island Provincial Nature Reserve
Block 2	Qi'ao Mangrove Wetland Park
Block 3	Pearl River Estuary China White Dolphin National Nature Reserve
Block 4	Mangzhou Wetland Park
Block 5	Erjingwan Wetland Park
Block 6	Huangyang River Wetland Park
Block 7	Aerotropolis Wetland Park
Block 8	Jinhu Wetland Park
Block 9	Glyptostrobus Pensilis Nature Reserve
Block 10	Lianjiang Wetland Park
Block 11	Dongwan Wetland Park
Block 12	Huafa Water County Provincial Wetland Park
Block 13	Pingsha New Town Wetland Park
Block 14	Sanzhaodamenkou Wetland Park
Block 15	Nanhu Lake Wetland Park

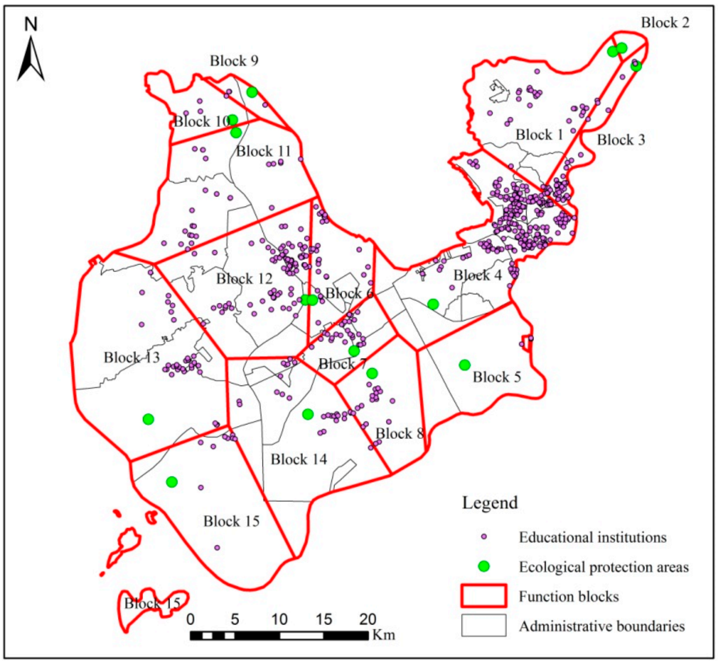

Figure 6. The division of field environmental education service functions in ecological protection zones.

4. Discussion

4.1. Study Innovations and Significance

This qualitative study explored spatial relationships between educational institutions and field environmental education bases, measured the respective levels of accessibility to those areas, and categorized the spatial scopes of environmental education services provided by ecological protection zones. Such provisions not only exceed the limitations of a traditional theoretical environmental education but also combine environmental education with practice, thus cultivating student awareness of the need for environmental protection and responsibility for different educational stages. In turn, students can establish environmentally friendly concepts of value in daily life. Meanwhile, this study's findings are critical for solving problems stemming from the spatial relationships between educational institutions and environmental education bases, thus improving the efficiency of field environmental education activities conducted by those institutions.

Compared to existing research from China and other countries, this study offers the following innovations: (1) Innovative research perspective: Most studies have implemented theoretical approaches when exploring and evaluating the management methods and ideas of environmental education. As such, there is a lack of practical evidence about both the accessibility of educational institutions to field environmental education bases and the spatial divisions of field environmental education service scopes, particularly from the field research perspective [43–45]. (2) Innovative research data and methods: Most previous studies have obtained data through questionnaire surveys. Further, relevant research on environmental education is usually conducted via qualitative methods, such as interviews. The basic data used in this study were derived from statistical information collected by relevant management departments. In addition, findings on the spatial relationships, accessibility, and service ranges of educational institutions and field environmental education bases were calculated using quantitative methods, which offer more robust scientific validity and accuracy [46,47].

4.2. Countermeasures and Suggestions

The characteristics of the analyzed spatial relationships between ecological protection zones and teaching institutions in Zhuhai City highlight some important measures that will help educational institutions more efficiently conduct field environmental education.

1. Educational institutions in Zhuhai are mainly located in the subdistricts of Cuixiang and Qianshan. Field environmental education resources are insufficient and have low accessibility to ecological protection zones in these areas. Therefore, the coastal ecological area resources in central and southern Xiangzhou District should be fully utilized. Moreover, the coastal ecological protection zones and the environmental protection demonstration bases in Xiangzhou District should be strengthened. This will provide a certain environmental education practice base for education institutions in Xiangzhou District while alleviating the burden of conducting field environmental education placed on Mangzhou Wetland Park. Simultaneously, such efforts will improve spatial accessibility between educational institutions in Xiangzhou District and field environmental education bases. However, strict limits should also be placed on natural resources development, planting, breeding, and other activities detrimental to the construction of ecological services in the ecological protection zones. In sum, this will aid in the proper management of field environmental education activities while leaving ecological functions undisturbed.

2. While the central and southern areas in Zhuhai City have many students, the ecological protection zones in these areas are limited. Thus, increasing the scales of ecological protection zones in central and southern Zhuhai City and developing marine parks with marine environmental protection in southern Zhuhai City is necessary. The marine park

will primarily be used to protect, repair, and properly use living resources through publicity and educational infrastructure construction. These efforts will improve the efficiency of field environmental education activities in central and southern Zhuhai City.

4.3. Outlook

This study explored spatial relationships between educational institutions and ecological protection zones in order to determine accessibility levels. While this allowed for a robust evaluation of the spatial service scopes of field environmental education activities conducted in these ecological protection zones, there were also the following limitations: (1) Due to the effects of leadership characteristics and other preferences, some educational institutions may not select ecological protection zones within their service scopes; rather, they tend to choose field environmental education bases that are in zones located further away. (2) Due to both the variability of marine climates and the complexity of marine traffic conditions, some educational institutions cannot currently access island-type ecological protection zones (e.g., Miaowan Coral Nature Reserve). For that reason, this study did not consider island-type nature reserves in its analyses. Additional research is therefore needed to investigate whether and how staff at teaching institutions select environmental education bases through questionnaires that incorporate marine climates and traffic conditions via the evaluation indicators used to assess the level of accessibility to ecological protection zones. This will clarify issues pertaining to island-type ecological protection zones and further divide the service scope of environmental education activities.

Future research should focus on field environmental education activities and field trips from a global perspective to meet the needs of educational institutions at different levels and improve their efficiency worldwide.

4.4. Mechanism Behind the Spatial Differences

1. The effect of regional economic development on educational institutions: Differences in economic development are the primary factor of the imbalanced spatial distribution of educational institutions within the city. Due to factors such as geographic location and industry structure, the economic development of districts in Zhuhai City varied significantly, leading to an imbalance in the investment of education and construction funding for educational institutions. Most educational institutions were highly concentrated in regions with rapid economic development, such as Xiangzhou District.
2. The demand for educational resources by population size: Population size was the core element affecting the spatial distribution of educational institutions, as large populations provide a stable source of students. Therefore, the concentration of educational institutions in a given region was positively correlated to its population size.

5. Conclusions

Using statistical data obtained from teaching institutions and ecological protection zones in Zhuhai, this study explored the spatial relationships between educational institutions and ecological protection zones via the kernel density estimation method, two-step floating catchment area method, and Thiessen polygons. This revealed whether educational institutions had appropriate access to these areas when conducting field environmental education while also providing a way to categorize spatial service scopes in each ecological protection zone. The main conclusions are as follows:

1. Educational institutions in Zhuhai are mainly located in the subdistricts of Xiangzhou District, with a "one primary and two secondary" spatial structure. Here, "one primary" refers to Cuixiang Subdistrict and Qianshan Subdistrict, while "two secondary" refers to Gongbei Subdistrict and Baijiao Town. Students in Zhuhai are mainly distributed in villages and towns in northeastern Xiangzhou District, with a "one core and two centers" structural characteristic. "One core" is Tangjiawan Town,

while "two centers" are Hongqi Town and Sanzao Town. The relatively large nature reserves are mainly distributed in Tangjiawan Town in northeastern Zhuhai, Jingan Town in central Zhuhai, and the adjacent area of the Baiteng Subdistrict. The ecological protection zones with relatively small areas are mainly distributed in southern and northwestern Zhuhai City. With this, we concluded that environmental education resources in both high-value and second-high-value areas of educational institution density are relatively scarce. In contrast, environmental education resources in the high-value and second-high-value areas of student density are relatively affluent.

2. Educational institutions with different levels and specialties had similar levels of spatial accessibility to ecological protection zones. Educational institutions with high and relatively high accessibility are mainly distributed in the township subdistricts in northeastern Xiangzhou District and central Doumen District. Educational institutions with general and relatively low accessibility are mainly located in township subdistricts in the central and southern sections of Zhuhai City. Finally, educational institutions with the poorest accessibility are mainly located in township subdistricts in the central part of the Xiangzhou District. Kindergartens and primary schools in Zhuhai City have the highest accessibility to environmental education bases in ecological protection zones; here, the spatial representation is the most similar to the overall accessibility of educational institutions. Junior high schools (secondary technical schools) and mixed high schools have the second highest accessibility to environmental education bases in ecological protection zones, while senior high schools (vocational high schools) and higher education institutions high schools have relatively low accessibility to environmental education bases in ecological protection zones. Meanwhile, special skills schools have the poorest level of accessibility to environmental education bases in ecological protection zones.
3. Zhuhai City can be divided into 15 field environmental education blocks. Block 1, block 3, and block 4 mainly provide field environmental education services to Xiangzhou District, while block 5 mainly provides services to Hengqin New District. Next, block 6, block 9, block 10, block 11, and block 12 mainly provide services to Doumen District, while block 13 and block 15 mainly provide services to Gaolan Port. Finally, block 7, block 8, and block 14 mainly provide services to Jinwan District, while block 2 does not provide any such services. There are relatively strong spatial dispersions among educational institutions located in Xiangzhou District, the western section of Jinwan District, and the western, central, and eastern sections of Doumen District with the ecological protection zones within their respective blocks. By contrast, relatively weak dispersions are found among educational institutions located in the central and eastern parts of Jinwan District and northern and southern parts of Doumen District, with the ecological protection zones within their respective blocks. Hence, we concluded that strong spatial dispersions exist among high-end educational institutions and relatively weak dispersion among second-high value areas.

Author Contributions: C.Z. contributed to all aspects of this work; D.Z. wrote the main manuscript text, conducted the experiment, and analyzed the data; X.H. revised the paper. All authors reviewed the manuscript. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data is contained within the article.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Heras, R. Contribution of environmental education centres to fieldtrips in primary schools (Original title in Catalan: Contribució delsequipaments d'educació ambiental a les sortides escolars del'educació primària). *Environ. Educ. Res.* **2015**, *22*, 438–439, doi:10.1080/13504622.2015.1118743.
2. Ordon, K.J.; Bartelheimer, M.; Asshoff, R. Biology student teachers' interest and self-efficacy in planning and conducting field trips after participation in a university course. *Environ. Educ. Res.* **2021**, *27*, 88–109, doi:10.1018/13504622.2020.1849565.
3. Tian, S.Z.; Li, X.M.; Yang, J.; Zhang, C.H.; Zhang, Y. Initial Study on Triaxiality of Human Settlements—In the Case of 10 Districts (Counties) of Dalian. *Sustainability* **2014**, *6*, 7276–7291, doi:10.3390/su6107276.
4. Rickinson, M. Learners and Learning in Environmental Education: A critical review of the evidence. *Environ. Educ. Res.* **2001**, *7*, 207–320, doi:10.1080/13504620120065230.
5. Detra, D.E.; James, L.P. Evaluating the Effectiveness of Residential Environmental Education Programs in Fostering Postive Attitudes toward Wildlife. *J. Environ. Educ.* **1999**, *31*, 33–39, doi:10.1080/00958969909598630.
6. Garret, S.R.T.; Granek, E.; Lengel, K.L.; Raboude, M.J.; Reason, P.F.; Sewall, B.J. Environmental education as a component of multidisciplinary conservation programs: Lessons from the conservation initiatives for critically endangered fruit bats in the Western Indian Ocean. *Conserv. Programs* **2005**, *19*, 75–85, doi:10.1111/j.1523-1739.2005.00548.x.
7. Jan, V.D.P.; Myrna, C.C.; Merlijn, V.W.; Wouter, T.D.G. Assessing the effectiveness of environmental education: Mobilizing public support for Philippine crocodile conservation. *Conserv. Lett.* **2011**, *4*, 313–323, doi:10.1111/j.1755-263X.2011.00181.x.
8. Kara, C.; Matthew, B. Environmental education: Time to reflect, time for change. *Eval. Program Plan.* **2010**, *33*, 155-158.
9. Joe, E.H. Environmental education evaluation: Reinterpreting education as a strategy for meeting mission. *Eval. Program Plan.* **2010**, *33*, 180–185, doi:10.1016/j.evalprogplan.2009.07.004.
10. Lucie, S. Environmental Education and Sustainable Development: A Further Appraisal. *Can. J. Environ. Educ.* **1996**, *1*, 7–34.
11. Ágnes, Z.; Zsuzsanna, M.S.; Anna, S.; Tamás, K. Greening due to environmental education? Environmental knowledge, attitudes, consumer behavior and everyday pro-environmental activities of Hungarian high school and university students. *J. Clean. Prod.* **2013**, *48*, 126–138, doi:10.1016/j.jclepro.2012.11.030.
12. Kuhar, C.W.; Bettinger, T.L.; Lehnhardt, K.; Osuo, T.; Cox, D. Evaluating for Long-Term Impact of an Environmental Education Program at the Kalinzu Forest Reserve, Uganda. *Am. J. Primatol.* **2010**, *72*, 407–413, doi:10.1002/ajp.20726.
13. Fu, H.L.; Liu, X.J.A Study on the Impact of Environmental Education on Individuals' Behaviors Concerning Recycled Water Reuse. *Eurasia J. Math. Sci. Technol. Educ.* **2017**, *13*, 6715–6724, doi:10.12973/ejmste/78192.
14. Damerell, P.; Howe, C.; Milner-Gulland, E.J. Child-orientated environmental education influences adult knowledge and household behaviour. *Environ. Res. Lett.* **2013**, *8*, 015016, doi:10.1088/1748-9326/8/1/015016.
15. Ballantyne, R.; Fien, J.; Packer, J. School Environmental Education Programme Impacts upon Student and Family Learning: A Case Study Analysis. *Environ. Educ. Res.* **2001**, *7*, 23–27, doi:10.1088/13504620124123.
16. Robert, L.R. The influence of landscape preference and environmental education on public attitudes toward wildfire management in the Northeast pine barrens (USA). *Landsc. Urban Plan.* **2012**, *107*, 55–68, doi:10.1016/j.lanLandurbplan.2012.04.010.
17. Arjen, E.J.; Wals, M.B.; Justin, D.; Robert, B.S. Convergence between Science and Environmental Education. *Science* **2014**, *344*, 583–584, doi:10.1126/science.1250515.
18. Shirley, V.; Will, F. Interdisciplinary environmental education: Elements of field identity and curriculum design. *J. Environ. Stud. Sci.* **2011**, *1*, 14–35, doi:10.1007/s13412-011-0007-2.
19. Chang, C.H.; Gillian, K. Considering geographical and environmental education at scales. *Intern. Res. Geogr. Environ. Educ.* **2021**, *30*, 91–94, doi:10.1080/10382046.2021.1912969.
20. Sufia, R.; Arisona, R.D. Introducing environmental education to early children through 3R activities (an effort for Indonesia free trash). *IOP Conf. Ser. Earth Environ. Sci.* **2021**, *747*, 012030, doi:10.1088/1755-1315/747/1/012030.
21. Chang, C.S.; Chen, T.S.; Hsu, W.H. The study on integrating Web Quest with mobile learning for environmental education. *Comput. Educ.* **2011**, *57*, 1228–1239, doi:10.1016/j.compedu.2010.12.005.
22. Vicente, A.C.B.; Rafael, M.D.; Víctor, A.C.B.; Ana, D.C.T.S. Environmental education for small- and medium-sized enterprises: Methodology and e-learning experience in the Valencian region. *J. Environ. Manag.* **2008**, *87*, 507–520, doi:10.1016/j.jenvman.2007.01.041.
23. Barbalios, N.; Ioannidou, I.P.; Tzionas, S.P. A model supported interactive virtual environment for natural resource sharing in environmental education. *Comput. Educ.* **2013**, *62*, 231–248, doi:10.1016/j.compedu.2012.10.029.
24. Nicole, B. Environmental education in Costa Rica: Building a framework for sustainable development? *Int. J. Educ. Dev.* **2008**, *28*, 348–358, doi:10.1016/j.ijedudev.2007.05.008.
25. Keith, G.T.; Marianne, E.K. Urban Environmental Education from a Social-Ecological Perspective: Conceptual Framework for Civic Ecology Education. *Cities Environ.* **2010**, *3*, 11, doi:10.15365/cate.31112010.
26. John, H. Locating Environmental Education between Modern Capitalism and Postmodern Socialism: A Reply to Lucie Sauvé. *Can. J. Environ. Educ.* **1999**, *4*, 36–45.
27. Elizabeth, A.C.R. Building Teacher Identity in Environmental and Sustainability Education: The Perspectives of Preservice Secondary School Geography Teachers. *Sustainability* **2021**, *13*, 5321, doi:10.3390/su13095321.
28. Niranjan, C. What Makes Environmental and Sustainability Education Transformative: A Re-Appraisal of the Conceptual Parameters. *Sustainability* **2021**, *13*, 5100, doi:10.3390/su13095100.

29. Annelise, C.H.; William, J.H. Challenges and opportunities for evaluating environmental education programs. *Eval. Program Plan.* **2010**, *33*, 159–164.
30. Alex, K.; Marianne, E.K.; Richard, C.S. The impact of environmental education on sense of place among urban youth. *Ecosphere* **2012**, *3*, 29, doi:10.1890/ES11-00318.1.
31. Zhang, D.H.; Zhou, C.S.; Xu, W.W. Spatial-Temporal Characteristics of Primary and Secondary Educational Resources for Relocated Children of Migrant Workers: The Case of Liaoning Province. *Complexity* **2020**, *13*, 7457109, doi:10.1155/2020/7457109.
32. He, X.; Yuan, X.D.; Zhang, D.H.; Zhang, R.R.; Li, M.; Zhou, C.S. Delineation of Urban Agglomeration Boundary based on Multisource Big Data Fusion—A Case Study of Guangdong–Hong Kong–Macao Greater Bay Area (GBA). *Remote Sens.* **2021**, *13*, 1801, doi:10.3390/rs13091801.
33. Bjarne, B.J.; Karsten, S. The Action Competence Approach in Environmental Education. *Environ. Educ. Res.* **1997**, *3*, 163–178.
34. Amy, M.K.; Shari, M.; Tina, G.; Allison, B.; Diana, M.; Shane, M.T.C. EcoMOBILE: Integrating augmented reality and probeware with environmental education field trips. *Comput. Educ.* **2013**, *68*, 545–556.
35. Cynthia, M.F.; Stephan, M.F. The importance of connection to nature in assessing environmental education programs. *Stud. Educ. Eval.* **2014**, *41*, 85–89, doi:10.1016/j.stueduc.2013.10.001.
36. Regula, K.G.; Kurt, H.; Balz, W. Studies on a socio-ecological approach to environmental education: A contribution to a critical position in the education for sustainable development discourse. *Environ. Educ. Res.* **2006**, *12*, 101–114, doi:10.1080/13504620500527840.
37. Li, C.X.; Gao, X.; He, B.J.; Wu, J.Y.; Wu, J.Y.; Wu, K.N. Coupling Coordination Relationships between Urban-industrial Land Use Efficiency and Accessibility of Highway Networks: Evidence from Beijing–Tianjing–Hebei Urban Agglomeration, China. *Sustainability* **2019**, *11*, 1446, doi:10.3390/su11051446.
38. Lu, C.P.; Xue, B.; Lu, C.Y.; Wang, T.; Jiang, L.; Zhang, Z.L.; Ren, W.X. Sustainability Investigation of Resource-Based Cities in Northeastern China. *Sustainability* **2016**, *8*, 1058, doi:10.3390/su8101058.
39. Yang, J.; Guo, A.D.; Li, X.M.; Huang, T. Study of the Impact of a High-Speed Railway Opening on China's Accessibility Pattern and Spatial Equality. *Sustainability* **2018**, *10*, 2943, doi:10.3390/su10082943.
40. Yang, J.; Yang, R.M.; Sun, J.; Huang, T.; Ge, Q.S. The Spatial Differentiation of the Suitability of Ice-Snow Tourist Destinations Based on a Comprehensive Evaluation Model in China. *Sustainability* **2017**, *9*, 774, doi:10.3390/su9050774.
41. Radke, J.; Mu, L. Spatial decomposition, modeling and mapping service regions to predict access to social programs. *Geogr. Inf. Sci.* **2000**, *6*, 105–112.
42. Luo, W., Wang F.H. Measure of spatial accessibility to healthcare in a GIS environment: Synthesis and a case study in Chicago. *Environ. Plan. B Plan. Des.* **2003**, *30*, 865–884.
43. Cheung, P.;Zhang, L. Environment for Preschool Children to Learn Fundamental Motor Skills: The Role of Teaching Venue and Class Size. *Sustainability* **2020**, *12*, 9774.doi:https://doi.org/10.3390/su12229774.
44. Tsebo, K.M. Action research and environmental education within a home-based setup to conscientise children towards littering. *Environ. Dev. Sustain.* **2021**, doi:10.1007/s10668-021-01251-0.
45. Claudio, Q.R.; Catherine, O.; Jessica, D.O.; Bárbara, S.R. Impact of 2020 COVID-19 lockdown on environmental education and leatherback sea turtle (Dermochelys coriacea) nesting monitoring in Pacuare Reserve, Costa Rica. *Biol. Conserv.* **2021**, *255*, 108981, doi:10.1016/j.biocon.2021.108981.
46. Parita, S.; George, A. Environmental education and awareness: The present and future key to the sustainable management of Ramsar convention sites in Kenya. *Int. Environ. Agreem. Politics Law Econ.* **2021**, doi:10.1007/s10784-021-09534-7.
47. Wang, R.; Jia, T.T.; Qi, R.; Cheng, J.H.; Zhang, K.; Wang, E.W.; Wang, X. Differentiated Impact of Politics-and Science-Oriented Education on Pro-Environmental Behavior: A Case Study of Chinese University Students. *Sustainability* **2021**, *13*, 616, doi:10.3390/su13020616.