



Article Implication of Buffer Zones Delineation Considering the Landscape Connectivity and Influencing Patch Structural Factors in Nature Reserves

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Abstract: Since habitat fragmentation results in species losses worldwide, considering the influence of buffer zones on the maintenance of connectivity provides a new perspective for buffer delimitation. In our study, the implications of buffer zones around nature reserves were studied at four sites in Fuzhou from the perspective of landscape connectivity based on a distance threshold of 1 km. We applied Graph-based connectivity indices at the landscape level and patch level to reveal the overall connectivity and patterns of change in patch importance for maintaining connectivity with various buffer zones. Based on the results of these analyses, we showed the relationship between structural factors and changes in patch importance by Spearman correlation analysis and redundancy analysis. The results indicate that in the sites with smaller habitat proportion (HP), the connectivity is relatively lower, and the changes in patch importance will be greater when the buffer zone increases. Different buffer zone sizes are suggested in four sites to maximize its benefits. Relatively small patches with high shape complexity and close proximity to patches outside the boundary contribute greatly to connectivity by acting as stepping stones.

Keywords: landscape connectivity; buffer zone; graph theory; redundant analysis; patch structural factor

1. Introduction

The implementation of buffer zones to minimize the influence of human activities on nature reserves was first proposed by Shelford [1], and the United Nations Educational, Scientific, and Cultural Organization (UNESCO) later adapted the concept to the Man and Biosphere (MAB) program and Biosphere Reserves (BRs) [2]. There are various definitions of buffer zones. Sayer [3] proposed that buffer zones should be established outside the core zone of nature reserves, emphasizing their ecological protection target and forbidding any economic development. Other researchers, such as Wild & Mutebi [4], proposed that scientific research, environmental education, and some kinds of sightseeing should be allowed in buffer zones, although these activities may weaken the impacts of ecological protection in core zones and the economic development of neighboring communities. However, the importance of buffer zones in ecology is unquestionable, since they provide migration corridors and temporary habitats for species [5] and eliminate edge effects to some degree by reducing the habitat differences inside and outside the boundary [6]. In the latest study on this topic, researchers from Brazil performed buffer zone delimitation by the analytical hierarchy process (AHP), taking several factors, such as soil vulnerability, groundwater characteristics, rainfall intensity, and land use and land cover changes, into consideration [7]. Researchers from Myanmar examined the floristic composition and species richness of moist evergreen forests by applying importance indices, such as the Simpson index, in the buffer zone of the Tanintharyi Nature Reserve to determine the current status of the area and need for further protection [8]. However, since habitat fragmentation has become one of the key drivers of species loss worldwide [9],



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Copyright: © 2021 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https:// creativecommons.org/licenses/by/ 4.0/). buffer zones should be planned considering their ability to maintain not only habitat quality but also connectivity. Brayan [10] conducted research in Rio Doce State Park on recovering connectivity by establishing ecological corridors in buffer zones, reforestation, and environmental enrichment; nevertheless, few quantitative indices were applied to verify the effects of these efforts. The latest study by Dematos [11] developed a forest sustainability index on the basis of landscape structural factors to determine the best plans for landscape restoration in protected areas and their surroundings, while the study did not focus on different functions of patches in maintaining connectivity.

Studying buffer delimitation from the perspective of landscape connectivity, graphbased connectivity indices are useful for quantifying [12]. The study uses these indices to characterize the connectivity as their reliability has been widely verified [13–15]. Merriam [16] first defined landscape properties resulting from the interactions among habitat patches as landscape connectivity. Later, this concept was characterized as the degree to which the landscape facilitates or impedes movement among resource patches [17]. Landscape connectivity is critical for supporting ecological flows and is necessary for the long-term persistence of biodiversity [18]. Assessing landscape connectivity is vital to understanding the ecology of landscapes, since it reveals the degree to which a landscape promotes or hampers the migration of a given species among habitat patches, which is important for conservation decisions [19,20]. There is growing interest in the use of graph theoretical methods, which describe complex landscapes by a simple graph with nodes and links, representing habitat patches and connections, respectively [21,22]. Due to the lack of field data, the idea of a threshold distance is widely accepted as a representative of the dispersal ability of species [23–25]; the threshold distance determines whether nodes are connected by links and the expected strength of those connections [26]. Consequently, the quantification of important landscape elements, such as patches, and the classification of conservation priorities are mainly based on topological indicators in these habitat graphs [27].

Landscape connectivity is deeply affected by the landscape structure, the elements of which include habitat proportion at the landscape level and patch size, patch shape, and patch position at the patch level [28,29]. Habitat proportion (abbreviated as HP) is used to indicate habitat quality, and is influenced by changes in total area and habitat distribution at various scales [28,30]. Jeffrey et al. [31] conducted research on the relationship between beetle abundance and forest proportion; they found that this relationship is strong at various scales. Patch size represents habitat quality to some degree and is the most frequent factor considered at the patch level since it has the strongest impact on patch functional performance, which includes providing habitats for species [32]. The third element considered is patch shape. The mean shape index (MSI) is one of the most sensitive metrics used to represent patch shape. Large buffer zones encompass more small patches far away from the core zone that may be influenced by human activity [33]. The final element considered is patch position, since patches near edges are likely to be "cut" into small patches by the nature reserve boundary [33] and small patches are recognized as stepping stones that are essential for maintaining landscape connectivity [15]. Moreover, patches close to the boundary are more likely to have connections with patches outside the boundary, which may be located in the buffer zone.

In our study, we put forward research questions about habitat connectivity in various buffer zones, and the influence brought by structural factors of habitat patches. Thus, we established virtual buffer zones with several sizes to make spatial analyses. Moreover, we hypothesized a specific threshold distance to define our objective species. Through this research, we aimed to find out common structural factors of important patches and provide suggestions for buffer delimitation from the perspective of landscape connectivity.

2. Materials and Methods

2.1. Study Area

Fuzhou city is located in southeastern China and covers an area of 11,968 km², extending from 25°15′ to 26°39′ latitude and from 118°08′ to 120°31′ longitude. The natural landforms in Fuzhou are complex and diverse, including hills and plains. Due to the subtropical monsoon climate, natural evergreen broadleaf, coniferous, bamboo, and timber forests are the main local vegetation types according to subclass data from the 2010 Fuzhou Forest Resources Second Class Survey.

In this research, we selected four sites with relatively good habitat protection in Fuzhou; soil and water conservation forests are the main forest types here. We selected ecological public welfare forests (a kind of natural forest) among various forest properties as habitat patches (highlighted in Figure 1). The four selected sites include Qishan National Forest Park (QS), Chongxi National Scenic Area (CX), Huangchulin National Nature Reserve (HC), and Gushan National Scenic Area (GS). With the development of tourism at these four sites, especially at GS (scenic spot 4A), plans for further protection, including establishing buffer zones, should be considered to address potential human interference. Moreover, since this study emphasizes the influence of landscape structural factors, selected study sites should have various HP and other basic conditions, such as the spatial distribution of habitat patches inside and around the area. The study used subclass data from the 2010 Fuzhou Forest Resources Second Class Survey; the accuracy of these data is above 90%, indicating that the data provide a realistic representation of the actual conditions.



Figure 1. Study sites in Fuzhou (QS, CX, HC, and GS) and the distribution of habitat patches.

2.2. Method

2.2.1. Buffer Zone Establishment

In China, buffer zone functions as anti-interference area, while it undertakes external communication as well, whose principles are mainly landscape homogeneity and ecological integrity [15]. In order to study habitat connectivity in various buffer zones, and provide suggestions for buffer delimitation, we considered various virtual buffer zones (0.5 km, 1 km, 1.5 km, and 2 km) for each of the four sites with ArcGIS 10.2 for spatial analyses, and

named accordingly; for example, the buffer zones for the QS site are referred to as QS-0.5 km, QS-1 km, QS-1.5 km, and QS-2 km, respectively. To make the results comparable among the four sites, we supposed that the buffer zones had the same width instead of irregular shapes. The choice of buffer zone size was generally based on both characteristics of species migration and natural conditions of four sites. From the point of species migration, according to the study by Corlett [34], a seed dispersal distance of approximately 10–100 m is reasonable for wind propagation; for dispersal by small birds and mammals, the distance can be 100 m–1 km, and large animals can move seeds up to 10 km. Considering that the buffer zone is larger than 2 km, our study involved a larger area with more human activity (east side of QS and CX and west side of GS), which makes the study result inaccurate.

2.2.2. Landscape Connectivity Indices and Threshold Distance

The variations in network connectivity when various buffer zones were added are shown by graph-based landscape connectivity indices calculated at both the landscape level and patch level. The connectivity of the four sites without buffer zones was described by indices calculated at the landscape level, and changes in connectivity with different buffer zones were analyzed in detail by indices calculated at the patch level. All of the connectivity indices were calculated by Conefor 2.6 software [35]. As shown in Table 1, the indices included in the analysis represent the number of links (NL) and number of components (NC) of a study site, demonstrating the basic condition in the landscape. The binary indices include the landscape coincidence probability (LCP) and integral index of connectivity (IIC). The presence of a connection is classified as either "yes" or "no". The probability index (i.e., the probability of connectivity (PC)) is calculated based on the assumption of the random diffusion of organisms. The study used both the binary and probability indices to determine the overall landscape connectivity, with patch size serving as a landscape attribute. Moreover, selected indices can be separated at the patch level to obtain detailed information. Thus, changes in the performance of individual patches for maintaining landscape connectivity are revealed by the patch importance index (dI). A relevant study showed that the PC index has wider applicability than other indices; therefore, in this article, patch importance is represented by the dPC index [12]. Conefor 2.6 software allowed us to separately evaluate how patches contribute to the connectivity and availability in the landscape. dPC is separated into dPCintra, dPCflux, and dPCconnector. dPCintra measures the contribution of a patch to habitat availability, dPCflux measures the extent to which patches support ecological flows, which is important when patches act as either starting or ending points in a connection, and dPCconnector measures the extent to which patches connect ecological flows by acting as stepping stones [36].

To focus on the impact of changing buffer zones, in this study, a threshold distance of 1000 m was assumed and input in Conefor software. On the one hand, a previous study in Fuzhou showed that the 1000 m threshold is relatively close to the transformation point of connectivity indices and ensures NC > 1, thus making the study meaningful (when the distance threshold increases, NC = 1 and all of the patches are connected as one component, which makes it difficult to recognize important patches) [32]. On the other hand, from an ecological perspective, the 1000 m threshold corresponds to the typical long-distance dispersal (LDD) of seeds, such as that of *Pinus massoniana*, which is the dominant species in Fuzhou. According to Nathan [37,38], species that experience LDD generally migrate more than 800 m. Considering both the need to study connectivity and the ecological meaning of the threshold value, a 1000 m distance was considered suitable for this study.

	Indices Type	Indices	Formula	Explanation	
		Number of links (NL)	/	Link: connection between patches	
Landscape level	Overall indices	Number of components (NC)	/	Component: a set of patches in which a link exists between every pair of patches	
	Binowindicos	Landscape coincidence probability (LCP)	$LCP = \sum_{i=1}^{NC} \left(\frac{c_i}{A_L}\right)^2$	<i>A_L</i> : maximum landscape attribute (total area in this article)	
	binary muttes	Integral index of connectivity (IIC)	$\text{IIC} = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} \frac{a_{i} \cdot a_{j}}{1 + nl_{ij}}}{A_{L}^{2}}$	a_i : landscape attribute of patch i	
	Probability indices	Probability of Connectivity (PC)	$PC = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} a_{i} \cdot a_{j} \cdot P_{ij}}{A_{L}^{2}}$	p_{ij} : maximum probability of all possible links between patches i and j	
Patch level	Patch importance	Patch importance (dI)	$dI_{k} = 100 \times \frac{I - I_{remove,k}}{I}$ $dI_{k} = dI_{intra\ k} + dI_{flux\ k} + dI_{connector\ k}$	<pre>dI_k: The importance of an existing patch k for maintaining landscape connectivity (* interpreted for the index dPC in this</pre>	

Table 1. Landscape connectivit	y indices chosen in this study
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2.2.3. The Selection of Landscape Structural Factors

In response to changing buffer zones, several groups of dPC values can be obtained, and this variation among groups is referred to as dPC-variation. To further reveal the contribution of landscape structural factors to landscape connectivity when the buffer zone changes, the HP indicator (representing habitat quality through the perspective of structure) was applied at the landscape level, and three other indicators, Area, MSI, and ND, were applied at the patch level after a test of multicollinearity (Table 2): area (representing patch size), MSI (representing patch shape), and ND (representing patch position). The values of these indicators were exported from Patch Analyst 5.2 software, a program extension in ArGIS, which was developed by the Centre for Northern Forest Ecosystem Research (CNRER) in Canada [39]. To eliminate biases due to the difference in dimensions, logarithmic transformation was performed on the data.

Table 2. Landscape structural factors chosen in this study.

Level	Index	Explanation
Landscape	Habitat proportion (HP)	Represents habitat quality through the perspective of structure
Patch	Area	Represents the size of a patch
Patch	MSI	Mean shape index;
1 ateri	WIGH	represents shape complexity
		Nearest distance;
Patch	ND	represents the nearest distance between a patch inside a
		boundary and a patch in a buffer zone

Among the factors chosen, MSI equals the sum of the patch perimeter (P_{ij} , m) divided by the square root of the patch area (a_{ij} , m²) for patches of the same type, which can be seen from formula (1); for a given patch, n = 1. As the shape of a patch becomes irregular, the MSI increases [40]:

$$MSI = \frac{\sum_{j=1}^{n} \left(\frac{p_{ij}}{2\sqrt{\pi \cdot a_{ij}}}\right)}{n_i}$$
(1)

Spearman correlation analysis was applied to determine the independent influence of each factor on the change in individual patch importance; this analysis was performed using SPSS 20.0 software. Based on the results, Canoco 5.0 software was used to perform the RDA,

which determines the influence of combinations of factors. During this progress, centering and standardization operations were performed for species data to meet the requirement of the RDA [41]. A similar method was used by Peng [42], whose research focused on the multiscale influences of urbanized landscape metrics on indigenous plant diversity.

3. Results

3.1. The Overall Landscape Connectivity of Four Study Sites without Buffer Zones

The ratio of habitat patches to the total area at each site was calculated and called the habitat proportion (HP). The study site names were abbreviated according to their HP, which were 23.50%, 36.19%, 36.26%, and 50.43% for QS, CX, HC, and GS, respectively. Table 3 shows the main features of the four study sites and demonstrates that sites with high HP, such as GS, have fewer components (based on the number of components NC). Figure 2 shows the values of the binary indices and probability indices (LCP, IIC, and PC) without considering buffer zones. The ranking of landscape connectivity according to the three connectivity indices is basically the same as that of HP. GS has the highest HP and the highest connectivity, while QS has the lowest HP and the lowest connectivity.

Table 3. Main features of the four study sites in Fuzhou City.

	QS-23	CX-36	HC-36	GS-50
Number of patches	289	263	473	519
Area of patches (ha)	3644.58	2937.56	5325.37	4791.46
Mean area (ha)	12.61	11.17	11.26	9.23
Total area (ha)	15,506.57	8117.59	14,685.54	9501.96
HP (%)	23.50%	36.19%	36.26%	50.43%
Number of links (NL)	2986	4082	6003	9518
Number of components (NC)	6	2	2	3



LCP PC IIC

Figure 2. The values of the landscape-level connectivity indices (LCP, IIC, and PC) of the four study sites.

However, although the HP of CX and HC are similar, there are still differences between these sites, especially in the PC value. This finding reminds us that in addition to HP, other patch-level structural factors should be analyzed when buffer zones are considered.

3.2. Main Landscape Features of the Four Study Sites Following the Addition of Buffer Zones

Table 4 shows that the HP of all four sites decreases with the increase in buffer zones, because the increase in the number of habitat patches is less than that in the total area. When the buffer zone is extended to 2 km, the HP of the QS site decreases from 23.50% to 20.29%,

and the HPs of CX, HC, and GS decrease to 28.20%, 23.88%, and 31.64%, respectively. However, when ranked by HP, the order of these four sites does not change; QS still has the lowest proportion, and GS has the highest proportion.

		QS-0.5 km	QS-1 km	QS-1.5 km	QS-2 km
D ((Number of patches	48	99	132	195
Buffer zone	Area of patches (ha)	433.22	1098.62	1630.34	2281.6
	Number of patches	337	1098.62 1630.34 2281.0 388 421 484 4743.2 5274.92 5926.1		484
Site with buffer	Area of patches (ha)	4077.8	4743.2	5274.92	5926.18
	HP (%)	21.33%	21.13%	20.46%	20.29%
		CX-0.5 km	CX-1 km	CX-1.5 km	CX-2 km
P. ((Number of patches	48	77	112	131
Buffer zone	Area of patches (ha)	597.53	1034.25	1462.63	1828.51
	Number of patches	311	340	375	394
Site with buffer	Area of patches (ha)	3535.09	3971.81	4400.19	4766.07
	HP (%)	34.69%	32.29%	30.28%	28.20%
		HC-0.5 km	HC-1 km	HC-1.5 km	HC-2 km
D (1	Number of patches	48	83	112	144
Buffer zone	Area of patches (ha)	661.91	1060.49	1348.18	1661.19
	Number of patches	521	556	585	617
Site with buffer	Area of patches (ha)	5987.28	6385.86	6673.55	6986.56
	HP (%)	32.22%	32.74%	26.01%	23.88%
		GS-0.5 km	GS-1 km	GS-1.5 km	GS-2 km
P. ((Number of patches	43	75	116	145
Buffer zone	Area of patches (ha)	446.08	846.64	1114.43	1445.75
	Number of patches	562	594	635	664
Site with buffer	Area of patches (ha)	5237.54	5638.1	5905.89	6237.21
	HP (%)	43.69%	39.01%	34.71%	31.64%

Table 4. Main features of the four study sites with buffer zones.

These results show that for each site, the decrease in HP has a positive correlation with the original HP. GS has the largest original HP (50.43%); when a 2 km buffer is considered, the HP in GS greatly declines by 18.79%. It shows that habitats in GS are concentrated, and there are relatively few habitat patches outside the core zone. In contrast, a relatively large number of habitat patches are located outside the core zone of QS, and these patches should be given attention.

3.3. Changes in Patch Importance for Maintaining Landscape Connectivity with Various Buffer Zones

 \sum dPC refers to the sum of the dPC components of all patches in the study site. Figure 3 shows that the \sum dPC value increases when the buffer zone is enlarged at all four sites. QS originally has the lowest HP, but it has the largest increase in \sum dPC. It indicates that with the increase in buffer zone, the lower the HP is, the greater the change in the dPC functional fraction is.

The value of \sum dPCflux is the largest among the three metrics considered (dPCflux, dPCintra, and dPCconnector), and the value of \sum dPCintra is the smallest, which means that patches contribute to connectivity mainly by supporting ecological flow. \sum dPCintra decreases, while both \sum dPCflux and \sum dPCconnector increase with increasing buffer zone size. Table 5 shows that dPCconnector plays an active role in increasing the \sum dPC value; this effect was suggested to be rare but significant in a previous study by Qi [32].



Figure 3. The variation trends of (a) \sum dPC, (b) \sum dPCintra, (c) \sum dPCflux, and (d) \sum dPCconnector in the four study sites with increasing buffer zone sizes.

	∑dPC	∑dPCintra	∑dPCflux	∑dPCconnector
$ riangle QS-0.5 \ \text{km}$	1.6%	-12.1%	0.1%	8.7%
$ riangle QS-1 \ \text{km}$	4.2% (+2.6%)	-22.9%	0.2%	23.4% (+14.7%)
$ riangle QS-1.5 \ \text{km}$	6.1% (+1.9%)	-29.2%	0.2%	33.9%
$ riangle QS-2 \ \text{km}$	6.9% (+0.8%)	-34.6%	0.2%	38.2%
\triangle CX-0.5 km	2.6%	-12.6%	0.1%	32.7%
\triangle CX-1 km	4.9% (+2.3%)	-15.8%	0.1%	61.0% (+28.3%)
\triangle CX-1.5 km	5.0% (+0.1%)	-19.4%	0.1%	62.0%
\triangle CX-2 km	5.7% (+0.7%)	-22.5%	0.1%	71.0%
\triangle HC-0.5 km	-0.5%	-10.4%	0.1%	-3.0%
\triangle HC-1 km	-0.1% (+0.4%)	-15.6%	0.1%	-0.8%
\triangle HC-1.5 km	0.8% (+0.9%)	-18.9%	0.1%	4.0% (+4.8%)
\triangle HC-2 km	1.4% (+0.6%)	-21.4%	0.1%	7.2%
$ riangle GS-0.5 \ \mathrm{km}$	0.7%	-8.0%	0.0%	16.1%
\triangle GS-1 km	1.4% (+0.7%)	-11.5%	0.0%	33.5% (+17.4%)
riangle GS-1.5 km	1.9% (+0.5%)	-13.0%	0.0%	45.2%
\triangle GS-2 km	2.0% (+0.1%)	-14.0%	0.0%	48.8%

Table 5. Changes in $\sum dPC$, $\sum dPC$ intra, $\sum dPC$ flux, and $\sum dPC$ connector when considering various buffer zones.

As Table 5 shows, the growth rate of the \sum dPC value decreases marginally as the size of the buffer zone increases. For QS, CX, and GS, when the buffer zone is expanded to 1 km, the \sum dPC values increase by 2.6%, 2.3%, and 0.7%, respectively, compared to that of the 0.5 km buffer zone. When the buffer zone of the HC expands to 0.5 km or 1 km, the \sum dPC value decreases. However, when the 1.5 km buffer zone is applied at this site, the \sum dPC value increases. Different nature reserves should employ different buffer zones to maximize benefits, even if they have similar original HP, such as CX and HC.

Furthermore, this study focused on the degree of importance of individual habitat patches in four sites with various buffer zones, which is determined by the dPC value using a 1000 m threshold distance. We have introduced its definition in Table 1. We rank the dPC values into three levels to distinguish patches with different degrees of importance according to recent study by Qi [43], making the spatial distribution and quantity distribution clearer for observing and analyzing. dPC \geq 1.0 indicates that a patch is highly important, 0.1 < Dpc < 1.0 indicates moderate importance, and dPC \leq 0.1 indicates relatively low importance.

Figure 4 shows the changes in the spatial distribution of patch importance in the four study sites. In general, patch importance in the core zone becomes more uniform spatially, and some patches close to the boundary or in buffer zones become important with the increase in the buffer zone size. This result is obvious in QS and CX. As the buffer zone expands in CX, important patch clusters tend to shift to the southwest. We analyzed the distribution of the quantity of important patches in the buffer zones of the four study sites. Figure 5 shows that patches with dPC \geq 1.0 account for 17.1% and 20.6% of the patches in QS and CX, respectively, which is much more than that in HC and GS.

3.4. Relationship between Structural Factors at the Patch Level and Changes in Patch Importance

To further reveal the patterns of changes in patch importance, especially the increase in the dPC values of patches close to the boundary, the following section focuses on the analysis of the impact of landscape structural factors at the patch level on the dPC value. Table 6 shows that at the 0.05 significance level, the dPC-variation of all four sites has a significant negative correlation with the factors Area (p < 0.01) and ND (p < 0.01) and a significant positive correlation with the factor MSI (p < 0.01). These results indicate that the smaller a patch is, the greater the shape complexity and that the shorter the distance to a patch in the buffer zone is, the more significant the effect of increasing the buffer zone is on the dPC value. For all four sites, the dPC-variation has the greatest correlation with area, which means that patch size has a great influence on whether patch importance changes considerably when the buffer zone changes. For all four sites, as the buffer zone expands, the correlation between dPC-variation and MSI increases, while the correlation between dPC-variation and the ND factor decreases at three of the four sites.

As shown above, Spearman correlation analysis explains the relationship between dPC-variation and each landscape structural factor, and RDA is then applied to further explain the performance of these factors when they are examined together. Through Canoco 5.0 software, the three patch-level factors mentioned above were analyzed. During this process, dPC-variation is centralized and standardized. Figure 6 present the RDA results and Table 7 presents the explanation and contribution ratio of each variable. The results show that the amount explained increases when the buffer zone expands, and the factor Area has the greatest explanatory power in all four sites, with contributions of more than 70% in each case. On the other hand, the contribution of the factor MSI is likely to be overestimated, since its contribution is less than 10%, especially in CX and HC.



Figure 4. The change in the spatial distribution of important patches, represented by the dPC value, in various buffer zones in (a) QS, (b) CX, (c) HC, and (d) GS.



Figure 5. The distribution of the quantity of important patches in a buffer zone of each study site.

	dPC-Variation	Area (ha)	ND (m)	MSI	MPFD
	0.5 km dPC-variation	-0.82	-0.29	0.20	-0.01
QS	1 km dPC-variation	-0.83	-0.29	0.20	-0.01
	1.5 km dPC-variation	-0.84	-0.30	0.21	0.02
	0.5 km dPC-variation	-0.84	-0.63	0.31	-0.33
CX	1 km dPC-variation	-0.84	-0.60	0.31	-0.36
	1.5 km dPC-variation	-0.77	-0.60	0.52	-0.57
	0.5 km dPC-variation	-0.74	-0.53	0.69	-0.62
HC	1 km dPC-variation	-0.78	-0.50	0.72	-0.65
	1.5 km dPC-variation	-0.78	-0.50	0.72	-0.66
	0.5 km dPC-variation	-0.89	-0.23	0.86	-0.82
GS	1 km dPC-variation	-0.90	-0.22	0.87	-0.82
	1.5 km dPC-variation	-0.91	-0.21	0.88	-0.83

Table	6.	Spearman	correlation	coefficients	between	dPC-	variation	and	landsca	pe structural	l factors.
		1									

Note: p < 0.01 for all of the results in this table.



Figure 6. Graph of the RDA results for (a) QS, (b) CX, (c) HC, and (d) GS.

			Explana	tion (%)			Contrib	ution (%)	
		0.5 km	1 km	1.5 km	2 km	0.5 km	1 km	1.5 km	2 km
	Area	35.4%	51.9%	59.6%	63.7%	72.6%	87.9%	91.2%	95.0%
JDCintine OC	ND	8.9%	5.1%	3.7%	2.1%	18.2%	8.6%	5.7%	3.1%
dPC-variation_Q5	MSI	4.5%	2.1%	2.0%	1.3%	9.2%	3.5%	3.1%	1.9%
	Sum	48.8%	59.1%	65.3%	67.1%				
	Area	36.0%	43.7%	50.8%	57.5%	79.0%	83.2%	87.2%	90.5%
JDC	ND	8.5%	6.9%	5.9%	4.8%	18.7%	13.1%	10.1%	7.6%
dPC-variation_CX	MSI	$1.0\% \ ^{1}$	1.9%	1.6%	$1.2\%^{-1}$	2.3%	3.7%	2.7%	1.9%
	Sum	45.5%	52.5%	58.3%	63.5%				
	Area	27.8%	29.1%	36.9%	32.9%	84.0%	76.8%	87.6%	80.4%
IDC solution LIC	ND	4.8%	8.5%	5.0%	7.8%	14.6%	22.4%	11.8%	19.0%
dPC-variation_HC	MSI	$0.5\%^{1}$	0.3% ²	0.3% ²	0.2% ²	1.4%	0.8%	0.7%	0.6%
	Sum	33.1%	37.9%	42.2%	40.9%				
	Area	20.3%	31.4%	35.2%	40.5%	71.9%	85.6%	88.7%	91.3%
IDC station CC	ND	5.8%	4.0%	3.4%	2.9%	20.6%	10.8%	8.6%	6.6%
arc-variation_GS	MSI	2.1%	1.3%	1.1%	0.9%	7.5%	3.7%	2.7%	2.1%
	Sum	28.2%	36.7%	39.7%	44.3%				

Table 7. Variation partitioning of the main and additional effects by patch-level RDA for each site.

Note: p < 0.01 for results without additional notes ¹ 0.01 < p < 0.05, ² p > 0.05.

In summary, we should pay more attention to patches close to the boundary, with relatively small patch sizes, high shape complexities, and close to patches outside the boundary. Moreover, important patches should be especially well protected by buffer zones to maintain better landscape connectivity between areas inside and outside boundaries.

4. Discussion

4.1. Implications for Buffer Zones from the Perspective of Landscape Connectivity

In this study, we provide the perspective of landscape connectivity to discuss buffer zone delineation in nature reserves. Some related researches provided suggestions through AHP technique and by establishing ecological corridors; however, species activities and quantified indices for effect verification were considered insufficiently [7,10]. De Matos [11] developed a forest sustainability index on the basis of landscape structural factors; however, the function of each patch was difficult to obtain without using patch importance indices such as dPC. As a complement to previous studies, this study focuses on factors of landscape connectivity, showing the potential for migration of species between patches by connectivity indices. Furthermore, this study reveals the characteristics of patches with various buffer zones that contribute to connectivity and how landscape structural factors influence connectivity to better inform the planning of buffer delimitation.

According to results of four sites, we find that in sites with smaller HP, the connectivity is relatively lower, and the changes in patch importance will be greater when the buffer zone increase. This indicates that adding buffer zones to those nature reserves with low original HP is more helpful than adding them to reserves with higher HP. This result is consistent with a previous study, emphasizing the importance of HP [44]. In this study, the law of diminishing margins is obvious in the \sum dPC values of three of the four study sites when the buffer zone was increased, reflecting that human interference becomes greater when the buffer zone is far away from the core zone. Based on existing habitat conditions, the study suggests different buffer zone sizes for various sites, emphasizing efficiency. Based on a 1 km distance threshold, buffer zones of 1 km for QS, CX, and GS and 1.5 km for HC resulted in the greatest benefits. The need to consider different buffer zones was confirmed by the study of Palomo [45], whose research compared two sites with buffer zones through the view of ecosystem services. In reality, the delimitation of nature reserve boundaries is inevitably complex, involving factors such as ecological value, landscape value, and social and economic values. Among these values, conflicts over land property

and the existence of administrative divisions may influence boundary decisions to some degree [46]. HC is located in the marginal zone of Fuzhou, and part of its boundary is the same as the administration borderline between Fuzhou and Ningde. Thus, the need of protection across administrative regions is highlighted again.

Meanwhile, as the results show, even though the original HP of CX and HC are similar, other structural factors, such as patch size, patch shape, and patch position, influence connectivity, resulting in different suggested buffer zones. When analyzing these three kinds of structural factors without distinguishing sites, Figures 7–9 show that with a 1 km distance threshold, relatively small patches (area ≤ 5 ha) and patches close to the boundary (ND = 0) should be given more attention. Among the patches with increased patch importance, 66.3% are less than 5 ha, and 82.2% are adjacent to patches in the buffer zone (ND = 0). The patterns of MSI are not as obvious as those of the other two indices, partly because the overall complexity of the patches in the four study sites is low compared to that in the study of De Matos [11,40], in which the MSI of native forest is equal to 3.17, indicating less pronounced habitat fragmentation. With the increase in habitat fragmentation, the importance of patches with high MSI values should be clear due to the positive relationship described above.







Figure 8. Position distribution of patches with increased dPC when the buffer zone is considered.



Shape distribution (%)



Based on the discussion above, we analyze the size and position distribution specifically for CX and HC under the circumstance of a 1 km buffer zone and 1000 m threshold distance, as shown in Figures 10 and 11. Table 8 shows that more patches in CX with a small size and close to the boundary have increased dPC-variation. This partly because more patches or larger patches located in the buffer zone are available at a specific distance threshold, acting as potential habitats. As shown in Figure 12, two patches from CX and HC are selected as an example, with increased dPC-variation of 1.17 and 0.70, respectively. Both of them have a size less than 5 ha and close proximity to patches outside the boundary. However, the patch distribution in the buffer zone in CX is more even and reachable. Such a landscape form has shown its superiority in maintaining connectivity.



Table 8. Comparisons between the number of patches with an Area \leq 5 ha and ND = 0 m, in CX and HC.

Figure 10. Size distribution of patches in CX and HC when a 1 km buffer zone is considered.



Figure 11. Position distribution of patches in CX and HC when a 1 km buffer zone is considered.



(a) Patch No.94 in CX

(b) Patch No.317 in HC

Figure 12. Position of (**a**) Patch No.94 in CX and (**b**) Patch No.317 in HC, which have a high increased dPC-variation when a 1 km buffer zone is considered.

4.2. Stepping Stones Close to the Boundary Contribute Greatly at a Specific Threshold Distance

Establishing a buffer zone involves many patches in a study site. By studying the form of patches contributing to connectivity, our study finds out that specific patches close to the boundary are more important than other patches, acting as stepping stones. Patches close to the boundary have large dPCconnector values, supporting the long-distance migration of species and linking patches inside and outside the boundary. These patches, with relatively small sizes, high shape complexity, and close proximity to patches outside the boundary, also generally match the structural characteristics of stepping stones according to the study by Herrera [15]. The conclusion that stepping stones contribute greatly to connectivity by functioning as connectors was put forward by Saura [36], and our study provides further evidence of the conditions created by different buffer zones from two perspectives. First, the habitat fragmentation phenomenon becomes more obvious as the distance from the core zone of a nature reserve increases, resulting in a lack of large patches contributing

to dPCintra. In fact, both few large and many small patches are necessary to maintain landscape connectivity, especially when studying nature reserves at different scales, as Verena [32,47] concluded. Second, in this study, the distance threshold is maintained at 1000 m; however, as we have mentioned in the introduction, changing the threshold can help to determine low-connectivity areas [48] by considering species with various migration abilities, which largely determine whether patches in buffer zones are accessible. According to a previous study by Saura [36], it is reasonable to assume that dPCconnector (acting as stepping stones) maintains a relatively high contribution to connectivity, with an intermediate distance threshold of 1 km, although the distance threshold increases or decreases constantly. The contribution of dPCflux to connectivity tends to be greater, since it determines the extent to which species are likely to reach destinations directly, and dPCintra contributes greatly when the distance threshold is short enough, since some species tend to stay in fixed patches instead of travelling across boundaries, thus reducing the need for stepping stones.

There are limitations in this study. First, as mentioned above, we should study the influence of the distance threshold in the future; in other words, we should consider more species' migration behaviors to make buffer zones more suitable. Second, in order to make the results comparable among the four sites, we supposed that the buffer zone had the same width instead of an irregular shape in this study. However, when considering more natural conditions, the buffer zone shape is more likely to be irregular and flexible. We are encouraged to change the way of establishing buffer zones in future research. Third, as discussed by Saura [36], different temporal scales should be considered, distinguishing between daily and seasonal behaviors; for example, we should also study long-distance but low-frequency activities. Fourth, when the buffer zones are more than 1 km, the southeastern area of QS and the northwestern area of CX overlapped, while only partial buffer is studied because of cross-border issue. Thus, we should study this further by breaking administrative borders in future research [49].

5. Conclusions

In our study, we intended to find out common structural factors of important patches for maintaining connectivity when considering buffer zone, and provide suggestions for buffer delimitation from the perspective of landscape connectivity. According to our study results, in the sites with a smaller HP, the connectivity is relatively lower, and the changes in patch importance will be greater when the buffer zones increase. We suggest different buffer zone sizes in sites based on the \sum dPC results. Those patches, with relatively small sizes, high shape complexities, and close proximity to patches outside the boundary, contribute greatly to connectivity by providing stepping stones.

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