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Maintenance-Weighted Biodiversity Return in Singapore Urban Green Spaces: Evidence from Parks and Streetscapes

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Abstract

Singapore's urban green spaces should promote biodiversity and yet be safe, legible, and cheap to maintain. Rapid vegetation growth and regular pruning are likely to reduce insect and bird faunas through reduced flowering, litter, understory, and nesting structures within humid tropical urban green spaces. This paper assesses 13 Singapore urban green spaces comprising 7 parks and 6 streetscapes and determines whether sites having high faunal capacity also generate high biodiversity return when subject to light maintenance activities. Assessment was based on data regarding vegetation density, maintenance class, planted vs. spontaneous vegetation, species richness, Shannon diversity, probable species numbers, and cross-taxon performance for aculeate hymenoptera, butterflies, and birds. Four calculated metrics were considered: composite faunal capacity, low-input biodiversity return, unfulfilled species numbers, and cross-taxon performance. While parks recorded high average composite faunal capacity values (0.765), streetscapes recorded high values of spontaneous vegetation (0.602). Sites maintained under low maintenance conditions produced the greatest biodiversity return, at 0.577, against medium maintenance levels (0.274) and high maintenance conditions (0.152). Current return was greatest for Tampines Eco-Green (0.429), Chuan Lane Park (0.368), NUS Ventus (0.291), and Admiralty Road West (0.241), while those showing low current return included West Coast Park, Jurong Central Park, and Sembawang Hot Spring Park, all of which exhibited greater maintenance release priority. Results indicate that biodiversity amounts and biodiversity returns give contrasting planning signals for tropical urban green spaces.

Keywords: urban biodiversity; tropical green space; maintenance intensity; spontaneous vegetation; species richness; Singapore; faunal capacity

1. Introduction

Today, urban green areas work as biodiversity refuges, adaptation tools, health landscapes and everyday civic infrastructure. Parks, institutional landscapes, road verges and streetscape plantings should be able to mitigate local temperature, manage stormwater flows, offer recreation possibilities and contribute to habitat resources while maintaining safety and visual attractiveness. Such demands place extra pressure on humid tropical cities, where vegetation thrives year-round and routine maintenance may quickly change a biodiverse-looking area into an overly

simplified ornamental landscape. Even if a site looks plant-rich, frequent trimming, grass-cutting, leaf clearing and plant replacement can limit flowering periods, seed production, nesting opportunities or understory cover. Alternatively, a less manicured area might have self-sown plants and require less intervention; however, whether it represents any ecological opportunity depends on its use by animal groups.

Maintenance intensity is a critical factor affecting the ability of an urban landscape to support faunal communities. Faunal richness, canopy cover, habitat area, plant inventories and taxon-specific counts have been extensively studied in urban ecosystems [1, 16, 20, 25]. These variables are essential for understanding biodiversity in a site but cannot demonstrate how much its potential has been realized under low-, moderate- or heavy-intervention conditions. A park with relatively rich faunal assembly in a highly maintained condition would differ in importance from a site with a similar community in a lighter maintenance state. The first one may contain unexploited ecological capacity, whereas the second one would better illustrate the balance between the existing vegetation and faunal use.

The relationship between species composition and site characteristics in urban systems has repeatedly demonstrated that factors like habitat amount, spatial configuration, connectivity, disturbance level and species filtering play a crucial role in shaping biological communities. The quantity of greenery does not necessarily reflect the ability of an urban site to attract new immigrants, maintain resource continuity and support a range of taxa. These landscape features are vital when dealing with mobile organisms like bees, butterflies and birds whose presence is contingent upon foraging range, host plant presence, habitat quality and habitat patch connectivity [9, 16, 28]. This aspect becomes particularly important in the context of rapid vegetation dynamics in humid tropics and high standards of visual order associated with the use of urban green areas. Maintenance is an essential ecological variable in this case.

The concept of spontaneous vegetation becomes significant under such circumstances. Vegetation that has established itself spontaneously can provide floral nectar and fruit, suitable host plants, soil cover, nesting material, leaf litter and vertical complexity, especially in landscapes lacking formal planting or characterized by frequent simplification. The idea of novel urban ecosystems points out that valuable habitats frequently arise from various types of vegetation including planted, remnants, and self-established plants rather than one specific historical condition [1, 15]. Lowering mowing frequency and applying meadow-style maintenance practices may lead to an increase in flowering and pollinator abundance at certain sites; however, reactions would strongly vary depending on site type, taxon studied and timing of the intervention [7, 10, 22]. Public perception of such interventions is another concern as less maintained vegetation may appear as untidy and poorly managed if communication is not provided [7, 17]. Therefore, spontaneous vegetation should be understood not as automatically positive but as an opportunity that needs careful site-specific assessment.

Singapore appears to be a good candidate for exploring the idea of biodiversity return under maintenance pressure. The city's urban greening efforts have always comprised intensive development and rich public landscapes; recently, the City in Nature policy has made ecological connectivity and biodiversity preservation a priority. Hwang, Tan and Lu have studied the correlation between faunal diversity, maintenance, planted vegetation and spontaneous vegetation in seven parks and six streetscapes located in Singapore [11]. This analysis seeks to compare faunal capacity, spontaneous vegetation contribution and maintenance intensity at the same time, which would make the results easily readable to maintenance practitioners. The goal is not to focus on vegetation quantity only but see how faunal richness, estimated richness, Shannon diversity and probable species support would determine biodiversity return at lower intervention levels.

The objective of the comparison is to reveal whether the sites that offer strong faunal capacity also represent high biodiversity return potential under less maintenance and whether parks and streetscapes hold distinctive positions in the light of vegetation origin and intervention intensity. Faunal capacity combines the information about richness, estimated richness, Shannon diversity and probable species support. The term "low-input biodiversity return" refers to the adjustment of faunal capacity for spontaneous vegetation share and maintenance credit. Unexpressed species potential measures the difference between the probable species count and observed richness. Finally, cross-taxon balance indicates how ecological performance is balanced between aculeate hymenoptera, butterflies and birds. The maintenance release priority identifies the sites where capacity and opportunity correspond to higher return under lower intervention. These values transform the 13-site data into the figures interpretable in terms of site type,

vegetation origin and maintenance class.

2. Materials and Analytical Procedure

2.1. Study Sites and Biodiversity Records

The assessment includes 13 Singapore urban green spaces, namely seven parks and six streetscapes. The names of parks include Jurong Central Park, Bishan–Ang Mo Kio Park, NUS Ventus, West Coast Park, Sembawang Hot Spring Park, Tampines Eco-Green and Chuan Lane Park. Streetscapes include Lorong Ah Soo, Punggol Field, Pasir Ris Industrial Drive 1, Ang Mo Kio Avenue 1, North Buona Vista Road and Admiralty Road West. Site-related variables used in the assessment consist of site type, vegetation density, maintenance intensity, surveyed area, planted vegetation number, spontaneous vegetation number, recorded richness, estimated richness, Shannon diversity and probable species count [11].

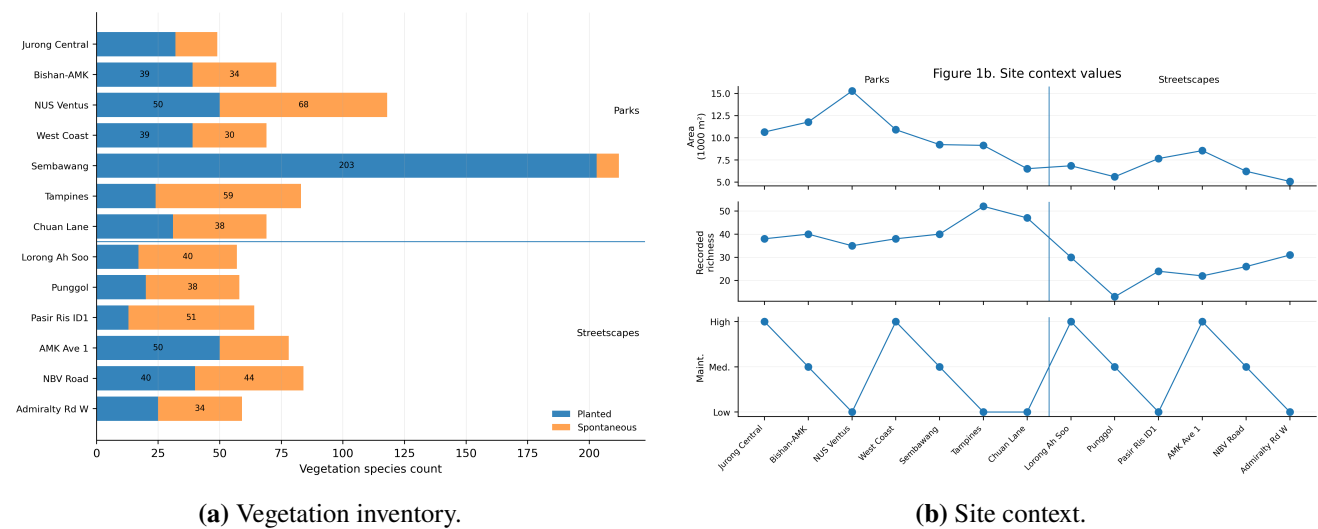


Figure 1. Site inventory.

The site inventory summary depicted in Figure 1 clearly indicates the reason why a single measure of greenness or number of planted species would not suffice for the analysis. The Sembawang Hot Spring Park emerges as dominant in terms of the planted species, with a total of 203 planted species, whereas the presence of spontaneous vegetation is more evident in NUS Ventus, Tampines Eco-Green, Pasir Ris Industrial Drive 1 and Lorong Ah Soo. However, the distinctions mentioned above are not only informative in a descriptive sense, but also serve as defining elements of the three categories of sites – those that have a lot of planted species, a combination of both vegetation types and those where natural vegetation dominates. The same panel proves that there are no clear links between the site area, its maintenance regime and the vegetation type.

The values in Table 1 reveal three important features of the site record. First, planted richness is highly uneven, with Sembawang Hot Spring Park far exceeding the other sites. Second, probable species count is not simply a function of planted richness; NUS Ventus has the largest probable species count at 336 despite lower planted richness than Sembawang Hot Spring Park. Third, the streetscapes are not uniformly weak or strong: Admiralty Road West has a high probable species count for a streetscape, whereas Punggol Field has low recorded richness and low probable species support. These patterns support an index structure that separates vegetation origin, faunal expression and opportunity.

Table 1. Site-level records used in the analysis.

Site	Type	Dens.	Maint.	Area (m ²)	Plant.	Spont.	RSR	ESR	<i>H</i>	Prob.
Jurong Central Park	Park	Low	High	10652.56	32	17	38	62	3.43	199
Bishan–Ang Mo Kio Park	Park	Low	Medium	11781.74	39	34	40	46	3.25	315
NUS Ventus	Park	Low	Low	15281.61	50	68	35	45	2.77	336
West Coast Park	Park	Medium	High	10912.50	39	30	38	116	2.66	242
Sembawang Hot Spring Park	Park	Medium	Medium	9230.30	203	9	40	63	3.31	236
Tampines Eco-Green	Park	Medium	Low	9143.89	24	59	52	82	3.71	307
Chuan Lane Park	Park	High	Low	6510.40	31	38	47	66	2.88	309
Lorong Ah Soo	Street	Low	High	6838.97	17	40	30	47	2.94	125
Punggol Field	Street	Low	Medium	5597.62	20	38	13	34	2.01	75
Pasir Ris Industrial Drive 1	Street	Low	Low	7657.75	13	51	24	29	2.35	187
Ang Mo Kio Avenue 1	Street	High	High	8552.20	50	28	22	28	2.88	182
North Buona Vista Road	Street	High	Medium	6219.72	40	44	26	55	2.82	209
Admiralty Road West	Street	High	Low	5072.28	25	34	31	49	2.84	278

2.2. Index Construction

For each site i , planted vegetation count is denoted by P_i and spontaneous vegetation count by S_i . Total floristic count and spontaneous vegetation share are

$$V_i = P_i + S_i, \quad \phi_i = \frac{S_i}{V_i}. \quad (1)$$

The spontaneous share is interpreted as a vegetation-origin quantity. It measures the proportion of vegetation that has established outside formal planting, but it is not treated as biodiversity by itself. This distinction matters because a high share may represent ecologically useful self-recruitment in one site and fragmented roadside vegetation in another. The study therefore reads spontaneous share through faunal capacity, cross-taxon balance and maintenance class rather than treating it as an independent success indicator.

Area-standardized floristic intensity is calculated as

$$D_i = \frac{V_i}{A_i/1000}, \quad (2)$$

where A_i is the surveyed area in square metres. Maintenance intensity is recorded as low, medium or high. The ordinal code is $m_i = 1$ for low maintenance, $m_i = 2$ for medium maintenance and $m_i = 3$ for high maintenance, giving the maintenance credit

$$\omega_i = \frac{4 - m_i}{3}. \quad (3)$$

This credit assigns 1.000 to low-maintenance sites, 0.667 to medium-maintenance sites and 0.333 to high-maintenance sites. It is intentionally simple because measured labour hours, pruning frequency, machinery use, herbicide input and direct maintenance cost are not available for every site. The recorded maintenance class therefore functions as an operational proxy. The interpretation remains transparent: two sites with equal faunal capacity receive different low-input return values if one requires more frequent intervention.

Four faunal quantities describe site capacity: recorded richness R_i , estimated richness E_i , Shannon diversity H_i and probable species count Q_i . Each is normalized by the maximum value in the 13-site set:

$$\tilde{x}_i = \frac{x_i}{\max_j(x_j)}. \quad (4)$$

Composite faunal capacity is then

$$C_i = \frac{1}{4} (\tilde{R}_i + \tilde{E}_i + \tilde{H}_i + \tilde{Q}_i). \quad (5)$$

The capacity value is not a replacement for field observations. It is a compact expression of four different faunal signals: what was recorded, what the richness estimator suggests, how evenly assemblages are distributed and how large the probable species pool may be. Equal weighting avoids privileging one conservation target over the others. The value provides a comparable site-level index while preserving the component values in the interpretation.

Low-input biodiversity return is calculated as

$$L_i = C_i (0.5 + 0.5\phi_i) \omega_i. \quad (6)$$

The vegetation-origin multiplier gives planted vegetation a partial contribution and adds weight as spontaneous share increases. The maintenance credit then reduces the return value when ecological capacity is expressed under heavier intervention. This formula is important because it does not assume that planted vegetation has no ecological value, nor does it assume that spontaneous vegetation is always superior. It asks how much faunal capacity is expressed under the combination of vegetation origin and recorded maintenance class.

Unexpressed species potential is

$$U_i = \frac{Q_i - R_i}{Q_i}. \quad (7)$$

Cross-taxon balance is calculated from the capacity values for aculeate hymenopterans, butterflies and birds. If C_{ig} is the capacity value for site i and taxon group g , balance is

$$T_i = \left(1 + \frac{\text{sd}(C_{i1}, C_{i2}, C_{i3})}{\text{mean}(C_{i1}, C_{i2}, C_{i3})} \right)^{-1}. \quad (8)$$

Maintenance-release priority is

$$M_i = U_i C_i (1 - L_i). \quad (9)$$

These final two values provide complementary interpretations. Unexpressed species potential is high when recorded richness is small relative to probable species support. Cross-taxon balance is high when the faunal signal is not concentrated in only one group. Maintenance-release priority is high when capacity and unexpressed potential coexist with lower current low-input return. A high priority value therefore does not mean the site is currently the best performer. It means that the site contains ecological evidence that may justify carefully delimited changes in intervention intensity.

2.3. Comparative Analysis

Site ranking, group means and descriptive Pearson associations are used for the 13 sites. The record is cross-sectional and does not contain repeated post-management observations, so the analysis is interpreted as comparative rather than causal. The resulting values are suited to screening and site interpretation for maintenance planning, not to claims about treatment effects.

The value panels in Figure 2 preserve differences in site-level vegetation and biodiversity rather than reducing all of the assessment to a single score. The description panel demonstrates that the spontaneous share is not simply an extension of floristic intensity. The capacity-return panel proves that low-input return is not simply a scaling of faunal capacity. The potential-balance panel differentiates between sites with large unexpressed potential and those with consistent cross-taxon expression. Finally, the maintenance-class summary shows that low-maintenance sites have the highest return values, even though high-maintenance sites do not lack faunal capacity. These graphical results are used in structuring the Results section.

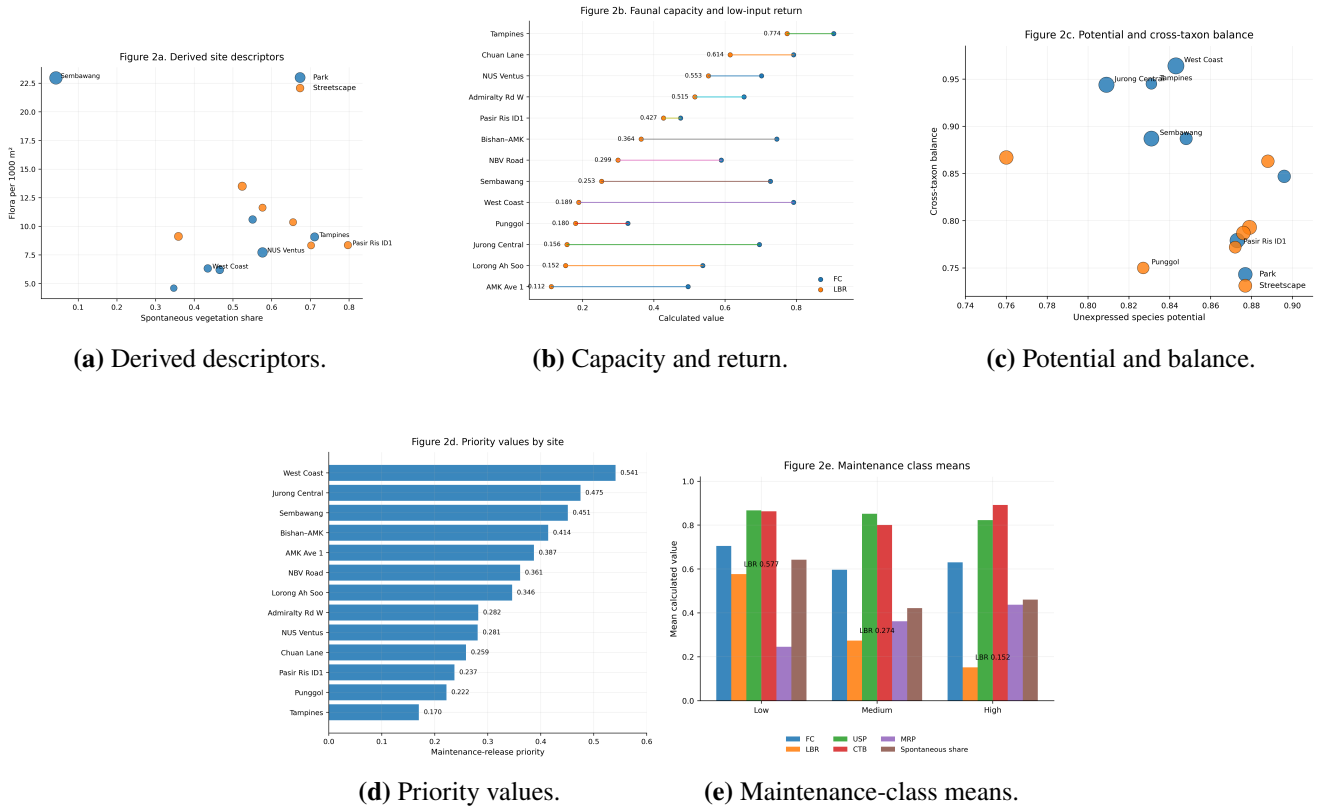


Figure 2. Computed values.

3. Results

3.1. Vegetation Origin and Site Structure

Total floristic count ranged from 49 at Jurong Central Park to 212 at Sembawang Hot Spring Park. The highest total count came from Sembawang, which had 203 planted and only 9 spontaneous species. Its low spontaneous share, 0.042, meant that it had the lowest spontaneous share in the set. Sembawang therefore qualified as a vegetation-rich and highly-managed site that would not be expected to deliver a high low-input return value. By contrast, Pasir Ris Industrial Drive 1 had the highest spontaneous share, at 0.797. Other sites with very high spontaneous shares included Tampines Eco-Green, at 0.711, and Lorong Ah Soo, at 0.702. Sites with high spontaneous shares were found both on roads and in parks, but the faunal outcomes varied greatly between road and park sites.

The difference between Tampines Eco-Green and Sembawang Hot Spring Park was particularly pronounced. Although Sembawang had the largest flora and the highest floristic intensity, its low-input return value of 0.253 was comparatively poor. Tampines Eco-Green had a lower vegetation count, but the highest species richness, the highest Shannon diversity, the lowest maintenance, and the highest spontaneous share. Its return value of 0.774 was the highest in the study site set. This finding showed that there could be considerable differences between plant richness and biodiversity return per maintenance investment. Planted richness should not be devalued as a signal of site ecological quality, but it should be recognized that it was a stronger indicator when it was coupled with faunal expression and maintained habitats.

There were also significant differences between park sites and streetscapes. Parks had a composite mean faunal capacity of 0.765, while streetscapes had a capacity of 0.513. Streetscapes also had the highest mean spontaneous share, at 0.602, compared to a mean for parks of 0.447. Since the two site types showed very similar means in unexpressed potential, with means of 0.847 and 0.850 respectively, it appeared that both parks and streetscapes had plenty of untapped opportunities. The difference between parks and streetscapes became clearer in cross-taxon balance, which was higher in parks: parks had a mean value of 0.893, whereas streetscapes showed 0.805.

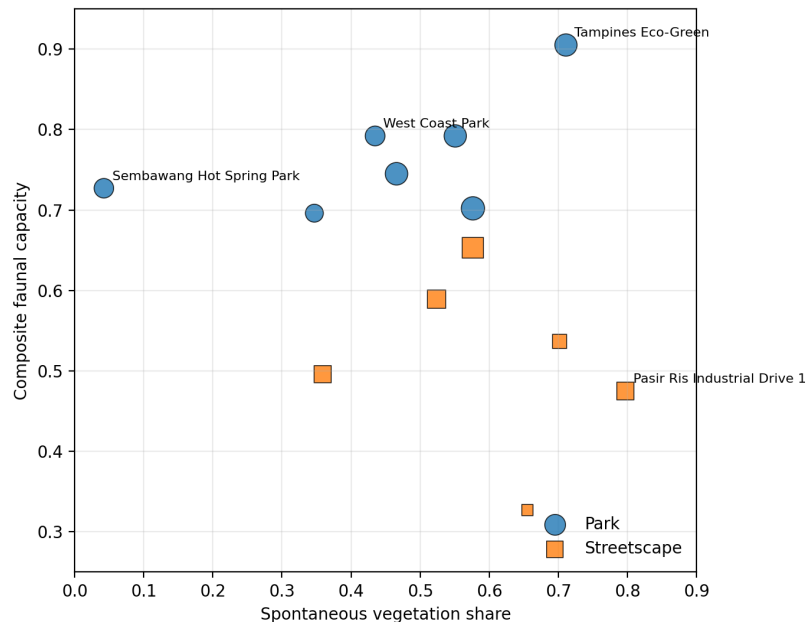


Figure 3. Vegetation origin and faunal capacity.

The vegetation-origin plane shown in Figure 3 revealed these differences clearly. The high-faunal capacity and high-spontaneous-share Tampines Eco-Green was in the top-right quadrant. Far on the left side of the plane was Sembawang Hot Spring Park, which had an extremely low spontaneous share, but still some faunal capacity despite an overwhelming vegetation inventory that was almost entirely planted. Pasir Ris Industrial Drive 1 was closer to the top-right corner, but still did not achieve high faunal capacity. Faunal capacity, therefore, was maximized by the spontaneous vegetation that contributed to faunal expression.

3.2. Faunal Capacity Across Site Types

The composite faunal capacity of the study sites ranged from 0.327 at Punggol Field to 0.905 at Tampines Eco-Green. Tampines Eco-Green had the highest capacity because it had the highest recorded richness, the highest Shannon diversity, strong estimated richness and probable species count. After it, in descending order, West Coast Park and Chuan Lane Park had values of 0.792. West Coast Park had a high composite capacity thanks to the highest estimated richness and highest cross-taxon balance, while Chuan Lane Park scored high due to high recorded richness, probable species count and low maintenance. The values 0.745, 0.727 and 0.702 were reported for Bishan–Ang Mo Kio Park, Sembawang Hot Spring Park, and NUS Ventus.

At the lower end of the capacity ranking, streetscapes dominated. Punggol Field had the lowest composite faunal capacity at 0.327 because it had the lowest richness, Shannon diversity and probable species count. Another low-ranked street site, Pasir Ris Industrial Drive 1, scored only 0.475 even though it had the highest spontaneous share in the set. Next was Ang Mo Kio Avenue 1, at 0.496 with a recorded richness of 22 and estimated richness of 28. The best streetscape in the set, Lorong Ah Soo, scored 0.537. Its value indicated that a relatively high spontaneous share was not enough to overcome the absence of strong faunal expression.

The correlations explained the key determinants of composite faunal capacity. This capacity showed the highest association with recorded richness ($r = 0.966$), probable species count ($r = 0.830$), Shannon diversity ($r = 0.752$) and estimated richness ($r = 0.731$). There was virtually no correlation between faunal capacity and floristic intensity ($r = -0.014$). One of the most important findings made in this study concerned the lack of correlation between faunal capacity and vegetation density. While Sembawang Hot Spring Park had high floristic intensity, but did not lead the capacity rankings, Tampines Eco-Green did despite low floristic intensity and high spontaneous share.

3.3. Maintenance-Adjusted Biodiversity Return

The ranking of study sites based on low-input biodiversity return changed because it was an intersection of faunal capacity, vegetation origin and maintenance. Thus, the first place was taken by Tampines Eco-Green with a value of 0.774. Second place was Chuan Lane Park with 0.614, which relied on high faunal capacity and low maintenance, as well as spontaneous share of 0.551. Third place belonged to NUS Ventus with 0.553, which had the lowest maintenance in the set, the highest spontaneous vegetation count and highest probable species count. Fourth place went to Admiralty Road West with 0.515, since it had the lowest maintenance and highest probable species count.

Fifth place went to Pasir Ris Industrial Drive 1, with a value of 0.427. Even though it was behind the top faunal capacity sites, the combination of low maintenance and very high spontaneous share elevated its return. Again, the reader must pay attention to the fact that this is a good score under the given assessment conditions, but does not make the site a leader in terms of biodiversity capacity. Sixth, seventh and eighth places went to Bishan–Ang Mo Kio Park (0.364), North Buona Vista Road (0.299), and Sembawang Hot Spring Park (0.253). In the case of the latter, a very high planted inventory had a limited return due to low spontaneous share.

The last three places in low-input return were taken by Ang Mo Kio Avenue 1, Lorong Ah Soo, and Jurong Central Park. The site with the lowest return was Ang Mo Kio Avenue 1, with the score of 0.112. Lorong Ah Soo also produced a low score, of 0.152, even though it had the highest spontaneous share. The low value was caused by high maintenance and only moderate faunal capacity. Likewise, high maintenance lowered the value of Jurong Central Park to 0.156 despite strong faunal capacity and high cross-taxon balance. It was clear that the low-input return was neither a rephrasing of spontaneous vegetation share, nor faunal capacity.

The conversion panels shown in Figure 4 demonstrated the relationship between maintenance and capacity. Both high-faunal capacity Tampines Eco-Green and Chuan Lane Park had high low-input returns because they had high capacities and low maintenance. Conversely, West Coast Park, Sembawang Hot Spring Park, and Jurong Central Park had low return because their capacity was reduced to some extent by maintenance. The difference in maintenance was also summarized in the maintenance-class panel. Sites with low maintenance scored a mean of 0.577, medium 0.274, and high 0.152, despite having a mean capacity of 0.630.

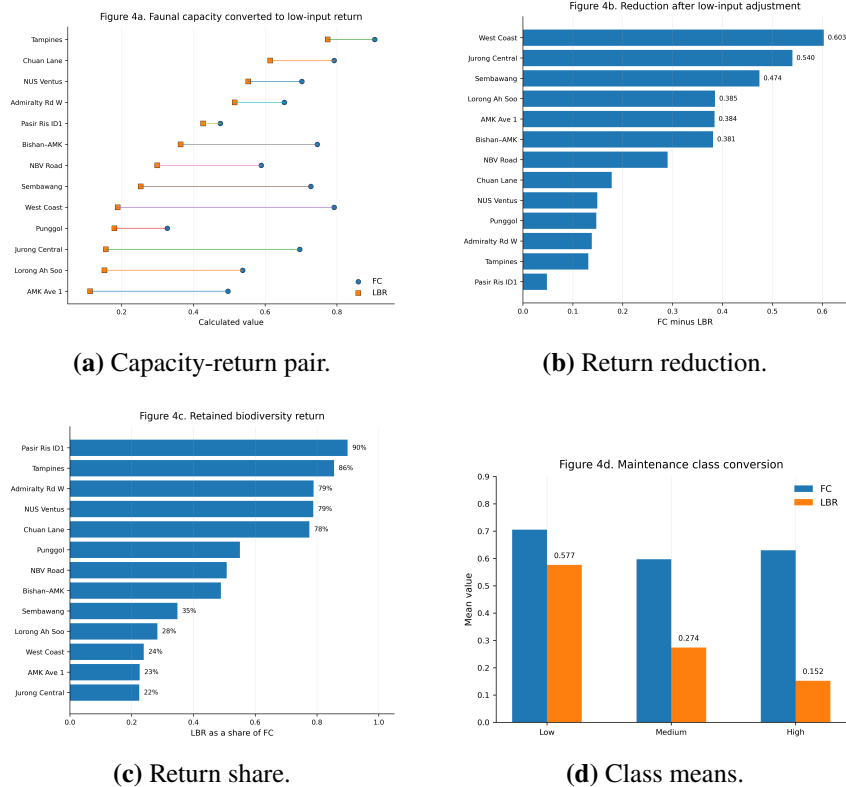


Figure 4. Capacity-return conversion.

3.3.1. Ecological Profiles of Grouped Sites

Site-type comparisons isolate the effects of site type from those of maintenance practices. Parks exhibited higher faunal capacity and cross-taxon balance but lower levels of spontaneity than streetscapes, whereas streetscapes had greater spontaneity. Sites with low maintenance practices had the highest low-input returns and the greatest average level of unexpressed species potentials. High-maintenance sites had low return but comparatively higher cross-taxon balance. It is vital to note that this combination suggests that high-maintenance sites may harbor a substantial faunal profile which fails to materialize due to constant interventions.

The grouped site profiles depicted in Figure 5 lend additional support to interpreting the rankings of the individual sites. The site-type panel clearly demonstrates the presence of stronger faunal capacity and cross-taxon balance in parks, whereas the maintenance panel makes it obvious that low maintenance is a significant predictor of high return. The floristic intensity panel avoids misinterpreting the results due to the vegetation density measure. Despite having the greatest mean floristic intensity, medium-maintenance sites do not necessarily generate the greatest return value. Finally, the return distribution panel indicates that the low-maintenance sites contain both the best park performer and high-performing streetscapes.

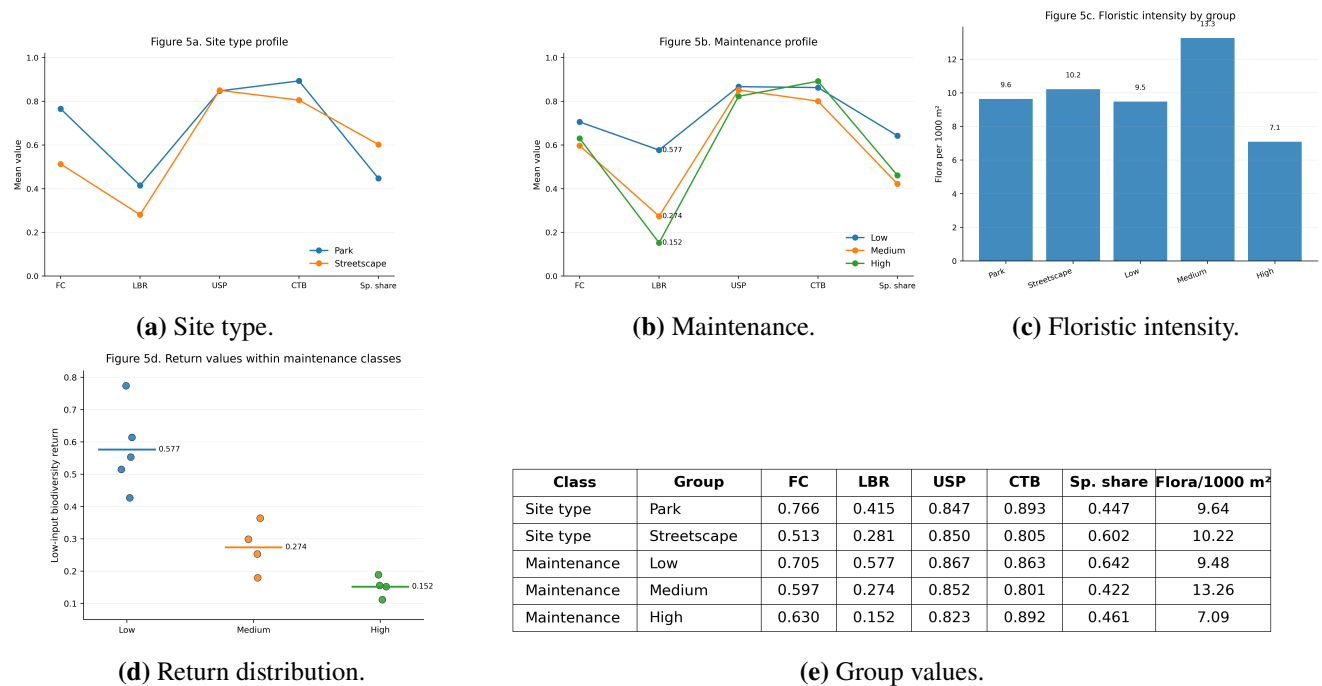


Figure 5. Group profiles.

The site values in Table 2 show that the strongest current return and the strongest maintenance-release priority are not held by the same sites. Tampines Eco-Green has the highest low-input return but the lowest priority value because it already expresses biodiversity efficiently under low maintenance. West Coast Park has the highest priority value despite low return because capacity, unexpressed potential and high maintenance coexist. Jurong Central Park and Sembawang Hot Spring Park follow the same pattern. The table therefore separates current performance from improvement opportunity, which is the main analytical distinction of the paper.

The group means in Table 3 support two conclusions. The first is that site type and maintenance class describe different ecological contrasts. Parks have stronger capacity and balance, but streetscapes have higher spontaneous share. The second is that maintenance class has the strongest effect on low-input return. Low-maintenance sites have the highest return even though they do not have the highest floristic intensity. This result is consistent with the broader finding that reduced mowing or carefully adjusted maintenance can support biodiversity in urban grassland and verge contexts, while also requiring site-specific design and public communication [7, 10, 13, 22].

The associations in Table 4 explain why the ranking changes across indices. Low-input return is strongly and

Table 2. Site index values.

Site	FC	LBR	USP	CTB	MRP
Jurong Central Park	0.696	0.156	0.809	0.944	0.475
Bishan–Ang Mo Kio Park	0.745	0.364	0.873	0.779	0.414
NUS Ventus	0.702	0.553	0.896	0.847	0.281
West Coast Park	0.792	0.189	0.843	0.964	0.541
Sembawang Hot Spring Park	0.727	0.253	0.831	0.887	0.451
Tampines Eco-Green	0.905	0.774	0.831	0.945	0.170
Chuan Lane Park	0.792	0.614	0.848	0.887	0.259
Lorong Ah Soo	0.537	0.152	0.760	0.867	0.346
Punggol Field	0.327	0.180	0.827	0.750	0.222
Pasir Ris Industrial Drive 1	0.475	0.427	0.872	0.772	0.237
Ang Mo Kio Avenue 1	0.496	0.112	0.879	0.793	0.387
North Buona Vista Road	0.589	0.299	0.876	0.787	0.361
Admiralty Road West	0.653	0.515	0.888	0.863	0.282

Table 3. Group means.

Group	FC	LBR	USP	CTB	Spont. share	Flora/1000 m ²
Park	0.765	0.415	0.847	0.893	0.447	9.641
Streetscape	0.513	0.281	0.850	0.805	0.602	10.219
Low maintenance	0.705	0.577	0.867	0.863	0.642	9.477
Medium maintenance	0.597	0.274	0.851	0.801	0.422	13.258
High maintenance	0.630	0.152	0.823	0.892	0.461	7.094

negatively associated with maintenance code, while its association with spontaneous share is positive but weaker. This means that spontaneous vegetation matters, but maintenance intensity governs how much of the faunal capacity is expressed as low-input return. Maintenance-release priority is positively associated with maintenance code and negatively associated with low-input return, confirming that priority captures opportunity under intervention pressure rather than current ecological quality.

Table 4. Descriptive associations.

Association	<i>r</i>
Low-input biodiversity return and maintenance code	-0.888
Low-input biodiversity return and spontaneous vegetation share	0.411
Low-input biodiversity return and composite faunal capacity	0.560
Composite faunal capacity and recorded richness	0.966
Composite faunal capacity and estimated richness	0.731
Composite faunal capacity and Shannon diversity	0.752
Composite faunal capacity and probable species count	0.830
Composite faunal capacity and floristic intensity	-0.014
Maintenance-release priority and low-input biodiversity return	-0.667
Maintenance-release priority and maintenance code	0.754

3.4. Interpretation by Site

Low maintenance priority yielded a different ranking from low-input return. West Coast Park ranked first for maintenance priority with a value of 0.541, second was Jurong Central Park with a priority of 0.475, Sembawang

Hot Spring Park at 0.451, Bishan-Ang Mo Kio Park at 0.414, and Ang Mo Kio Avenue 1 at 0.387. However, these locations did not rank highly in terms of low-input return. The reasons why they had high priority value was that they exhibited high species potential and fauna capacity in the face of lower current return under medium to high maintenance levels.

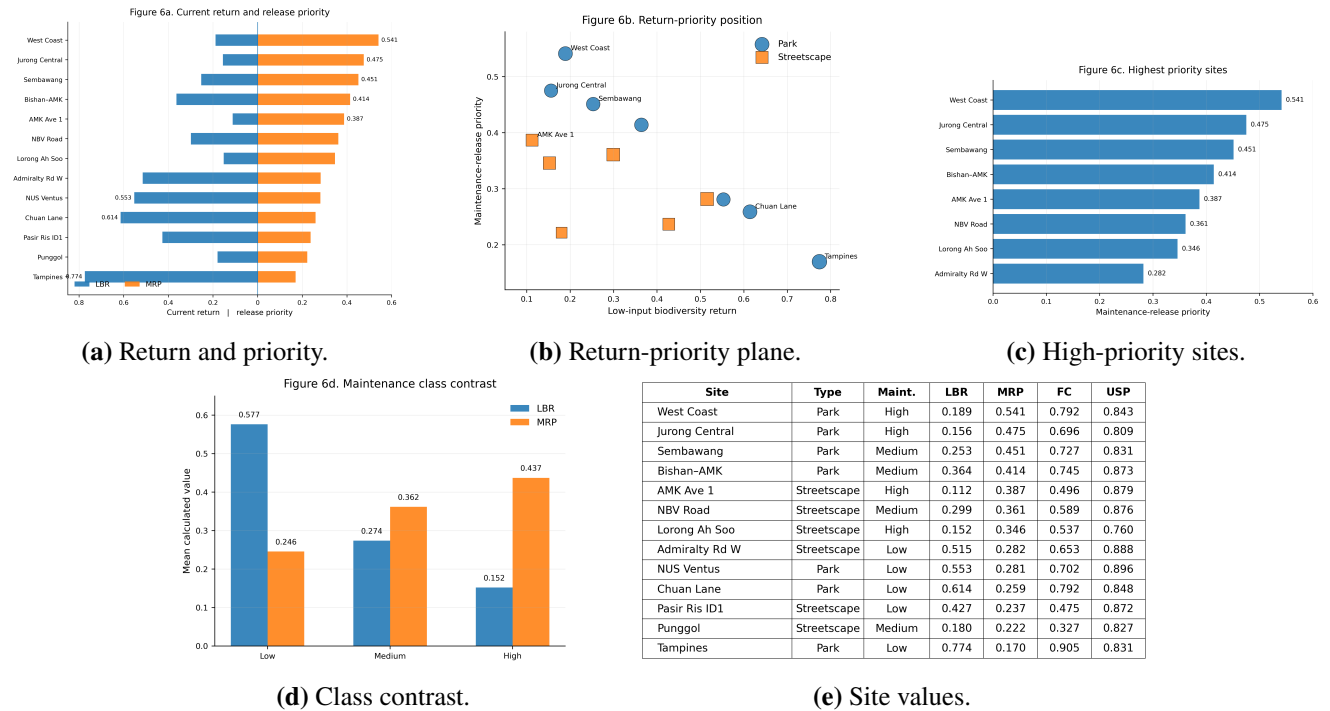


Figure 6. Return and release priority.

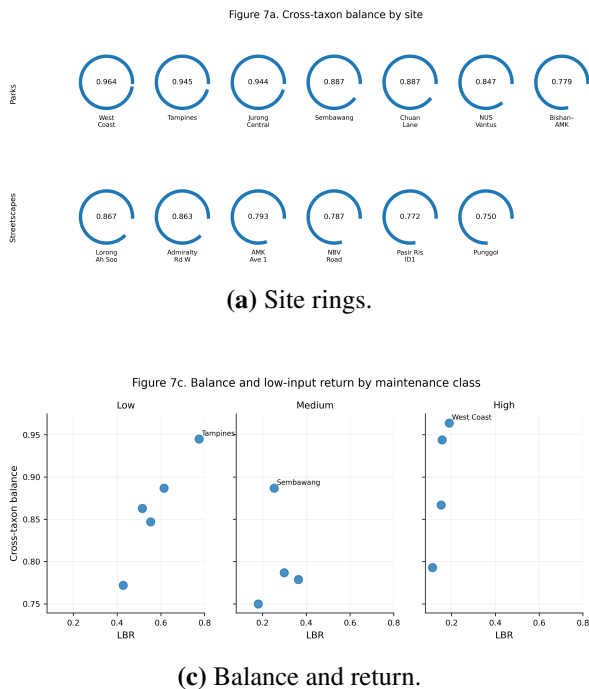
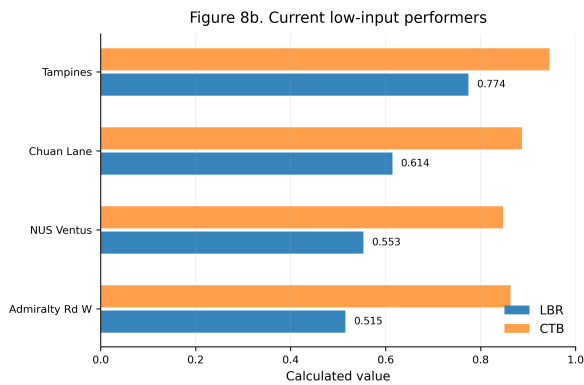


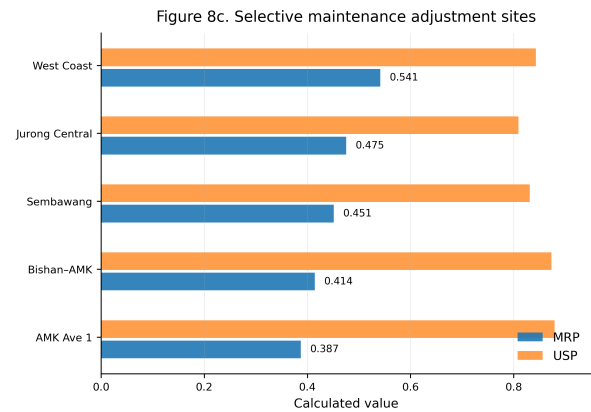
Figure 7. Cross-taxon balance.

Site interpretation	Site	Type	Maint.	LBR	MRP	CTB
Current low-input performer	Tampines	Park	Low	0.774	0.170	0.945
Current low-input performer	Chuan Lane	Park	Low	0.614	0.259	0.887
Current low-input performer	NUS Ventus	Park	Low	0.553	0.281	0.847
Current low-input performer	Admiralty Rd W	Streetscape	Low	0.515	0.282	0.863
Selective maintenance adjustment	West Coast	Park	High	0.189	0.541	0.964
Selective maintenance adjustment	Jurong Central	Park	High	0.156	0.475	0.944
Selective maintenance adjustment	Sembawang	Park	Medium	0.253	0.451	0.887
Selective maintenance adjustment	Bishan-AMK	Park	Medium	0.364	0.414	0.779
Selective maintenance adjustment	AMK Ave 1	Streetscape	High	0.112	0.387	0.793
Habitat enrichment first	Lorong Ah Soo	Streetscape	High	0.152	0.346	0.867
Habitat enrichment first	Punggol	Streetscape	Medium	0.180	0.222	0.750
Habitat enrichment first	NBV Road	Streetscape	Medium	0.299	0.361	0.787
Habitat enrichment first	Pasir Ris ID1	Streetscape	Low	0.427	0.237	0.772

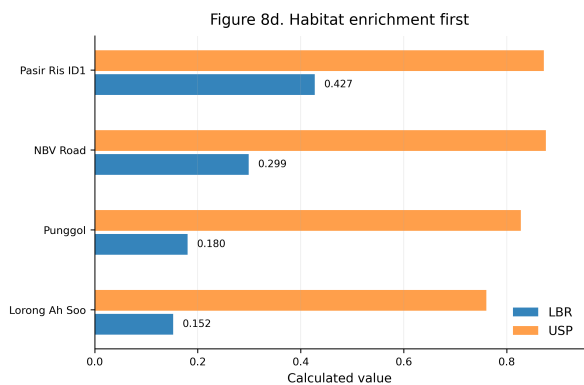
(a) Site groups.



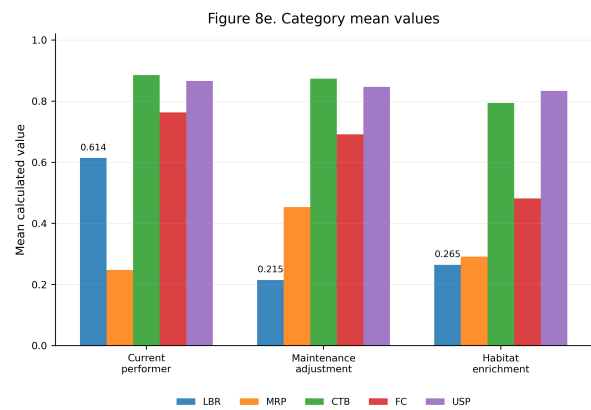
(b) Current performers.



(c) Adjustment sites.



(d) Enrichment first.



(e) Category means.

Figure 8. Site interpretation.

On the other hand, the location with the lowest priority was Tampines Eco-Green with a score of 0.170. That does not imply poor value of biodiversity, but instead shows that the current biodiversity return is high under low input in this location. In a similar vein, current return at the parks Chuan Lane Park and NUS Ventus is also relatively high. Low priority at Punggol Field implies that fauna capacity and probable number of species are low. Finally, Pasir Ris Industrial Drive 1 has low to moderate priority because even though favorable low-input conditions are observed, the fauna capacity is still low. These results imply that priority needs to be analyzed in relation to return and capacity.

Figure 6 highlights that the return priority panels are two different sets of signals about the management of biodiversity. Specifically, return values on the left side highlight sites that are already performing well with respect to biodiversity under current low input conditions. Priority values, on the other hand, indicate locations where the ecological value of a site is partially obscured by current intervention. West Coast Park is a good example of a

site that ranks high in terms of maintenance priority because of its capacity, high species potential, and cross-taxa balance and high maintenance. Tampines Eco-Green is an opposite case.

The cross-taxon panels in Figure 7 show that balanced faunal expression is not restricted to low-maintenance sites. West Coast Park had the strongest cross-taxon balance at 0.964, followed by Tampines Eco-Green at 0.945 and Jurong Central Park at 0.944. Punggol Field recorded the lowest balance at 0.750. The result is important because it shows that maintenance-release priority should not be based only on current low-input return. A highly maintained site with strong cross-taxon balance may contain habitat or landscape conditions that already support multiple faunal groups and could respond positively to carefully delimited reductions in disturbance.

Figure 8 shows how the calculated indices translate into the three managerial implications described above. The current low-input performers are Tampines Eco-Green, Chuan Lane Park, NUS Ventus and Admiralty Road West. Bishan-Ang Mo Kio Park, Ang Mo Kio Avenue 1, Sembawang Hot Spring Park, West Coast Park and Jurong Central Park offer opportunities for maintenance release. Punggol Field, Pasir Ris Industrial Drive 1 and Lorong Ah Soo require a different consideration due to potential habitat enrichment or continuity.

4. Discussion

4.1. Intervention Influence on Biodiversity Return

The current study provides a practical interpretation of the Singapore site dataset by distinguishing biodiversity amount from its return through maintenance. This distinction corresponds with ecological research, which shows that faunal species richness is insufficient to represent habitat quality, management feasibility or multi-taxa dynamics [4, 16, 25]. The results show that planted richness, spontaneous vegetation and faunal capacity cannot be substituted. The current low-input return of the Sembawang Hot Spring Park proves the importance and limitations of the planting richness: it has the largest floristic inventory, significant faunal capacity and good cross-taxon balance, but only moderate return. The current low-input return of Tampines Eco-Green proves the opposite condition: high faunal capacity, low maintenance and high spontaneous share are required for the best return.

This distinction is useful because the index set does not assume a rigid ecological classification for all locations. There is a difference between current low-input performers and high-priority maintenance-release sites. Tampines Eco-Green is not the first priority maintenance release site, since it already works effectively in the low-input environment. However, West Coast Park is not the best current low-input performer, despite the high estimated richness and high cross-taxon balance. This site is the strongest priority because it has the highest maintenance level. Such an interpretation is important because limited resources can be devoted either to preserve current low-input success or experiment with intervention.

In addition, this result confirms the value of high-maintenance sites for ecological research and biodiversity planning. A high level of maintenance does not necessarily imply the low species richness, but the low return of the ecological value through intervention. This interpretation matches the maintenance ecology literature, which reports varied influences of mowing and vegetation removal on plant and invertebrate richness [10, 13, 22]. Instead of applying the general reductionist approach to maintenance, one needs to investigate the unique ecological characteristics of each site and adapt intervention methods.

4.2. Role of Spontaneous Vegetation in Biodiversity Return

Spontaneous vegetation plays a crucial role in the current interpretation, although the results disprove the common assumption about its importance. Pasir Ris Industrial Drive 1 and Lorong Ah Soo are examples of this idea. Despite the presence of spontaneous vegetation, these two locations demonstrate lower faunal capacity compared with park locations. Pasir Ris Industrial Drive 1 has high spontaneous share and low maintenance. Therefore, its low-input return is relatively high. However, Lorong Ah Soo has similar spontaneous share but moderate faunal capacity and high maintenance, leading to poor return. Hence, spontaneous vegetation requires other conditions to translate into faunal capacity: habitat depth, continuity, flowering, host plants and specific faunal resources.

Ecological literature corroborates the results and suggests that the benefits of spontaneous vegetation are subject to certain environmental conditions, design and management timing [7, 12, 17]. While urban meadows and reduced mowing can support faunal activity, a mosaic of vegetation structures can have a more positive influence [22]. Moreover, street landscapes face specific challenges due to the risk of traffic exposure, small size, fragmented structure and vegetation edges. While linear vegetation can create the faunal corridor, this corridor should connect continuous resources for the mobile taxa [9, 16, 28].

The Singapore results suggest that spontaneous vegetation should not be left unmanaged in street landscapes. Self-established vegetation should be retained where it enhances floral and faunal diversity through flowering, host plants, litter creation and habitat structure. Where possible, spontaneous vegetation should be removed in order to eliminate any risks of traffic safety, invasive species introduction and dead-end corridors. Planted vegetation remains essential to ensure canopy coverage, legibility and stable structure. The key for biodiversity maintenance lies in creating a complex interaction of planted and spontaneous components under adequate maintenance regime.

4.3. Biodiversity in Urban Landscapes of the Tropics

As discussed above, the findings are useful for further biodiversity planning in tropical landscapes. Temperate landscapes can vary in the seasonality of mowing, which creates periodic intervention. However, urban landscape maintenance in the tropics is year-round. This creates a need for precise timing and intervention distribution in order to allow some vegetation types to develop during non-maintenance time. It is not necessary to preserve all the site area. Some meadow strips, drainage margins, slope edges, understory patches and lawn zones can provide such opportunities for maintenance adjustment.

The current study offers a few interesting candidates for experimental adjustment. First, West Coast Park and Jurong Central Park are both high in maintenance and low in low-input return. However, they remain high in estimated richness and cross-taxon balance. The current maintenance intensity prevents biodiversity return; however, some selective changes can bring improvement. Specifically, the West Coast Park offers the greatest opportunities due to the highest richness estimation. It is recommended to introduce carefully delimited trials comparing mowing intervals, retention zones, flowering and understory protection with bird, butterfly and hymenoptera observation.

The Sembawang Hot Spring Park requires an entirely different consideration. Although it has the highest planted richness, the spontaneous share is low. However, its cross-taxon balance remains high. Therefore, the appropriate maintenance change does not involve the reduction of planting richness. Instead, the site requires a careful preservation of selected portions of spontaneous vegetation in the planted area, where floral and faunal activity should be sustained during non-maintenance periods. Such maintenance will be able to reveal faunal potential, even in a high-planted site.

The street landscape sites require even more precision. While Admiralty Road West performs well under low-input intervention, the other two have more mixed results. Pasir Ris Industrial Drive 1 is a good candidate for maintenance adjustment due to the presence of spontaneous vegetation. However, its faunal capacity is somewhat lower, which suggests that some habitat enrichment might be necessary. Finally, Punggol Field has low capacity and low probable species richness, which means that it is unlikely to gain from the simple maintenance adjustment. These results confirm the need for more faunal-friendly street design.

4.4. Urban Biodiversity Planning

The current results belong to the wider transition towards biodiversity-aware greening. Cities increasingly use the indicator-based approach to track local species, ecosystem services and biodiversity-related actions [24]. However, such an indicator is useful for citywide assessments, not site-specific management decisions. When the city has numerous green spaces, it needs to distinguish which site should be preserved as a low-input performer, which site should have adjusted maintenance, and which site requires habitat enrichment before such adjustment is feasible.

This study makes an important contribution to solving this problem. It maintains faunal parameters and interprets them through maintenance class, which is critical for making site-specific decisions. It is often assumed that

intervention intensity does not matter much and that maintenance should be considered as an operation. However, the results show that intervention level significantly changes biodiversity value, although faunal capacity remains intact. If such an approach is extended to larger inventories, it will involve additional variables, such as labour time, pruning cycles, irrigation, chemicals and cost.

Eventually, the ordinal credit should become more detailed and quantitative to provide greater precision. However, the ordinal credit is useful because it clearly and precisely accounts for routine intervention intensity. Since it can be applied to the existing Singapore data, no additional data collection is necessary. Although the ordinal credit does not provide all details, it is still sufficient for the site analysis. Moreover, it could be applied to larger inventories if maintenance, taxon and vegetation records are provided.

5. Limitations

The analysis is based on site summaries, not abundance records, detection history or repeated seasonal observations. The model cannot estimate detection probability, species occupancy, population viability and seasonal turnover of individual taxa. Normalization and aggregation are used for recorded richness, estimated richness, Shannon diversity and probable species count. The probable species count helps with planning, but it should not be considered the future assemblage of the site. Probable species count reflects the potential of a site to express biodiversity.

The maintenance credit remains ordinal. It distinguishes low, medium and high maintenance levels but does not account for labour costs, machines, mowing and pruning frequency, irrigation, fertilizers, herbicides and cost. More detailed information could increase the precision of the calculation, but the credit is currently sufficient because it estimates the maintenance intervention intensity precisely and reproducibly. The credit is not based on measurable factors, such as cost, but on routine maintenance activities.

Normalization is internal to the set of 13 sites. Addition of new sites will result in recalculation of the maximum values and modification of the normalization process. If the indices should be applied throughout a larger citywide inventory, the same indices should be recalculated after sensitivity tests. Finally, equal weight for four indicators reflects a simplified approach. Alternative weights could be applied if management goals prefer a particular taxon, endangered species or landscape service.

6. Conclusion

Analysis of the Singapore site record has shown that the locations with the highest faunal capacity are not necessarily the locations with the strongest biodiversity return in low-input conditions. Intervention level combined with vegetation origin creates distinct operational categories. Faunal capacity, biodiversity return and priority of maintenance change are not identical indices. Tampines Eco-Green demonstrates the greatest current low-input return thanks to high faunal capacity, low maintenance and spontaneous vegetation. Chuan Lane Park, NUS Ventus and Admiralty Road West also perform well under low-input conditions. Sembawang Hot Spring Park, West Coast Park and Jurong Central Park contain significant faunal capacity, but high intervention or low spontaneous share lowers their return.

Therefore, the conclusion is that a high level of spontaneous vegetation or low intervention does not automatically guarantee high biodiversity return. Spontaneous vegetation alone and reduced mowing alone cannot solve the problem, but they should be considered together with faunal capacity, planted vegetation and maintenance intensity. Even if the location has high planting richness, it can contain the unexpressed biodiversity. Similarly, even if the location contains the unexpressed biodiversity, the spontaneous vegetation needs additional habitat depth, connectivity and resources to become effective.

For tropical urban landscapes, the most defensible method of maintaining biodiversity is trial-based selective intervention. The sites that currently perform well under low-input maintenance should be preserved from unnecessary simplification. The high-priority sites should be subjected to targeted trials that modify the maintenance

regime to test the effects of reduced mowing, flowering windows and understory protection. High spontaneous share with low faunal capacity should be enriched before any low-input experiments can occur.

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