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# Multi-Scale Assessment of Urban Gardens as Constructed Habitats for Biodiversity Conservation in Jeddah, Saudi Arabia

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## Abstract

Biodiversity in arid urban environments depends upon habitat formation that balances both bioclimatic and biophysical environment needs. There is the potential for urban gardens to establish symbiotic ecosystem services from microhabitat formation that collectively form an assemblage of ecological patches to connect a diverse range of flora and fauna, and establish community driven nursery and seed collection initiatives. This study of urban garden habitats situated within a new urban district of Jeddah Saudi. The analysis concentrates on the ability of garden spatial formations to construct a heterogeneous spatial morphology of sub-patch within the larger urban landscape patch.  Patch and subpatch formations are examined based on the criteria of (I) assemblage of the spatial habitat (characterized by shape and spatial organization); (II) integration of spatial, functional and vegetation plantation patterns; (III) connectivity. Findings reveal that garden layout is structured by the integration and layering of plant types to generate cool understory habitat with seedling establishment, and water conservation. Designed layout of the garden as a spatial pattern is augmented with a range of microclimate mediators to dim solar exposure within the plantation habitat. A strong heterogeneity in plant formations and combinations is seen to dominant the garden formations.



***Keywords***

*Arid Urban Garden; Spatial Morphology; Heterogeneous; Constructed Habitat; Biodiversity; Spatial Scales*

## 1. Introduction

2020 has been established as a significant milestone to achieve proposed targets set by the Global Strategy for Plant Conservation. (Hall et al., 2011) A preliminary 2010 IUCN Red list assessment of the Arabian Peninsula‘s most important plant areas (classified on a national basis) highlights the need for immediate conservation of at risk endemic flora. The consistent taxonomy checklist of plants in the Arabian Peninsula is being compiled at the Royal Botanic Garden Edinburgh. (Hall et al., 2011) In Yemen 699 endemic tax have been reported on (69%) identifying 220 species at Risk of Extinction, 20 Critically Endangered, and 38 Endangered, with 162 species identified as Vulnerable. In the valley forests of the western escarpment mountains in Yemen and Saudi Arabia, 13 of 18 regionally rare species are assessed as Critically Endangered and 5 as Endangered. (Hall et al., 2011) Strengthening the development of ecosystem services in urban areas assists in achieving the proposed GSPC Targets 2011-2020 specifically *GSPC Object II: Plant diversity is urgently and effectively conserved; Target 8: At least 75 per cent of threatened plan species in ex-situ collections, preferably in the country of origin, and at least 20 per cent available for recovery and restoration programmes*. (Hall et al., 2011)

The kingdom of Saudi Arabia became a signature to the Convention of Biodiversity (CBD) in 2005 establishing their first strategic action plan soon after. The Saudi Arabian CBD strategy concentrates on ways to stabilize ecosystems to immediately address the loss of biodiversity. (Hall et al., 2011) Government stakeholders such as the High Commission for the Development of Arriyadh, have documented the tax. of endemic plants, engaging in a number of initiatives to disseminate indigenous plant knowledge. (High Commission for the Development of Arriyadh 2014) The High Commission has also initiated field research centers at Thumamah Park to investigate the cultivation of at risk endemic species. Their publication on the taxonomy of vegetation found in the central Najd region is a good starting point to identifying a conservation strategy that reintroduces endemic vegetation into the natural habitats constructed in urban areas. This paper aims to contribute insights into how urban gardens as naturalistic constructions are being structured in extreme arid urban environments.

## 2. Literature review

### 2.1. Habitat construction for biodiversity conservation in extreme arid landscape contexts

The main drivers of biodiversity loss relate to the rapid expansion of settlements combined with the interaction of economic, social and cultural factors, and the increasing occurrence of extremely high temperatures and uneven rainfall, with endemic vegetation at risk due to the frequent planting of mono-plant cultures. (Abdulaziz et al., 2005) Changes in agricultural practices in the southwestern region of the country relate to the enlargement of farm areas, has also led to the loss of agricultural terraces. This in turn has resulted in the loss of microhabitats for plants and increases soil erosion and flash flooding. Subsequently as people relocate to urban environments, there is also a loss of traditional knowledge relating to traditional agricultural practices, and understandings of ecosystem management. The gathering of naturally occurring foods and medicines is still important to the people and economy of the country.

Additionally, recognizing the importance of plant habitat in cities is an important criteria for selecting sites for conservation action. To date the majority of research on mosaic landscapes has focused on the loss of natural habitats and/or their fragmentation rather than on the construction of new habitats in extremely damaged or at risk ecosystem ecologies. Investigating the spatial range of simple to complex constructed habitats that may be sustained in extreme ecology contexts such as those found in the Arabian Peninsula, constructing urban garden habitats will generate a natural diversity and through scaling of these initiatives over time, will enable larger habitat formation for at risk species. (Goodard 2010) Constructing habitats in cities also will contribute significantly to the development of ecosystem services. At the present time, exploring the construction of urban garden habitats for biodiversity has not been incorporated into the Saudi Arabia's biodiversity conservation action plans.

The city of Arriyadh has actively engaged in establishing new habitat, but a number of key challenges face regional and local stakeholders, the primary being the absence of design research and guidelines on how to establish and sustain biodiverse ecological patches in extremely arid ecosystems. There is a need to define the specifications of habitat types to be constructed, in addition to establishing guidelines for the design and construction of ecological corridors and their connectivity range. Policies are also needed at the local governmental level administration and maintenance of neighborhood community garden initiatives. There is also an absence of assessment metrics for arid constructed habitats specific to urban areas in the Arabian Peninsula.

### 2.2. Constructing habitats in cities for biodiversity

Urban gardens enable people to interact with nature and establish ecosystem services that impact the quality of urban life. The management of urban gardens alters land cover and species diversity, with groups of gardens forming green patches that become important refuges for natural species. Information on wildlife gardening is limited in ecological research, with the majority of research undertaken in developed countries. (Goodard 2010) Urban habitats are constructed with varying types of vegetation or landcover to form a distinctive environmental condition, providing natural resources required by different species or species group. (Wang 2008) The design of biodiversity enabling habitats is related to the need to increase the abundance of birds, butterflies, and other animals and plants valued for their aesthetic and functional attributes. (Hough 2004) Numerous challenges face municipalities seeking to balancing recreational and ornamental need with the construction of greenspace that will sustain and increase the density of native biodiversity. Different spatial arrangements at macro and micro scales enables the formation of heterogeneity, an important structuring consideration for sustainable biodiverse habitat formation. (Goodard 2010) Understanding the relationships between ecological function and spatial structure and scale will also enable the ecological consequences of proposed spatial solutions or risks to be anticipated and modeled. (Leitao 2002, Pace et al., 2015) To date there is a limited understanding of how constructed spatial habitats relate to ecological processes, species establishment and dispersal, and species responses in extreme arid climates of the Arabian Peninsula. Arid urban environments pose challenges to constructing habitats for biodiversity due to the absence of water, good soil types, present vegetation range, and a symbiotic background mosaic. In extreme arid urban contexts, spatial patterning of habitats and their patches as discrete or integrated assemblages may expose constructed habitats to higher risk and need for ecoservice management due to the type and patterning of land cover. (Landis 2017, Pace et al., 2015) The identification of ideal urban sites and neighborhoods to establish urban garden initiatives requires study of the site solar exposure and above variables, but also depends upon the symbiotic commitment of local community caretakers to sustain the urban gardens over time, and the municipalities design expectations of constructed biodiverse habitats as compared to ornamental or recreational urban landscapes.

## 2.3. Heterogeneous spatial structure and biodiversity

One of the central concerns of landscape ecology is how spatial heterogeneity shapes the dynamics of ecological systems and temporal processes. (Pickett and Cadenasso 1995) Increasing the heterogeneity of landscape ecologies depends more on the spatial structuring of patches and habitats rather than the spatial range of scales. (Pickett and Cadenasso 1995) Different approaches to the spatial structuring of constructed habitats have been found to limit the ability of the habitat to expand over time, resulting in a stigmed resilience to rapidly changing ecosystem characteristics. (Pace et al., 2015) Research suggests that urban habitats create a consistent set of habitat templates (hard-surfaced environments with shallow compacted soil and extreme hydrological conditions and temperatures) that tend to attract species drawn disproportionately from rocky habitats (Larson et al., 2000, 2004) Urban landscaping practices in Saudi Arabia focus on imported monoculture vegetation acclimatized to the extreme arid and solar environment. (Abdulaziz 2005) Different spatial habitat formations represent different conditions that attract different flora original or imported, and distinctive vegetation composition. (Lundholm et. al 2006) Different taxa will perceive and respond to landscape structure at many spatial scales depending on a range of parameters. A key challenge is to maximize vegetation complexity throughout the ecosystem. (Goodard 2010)

## 2.4. Describing heterogeneous dimensions of constructed and natural habitats

Constructed habitats display variations in how they assemble patches for different species of flora and fauna. Studies of spatial heterogeneity of a habitat frequently link to the functional ability of the habitat to support and generate variety, richness and abundance of living organisms. (Landis 2017) Describing the morphology of spatial patterns in constructed habitats (urban gardens) requires a fine grain analysis of patch and sub-patch, in order to understand how constructed habitats form resiliency and change over time. Studying spatial patterns reveals regularities in underlying ecological processes, and function of ecological parameters within them. The fine grain patterns present in urban gardens may enable them to enhance biodiversity due to more frequent and diverse disturbances in the patch system. (Pickett et.al., 1995)

Essential characteristics of natural and constructed habitats are their assemblage of spaces (patches and sub-patches), and shape (geometry, size, vertical height). Assemblage complexity enables the formation of a larger more intact habitat area. The integration of vegetation patterns of different taxa, different specie, maturity range, with a diversity of spatial assemblage approaches will provide richer more dynamic habitat formation that is more resilient to ecosystem change. The size and shape of patches has been shown to determine to a large degree their ecological and functional characteristics with patch spatial structure, described as homogeneous or heterogeneous. (Pickett and

Cadenasso 1995, Landis 2017, Pace et al., 2015) The connectivity of patches is an additional essential structure that enables the movement of flora and fauna across patches and meta-zones. (Leitao et al., 2002) Corridors that form connecting linkages allow both the dispersion of flora and fauna throughout the urban system across spatial scales. In contrast discrete design approaches exhibit strong edges, boundaries or limits with no apparent connectivity, that inhibit the formation and expansion of bio-diverse ecosystems. Discrete patches may be differentiated by biotic and abiotic structure or composition. (Pickett and Cadenasso, 1995) Edges or overlapping formations are characteristics of shape that have been associated with the spatial dimension of habitats and ecological processes. (Landis, 2017) Constructed habitats have been found to reshape the existing microclimate profile of a site by the organization of vegetation patterns to reduce the lands exposure to solar radiation and high winds.(Lin, 2018) Three types of landscape function are associated with the shape and complexity of landscape habitat patches; *Production* such as food, wood, recreation and community services; *Protection* natural functions maintenance and enhancement of biological species; *Regulation* – microclimate formation, temperature, wind and air quality. (Leitao et al., 2006) The minimum habitat requirement for an indicator species has generally been identified to be in the area of at least 0.3-0.5 hectares. (Redpath 1995, van Apeldoorn et al., 1992, Harris 1984, Robbins et al., 1989, Rudd, 2002)

Table 1.Concepts supporting heterogeneity in constructed habitats.

| Concept | Selected Criteria |
|---|---|
| **Assemblage** | Complex assemblages of patches and vegetation is better for wildlife and more highly appreciated by people.(Roetman and Daniels 2008) |
| **Shape complexity** | Patch shape complexity (Leitao et al 2006) Exterior and interior volumes, canopy and wall structure.(Farinha-Marques et al., 2016) |
| **Spatial organization** | Patches are layered out as linear or nonlinear areas that differ from the surrounding background landscape (Linehan 1995) and exhibit connectivity within and across patch/nodes.(Farinha-Marques et al., 2016) |
| **Spatial scale** | Landscape scale factors affect microclimate (grasses, trees and shrubs). (Lin et al., 2018) |
| **Integration** | A dynamic measure of ecosystems patterns, shape complexity, functional distribution, taxa. variety, and spatial types. |
| **Vegetation pattern** | Layering of vegetation (horizontal and vertical) (Farinha-Maraques et al., 2016) Patch integration is nested or polygonal in both vertical and horizontal orientation. |
| **Functional distribution** | Multifunctional diversity is measured by the distribution of functional types, spatial structure and taxa relationships in the habitat. (Landis 2017) |
| **Planting phases** | Different planting phases are introduced at intervals to enable all planting phases and managed succession (mature, junior, seedlings). (Hough 2004) |
| **Seasonal disturbance** | Includes canopy ground cover closure and thinning, invasive barriers and edges, patch turnover (Hough 2004, Landis 2017) |
| **Connectivity** | Patch connectivity is linear/discrete or multi dimensional (heterogenous) |

In arid environments the territorial range may be substantially lower as a single tree may form an important mediating link in a stressed ecosystem. Microclimates result from the interaction between prevailing climate and objects in the landscape. (Brown & Gillespie 1995) By focusing on the solar path orientation around the site vegetation placement in gardens may construct shading screens and canopies to decrease solar exposures of the garden sites. Tree shading is an important mediator for bioclimatic formation. A study of olive tree shadow on soil temperature during summer period can reduce the temperature by 11° C. (Panagopoulos 2007). Urban green structures cool hot air by evapotranspiration, provide shading to the ground and adjacent building walls, and reduce the velocity of wind, regenerate air quality, absorb air borne dust and filter noise.

## 3. Methodology

### 3.1. Research framework

The aim of this study is to describe the spatial heterogeneity composition of two recently established urban garden habitats, and describe their spatial formation.

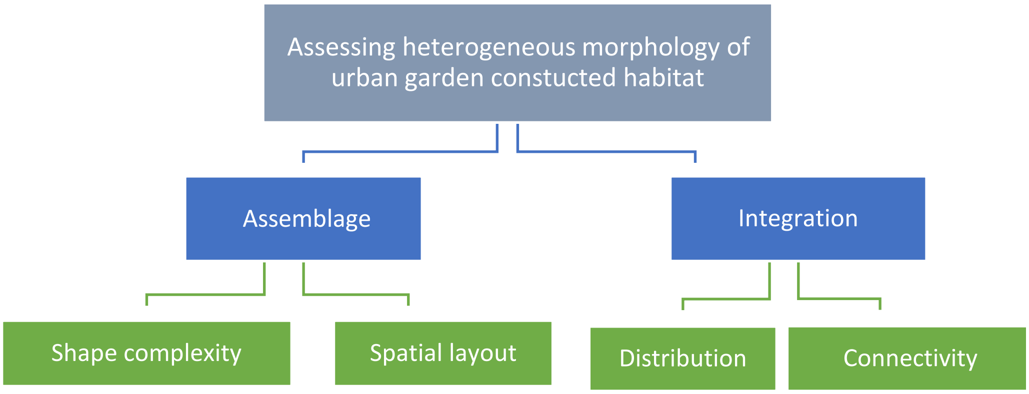



Figure 1 Research Framework

A literature review was undertaken to identify morphologies of heterogeneous spatial formations and discuss their affordances to structure urban habitat construction for biodiversity application. The survey of two urban habitat nodes describe the morphology of the landscape ecology patch structure at the intermediate-micro scale. The survey examined two parameters of heterogeneous habitat construction; (I) the assemblage of patch and sub patches (characterized by shape and spatial organization); (II) integration of the patch structure characterized by the functional diversity range (characterized as seasonal or phased). A linear study of the two urban garden node sites morphogenesis over time was documented through frequent photographs to capture seasonal and annual patch structural changes (sub patch shape, space and vegetation pattern). A descriptive matrix of the heterogeneity morphology of the urban garden patch formations establishes a comparative framework for future studies.

### 3.2. Background bio-climatic environment context

Saudi Arabia contains three distinct climate area's, coastal area's, internal dry area's, and highlands. (Alrashed et al. 2015) In Jeddah, a city on the Red Sea coast, residents experience an average temperatures of 32° C to 49° C, with 45° C in the shade during summer months.  In winter, average temperatures range from 24° C – 30° C. Relative humidity varies seasonally from 55% - 65% with significant levels of air pollution and airborne dust. Vegetation in the Makkah region and city of Jeddah is generally sparse with 60% in low-lying areas. Cool high mountains, arid deserts and steeps, and hot semi-arid coastal plains characterize Saudi Arabia's natural environment. Dry hot winds are especially threatening to bird and plant resilience during summer months.  Low and unpredictable rainfall, and severe droughts pose challenges to conserving the kingdoms biological diversity. Infrequent rain primarily falls in the southwestern escarpment on the Red Sea coast.

### 3.3. Urban Gardens as constructed habitats in Jeddah

In this study of urban gardens, heterogeneous patches are examined in two habitat nodes, (garden sites) surrounded by an ecosystem context of larger spatial expanses of hot dry desert. This natural environment experiences hot dusty soils that shift in the wind, and extreme solar radiation exposure. The solar irradiance at the King Abdulaziz University main campus station, Latitude 21.49604, Longitude 39.24492 Elevation 75(m), finds the annual average temperatures ranges from 30.7 °C to a maximum daily average temperature of 37.6 °C at this station. Daily solar irradiance levels (Zell 2015) are recorded as:

| | | |
|---|---|---|
| **GHI** (Wh/m2) | **DNI** Average Daily | **DHI** Average Daily |
| Average /Maximum | Average /Maximum | Average /Maximum |
| 5925/8066 | 5142 /9327 | 2329/5107 |

Biodiversity loss due to habitat fragmentation, and species decline in Saudi Arabia will continue to increase rapidly with climate change and the expansion of cities and human settlements into resource rich natural enclave habitats. Currently municipal landscape strategies in Jeddah persist to establish limited patch types resulting in segregation and bounding of biodiversity species, ultimately limiting the natural reproduction of biota.

(a) (b) (c)

Figure 2 Character of the landscape matrix found in the study area. (a) Warood 2 district of Jeddah; (b)Site of Garden 1 composed of three patches; (c) Site of garden 2 composed of two patches.

(a) (b)

Figure 3 (a) Garden 1 mix of urban agriculture taxa. (b) Garden 2 constructs urban forest mixing citrus and banana fruit with a range of tree species and flowering shrubs.

## 4. Findings

### 4.1. Overview

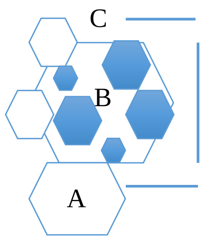
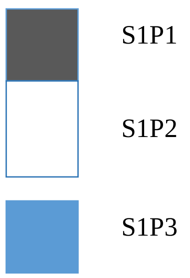
This visual survey of Jeddah urban gardens, establish by private individuals on vacant land in a new urban district, examine how the gardens are spatially formed to construct patch habitats for a range of vegetation species. Two constructed habitat (CH) nodes are distinguished as Site 1 (S1) and Site 2 (S2). Patch formations within the node are identified as Patch 1,2,3 (P1, P2). Assemblage heterogeneity of the spatial morphology of the garden is coded to (A) describe the dimension of sub-patch, (B) describes patch core dimension, (C) describes the edge position. Site position in the connectivity matrix is shown in dark grey. A limited description of the taxa classification is made.

## 4.2. Visual Survey Spatial scale and heterogeneity

### 4.2.1. S1 P1 Longitudinal Garden Observations

Garden 1, 5 years old, uses modified root watering with inverted water bottles, and garden hoses. This patch is highly stable with minor adjustment in plantation within B, the main tree cluster. This area is used for sprouting of seeds and seedling establishment for later transplantation. The constructed patches establish microclimates through their assemblage of space and space, and integration of vegetative patterning and functional distribution and the formation of sub-patches and layering, are found to integrate different plant taxa and create microclimate. Garden management problems focus chickens invading this garden from S2 garden. Clear activity zones are established and the area is used by neighborhood community members.

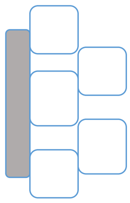
Table 2. Description of constructed habitat patch types found in Jeddah Saudi Arabia

| S1P1 | Heterogeneity | Spatial Description | Photographs |
|---|---|---|---|
| **Assemblage**<br>Spatial formation<br>Shape<br>Edges | Semi-discrete rectangular – oval patches, high density compact core cluster, surrounded by dense natural ground cover.<br>A dense canopy of foliage establishes evapotranspiration and microclimate. High ground cover with compact patch cluster in center. | **Assemblage Heterogeneity**<br><br>B Core size:26 m x30 m<br>A Sub-patch size:<br>20 m x 25 m | <br><br> |
| **Functional Distribution** | Microclimate, eco-system services. | Restricted spatial development. | |
| **Connectivity** | Adjacent patches (3)<br>Radial<br>(C ) Edges (E,S,W)<br>A large variety of plant species with trees planted in close proximity to seedlings and small plant varieties positioned in the understory. |  | |
| **Taxa. Biodiversity** | (A) Butterfly birds, vegetation, ecosystem service. (B) Plantains, carica papaya, aubergine, bamia, palm, mango, lime tree, other trees. (A) Ornamental /Herbaceous/ moliheya | | |
| **Garden Management** | Seasonal micro-scale agriculture shared with local neighborhood. High visibility and sociability. | | |

### 4.2.2. S1 P2 Longitudinal Garden Observations

Irrigation methods are variable depending on the knowledge and availability of financial resources, Garden 1 uses modified root watering with inverted water bottles, and garden hoses, while Garden 2 uses irrigation canals.

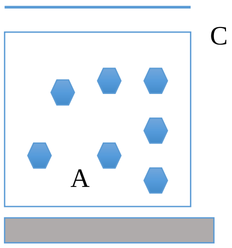
Table 3. Site1 Patch1 description of constructed habitat

| S1P2 | Heterogeneity | Spatial Description | Photographs |
|---|---|---|---|
| **Assemblage**<br>Spatial formation<br>Shape<br>Edges | Limited heterogeneity<br>Patch organization establishes seasonal agriculture.<br>Linear-horizontal | **Assemblage Heterogeneity**<br> | <br><br> |
| **Functional Distribution** | Restrictive spatial development -phased seasonal. Limited shade and microclimate formation. | B Core 35 m x 20 m<br>A Sub-patch size:<br>5 m x 10 m<br><br>S1P1<br>S1P2<br>S1P3 | |
| **Connectivity** | Linear, horizontal, discrete patch, adjacent patches. Moderate-high flexibility | Adjacent sub-patch organization | |
| **Taxa. Biodiversity** | Onion, garlic, bamia, eggplant, moliheya, khatti meeth lauki squash, basil, carica papaya,<br>Naturalistic ground cover, very good soil formation. Free-range chickens from adjacent garden plot pose challenges for seed dispersal, plantation patterns. | | |
| **Garden Management** | Seedlings are established in close proximity to the denser canopy, with a variety of shading constructions used. The site is primarily agricultural. | | |

### 4.2.3. S1 P3 Longitudinal Garden Observations

The constructed patches establish microclimates through their assemblage of space and space, and integration of vegetative patterning and functional distribution and the formation of sub-patches and layering, are found to integrate different plant taxa and create microclimate. Irrigation methods are variable depending on the knowledge and availability of financial resources, Garden 1 uses modified root watering with inverted water bottles, and garden hoses, while Garden 2 uses irrigation canals.

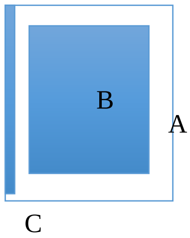
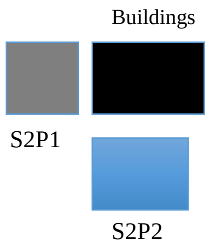
Table 4. S1 P3 description of constructed habitat

| S1P3 | Heterogeneity | Spatial Description | Photographs |
|---|---|---|---|
| **Assemblage**<br>Spatial formation<br>Shape<br>Edges | Restrictive spatial development, Shaded ground cover<br>Rectilinear.<br>(C) Bounded fence patch, Edges (S, W),<br>Sidewalk (N) | **Assemblage Heterogeneity**<br><br>Patch 30' x 30' | <br><br> |
| **Functional Distribution** | Eco-system services as a community social node, it establishes seasonal agriculture, free-range chickens. Fencing establishes garden identity in the community. | S1P1<br>S1P2<br>S1P3 | |
| **Connectivity** | Limited. Site is bounded by tall buildings, the patch is related to adjacent subpatches in linear formation. | | |
| Taxa. Biodiversity | Onion, garlic, bamia, eggplant, khatti meeth lauki squash, basil, carica papaya,<br>chili pepper, cucumber, tomato, mints. | | |
| **Garden Management** | Strong boundary edge is maintained with constructed fencing. Plants are distributed across the site with minimal species integration. Canopy formation by papaya. Limited layering. Papaya used to generate solar shading across the garden. | | |

### 4.2.4. S2 P1 Longitudinal Garden Observations

The constructed patches establish microclimates through their assemblage of space and space, and integration of vegetative patterning and functional distribution and the formation of sub-patches and layering, are found to integrate different plant taxa and create microclimate. Irrigation methods are variable depending on the knowledge and availability of financial resources, Garden 1 uses modified root watering with inverted water bottles, and garden hoses, while Garden 2 uses irrigation canals.

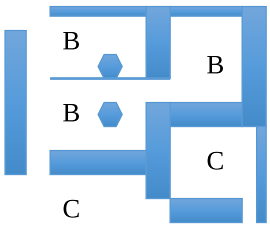
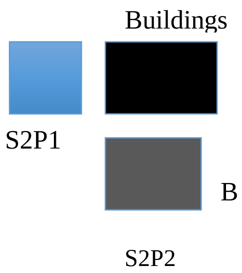
Table 5. Site 2 Patch1 description of habitat construction

| S2P1 | Heterogeneity | Spatial Description | Photographs |
|---|---|---|---|
| **Assemblage**<br>Spatial formation<br>Shape<br>Edges | Restrictive spatial development as radial edges<br>Shaded ground cover with grasses<br>(B) Open patch,<br>Strong edges formed by tree line (S, W), Sidewalk and building (N) Edges constructed to mediate solar and wind forces. | **Heterogeneity Assemblage**<br><br>A Patch 40.5 m x 20 m<br>B Core 30 m x 15 m Linear tree line is on the right (S) facing. |  |
| **Functional Distribution** | Eco-system services, microclimate formation, node for community socialization as indicated by trace chair positions. |  | |
| **Connectivity** | Open within a district with limited connectivity for species and flora dispersion. | Alignment to S2P2 | |
| **Taxa. Biodiversity** | Bird habitat formation. Endemic trees, herbatious shrubs, ornamental trees, citrus trees, grasses, plantain, palm. | Non-layered | |
| **Garden Management** | Earth berms and tree line on the western edge establish wind flow away from garden. Trees provide shading at peak solar irradiance times. Irrigation canals establish seedling nursery for future transplantation. Fallen leaves are used to cover water canals. | | |

#### 4.2.5. S2 P2 Longitudinal Garden Observations

This garden transformation is slower than garden S1. This site is used as a nursery for small trees and shrubs that are transplanted into S2 P1. The constructed patches establish microclimates through their assemblage of space and space, and integration of vegetative patterning and functional distribution. Soil formation is highlighted in this garden. Observations highlight constructions of shading devices using different techniques and plant species as seen in the photographs in Table 5. This constructed habitat is ideal for establishment of at risk species through use as a small scale nursery. It presents an ideal model to support local district development of gardens of similar typology.

Table 6. Site 2 Patch2 description of habitat construction

| **S2P2** | **Heterogeneity** | **Spatial Description** | **Photographs** |
|---|---|---|---|
| **Assemblage**<br>Spatial formation<br>Shape<br>Edges | Restrictive spatial development; Convex spaces establish patch pattern.<br>Canopy formation<br>Height: 10 – 20 m<br>Edges are vegetation linear wall formations used to generate shading structure on patch core.<br>(E, S, W), | **Heterogeneity Assemblage**<br> |  |
| **Functional**<br>**Distribution** | Eco-system services,<br>Strong microhabitat formation.<br>Moderate high variation trees and shrubs with mixed maturity and type in vegetation patterning. |  | |
| **Connectivity** | Limited district | | |
| **Taxa. Biodiversity** | Birds and endemic plants. | | |
| **Garden Management** | Canopy bridges are used to construct shading in the inner field with climbing vines. Zipties shape stem/branch growth. Plantation is aligned to irrigation canals. | | |

### 4.3. Observed Integration of Multiple Spatial Scales

Table 7.Typology of spatial structures found in this study of heterogeneous constructed habitat.

| Patch Type | Criteria | Patch |
|---|---|---|
| Meta-population zone identified as habitat node in this study. | Areas within an urban environment bounded by major physical barriers (roads, highways, water ways) that inhibit the migration of flora and fauna. Multiple types of green space patches may co-exist in a zone. | S1;S2 |
| Patch network | Interaction between nodes is more accurately measured as the minimum distance between green spaces, as this distance is more reflective of that to be crossed by biota rather than the distance from the geometric center of one green space to another.(Rudd 2002) | S1P1,P2, P3,+ under construction; S2P1,P2; |
| Corridor | Core habitats are linked together to allow birds and wild life  and plants to move from one area to another. The construction of habitat corridors in addition to establishing patch connectivity is a spatial organization tactic that enables the mobility and increases spatial range to sustain biodiversity of flora and fauna in cities. | Strong S1 and S2 interior connectivity.<br>Poor S1 & S2 node connectivity |
| Urban block corner | Distinctive plantation patch positioned adjacent to pedestrian or vehicular traffic. | S1P1;<br>S2P1, P2 |
| Urban block side edge | Distinctive patch positioned on the patch side adjacent to traffic pedestrian or traffic that establishes vertical wall /screen. | S1P2, P3 |
| Sidewalk edge | Linear spacing between individual sidewalk blocks (Lundholm 2006) | S1P1;S2P1,P2 |
| Sidewalk pavement | Horizontal, flat concrete built structure, human foot traffic (Lunholm 2006) | Boundary to S1P2-P3 |
| Planted  Grasses area large | Patch area planted with grasses, shrubs, agricultural vegetation, ornamental types | S2P1 |
| Planted area medium-small | Distinguished by spatial permeability in a layout defined by wall plantations, irrigation and/or canopy cover. | S1, P1;S2P2 |
| Planted walls to generate shading | Distinguished by enclosing wall plantation, irrigation and/or canopy cover. | S2P1, P2 |
| Seedling Nursery | Vegetation range is developed in small planters spatially structured as a nursery. | S2P1, P2 |
| Seedling understory | Young plants are positioned adjacent to mature vegetation which provides shading. | S1P1, P3;S2 P1,P2 |

## 5. Conclusion

Arid regions are commonly perceived to contain less plants and animal species, yet microclimate and biodiverse habitat formation in extreme arid environments is possible. How landscapes are structured and the interactions they generate are fundamental questions in landscape ecology. (Pickett 1995) Extending and expanding biodiversity in arid cities requires researchers to explore a range of generative morphologies that shape formations of ecological scale, structure, and process. Classical approaches to landscape ecology typically focus on how the structural adjacencies and distribution of function affect discrete or heterogeneous communities and eco-systems. (Pickett and Cadenasso 1995)

This visual survey reveals three key aspects of the urban garden management that are of interest to developing future strategies for arid urban city contexts. Urban gardens may be used to construct a range of habitats that will collectively form an assemblage of ecological patches to connect a diverse range of flora and fauna. As local hotspots urban gardens can infuse the city and its public spaces with a diverse green infrastructure and provide tremendous value to achieve action towards the conservation of biodiversity. As constructed habitats, urban gardens provide vegetative structure and biodiversity for ecosystems, establish microclimates, and open recreational spaces. Urban gardens also provide a spatial scale that supports much needed experimentation in the construction of novel habitats in arid climates. These habitats may be focused to establish or integrate a range of taxa. that range from forest formations to urban agriculture and ornamental gardens. Through careful management and engagement with local community members, opportunities for seed collection and seedling plantations are possible to be used to restore regional natural ecosystems. Future studies would ideally examine the indigenous varieties vs. the imported plant taxa used in the garden.

The urban gardens reviewed in this study also establish ecosystem services for education and awareness programs are also supported by urban community gardens initiatives, providing opportunities to increase cooperation and local resource capacity for managing and conserving biodiversity. Traditional indigenous agricultural practices are proven and often are the only effective means to conserving the genetic diversity of land race crops with a rich assemblage of species. Gardens are an informal means to increase public awareness of biodiversity, provide education, and enhance benefit sharing with local communities while instituting systems of collaborative management of resources and the transfer of knowledge of eco-systems and plants. Community gardens also provide linkages to socio-economic development, provide outdoor recreation and promote co-operation in local communities. To establish constructed habitats in Saudi Arabia a number of factors must be carefully coordinated to avoid future risks of established habitat loss and ensure successful outcomes and return on development investment.

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