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## Vegetation trends associated with urban development: the role of golf courses --Manuscript Draft--

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Abstract:	Globally, cities are growing rapidly in size and density and this has caused profound impacts on urban forest ecosystems. Urbanization requiring deforestation reduces ecosystem services that benefit both city dwellers and biodiversity. Understanding spatial and temporal patterns of vegetation changes associated with urbanization is thus a vital component of future sustainable urban development. We used Landsat time series data for three decades from 1988 to 2018 to characterize changes in vegetation cover and habitat connectivity in the Perth Metropolitan Area, in a rapidly urbanising Australian biodiversity hotspot, as a case study to understand the impacts of urbanization on urban forests. Moreover, as golf courses are a major component in urban areas, we assessed the role of golf courses in maintaining vegetation cover and creating habitat connectivity. To do this we employed (1) land use classification with post-classification change detection, and (2) Morphological Spatial Pattern Analysis (MSPA). Over 17,000 ha of vegetation loss and gain were different in each of the three decades. The spatial patterns of vegetation loss and gain were different in each of the three decades (1988-2018) reflecting the implementation of urban planning. Furthermore, MSPA analysis showed that the reduction in vegetation cover led to habitat fragmentation with a significant decrease in the core and bridge classes and an increase in isolated patches in the urban landscape. Golf courses played a useful role in maintaining vegetation cover and contributing to connectivity in a regional biodiversity hotspot. Our findings suggest that for future urban expansion, urban planning needs to more carefully consider the impacts of deforestation on connectivity in the landscape. Moreover, there is a need to take into consideration opportunities for off-reserve conservation in smaller habitat fragments such as in golf courses in		
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#### Vegetation trends associated with urban development: the role of golf 1 2 courses Thu Thi Nguyen<sup>1,3\*</sup>, Paul Barber<sup>2,3</sup>, Richard Harper<sup>3</sup>, Tran Vu Khanh Linh<sup>4</sup>, Bernard Dell<sup>3</sup> 3 4 <sup>1</sup>Vietnam National University of Forestry (VNUF), Xuan Mai, Chuong My, Ha Noi, Vietnam, 5 <sup>2</sup> ArborCarbon Pty Ltd, 1 City Farm Place, East Perth, WA 6004, Australia <sup>3</sup>Agricultural and Forestry Sciences, Murdoch University, Murdoch, WA 6150, Australia 6 7 <sup>4</sup> Faculty of Forestry, Nong Lam University - Ho Chi Minh City, Thu Duc District, Ho Chi Minh City, 8 Vietnam 9 10 \*Corresponding author 11 12 Emails: Thu.Nguyen@murdoch.edu.au; thu.nguyen.2k14@gmail.com 13 14 15 Abstract

16 Globally, cities are growing rapidly in size and density and this has caused profound impacts on urban 17 forest ecosystems. Urbanization requiring deforestation reduces ecosystem services that benefit both 18 city dwellers and biodiversity. Understanding spatial and temporal patterns of vegetation changes 19 associated with urbanization is thus a vital component of future sustainable urban development. We 20 used Landsat time series data for three decades from 1988 to 2018 to characterize changes in vegetation 21 cover and habitat connectivity in the Perth Metropolitan Area, in a rapidly urbanising Australian 22 biodiversity hotspot, as a case study to understand the impacts of urbanization on urban forests. 23 Moreover, as golf courses are a major component in urban areas, we assessed the role of golf courses in 24 maintaining vegetation cover and creating habitat connectivity. To do this we employed (1) land use 25 classification with post-classification change detection, and (2) Morphological Spatial Pattern Analysis 26 (MSPA). Over 17,000 ha of vegetation were cleared and the area of vegetation contributing to 27 biodiversity connectivity was reduced significantly over the three decades. The spatial patterns of 28 vegetation loss and gain were different in each of the three decades (1988-2018) reflecting the 29 implementation of urban planning. Furthermore, MSPA analysis showed that the reduction in vegetation 30 cover led to habitat fragmentation with a significant decrease in the core and bridge classes and an 31 increase in isolated patches in the urban landscape. Golf courses played a useful role in maintaining vegetation cover and contributing to connectivity in a regional biodiversity hotspot. Our findings suggest 32 33 that for future urban expansion, urban planning needs to more carefully consider the impacts of 34 deforestation on connectivity in the landscape. Moreover, there is a need to take into consideration 35 opportunities for off-reserve conservation in smaller habitat fragments such as in golf courses in 36 sustainable urban management.

#### 37 1 Introduction

Globally, cities have grown rapidly in number and size over recent decades [1, 2]. This trend is predicted to continue as urban areas are expected to absorb most global population growth [3]. While the process of urbanization presents key implications for changes in physical landscapes and demographic characteristics, it can cause profound impacts on environmental components, especially on urban forest ecosystems [4, 5].

43 Vegetation in urban landscapes is critically important because provides goods and services, and full 44 ecosystem functions that benefit city dwellers and the environment. On the one hand, a remarkable range 45 of human well-being benefits are derived from urban green spaces including mitigating the urban heat island (UHI) effect which is a threat to human health [6, 7]; reducing stress [8], improving healing times 46 47 [11], increasing self-esteem and empowerment [12], and improving cognitive ability [13]. On the other 48 hand, urban green spaces provide various ecosystem services such as strengthening resistance to some 49 kinds of natural disasters for example, floods [14], promoting biological processes such as pollination 50 [15], and reducing surface erosion from stormwater runoff [16]. The amount of vegetation in cities 51 strongly influences biodiversity, especially where vegetation is set aside during the process of 52 urbanization [17]. However, if species dispersal and exchange among these patches is insufficient to 53 allow gene flow and diversity, loss of regional biodiversity is inevitable [18]. Therefore, urban 54 development that requires deforestation, with habitat loss and fragmentation is a threat to biodiversity 55 [17, 19].

56 Urban conservation strategies must therefore consider not only the size and quality of habitat reserves, 57 but the connectivity in the intervening urban vegetation matrix [19]. While the need to protect large 58 habitat reserves is obvious, opportunities for off-reserve conservation of smaller habitat fragments 59 should not be overlooked [20]. Understanding spatial and temporal patterns of vegetation change

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associated with urbanization, as well as opportunities for the preservation of green spaces outside natural
 reserves, is vital for future sustainable urban development especially in areas of global ecological
 importance.

63 As the number of golf courses is rapidly increasing in many urban areas worldwide [21], there have 64 been many environmental arguments about this green space category in urban landscapes. Golf courses 65 are sometime considered to be major polluters of the environment through pesticide and fertilizer use 66 [22]. In fact, golf courses have been established for recreational purposes, which are a mix of bushland, 67 fairways and infrastructure. Though they are not fully ecologically functional as with a natural parks, 68 previous studies investigated the condition of vegetation inside the golf courses and indicated that the 69 bushland in non-playing areas of golf courses are significantly important to biodiversity conservation 70 and the provision of ecosystem services in cities [24], such as providing refuge habitats for urban-71 avoiding wildlife [23, 25, 26]. Therefore, potentially, together with the natural reserves, golf courses 72 can play some roles as off-reserve sites for purposeful biodiversity conservation in urban landscapes. 73 Nevertheless, little research has been undertaken to comprehensively assess the role of golf courses in 74 maintaining vegetation patches as interconnected nodes in urban landscapes during a long period of 75 urban development where deforestation was significant.

Deforestation for urban expansion can occur gradually over multiple years. Satellite-based remote sensing holds certain advantages in the characterization of these changes in urban landscapes because of the large spatial coverage, high time resolution, and wide availability of data [27]. For example, medium resolution Landsat images allow mapping of large urban areas [28]. For example, used to detect, monitor and quantify vegetation changes, but differences in vegetation index and land use classification are the most widely used methods for vegetation change over a long period of time [28].

A great number of vegetation indices have been proposed, ranging from very simple to very complex band combinations [29]. The most widely-used vegetation index is the Normalized Difference Vegetation Index (NDVI), which is the first efficient and simple metric to identify vegetated areas and their condition [30]. This separates green vegetation from other surfaces based on the ability of 87 chlorophyll to absorb red light for photosynthesis and reflect the near-infrared (NIR) wavelengths [31].

Furthermore, information on vegetation cover dynamics can be combined with Morphological Spatial
Pattern Analysis (MSPA) to describe the spatial configuration of the ecosystem at the pixel level, making
it possible to detect temporal changes in the structural connectivity of habitats in urban settings [32].

91 Therefore, to enhance the understanding of vegetation dynamics associated with urbanization and the 92 role of golf courses in maintaining urban forests, we used Landsat imagery to map vegetation cover and 93 to assess its spatial and temporal distribution over three decades from 1988 to 2018. Maps of vegetation 94 cover were used for MSPA analysis to detect changes in habitat connectivity. We chose the Perth 95 Metropolitan area for the study as it lies within a rapidly urbanizing biodiversity hotspot in Australia. 96 The three primary research objectives were to: (1) determine the spatial and temporal patterns of 97 deforestation in urbanization; (2) evaluate the spatial and temporal patterns of green landscape 98 connectivity; and (3) assess the role of golf courses in preserving green spaces and biodiversity in an 99 urban landscape. This analysis will provide a useful perspective on the land-use pressure facing 100 vegetation remnants in this region which is recognised as one of 35 international biodiversity hotspots 101 with over 1500 plant species with a high degree of endemism [33], and provide a framework for planning 102 urban expansions both in this region and globally.

#### 103 **2** Methods

#### 104 2.1 Study area

The study area belongs to the Perth Metropolitan region covering four sub-regions (North West, Middle Central, Inner Central and South West). Perth has a Mediterranean-type temperate climate with a hot and dry summer, and a cold and rainy season occurring between May and October [34]. Under future climate-change scenarios, this area is projected to experience a lower annual rainfall [35].

Perth belongs to the Australia's southwest corner, which is recognized as a global biodiversity "hotspot" with outstanding natural environments. Our study area occurs on the Swan Coastal Plain which is part of the southwest of Australia which in turn has the highest concentration of rare and endangered species on the entire continent (at least 1,500 endemic species). More than 6,000 species of native plants and 100 native mammals, birds, frogs and reptiles occur in this region, making it a <u>biodiversity "hotspot"</u>
[33, 36].

115 Perth has retained a significant area of natural vegetation which has conservation significance thanks to 116 the introduction of legislation and policies aimed primarily at protecting biophysical environmental 117 values. This includes the Western Australian Environmental Protection Act 1986 [37]; the Federal 118 Government's Environment Protection and Biodiversity Conservation Act 1999 [38]; and more recently, 119 Bush Forever [39, 40], a policy which took a whole-of-government approach to identify and protect 120 biologically significant bushland and wetlands within the Perth metropolitan area. However, Perth has 121 experienced extensive urban development since the 1980s [42]. The expansive growth of the Perth 122 metropolitan footprint has contributed to the loss of biodiversity, together with the ecosystem services 123 provided by natural areas. Together with urbanization, the golf industry has expanded contributing to a growing proportion of Perth's urban green space with 34 golf courses in the study area (Figure 1). 124

Excellent additions

125

#### Figure 1. Location of the study area

(The Landsat 8 on 30 September 2018 from USGS EROS (Earth Resources Observatory and Science
 (EROS) Center) in the public domain: http://eros.usgs.gov)

#### 128 2.2 Approaches

We conducted two types of analyses in this study: (1) assessment of vegetation cover change in golf courses since 1988 relative to surrounding areas to provide a broad overall context of the urban vegetation changes that have taken place throughout the region and the role of golf courses; and (2) assessment of MSPA. In these analyses, we used four data sets (1988, 1998, 2008, 2018) covering thirty years of urban development. The steps taken in this study are summarized in a flow chart (Figure 2).

134 2.2.1 Landsat data and pre-processing

Three Landsat 5 Thematic Mapper images (WRS path 113 row 82) were acquired from 1988 to 2008 and one Landsat OLI 8 (WRS path 113 row 82) was acquired in 2018 at four time steps, including year 1988 (11<sup>th</sup> December), year 1998 (7<sup>th</sup> December), year 2008 (18<sup>th</sup> December), year 2018 (14<sup>th</sup> December). The Landsat imagery were obtained from the US Geological Survey (USGS) of the Earth

139 Resources Observation and Science Center (EROS). Image dates were selected acquired during 140 December (summer, dry season) to reduce the seasonal difference effects. All images selected are cloud-141 free scenes or little cloud cover (0.05% and 0.4%) scenes with the whole study area is cloud-free; 142 Therefore, is no requirement for removing cloud. Georeferencing was performed at the USGS prior to 143 downloading the data (L1T level of systematic geometric accuracy) and no further refinement was undertaken. Atmospheric and topographic corrections were performed on the Landsat data sets. The 144 145 atmospheric correction was carried out to adjust the multitemporal dataset to a common radiometric 146 scale [43].

147 The first process of atmospheric correction was conversion of the digital number (DN) remote sensing 148 data values to at-sensor radiance based on the image header file. After that we employed the image-149 based models - dark object subtraction (DOS) to correct atmospheric scattering scene-by-scene. This 150 method is a widely used and effective method in atmospheric correction [44-50]. Topographic correction 151 was conducted to remove topographic effects. We used a sun-canopy-sensor (SCS) correction based on 152 the 30 m digital elevation model (DEM) because topographic shading is not only due to slope but also to shadowing of one tree crown over another and this is one of the most widely and effective used 153 methods of topographic correction [51]. 154

#### 155 Figure 2. Flow chart summarizing the major steps taken during the investigation.

#### 156 2.2.2 Classification

In a preliminary step, we used a decor relation stretch to enhance the image for more effective visualization. Prior to image classification, NDVI images were generated. A classification technique was then applied to the NDVI images of 1988, 1998, 2008 and 2018 using Arc-GIS 10.3 software. NDVI images were obtained by calculating the ratio between the red (R) and near infrared (NIR) values of the satellite image using Equation 1:

162 
$$NDVI = \frac{(NIR-R)}{(NIR+R)}$$
(1)

163 In Landsat 4-7, NDVI = (Band 4 - Band 3) / (Band 4 + Band 3).

164 In Landsat 8, NDVI = (Band 5 - Band 4) / (Band 5 + Band 4).

Landsat TM data from different dates were independently classified based on the NDVI values. Water
bodies have negative NDVI values, whereas, bare soil and built-up areas have an NDVI value of around
zero. Chlorophyll in green vegetation, on the other hand, has consumed RED to drive photosynthesis
thereby providing moderate and high NDVI values close to +1 [52]. Based on this understanding, the
four NDVI images were classified into three classes (Vegetation, Built up + bare soil, Water bodies)
using the NDVI threshold ranges technique in Arc-GIS 10.3 software.

171 The classification based on NDVI threshold was evaluated using accuracy assessment. An error matrix 172 compared information from a classified image or land cover map to known reference (truth) sites for a 173 number of sample points assessed in 2018. We obtained photographs of representative land use 174 categories with GPS locations to assist in our image interpretations. Also, we used Google Earth images, 175 true and false colour combination images and knowledge-based information including expert 176 knowledge, land use maps and reports. For historical images, Google Earth was used to substitute the 177 traditional reference data collection on each of the sites [53]. Based on data of accuracy assessment, we 178 reclassified the preliminary land use classification maps to improve the accuracy of classification.

179 2.2.3 Vegetation change detection

In order to detect the vegetation cover change, we created binary maps of vegetation and non-vegetation from the classified maps in the previous analysis, one for each adjacent pair of time steps, which depict where degradation occurred within a decade of urbanization. This post-classification analysis uses two images from different dates and classifies them independently. We then calculated changes in vegetation cover type using Equation 2:

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where D1 and D2 are the area of the target vegetation cover at the beginning and the end of the studyperiod, respectively. This analysis allows the calculation of vegetation loss and gain in each period.

(2)

Change area =  $D_2 - D_1$ 

188 2.2.4 Golf courses Analysis 1

We compared the vegetation cover, and the change (vegetation loss and gain) taking place within all golf courses in the study area, and in their surrounding regions. After creating the GIS boundaries of the golf courses, we extracted the vegetation cover and the vegetation change within these boundaries at four time steps in 1988, 1998, 2008 and 2018 to compare vegetation dynamics within the golf courses and the whole study area over time.

# 194 2.2.5 Morphological Spatial Pattern Analysis (MSPA) for the structural connectivity of 195 habitats

MSPA was employed to describe the structural connectivity of habitats in Perth for four time steps in 197 1988, 1998, 2008 and 2018. This method describes the spatial and temporal configuration of the 198 ecosystem at the pixel level [32], which was based on the concept of "habitat availability" and "graphic 199 theory" [54, 55] in which the landscape is considered as a collection of nodes, and links with a node is 200 a place where connectivity exists and will depend on the width of itself. The output of the MSPA analysis 201 includes the seven structural categories into which habitats are divided, including core, edge, 202 perforation, bridge, loop, branch and islet [56] and [57] and is summarized in Table 1.

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and background that form the outer edge and non-vegetation areas. Perforation The transition pixels between foreground unnatural patch inside the core area. and background inside core areas that form the inner edge			
interconnected and greater than the user- specified edge width from backgroundconnectivityEdgeTransition pixels between the foreground and background that form the outer edgeThe transition zone between vegetation and non-vegetation areas.PerforationThe transition pixels between foreground and background inside core areas that form the inner edgeUnnatural patch inside the core area.BridgeA set of linear foreground pixels between two cores that connect two or more core 	Class	Description	Ecological Meaning
and background that form the outer edgeand non-vegetation areas.PerforationThe transition pixels between foreground and background inside core areas that form the inner edgeUnnatural patch inside the core area.BridgeA set of linear foreground pixels between two cores that connect two or more core areas.The striped ecological land that connect two cores, which is equivalent to the connecting corridor of the green space network.LoopLinearly oriented foreground pixels extended from core that connect score area to itself.Connecting corridor inside a large natural patch.BranchLinearly oriented foreground pixels extended from core that do not connect to any other core areaStriped ecological land with low connectivity.IsletA collection of foreground pixels which is smaller than the core zone and do notSmall natural patches that are isolated and on ot connect to each other.	Core	interconnected and greater than the user-	
and background inside core areas that form the inner edgeThe striped ecological land that connect two cores, which is equivalent to the areas.BridgeA set of linear foreground pixels between two cores that connect two or more core areas.The striped ecological land that connect two cores, which is equivalent to the connecting corridor of the green space network.LoopLinearly oriented foreground pixels extended from core that connects core area to itself.Connecting corridor inside a large natural patch.BranchLinearly oriented foreground pixels extended from core that do not connect to any other core areaStriped ecological land with low connectivity.IsletA collection of foreground pixels which is smaller than the core zone and do notSmall natural patches that are isolated and do not connect to each other.	Edge	· ·	The transition zone between vegetation and non-vegetation areas.
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<ul> <li>extended from core that connects core area to itself.</li> <li>Branch</li> <li>Linearly oriented foreground pixels extended from core that do not connect to any other core area</li> <li>Islet</li> <li>A collection of foreground pixels which is smaller than the core zone and do not</li> <li>Small natural patches that are isolated and onot connect to each other.</li> </ul>	Bridge	two cores that connect two or more core	connecting corridor of the green space
extended from core that do not connect to any other core areaconnectivity.IsletA collection of foreground pixels which is smaller than the core zone and do notSmall natural patches that are isolated and do not connect to each other.	Loop	extended from core that connects core area	
smaller than the core zone and do not and do not connect to each other.	Branch	extended from core that do not connect to	
	Islet	smaller than the core zone and do not	_

### 213 Table 1. Definition of Morphological Spatial Pattern Analysis (MSPA) classes

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In order to undertake the MSPA analysis, we defined the input data (foreground class). For this study, we used the classified maps for 1988, 1998, 2008, 2018 in Analysis 1 to create the binary maps which contained vegetation and non-vegetation classes. Hence, the high and full covered vegetation pixels were defined as the foreground pixels (green landscape) in the MSPA approach. The results of MSPA analysis for the four time steps allowed us to assess the changes in habitat connectivity over 30 years of
urbanization.

### 221 2.2.6 Golf course analysis 2

To assess the role of golf courses in maintaining biodiversity connectivity over 30 years, we compared the habitat connectivity within all golf courses in the study area and in their surrounding green spaces. Using the GIS boundaries of the golf courses, we extracted the habitat connectivity within the golf course boundaries for four time steps (1988, 1998, 2008 and 2018).

#### 226 **3 Results**

#### 227 3.1 Land use classification in Perth

Data sets representing four time periods (1988, 1998, 2008 and 2018) are shown in Figure 3 and Table 3, which provide an overview of the land cover changes (vegetation, built up and bare land, water bodies) over recent decades. From the 1988 and 1998 data sets, it is evident that over half of the region was vegetated. However, the urban footprint of built up and bare land area had increased 10% from 1998 to 2018. As a consequence, there was a significant decrease in vegetation cover, which comprised 56% of the land surface in 1988 and declined by 10.1% over the next 30 years (Table 2).

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## 242 Table 2. Land cover classification within the Perth Metropolitan Region.

					Land cove	r category		
			Whole area			Golf course		
			Vegetation	Built up and bare soil	Water bodies	Vegetation	Built up and bare soil	Water bodies
	1988	Area (ha)	98,446	74,376	2,667	929	210	0.1
		Proportion (%)	56.1	42.4	1.5	81.5	18.5	0.0
	1998	Area (ha)	91,754	81,464	2,271	1,042	97	0.7
		Proportion (%)	52.3	46.4	1.3	91.4	8.5	0.1
	2008	Area (ha)	88,341	84,971	2,176	1,084	55	0.2
		Proportion (%)	50.3	48.4	1.2	95.1	4.9	0.0
	2018	Area (ha)	80,755	92,243	2,491	1,093	46	0.7
		Proportion (%)	46.0	52.6	1.4	95.9	4	0.1
247 248		the three classes (T	,					
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### 256 Table 3. Accuracy assessment of land cover maps generated

	Manad (*	Year 1988	Weter D 1	T ( 1
LULC Class	Vegetation	Build Up and Bare Soil	Water Bodies	Total
Vegetation	14	1	0	15
Build Up and Bare Soil	1	12	2	15
Water Bodies	0	0	15	15
Total	15	13	17	45
		Overal Accuracy	87%	
		Overal Kappa	0.91	
		Year 1998		
LULC Class	Vegetation	Build Up and Bare Soil	Water Bodies	Total
Vegetation	15	0	0	15
Build Up and Bare Soil	0	13	2	15
Water Bodies	1	0	14	15
Total	16	13	16	45
		Overal Accuracy	90%	
		Overal Kappa	0.93	
		Year 2008		
LULC Class	Vegetation	Build Up and Bare Soil	Water Bodies	Total
Vegetation	14	1	0	15
Build Up and Bare Soil	1	14	0	15
Water Bodies	0	0	15	15
Total	15	15	15	45
		Overal Accuracy	93%	
		Overal Kappa	0.96	
		Year 2018		
LULC Class	Vegetation	Build Up and Bare Soil	Water Bodies	Total
Vegetation	15	0	0	15
Build Up and Bare Soil	0	13	2	15
Water Bodies	1	1	13	15
Total	16	14	15	45
		Overal Accuracy	87%	
		Overal Kappa	0.91	

257 I highly suggest the tables be restructured to show change in each class for all years on the same tables/Columns. This will make is easier to read and understand.

258 Using the GIS layer of land use categories, we also extracted the data for three classes within the golf

259 courses in comparison with the whole area (Table 2). Our analysis shows that while there was a

260 significant decrease in vegetation cover throughout the region, the total area of golf courses remained

unchanged at around 1,093 ha over the last 30 years.

#### 262 Figure 4. Land cover classification showing a detailed view of the Collier Park Golf

#### 263 Course for a) Landsat data; b) NDVI values; c) Land cover classification

#### 264 3.2 Spatial patterns of vegetation change

To characterize spatial patterns of vegetation dynamics, we detected the vegetation loss and gain for each of the three decades (Figure 5). In the period 1988 to 1998, deforestation occurred intensively in the central and north regions. From 1998 to 2008, vegetation loss expanded to the north and south of the city. However, in the last decade from 2008 to 2018, vegetation loss accelerated in the distal regions with urbanization. However, there was also some vegetation gain over the three decades (Figure 5, Table 4) predominantly in the northern part of the city.

#### Figure 5. Change in vegetation cover over the period 1988 to 2018 for the Perth region

		Period			
		1988-1998	1998-2008	2008-2018	
Whole Area	Vegetation loss	22,231	19,250	20,178	
	Vegetation gain	15,538	15,838	12,591	
	Net loss	6,692	3,412	7,587	
Golf courses	Vegetation loss	68	27	40	
	Vegetation gain	219	92	43	
	Net gain	152	64	4	

#### Table 4. Vegetation loss and gain (ha) between 1988 and 2018.

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Calculation of changes within the golf courses and in the whole area (Table 4) showed that the major urban area of Perth experienced a net loss in vegetation cover. Though vegetation compensation occurred together with deforestation over 30 years of urbanization, the vegetation loss was always much larger than vegetation gain with the largest net vegetation loss occurring in the last decade. However, the golf courses showed a different trend where the net gain of vegetation cover happened over three decades and the largest gain was between 1988 and 1998.

#### 280 3.3 Analysis of connectivity components of green space networks

281 Results of the MSPA analysis indicate that the reduction in vegetation cover over the last thirty years 282 has led to a decline in connectivity (Table 5). Among the two MSPA classes that are important for 283 connectivity (core and bridge), the total area of core class decreased by about 10% over three decades 284 while the bridge class was maintained at around 37,000 ha, but the proportion of this class per total 285 vegetation cover area (VCA) increased due to the reduction of vegetation cover over time (Table 5). This 286 analysis also shows the fluctuation in the areas of the rest of the MSPA classes including islets, loops, 287 edges, perforations, and branches which do not contribute to connectivity in the landscape. The 288 proportion of these classes increased through time from 24% in 1988 to 30% in 2008 and 2018.

Figure 6 shows that the core area was distributed mostly in the northern part of the city and their areas decreased significantly in later years. In 1988, the bridge class covered a large area of the city's central region but this decreased over time. In recent years, most of the vegetation cover in the central region of the city belongs to the islet, loop, edge, perforation and branch classes, illustrating that isolation became more serious in the central region of the city over the three decades.

# Figure 6. Results of the Morphological Spatial Pattern Analysis (MSPA) for the Perth region from 1988 to 2018

The vegetation cover within golf courses also contributes to connectivity. The proportion of core area within golf courses fluctuated between 12% and 27%. Moreover, the largest proportion of vegetation in golf courses was classified as bridge but it experienced a downward trend from 52% to 41% in three decades. Of the remaining classes which do not contribute to connectivity, the edge and loop classes accounted for a higher proportion with each of them contributing 7% to 16% of total vegetation cover.

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Landscape type	Year	Perth Metrop	Perth Metropolitan Region		Within golf courses	
		Area (ha)	Proportion of total VCA (%)	Area (ha)	Proportion of total VCA (%)	
Core	1988	32,012	32.6	325	23.2	
	1998	20,607	22.5	171	12.7	
	2008	22,251	25.3	230	16.7	
	2018	18,101	22.5	383	27.3	
Bridge	1988	37,127	37.9	738	52.6	
	1998	39,412	43.0	814	60.2	
	2008	37,902	43.1	732	53.1	
	2018	37,503	46.7	588	42.0	
Islet	1988	10,396	10.6	31	2.2	
	1998	16,436	17.9	78	5.8	
	2008	12,922	14.7	15	1.1	
	2018	12,349	15.4	37	2.7	
Perforation	1988	1,099	1.1	3	0.2	
	1998	486	0.5	-	-	
	2008	834	1.0	-	-	
	2018	406	0.5	6	0.4	
Edge	1988	7,430	7.6	162	11.5	
	1998	4,814	5.3	95	7.0	
	2008	4,986	5.7	147	10.7	
	2018	5,218	6.5	230	16.4	
Loop	1988	5,670	5.8	112	8.0	
	1998	6,295	6.9	146	10.8	
	2008	5,607	6.4	209	15.2	
	2018	3,669	4.6	129	9.2	
Branch	1988	4,361	4.5	32	2.3	
	1998	3,619	4.0	47	3.5	
	2008	3,491	4.0	43	3.2	
	2018	3,117	3.9	29	2.1	

# Table 5. Results of Morphological Spatial Pattern Analysis (MSPA) analysis of connectivity of Perth's vegetation from 1988 to 2018.

#### 310 Discussion 4

311 We used Landsat imagery to characterize the patterns of vegetation change, habitat connectivity and the 312 role of golf courses in maintaining green spaces and connectivity in an urban landscape. We found that 313 deforestation led to a reduction in habitat connectivity in the Perth Metropolitan Region. However, golf 314 courses can play an important role in maintaining vegetation and supporting biodiversity connectivity 315 in urban landscapes. Previous studies have documented the increase in the urban footprint of Perth using 316 multi-temporal urban expansion statistics derived from Satellite imagery [58]; However, their work did 317 not address the issues of vegetation dynamics, nor the biodiversity and structure of the vegetation and 318 habitat connectivity in the Perth Metropolitan Region. Therefore, our study addresses this gap.

#### 319

#### 4.1 **Deforestation and urbanization**

320 The vegetation dynamics in the major urban areas of Perth reflect the pattern of urbanization over time. 321 The reduction in green space found in this study can be explained as a close relation to the process of 322 development in this city. Over the last three decades, urban development in Perth has taken place at an 323 unsustainable rate [42]. In the early 1990s to 2006, Perth's population grew by around 1.8%, but the 324 figure has nearly doubled since then [59]. Also, this study indicated that, from 1988 to 2018, Perth's 325 urban footprint increased from 74,376 to 92,243 ha (Table 2) and is consistent with previous research 326 in urban growth in this region [58]. In the last 20 years, on average, 740 ha/yr of urban and urban deferred 327 zoned land was consumed by subdivision, and 830 ha/yr was consumed by construction in the Perth 328 metropolitan area and nearby Peel region [60]. In addition to this expansion, the city has become denser 329 with the construction of new residential dwellings in urbanised areas. Although vegetation gain occurred 330 in some places as a result of natural increase in canopy cover as urban vegetation grows through the 331 conservation efforts, vegetation offset from development projects (e.g. mining), the plantation programs 332 of the government taking place in bare soils in some suburbs, and efforts to increase green spaces from 333 private land owners, the vegetation loss associated with urbanization has been more significant.

334 The difference in spatial patterns of vegetation loss are also related to the urban plans of this city. Our 335 results show that between 1988 and 1998, there was significant vegetation loss in the central region of 336 the city which can be linked to The Corridor Plan [61]. Historically, Perth's development pattern from 1970s to 1990s was based on linear corridors stretching out from the city's core, with large non-urban wedges between each of these corridors [61]. However, from 1998 to 2008 and from 2008 to 2018, deforestation was more significant in the outer subregions north-west and south-west of the city due to the adoption of Metroplan [62]. Perth recently has been divided into subregional areas, rather than corridors for planning purposes. The two coastal subregions (the North-West and South-West) included in our study have consistently achieved higher rates of population growth under Metroplan [63].

Originally the region was covered by woodlands dominated by eucalypts and banksias and coastal heath interspersed with chains of wetlands. Perth is home to a rich biodiversity, with more than 1,700 species of flowering plants and iconic species of threatened fauna in the region [64]. Therefore, such deforestation for urbanization has resulted in the devastating loss of significant natural habitats in this biodiversity hotspot city, leading to the designation as an endangered ecological community by the Australian Government [41].

#### 349 4.2 Connectivity of green space networks in urban landscapes

350 The MSPA analysis indicates that the loss of vegetation as a consequence of urban expansion has led to 351 a marked reduction in connectivity of green space networks in the Perth urban landscape. As only cores 352 (the stepping stones between forest habitat patches) and bridges (the structural corridors to link core 353 areas) can contribute to the connectivity between the habitat areas in the landscape [65], the reduction 354 of these areas in Perth associated with urbanization throughout the time indicates the high impact of 355 urban development on habitat connectivity. This analysis also shows the increase in proportion of islets, 356 which are totally isolated patches, and other classes (perforations, loops, branches, edges) that cannot 357 reach a new core habitat area for originating the potential movement [65]. Clearly, expansion of Perth 358 city has fragmented the remaining blocks of natural habitat and increased isolation of natural habitats. 359 This may reduce population and gene flow among patches and may disrupt the connection between 360 subpopulations and a large regional population [66] and thus threaten the long-term viability of relict 361 populations.

Fragmentation was obvious in the central region of the city and in recent decades it has become more serious in the outer parts of the city. This is critical as Perth is within a globally recognised biodiversity hotspot, which is home to rich biodiversity found nowhere else in the world. The connectivity in the
major urban area of Perth is not only critical for the linkage of habitats within the Swan Coastal Plain
but also for the connection of these coastal habitats to a large regional biosphere in south-western
Australia.

368 The results also illustrated that a 'Core' area and a network of 'Bridge' types exist in the central and 369 outer subregions of Perth. This is the consequence of early conservation efforts of the government which 370 created protected areas such as Kings Park, Bold Park and other significant areas. Very few cities in the 371 world have such large areas of natural bushland in the centre of a big city [67]. However, future urban 372 growth will continue to put pressure on the biodiversity. If current policies (Perth and Peel@3.5million) 373 are fully implemented, existing stocks of urban and urban deferred land would be consumed by about 374 2075 [68]. The challenge for urban planning to preserve urban forests and biodiversity is thus increasing, and it is clear that planning for future expansion should also include large protected areas. 375

Our MSPA output with spatial distribution of seven classes provides fundamental information for future urban planning. There is a need to maintain important green spaces which are classified as cores and bridges in the city, especially in the central region where most of the natural vegetation exists as islands. Also, the MSPA branch classes can be used to identify candidate ecological restoration areas. The branch class can be thought of [69] as a foundation of a potential corridor that could, if revegetated, connect two spatially disjunct core areas to improve connectivity in the larger region.

Although other analyses, such as functional connectivity, should be taken into account in landscape connectivity assessment [32], the structural connectivity analysis in this study will be useful for determining the priority protection level and critical areas of the connecting corridor, informing conservation strategies at a variety of scales, especially when the biodiversity values of this region are suffering from various threats including deforestation, feral animals, weed incursions, more frequent fires through arson and tree disease [64].

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#### 388 4.3 The role of golf courses in maintaining urban forest

Our study indicates that golf courses account for a significant proportion of the urban area of Perth. This category of land use has been vital in maintaining green space in urban areas over the past thirty years. In contrast to the overall decline in urban green space, golf courses have preserved green spaces within urban settings and even created a net gain of vegetation cover over time. The highest net gain was seen in the period between 1988 to 1998 when some golf courses were established resulting in the planting of trees.

In the green 'matrix' of Perth, golf courses with their significant area of vegetation cover have contributed considerably to the connectivity in the urban landscape. A significant proportion of their green space was classified as core or bridge categories. The proportion of vegetation within golf courses classified as bridges was higher than in the whole study area. Golf courses with large areas of native vegetation provide "links" to other large natural patches of urban vegetation.

Although there are concerns with the environmentally negative impacts of golf courses as a source of pollution through pesticide and fertiliser usage [22], habitat modification [25] and high water usage [70], previous studies provide evidence about the biological values of golf courses, such as providing refugial habitat for urban-avoiding wildlife [24, 71-79]. Our study indicates that golf courses in urban settings have been maintaining large green-area habitats and played an important role in biodiversity connectivity in the city.

#### 406 4.4 Monitoring urban forest dynamics

In this study, we utilized medium-resolution satellite remote sensing data to identify land use classes, characterise vegetation dynamics and connectivity. The data maps the spatial and temporal patterns of land use types characterizing a consistent, detailed vegetation dynamic of the city [58, 80]. Clearly, the biophysical elements of urban landscapes are well-reflected through physical features (NDVI) derived from remote sensing data with an accuracy of up to 89%.

412 Despite these kinds of data, it is hard to describe the detailed information of ecosystem such as species413 composition and forest structure. However, they show their advantage in mapping land cover dynamics

414 across large areas of big cities over time when high resolution imagery is not available. For monitoring 415 urban forests in big cities, the large scale and long temporal datasets are more advantageous compared 416 with datasets that focus only on discerning a specific land use type in a relatively small area [27, 81, 417 82]. This is because it allows spatially detailed identification of changes associated with development 418 over time. Therefore, the approach described in this paper provides baseline information for sustainable 419 urban planning and development. In addition, the MSPA analysis can further evaluate the dynamic of 420 vegetation cover by the describing the spatial configuration of ecosystems at the pixel level, detecting 421 changes of habitat connectivity over time [32].

#### 422 **5** Conclusions

423 With rapid urban expansion, the most meaningful question to address is how to balance urban 424 development and urban forest preservation. Urbanization requiring deforestation is inevitable in many 425 cities worldwide. Our study found a significant loss of vegetation cover in a biodiversity hotspot over 426 three decades of urbanization, which led to a reduction in habitat connectivity in the urban landscape. A 427 lesson learned from the experience of urbanization in Perth is that any future urban growth following 428 the patterns observed over the past three decades will continue to put pressure on maintaining urban 429 forest ecosystems and biodiversity conservation. As cities continue to grow in response to socio-430 economic development, considering all opportunities for urban biodiversity conservation is important. 431 Urban conservation strategies must therefore consider not only the protected areas, but also the off-432 reserve sites.

433 Our study indicates that golf courses in urban settings have been maintaining green-area habitats and 434 have played an important role in biodiversity connectivity in the city. Potentially, urban golf courses 435 could become more purposefully managed for biodiversity conservation and the improvement of critical 436 ecosystem services in urban areas. In rapidly urbanizing biodiversity hotspots like Perth, where 437 fragmentation is one the biggest threats to biodiversity, the way that golf courses contribute to increase 438 the connectivity in the intervening urban matrix should not be underestimated. Therefore, it is important 439 for government authorities and golf courses owners to pay more attention in maintaining ecosystem health in urban golf courses. 440

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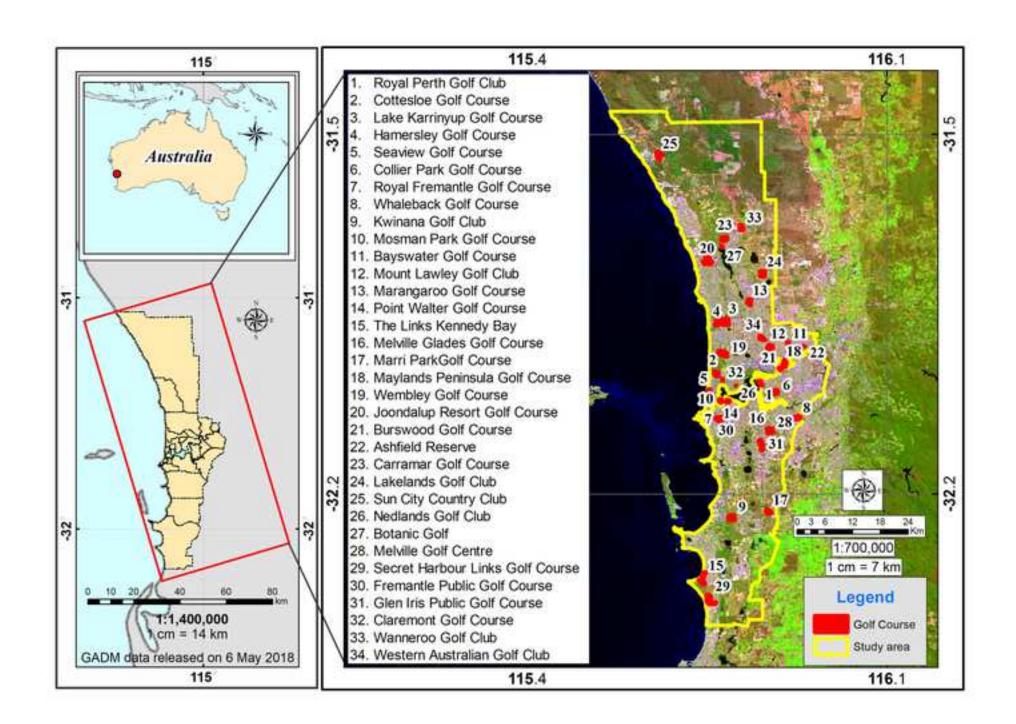
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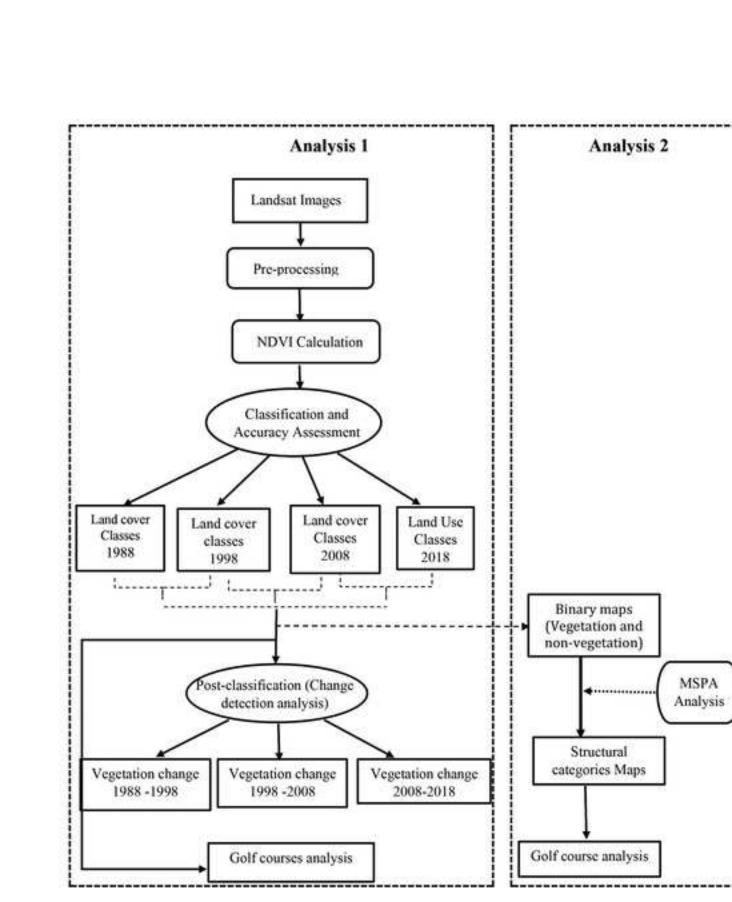
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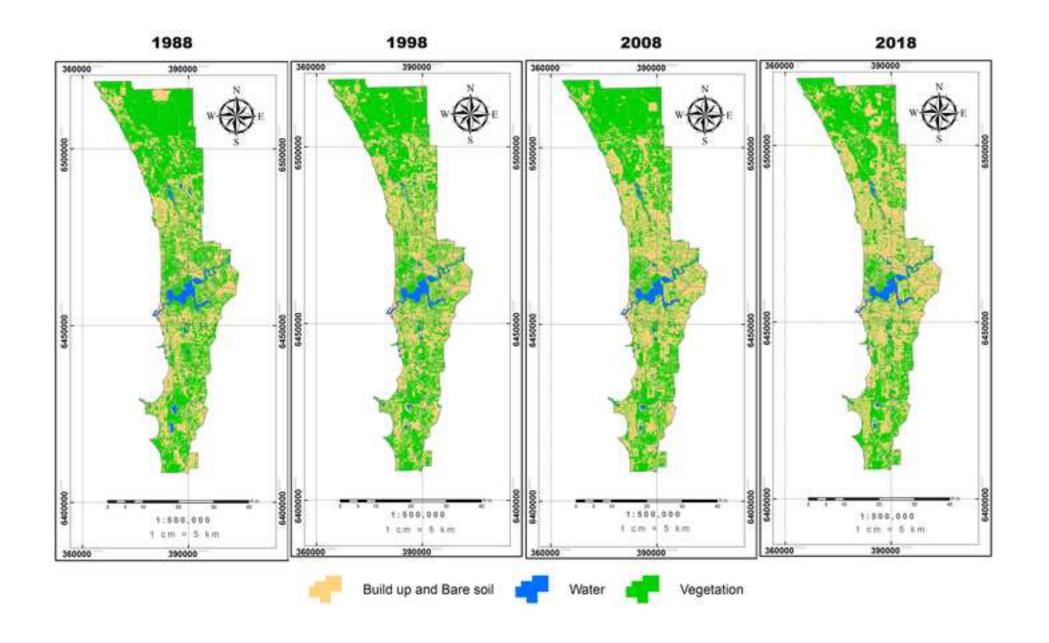
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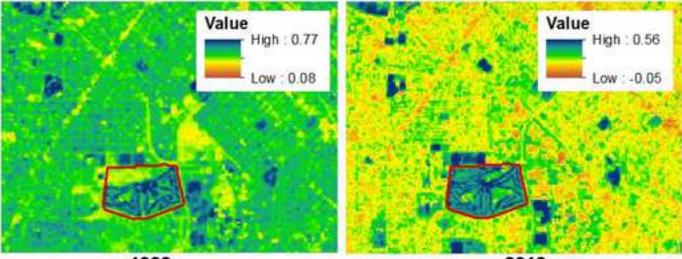




### a. Landsat Image

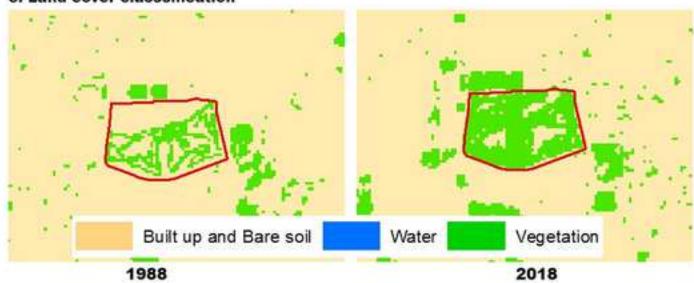


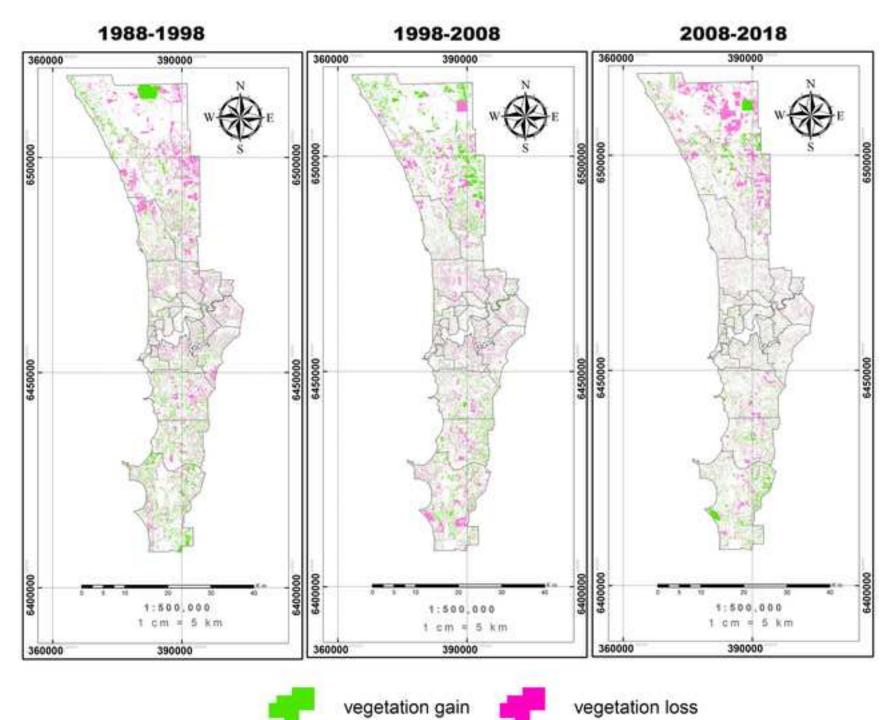
b. NDVI Value



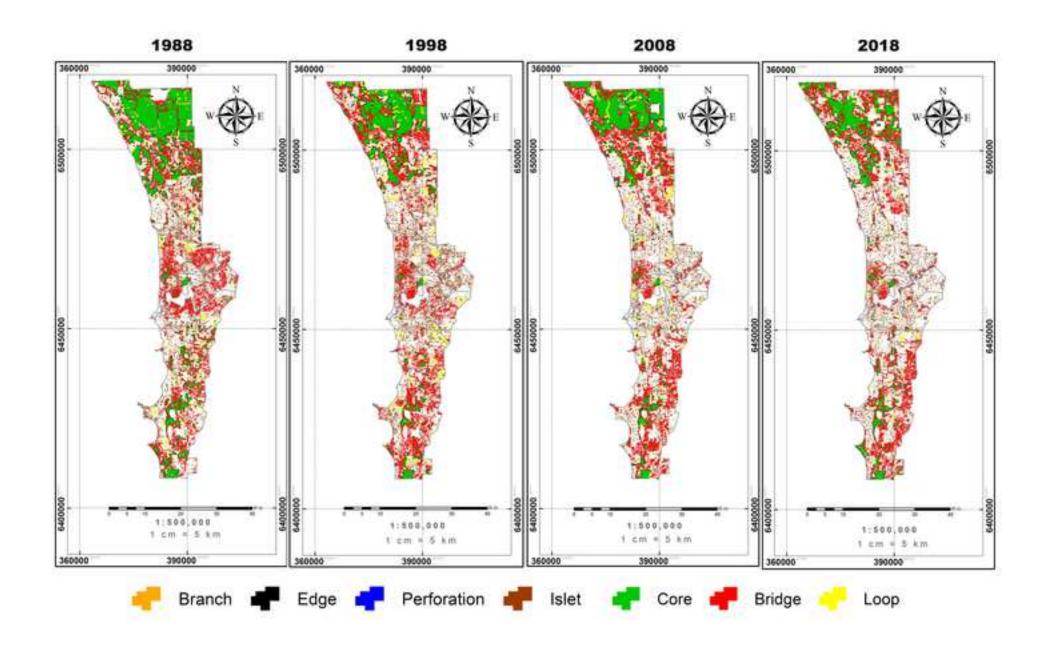
1988 c. Land cover classification

2018









1	Vegetation trends associated with urban development: <del>T</del> the role of golf	 Style Definition: Normal: Font: Times, Line spacing: Double
2 3	<u>courses</u> Trends in vegetation dynamics associated with urban development: The role of golf courses	<b>Style Definition:</b> Heading 1: Font: Bold, Font color: Text 1, Outline numbered + Level: 1 + Numbering Style: 1, 2, 3, + Start at: 1 + Alignment: Left + Aligned at: 0" + Indent at: 0.3"
4 5 6	Thu Thi Nguyen <sup>1,3*</sup> , Paul Barber <sup>2,3</sup> , Richard Harper <sup>3</sup> , Tran Vu Khanh Linh <sup>4</sup> , Bernard Dell <sup>3</sup>	<b>Style Definition:</b> Heading 2: Font: Bold, Italic, Outlin numbered + Level: 2 + Numbering Style: 1, 2, 3, + Start at: 1 + Alignment: Left + Aligned at: 0" + Inde at: 0.4"
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18 19	-Emails: Thu.Nguyen@murdoch.edu.au; thu.nguyen.2k14@gmail.com	Formatted: Font: (Default) Times, 11 pt, Not Bold, F color: Auto, Superscript
20 21		<b>Formatted:</b> Font: (Default) Times, 11 pt, Font color: Auto
22 23	Abstract	Formatted: Font: (Default) Times, 11 pt, Not Bold, F color: Auto, Superscript
24	Globally, cities have are growing rapidly in size and density and this has caused profound impacts on	Formatted: Font: (Default) Times, 11 pt, Font color: Auto
25	urban forest ecosystems. Urbanization requiring clearing deforestation of vegetation reduces	<b>Formatted:</b> Font: (Default) Times, 11 pt, Font color: Auto, Superscript
26	ecosystem services that benefit both city dwellers and biodiversity. Understanding spatial and	<b>Formatted:</b> Font: (Default) Times, 11 pt, Font color: Auto
27	temporal patterns of vegetation changes associated with urbanization is thus a vital for component of	Formatted: Font: (Default) Times, 11 pt, Not Bold, F color: Auto, Superscript
28	future sustainable urban development. We used Landsat time series data for the three decades from	<b>Formatted:</b> Font: (Default) Times, 11 pt, Font color: Auto
29	period-1988 to 2018 to characterize changes in vegetation cover and habitat connectivity in the Perth	Formatted: Justified
30	Metropolitan Area, in a rapidly urbanising Australian biodiversity hotspot, as a case study to	Formatted: Font: Times, 11 pt
21	understand the impacts of urbanization on urban forests. Moreover, as golf courses are rapidly	Formatted: Font: Times, 11 pt
31	understand the impacts of urbanization on urban forests. Moreover, as gon courses are rapidly	Field Code Changed
32	increasing a major component in many-urban areas, we assessed the role of golf courses in maintaining	Formatted: Font: Times, 11 pt
33	vegetation cover and creating habitat connectivity. We To do this we employed (1) land use	<b>Formatted:</b> Font: (Default) Times, 12 pt, Font color: Auto
34	classification with, post-classification change detection, and (2) Morphological Spatial Pattern	Formatted: Normal
25		Formatted: Font: (Default) Times, 12 pt
35	Analysis (MSPA). Over 17,000 heetares ha of vegetation were cleared and the area of vegetation	Formatted

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36	contributing to biodiversity connectivity was reduced significantly over the three decades. The spatial		
37	patterns of vegetation loss and gain were different in each of <i>last</i> the three decades (-1988-2018), the		<b>Formatted:</b> Font: (Defau Auto, English (Australia)
38	three decades reflecting the implementation of urban planning. Furthermore, MSPA analysis showed		Formatted: Font: (Defau
39	that the reduction in vegetation cover led to habitat fragmentation with a significant decrease in the		Auto, English (Australia) Formatted: Font: (Defau
40	core and bridge classes and an increase in isolated patches in the urban landscape. Golf courses played		Auto, English (Australia)
41	a useful role in maintaining vegetation cover and contributing to connectivity in a regional biodiversity		
42	hotspot. Our findings suggest that for future urban expansion, urban planning needs to more carefully	-(	Formatted: Font: (Defau
43	consider land elearing and itsthe impacts of deforestation on connectivity in the landscape. Moreover,	-(	Formatted: Not Highlig
44	there is a need to take into consideration opportunities for off-reserve conservation in smaller habitat		Formatted: Font: (Defau
45	for such as in calf assumed in sustainable when more assumed	$\sum$	Formatted: Not Highlig
45	fragments such as in golf courses in sustainable urban management.	1	Formatted: Font: (Defau
46	1 Introduction		

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48	Introduction	Formatted: F
49	Globally, cities have grown rapidly in number and size over recent decades [1, 2]. This trend is	Formatted: F Text 1
50	predicted to continue as urban areas are expected to absorb most of the global population growth [3]	Formatted: C
51	While the process of <u>urbanization</u> presents key implications for changes in physical landscapes and	Formatted: L spacing: sing
52	demographic characteristics, it can cause profound impacts on environmental components, especially	Field Code C
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53	on urban forest ecosystems [4, 5].	Formatted: D
54	Vegetation in urban landscapes is critically important because it can provides goods and services, and	Field Code Cl Formatted: F
55	full ecosystem functions that benefit city dwellers and the environment. On the one hand, a remarkable	Formatted: D
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56	range of human well-being benefits are <u>derived</u> delivered from urban green spaces including mitigating	Formatted: F
57	the <u>urban heat island</u> (UHI) effect which is a threat to human health [6, 7]; reducing stress [8], risk of	Auto, English
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58	poor mental health [9] and mortality from cardiovascular disease [10]; and improving healing times	Formatted: F
59	[11], <u>increasing self-esteem and empowerment</u> [12], and <u>improving cognitive ability</u> [13]. On the other	Formatted: D
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60	hand, urban green spaces provide various ecosystem services such as strengthening resistance to some	Formatted: C
61	kinds of natural disasters; for example, floods natural disasters-[14], promoting biological processes	Formatted: C
62	such as pollination [15], and reducing surface erosion from stormwater runoff [16]. The amount of	Formatted: C
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63	vegetation in cities strongly influences biodiversity, especially where vegetation is set aside during the	
64	process of urbanization [17]. However, if species dispersal and exchange among these patches is	
65	insufficient to allow gene flow and diversity, loss of regional biodiversity is inevitable [18]. Therefore,	
66	urban development that requires clearing of vegetationdeforestation, due to causes reduction in	
67	vegetation cover, with habitat loss and fragmentation is, and hence may be considered a threat to	
68	biodiversity [17, 19].	
69	Urban conservation strategies must therefore consider not only the size and quality of habitat reserves,	Formatted: F
70	but the connectivity in the intervening urban vegetation matrix [19]. While the need to protect large	Formatted: F
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habitat reserves is obvious, opportunities for off-reserve conservation of smaller habitat fragments

- should not be overlooked [20]. Understanding spatial and temporal patterns of vegetation change
- 73 associated with urbanization, as well as opportunities for the preservation of green spaces outside

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74 natural reserves, is vital for future sustainable urban development especially in areas of global

#### 75 ecological importance.

- As the number of golf courses is rapidly increasing in many urban areas worldwide [21], there have
- 577 been many environmental arguments about this green space category in urban landscapes. Golf
- 78 courses are <u>sometime</u> considered to be major polluters of the environment through pesticide and
- 79 fertilizer use [22]. However, golf courses in urban settings create large green area habitats, which even
- 80 surpass many nature reserves in size [23]. In fact, golf courses have been established for recreational
- 81 purposes, which are a mix of bushland, fairways and infrastructure. Though they are not fully
- 82 ecologically functional as with a natural parks, previous studies investigated the condition of
- 83 vegetation inside the golf courses and indicated that the bushland in non-playing areas of golf courses
- 84 are significantly important to biodiversity conservation and the provision of ecosystem services in
- 85 cities [24], such as providing refuge habitats for urban-avoiding wildlife [23, 25, 26]. Therefore,
- 86 potentially, together with the natural reserves, golf courses can play some roles as off-reserve sites for
- 87 purposeful biodiversity conservation in urban landscapes. Potentially, urban golf courses could
- 88 become more purposeful areas for biodiversity conservation and the provision of ecosystem services
- 89 in cities [24]. Previous studies have identified some of the biological values of golf courses, such as
- 90 providing refuge habitats for urban-avoiding wildlife [23, 25, 26]. Nevertheless, little research has
- 91 been undertaken to comprehensively assess the role of golf courses in maintaining vegetation patches
- 92 as interconnected nodes in urban landscapes during a long period of urban development where
- 93 vegetation clearingdeforestation was significant.
- 94 <u>Vegetation clearingDeforestation</u> for urban expansion can occur gradually over multiple years.
- 95 Satellite-based remote sensing holds certain advantages in the characterization of these changes in
- 96 urban landscapes because of the large spatial coverage, high time resolution, and wide availability of
- 97 data [27]. For example, medium resolution LL-andsat images of medium-resolution allow for mapping
- 98 of large urban areas at a large spatial scale [28]. Many methods have been used to detect, monitor and
- 99 quantify vegetation changes, but differences in vegetation index and land use classification are the
- 100 most widely used methods for vegetation change over a long period of time [28].

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101 102 103 104 105 106 107 108	A great number of vegetation indices have been proposed, ranging from very simple to very complex band combinations [29]. The most widely-used vegetation index is the Normalized Difference Vegetation Index (NDVI) <sub>e</sub> -[29] <u>which is the most efficient and simple metric to identify vegetated</u> <u>areas and their condition [30].<sub>e</sub><u>whichThis</u> separates green vegetation from other surfaces based on the ability of chlorophyll to absorb red light for photosynthesis and reflect the near-infrared (NIR) wavelengths [31]<sub>e</sub>- Furthermore, information on vegetation cover dynamics can be combined with Morphological Spatial Pattern Analysis (MSPA) to describe the spatial configuration of the ecosystem</u>	<ul> <li>Formatted: Font: (Default) Times, 11 pt, No underline, Font color: Auto, Not Highlight</li> <li>Formatted: Left, Space Before: 0 pt, After: 0 pt, Line spacing: single, Adjust space between Latin and Asian text, Adjust space between Asian text and numbers</li> <li>Formatted: Font: (Default) Times, 11 pt, Not Highlight</li> <li>Formatted: Font: 11 pt, English (Australia)</li> <li>Formatted: Font: 11 pt, English (Australia)</li> </ul>
103 104 105 106 107	Vegetation Index (NDVI) <sub>e</sub> -[29] <u>which is the most efficient and simple metric to identify vegetated</u> areas and their condition [30]. <u>e</u> which This separates green vegetation from other surfaces based on the ability of chlorophyll to absorb red light for photosynthesis and reflect the near-infrared (NIR) wavelengths [31] Furthermore, information on vegetation cover dynamics can be combined with	spacing: single, Adjust space between Latin and Asian text, Adjust space between Asian text and numbers <b>Formatted:</b> Font: (Default) Times, 11 pt, Not Highlight <b>Formatted:</b> Font: 11 pt, English (Australia)
104 105 106 107	areas and their condition [30]. which This separates green vegetation from other surfaces based on the ability of chlorophyll to absorb red light for photosynthesis and reflect the near-infrared (NIR) wavelengths [31]. Furthermore, information on vegetation cover dynamics can be combined with	Formatted: Font: (Default) Times, 11 pt, Not Highlight Formatted: Font: 11 pt, English (Australia)
105 106 107	ability of chlorophyll to absorb red light for photosynthesis and reflect the near-infrared (NIR) wavelengths [31] Furthermore, information on vegetation cover dynamics can be combined with	Formatted: Font: 11 pt, English (Australia)
106 107	wavelengths [31] - Furthermore, information on vegetation cover dynamics can be combined with	
107		Tormatted. Fond TT pt, English (Adstralid)
	Morphological Spatial Pattern Analysis (MSPA) to describe the spatial configuration of the ecosystem	
108		
	at the pixel level, making it possible to detect temporal changes in the structural connectivity of	
109	habitats in urban settings [32].	Formatted: Default Paragraph Font, Font: 11 pt
110	Therefore, to enhance the understanding of vegetation dynamics associated with urbanization and the	
111	role of golf courses in maintaining urban forests, we used Landsat imagery to map vegetation cover	
112	and to assess its spatial and temporal distribution over three decades from 1988 to 2018. Then, mMaps	
113	of vegetation cover were used for MSPA analysis to detect changes in habitat connectivity. We chose	
114	the Perth Metropolitan area for the study as it lies within a rapidly urbanizing biodiversity hotspot in	
115	Australia. The three primary research objectives were to: $(1)$ determine the spatial and temporal	Formatted: Font: Not Bold
116	patterns of vegetation clearingdeforestation in urbanization; (2) evaluate the spatial and temporal	
117	patterns of green landscape connectivity; and (3) assess the impact role of golf courses on in	
118	preserving green spaces and biodiversity in an urban landscape. This analysis will provide a useful	
119	perspective on the land-use pressure facing vegetation remnants in in this the region and their	
120	connectivity in the Southwest Australia Ecoregion (SWAE) which is recognised as one of 35	
121	international biodiversity hotspots, and is home to with over 1500 plant species with a high degree of	
122	endemism [33], and provide a framework for planning urban expansions both in this region and	
123	globally	
124	2 Methods	Formatted: Line spacing: single
125	2.1 Study area	Formatted: Heading 2, Space Before: 0 pt, After: 0 pt
	The study area belongs to the Perth Metropolitan area region covering four sub-regions (North West,	Line spacing: single
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126 127	Middle Central, Inner Central and South West). Perth has a Mediterranean-type temperate climate	Formatted: Left, Line spacing: single

128 with a hot and dry summer, and a cold and rainy season occurring between May and October

- 129 [34].\_West) (Fig 1).U-[34]nder future climate-change scenarios, this area is projected to experience a
- 130 lower annual rainfall in the future [35].
- 131 Although Perth may be the driest regions on Earth, it is still home to some amazing biodiversity. Perth
- 132 <u>belongs to the Australia's southwest corner, which is recognized as a global biodiversity "hotspot"</u>
- 133 with outstanding natural environments. Our study area eversoccurs on most of the Swan Ceoastal
- 134 Pplain. This plain which is connected with the valleys around Perth, the Esperance plains, and
- 135 the jarrah karri eucalyptus forests, makingpart of the southwest of Australia which in turn has the
- 136 highest concentration of rare and endangered species on the entire continent (at least 1,500 endemic
- 137 species). More than 6,000 species of native plants and 100 native mammals, birds, frogs and reptiles
- 138 <u>foundoccur in this region, making it a biodiversity "hotspot" [33, 36].</u>
- 139 Perth has retained a significant area of natural vegetation which have has conservation significance
- 140 thanks to the introduction of some of legislation, and policies aimed primarily at protecting
- 141 <u>biophysical environmental values</u>. Some of those policies are This includes, the Western Australian
- 142 *Environmental Protection Act* 1986 [37]; the Federal Government's *Environment Protection and*
- 143 *Biodiversity Conservation Act* 1999 [38]; and more recently, Bush Forever [39, 40], a policy which
- 144 took a whole-of-government approach to identify and protect biologically significant bushland and
- 145 <u>wetlands within the Perth metropolitan area. However, Perth Perth is located in a globally recognised</u>
- 146 biodiversity hotspot [41] in a region of Mediterranean type climate and has experienced extensive
- 147 urban development at an unsustainable ratesince the 1980s [42]. The expansive growth of the Perth
- 148 <u>metropolitan footprint has contributed to the loss of biodiversity, together with the ecosystem services</u>
- 149 provided by natural areas.[37-40]
- Together with urbanization, the golf industry has expanded contributing to a growing proportion of
  Perth's urban green space. There are with 34 golf courses in the study area (FigFigure 1).

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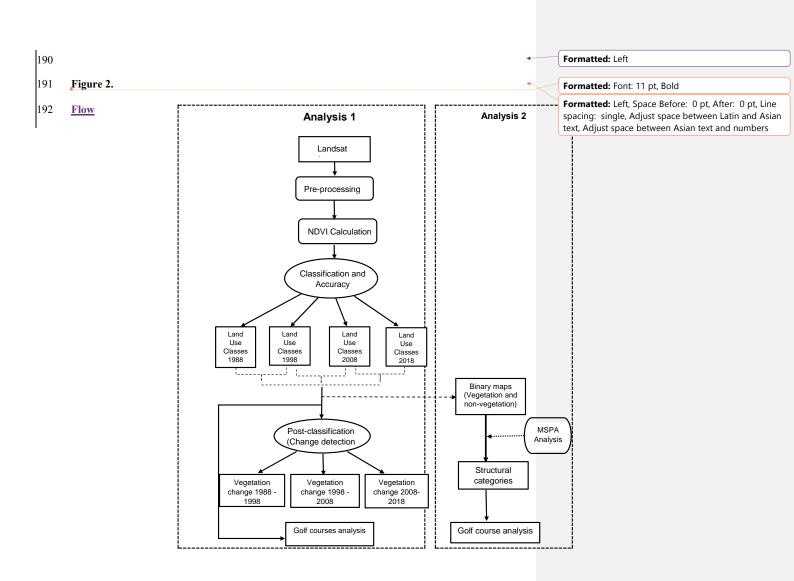
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154		•	<b>Formatted:</b> Left, Line spacing: single, Tab stops: 1.25", Left
155	Figure 1. Location of the sStudy area (from USGS EROS (Earth Resources Observatory and		
156	Science (EROS) Center) in the public domain: http://eros.usgs.gov/#)		
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159	<u>2.2</u> Approaches		Formatted: Left, Line spacing: single
160	We conducted two types of analyses in this study: (1) assessment of vegetation cover change in golf	•	Formatted: Font: (Default) Times, 12 pt
171	courses sizes 1000 relative to current diagonases to manife a broad event) content of the unber	$\langle \rangle$	Formatted: Font: (Default) Times, 12 pt, Not Bold
161 162	courses since 1988 relative to surrounding areas to provide a broad overall context of the urban vegetation changes that have taken place throughout the region and the role of golf courses; and (2)		Formatted: Heading 2, Space Before: 0 pt, After: 0 pt, Line spacing: single
102			Formatted: Left, Space Before: 0 pt, After: 0 pt, Line
163	assessment of MSPA. In these analyses, we used four data sets (1988, 1998, 2008, 2018) covering		spacing: single, Adjust space between Latin and Asian text, Adjust space between Asian text and numbers
164	thirty years of urban development. The steps taken in this study are summarized in a flow chart		
165	( <del>FigFigure</del> 2).		
166	2.2.1 Landsat data and pre-processing		Formatted: Font: 12 pt, Not Bold, Font color: Auto
167	Three Landsat 5 Thematic Mapper images (WRS path 113 row 82) were acquired from 1988 to 2008		
168	and one Landsat OLI 8 (WRS path 113 row 82) was acquired in 2018 at four time steps, including		
169	(year 1988 (11th December), year 1998 (7th December), year 2008 (18th December), year 2018 (14th	_	Formatted: Superscript
170	December). The Landsat imagery were obtained from the US Geological Survey (USGS) of the Earth	$\square$	Formatted: Superscript
		_//	Formatted: Superscript
171	Resources Observation and Science Center (EROS). Earth Resources Observation. Image dates were		Formatted: Superscript
172	selected from cloud free scenes acquired during December (summer, dry season) to reduce the		<b>Formatted:</b> Font: (Default) Times, 11 pt, English (Australia)
173	seasonal difference effects (Ttable 1). All images selected are cloud-free scenes or little cloud cover		
174	(0.05% and 0.4%) scenes with the whole study area is cloud-free; Therefore, is no requirement for		
175	removing cloud. Georeferencing was performed at the USGS prior to downloading the data (L1T level	1	
176	of systematic geometric accuracy) and no further refinement was undertaken. Atmospheric and		Formatted: Font color: Auto
177	topographic corrections were performed on the Landsat data sets. The atmospheric correction was		Formatted: Font color: Auto
			Formatted: Font: (Default) Times, Bold
178	carried out to adjust the multitemporal dataset to a common radiometric scale [43].		Formatted: Left
170			Formatted: Font: Bold, Pattern: Clear
179	Table 1. Landsat scenes used in the study	•/	Formatted: Font: (Default) +Body (Calibri), 11 pt, Bold

180	A						Formatted: Font: Bold
	Type of imagery	<u>Year</u>	<del>Day/month</del>	Cloud-Cover	Resolution (m)		<b>Formatted:</b> Don't adjust space between Latin and Asian text, Don't adjust space between Asian text and numbers
	Landsat 5 TM	<del>1988</del>		0%	<del>30m</del>	-	<b>Commented [RH1]:</b> Add data in this column
		<del>1998</del>		0%	<del>30m</del>		Formatted Table
		2008		0%	<u>30m</u>		
	Landsat 8-OLI	<u>2018</u>		<u>0%</u>	<u>30m</u>		
181						_	
182	The first process of a	tmospheric cor	rection was conversion o	f the digital numbe	r (DN) remote sensir	ισ 🖣	Formatted: Left. Space Before: 0 pt, After: 0 pt, Line
183	1	1	ed on the image header f	e	· · ·	5	spacing: single, Adjust space between Latin and Asian text, Adjust space between Asian text and numbers
184	based models - dark	object subtraction	on (DOS) to correct atmo	ospheric scattering	scene-by-scene <u>. +Th</u>	i <u>s</u>	
185	method is a widely us	sed and effectiv	e method in atmospheric	correction [44-50]	l. Topographic		
186	correction was condu	cted to remove	the topographic effects.	We used <u>a</u> sun-can	opy-sensor (SCS)		
187	correction based on t	he 30 m digital	elevation model (DEM)	because topograph	ic shading is not only	,	Formatted: Pattern: Clear
188	due to slope but also	to shadowing o	f one tree crown over and	other and this is on	e of the most widely		
189	and effective used me	ethods of topog	raphic correction [51].				Formatted: Font: 11 pt



193 <u>chartPipelines Flow chart</u> summarizing the major steps taken during the investigation,

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194	(NDVI: Normalized Difference Vegetation Index; MSPA: Morphological Spatial	Formatted: Font: Times, 12 pt
195 196	Pattern Analysis) 2.2.2 Classification	<b>Formatted:</b> Heading 3, Left, Space Before: 0 pt, After: 0 pt, Line spacing: single, Adjust space between Latin
197	In a preliminary step, we used a decor relation stretch to enhance the image for more effective	and Asian text, Adjust space between Asian text and numbers
198	visualization. Prior to image classification, NDVI images were generated. A classification technique	Formatted: Font: 12 pt, Not Bold
199	was then applied to the NDVI images of 1988, 1998, 2008 and 2018 using Arc-GIS 10.3 software.	
200	NDVI images were obtained by calculating the ratio between the red (R) and near infrared (NIR)	Formatted: Font: (Default) Times, 11 pt, Font color:
201	valuesthe visible (VIS) and near infrared (NIR) bands of the satellite image by using Eequation 1:	Auto
201	values are visible (vis) and near inflated (vine) bands of the satellite inflage by using Dequation 1.	Formatted: Font: (Default) Times, 11 pt
202	$NDVI = \frac{(NIR - VISR)}{(NIR + VISR)} $ (1)	Formatted: Font: 11 pt
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203	In Landsat 4-7, $NDVI = (Band 4 - Band 3) / (Band 4 + Band 3).$	Formatted: Font: 11 pt
		Formatted: Font: 11 pt
204	In Landsat 8, NDVI = (Band 5 – Band 4) / (Band 5 + Band 4),	Formatted: Font: Times, 11 pt
205		Formatted: Font: +Body (Calibri), 11 pt
205	Landsat TM data of from different dates were independently classified based on the NDVI values. The	<b>Formatted:</b> Font: (Default) Times, 11 pt, Font color: Auto
206	** <u>W</u> ater bodies have negative NDVI values, whereas, bare soil and built-up areas have an NDVI value	Formatted: Space After: 0 pt, Pattern: Clear
207 208	of around zero. <u>Chlorophyll in gGreen vegetation</u> , on the other hand, has <u>consumed RED to drive</u> <u>photosynthesis stronger near infrared reflectance</u> thereby providing moderate and high NDVI values	Formatted: Left, Space Before: 0 pt, After: 0 pt, Line spacing: single, Adjust space between Latin and Asian text, Adjust space between Asian text and numbers
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209	close to +1 [52]. Based on this informationunderstanding, the four NDVI images were classified into	Formatted: Font: Times
210	three classes (Vyegetation, Built up and + bare soil, Wywater bodies) by using the NDVI threshold	Formatted: Font: Times
211	ranges technique in Arc-GIS 10.3 software.	Formatted: Font: Times
		<b>Formatted:</b> Font: (Default) Times, 11 pt, Font color: Auto, English (Australia)
212	The classification based on NDVI threshold was evaluated using accuracy assessment. An error matrix	Formatted: Font: (Default) Times, 11 pt
213	compared information from a classified image or land cover map to known reference (truth) sites for a	Formatted: Font: Times
214	number of sample points assessed in 2018. We obtained photographs of representative land use	Formatted: Font: (Default) Times, 11 pt
214	categories with GPS locations to assist us-in our image interpretations. Also, we used Google Earth	<b>Formatted:</b> Font: (Default) Times, 11 pt, Font color: Auto, English (Australia)
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216	images, true and false colour combination images and knowledge-based information including expert	Formatted: Font: Times
217	knowledge, land use maps and reports. For historical images, Google Earth was used to substitute the	Formatted: Font: Times
218	traditional reference data collection on each of the sites [53]. Based on data of accuracy assessment,	Formatted: Font: Times
	authorial reference and concerton on each of the sites [55]. Dased on data of accuracy assessment,	Formatted: Font: Times
219	we reclassified the preliminary land use classification maps to improve the accuracy of classification.	Formatted: Font: Times, Font color: Auto
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220	2.2.3 Vegetation change detection	Earmatted: Font: 12 nt Not Pold
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221	In order to detect the vegetation cover change, we created binary maps of vegetation and non-	Formatted: Left, Space Before: 0 pt, After: 0 pt, Line
222	vegetation from the classified maps in the previous analysis, one for each adjacent pair of time steps,	spacing: single
223	which depict where degradation occurred within a decade of urbanization. This post-classification	
224	analysis uses two images from different dates and classifies them independently. We then calculated	
225	changes in vegetation cover type using $\underline{E}$ equation 2:	
226	Change area = $D_2 - D_1$ (2)	
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227	where D1 and D2 are the area of the target vegetation cover at the beginning and the end of the study	<b>Formatted:</b> Left, Space Before: 0 pt, After: 0 pt, Line spacing: single
228	period, respectively. This analysis allows the calculation of vegetation loss and gain in each period.	Formatted: Not Superscript/ Subscript
1		Formatted: Not Superscript/ Subscript
229	2.2.4 Golf courses Analysis 1	Formatted: Font: 12 pt, Not Bold
230	We compared the vegetation cover, and the change detection (vegetation loss and gain) taking place	<b>Formatted:</b> Heading 3, Left, Space Before: 0 pt, After: 0 pt, Line spacing: single, Adjust space between Latin
231	within all golf courses in the study area, and in their surrounding regions. After creating the GIS	and Asian text, Adjust space between Asian text and numbers
232	boundaries of these golf courses, we extracted the vegetation cover and the vegetation change within	
233	these boundaries at four time steps in 1988, 1998, 2008 and 2018 to compare vegetation dynamics	
234	within the golf courses and the whole study area over time.	
1		
235 236	2.2.5 Morphological Spatial Pattern Analysis (MSPA) MSPA analysis for the structural connectivity of habitats	Formatted: Font: 12 pt, Not Bold
237	MSPA was employed to describe the structural connectivity of habitats in Perth for four time steps in	
238	1988, 1998, 2008 and 2018. This method describes the spatial and temporal configuration of the	
239	ecosystem at the pixel level [32], which was based on the concept of "habitat availability" and	
240	"graphic theory" [54, 55] in which the landscape is considered as a collection of nodes, and links with	
241	a node is a place where connectivity exists and will depend on the width of itself. The output of the	Formatted: Font color: Auto
242	MSPA analysis includes the seven structural categories into which habitats are divided, including core,	
243	edge, perforation, bridge, loop, branch and islet [56] and [57] which and are is summarized in -Table	Formatted: Font: 11 pt, Not Bold
		Formatted: Font: 11 pt, Not Bold
244	<u>+)]2. [56]-and-[</u> 57]-	Formatted: Font: Bold
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Table 1 <del>21.:</del> De	finition of Morphological Spatial Patterr	n Analysis (MSPA) <del>MSPA-</del> classes <del>. (see</del>	Formatted: Font: +Body (Calibri), 11 pt, Not	Bold
_			Formatted: Font: 11 pt, Not Bold	
[56] <del>-and-</del> [57] <del>).</del>	۸	/	Formatted: Font: +Body (Calibri), 11 pt, Not	Bold
<u></u>			Formatted: Font: 11 pt, Not Bold	
Class	Description	Ecological Meaning	Formatted: Font: 11 pt	
Core	A collection of foreground pixels	Large-scale natural patches with high	Formatted: Font: 11 pt	
•	which are interconnected	connectivity	Formatted	
	Foreground surrounded by		Formatted	
	foreground and greater than the user-		Formatted: Font: 11 pt	
	•		Formatted: Font: (Default) +Body (Calibri), 1	1 pt
	specified edge width from		Formatted: Font: +Body (Calibri), 11 pt	
	background		Formatted: Font: 11 pt, Not Bold	
Edge	Transition pixels between the	The transition zone between vegetation	Formatted	
	foreground and background that form	and non-vegetation areas. The transition	Formatted: Font: 11 pt	
	the outer edge <del>Foreground that</del>	zone between green space and non-green	Formatted: Font: 11 pt	
	separates core from background	space,	Formatted	
			Formatted: Font: +Body (Calibri), 11 pt	
Perforation	The transition pixels between	Unnatural patch inside the core area.	Formatted: Font: (Default) +Body (Calibri), 1	1 pt
	foreground and background inside		Formatted: Font: 11 pt, Not Bold	
	core areas that form the inner edge		Formatted	
	Foreground that separates core from		Formatted: Font: 11 pt	
	interior areas of background		Formatted: Font: 11 pt	
			Formatted: Font: +Body (Calibri), 11 pt	
Bridge	A set of linear foreground pixels	The striped ecological land that connects	Formatted: Font: +Body (Calibri), 11 pt	
	between two cores that connect two	two cores, which is equivalent to the	Formatted: Font: 11 pt, Not Bold	
	or more core areas. Linearly oriented	connecting corridor of the green space	Formatted	
		network.Striped ecological land between	Formatted: Font: 11 pt	
		core areas with high connectivity, which	Formatted: Font: 11 pt	
			Formatted	

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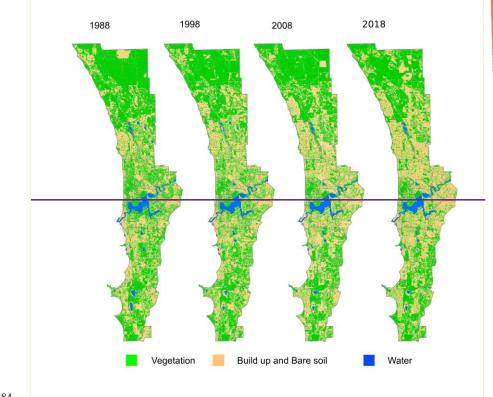
	foreground that connects two disjunct	is equivalent to the connecting corridor	Formatted: Font: +Body (Calibri), 11 pt
	core areas	of the green space network.	aee networks, Formatted: Font: Octaulty Heady (Calibri), 11 pt Formatted: Font: 11 pt, Not Bold Formatted: Font: 11 pt, Not Bold Formatted: Font: 11 pt Formatted: Font: 11 pt, Not Bold Formatted: Font: 11 pt Formatted: Font: 12 pt, Not Bold Formatted: Font: 12 pt, Not Bold F
Loop	Linearly oriented foreground pixels	Connecting corridor inside a large	Formatted: Font: 11 pt, Not Bold
Loop	that extendeds from core and econects back to the same core area	natural patch.	between Latin and Asian text, Adjust space between
	(e.g. a handle) that connects core area		Formatted: Font: 11 pt
	to itself.		Formatted: Font: 11 pt
Branch	Linearly oriented foreground pixels	Striped ecological land with low	between Latin and Asian text, Adjust space between
	extended from core that do not	connectivity.	Formatted: Font: (Default) +Body (Calibri), 11 pt
	connect to any other core area		Formatted: Font: +Body (Calibri), 11 pt
			Formatted: Font: 11 pt, Not Bold
<u>Islet</u> Brane	A collection of foreground pixels     which is smaller than the core zone     and do not connect to any other	Small natural patches that are isolated and do not connect to each other. Striped ecological land with low connectivity.	between Latin and Asian text, Adjust space between
	foreground cellsLinearly oriented	congreat and with low connectivity	Formatted: Font: 11 pt
			Formatted: Font: 11 pt
	foreground that extends from core and terminates in background.		between Latin and Asian text, Adjust space between
			Formatted: Font: (Default) +Body (Calibri), 11 pt
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			between Latin and Asian text, Adjust space between
In order to	undertake the MSPA analysis, we defined the i	nput data (foreground class) For this study	Formatted: Font: 11 pt
	•		Formatted: Font: 11 pt
	e classified maps for 1988, 1998, 2008, 2018 in ained vegetation and non-vegetation classes. He		between Latin and Asian text, Adjust space between
nixels were	defined as the foreground pixels (green landsc	ape) in the MSPA approach The results of	Formatted: Font: (Default) +Body (Calibri), 11 pt
•		.,	Formatted: Font: +Body (Calibri), 11 pt
	sign of Porth over 20 were of when institute	s the changes in habitat connectivity in the	
<del>major urbai</del>	area of Perth over 30 years of urbanization,		Formatted: Font: Not Bold
			Formatted: Font: 12 pt, Not Bold
To assess th	<i>If course analysis 2</i> ne role of golf courses in maintaining biodivers		0 pt, Line spacing: single, Adjust space between Latin and Asian text, Adjust space between Asian text and
the habitat	connectivity taking place within all golf course	s in the study area and in their surrounding	Formatted: Pattern: Clear

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264	green spacesregions. Using the GIS b	oundaries of the gol	f courses, w	ve extracted the ha	bitat			
265	connectivity within the golf course bo	undaries for four tir	na stans (10	1008 2008 a	ad 2018)		Formatted: Font: +Body (Calibri), Pattern: Clea	ar
205	connectivity within the gon course of		ne steps (1)	700, 1770, 2000 al	u 2010).	/	Formatted: Font: (Default) Times, 12 pt, Font of Text 1	color:
266	3 Results						Formatted: Font: (Default) Times, 12 pt	
267	<u>3.1</u> Land use classification in F	Perth				-	Formatted: Heading 2, Space Before: 0 pt, Af Line spacing: single	ter: 0 pt,
268	Data sets representing four time period	ds (1988-1998-200	8 and 2018	) are shown in Fig	ure 3 and 1	able •	Formatted: Font: (Default) Times, 12 pt, Not B	old
269	23, which provides an overview of th			_			<b>Formatted:</b> Left, Space Before: 0 pt, After: 0 spacing: single, Adjust space between Latin ar text, Adjust space between Asian text and nun	nd Asian
270	water bodies) over recent decades. Fr	om the 1988 and 199	98 data sets	, it is evident that	over half of	f the	Formatted	
271	region was vegetated. However, the u	rban footprint of bu	ilt up and b	are land area had i	ncreased 1	0%	Formatted: Font: Not Bold	
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272	from 1998 to by 2018. As a conseque	nce, there was a sign	ificant deci	rease in vegetation	1 cover, wh	ich	Formatted: Font: Bold	
273	comprised 56% of the land surface in	1988 and declined b	y 10.1% ov	ver the next 30 year	ırs (Table <del>2</del>	<u>23</u> ).	<b>Formatted:</b> Left, Space Before: 0 pt, After: 0 spacing: single, Adjust space between Latin and	nd Asian
274	We obtained an <u>The analysis had an</u> o	verall accuracy (OA	<del>) of classifi</del>	cation of 87% and	<del>a kappa</del>	/	text, Adjust space between Asian text and nun	nbers
275	coefficient of 91% for the three class	<del>35.</del>					Formatted	
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282	Table <u>23</u> 2. Land <u>coveruse</u> classifica	tion within the Per	th Metropo	olitan Region.			Formatted	
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		Ī	and covert	ise category		-	Formatted: Left, Line spacing: Multiple 1.15 li	i
	Land use category	Whole area		Gol	f course	•	Formatted: Font: (Default) +Body (Calibri), 11	pt
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	Veget	ation Built up and bare	Water bodies	Vegetation	Built up and bare	Water bodies	Formatted	
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	1988 Area (ha) 98,44	6 74,376	2,667	929	210	0.1	Formatted	
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			Ī	and coveru	<del>se</del> category		•
Land u	se category		Whole area		G	olf course	•
		Vegetation	Built up and bare soil	Water bodies	Vegetation	Built up and bare soil	Wate
	Proportion (%)	56.1	42.4	1.5	81.5	18.5	0.0
1998	Area (ha)	91,754	81,464	2,271	1,042	97	0.7
	Proportion (%)	52.3	46.4	1.3	91.4	8.5	0.1
2008	Area (ha)	88,341	84,971	2,176	1,084	55	0.2
	Proportion (%)	50.3	48.4	1.2	95.1	4.9	0.0
2018	Area (ha)	80,755	92,243	2,491	1,093	46	0.7
	Proportion (%)	46.0	52.6	1.4	95.9	4	0.1



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## Figure 3. Map of land <u>coveruse classification for Perth in four time steps between 1988</u> and 2018<sub>7</sub>

287 The analysis had the overall accuracy (OA) of classification from 87% and the kappa coefficient from

288 <u>91% for the three classes (Table 3).</u>

#### 289 Table 3. Accuracy assessment of land cover maps generated

- <u>sectation</u> <u>15</u> <u>0</u> <u>1</u> <u>16</u> - -	1         12         0         13         Overal Accuracy         Overal Kappa         Year 1998         Build Up and Bare Soil         0         13         0         13         0         13         0         13         0         13         0         13         0         13         Overal Accuracy         Overal Kappa         Year 2008         Build Up and Bare Soil	Water Bodies           0           2           15           17           87%           0.91           Water Bodies           0           2           14           16           90%           0.93           Water Bodies		Formatted Formatted
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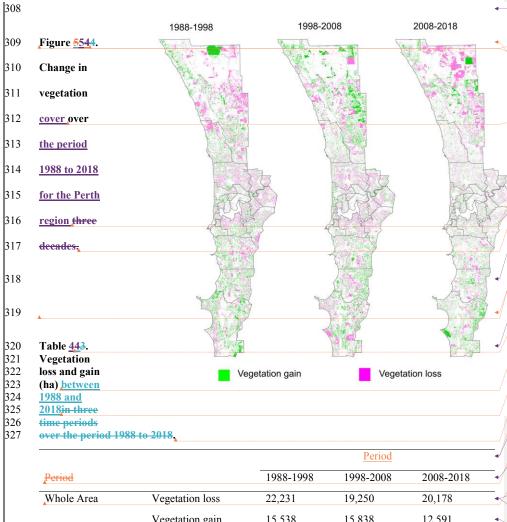
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<ul> <li>297 <u>Course for a) Landsat data; b) NDVI values; c) Land cover classificationFigure 4. Land</u></li> <li>298 <u>cover changes in the Collier Park Golf Course throughout the time</u></li> <li>299</li> <li>300</li> <li>300</li> <li>301 <u>3.2 Spatial patterns of vegetation change</u></li> <li>302 To characterize spatial patterns of vegetation dynamics, we detected the vegetation loss and gain for</li> <li>303 each of the three decades (FigFigure 54). In the period 1988 to 1998, vegetation clearingdeforestation</li> <li>304 occurred intensively in the central and parth ragions. From 1998 to 2008, vegetation loss any and det to</li> </ul>	291	Using the GIS layer of land use categories, we also extracted the data for three classes within the golf		
<ul> <li>294 unchanged at <u>around 1,0+9340</u> ha over the last 30 years.</li> <li>295</li></ul>	292	courses in comparison with the whole area (Table $\frac{223}{2}$ ). Our analysis shows that while there was a		
<ul> <li>Figure 4. Land cover classification showing a detailed view of the Collier Park Golf</li> <li>Figure 4. Land cover classification showing a detailed view of the Collier Park Golf</li> <li>Course for a) Landsat data; b) NDVI values; c) Land cover classificationFigure 4. Land</li> <li>cover changes in the Collier Park Golf Course throughout the time</li> <li>cover changes in the Collier Park Golf Course throughout the time</li> <li>formatted: Font: (Default) Times New Roman, 12 pt, Bold</li> <li>Formatted: Font: (Default) Times New Roman, 12 pt, Bold</li> <li>Formatted: Font: (Default) Times New Roman, 12 pt, Bold</li> <li>Formatted: Font: (Default) Times New Roman, 12 pt, Bold</li> <li>Formatted: Font: (Default) Times New Roman, 12 pt, Bold</li> <li>Formatted: Font: (Default) Times, 12 pt, After: 0 pt, Line spacing: single</li> <li>Formatted: Font: (Default) Times, 12 pt, Not Bold</li> <li>Formatted: Fon</li></ul>	293	significant decrease in vegetation cover throughout the region, the total area of golf courses remained		
<ul> <li>Bold</li> <li>Figure 4. Land cover classification showing a detailed view of the Collier Park Golf</li> <li>Course for a) Landsat data; b) NDVI values; c) Land cover classificationFigure 4. Land</li> <li>cover changes in the Collier Park Golf Course throughout the time</li> <li>cover changes in the Collier Park Golf Course throughout the time</li> <li>formatted: Normal, Left, Space Before: 0 pt, After: 0 pt, Line spacing: single</li> <li>Formatted: Normal, Left, Space Before: 0 pt, After: 0 pt, Line spacing: single</li> <li>Formatted: Normal, Left, Space Before: 0 pt, After: 0 pt, Line spacing: single</li> <li>Formatted: Normal, Left, Space Before: 0 pt, After: 0 pt, Line spacing: single</li> <li>Formatted: Font: (Default) Times, 12 pt</li> <li>Bold</li> <li>Formatted: Normal, Left, Space Before: 0 pt, After: 0 pt, Line spacing: single</li> <li>Formatted: Heading 2, Space Before: 0 pt, After: 0 pt, Line spacing: single</li> <li>Formatted: Font: (Default) Times, 12 pt, Not Bold</li> <li>Formatted: Font: (Default) Times, 12 pt, Not Bold</li> <li>Formatted: Normal, Left, Space Before: 0 pt, After: 0 pt, Line spacing: single</li> <li>Formatted: Normal, Left, Space Before: 0 pt, After: 0 pt, Line spacing: single</li> <li>Formatted: Normal, Left, Space Before: 0 pt, After: 0 pt, Line spacing: single</li> <li>Formatted: Normal, Left, Space Before: 0 pt, After: 0 pt, Line spacing: single</li> <li>Formatted: Normal, Left, Space Before: 0 pt, After: 0 pt, Line spacing: single</li> <li>Formatted: Normal, Left, Space Before: 0 pt, After: 0 pt, Line spacing: single</li> <li>Formatted: Normal, Left, Space Before: 0 pt, After: 0 pt, Line spacing: single</li> <li>Formatted: Normal, Left, Space Before: 0 pt, After: 0 pt, Line spacing: single</li> <li>Formatted: Normal, Left, Space Before: 0 pt, After: 0 pt, Line spacing: single</li> <li>Formatted: Normal, Left, Space Before: 0 pt, After: 0 pt, Line spacing: single</li> <li>Formatted: Normal, Left, Space Before: 0 pt, After: 0 pt, Line spacing: single</li> <li>Formatted</li></ul>	294	unchanged at <u>around 1,019340</u> ha over the last 30 years.		Formatted: English (Australia)
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298       cover changes in the Collier Park Golf Course throughout the time       Bold         299       Bold         300       Formatted: Font: (Default) Times New Roman, 12 pt, Bold         300       Formatted: Normal, Left, Space Before: 0 pt, After: 0 pt, Line spacing: single         301 <u>3.2</u> Spatial patterns of vegetation change,         302       To characterize spatial patterns of vegetation dynamics, we detected the vegetation loss and gain for         303       each of the three decades (FigFigure 54). In the period 1988 to 1998, vegetation clearingdcforestation         304       occurred intensively in the central and north regions. From 1998 to 2008, vegetation loss         305       the north and south of the city. However, in the last decade from 2008 to 2018, vegetation loss         306       accelerated in the distal regions with urbanization. However, there was also some vegetation gain over			$\mathbb{N}$	<b>Formatted:</b> Normal, Left, Space Before: 0 pt, After: 0 pt, Line spacing: single
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<ul> <li>301 3.2 Spatial patterns of vegetation change</li> <li>302 To characterize spatial patterns of vegetation dynamics, we detected the vegetation loss and gain for</li> <li>303 each of the three decades (FigFigure 54). In the period 1988 to 1998, vegetation clearingdeforestation</li> <li>304 occurred intensively in the central and north regions. From 1998 to 2008, vegetation loss expanded to</li> <li>305 the north and south of the city. However, in the last decade from 2008 to 2018, vegetation loss</li> <li>306 accelerated in the distal regions with urbanization. However, there was also some vegetation gain over</li> </ul>				
To characterize spatial patterns of vegetation dynamics, we detected the vegetation loss and gain for each of the three decades (FigFigure 54). In the period 1988 to 1998, vegetation clearingdeforestation occurred intensively in the central and north regions. From 1998 to 2008, vegetation loss expanded to the north and south of the city. However, in the last decade from 2008 to 2018, vegetation loss accelerated in the distal regions with urbanization. However, there was also some vegetation gain over	300			<b>Formatted:</b> Normal, Left, Space Before: 0 pt, After: 0 pt, Line spacing: single
302       To characterize spatial patterns of vegetation dynamics, we detected the vegetation loss and gain for         303       each of the three decades (FigFigure 54). In the period 1988 to 1998, vegetation clearingdeforestation         304       occurred intensively in the central and north regions. From 1998 to 2008, vegetation loss expanded to         305       the north and south of the city. However, in the last decade from 2008 to 2018, vegetation loss         306       accelerated in the distal regions with urbanization. However, there was also some vegetation gain over	301	<u>3.2</u> Spatial patterns of vegetation change		Formatted: Font: (Default) Times, 12 pt
<ul> <li>accelerated in the distal regions with urbanization. However, there was also some vegetation gain over</li> <li>Formatted: English (Australia)</li> </ul>	302	To characterize spatial patterns of vegetation dynamics, we detected the vegetation loss and gain for		<b>Formatted:</b> Heading 2, Space Before: 0 pt, After: 0 pt, Line spacing: single
<ul> <li>occurred intensively in the central and north regions. From 1998 to 2008, vegetation loss expanded to</li> <li>the north and south of the city. However, in the last decade from 2008 to 2018, vegetation loss</li> <li>accelerated in the distal regions with urbanization. However, there was also some vegetation gain over</li> </ul> Formatted: Normal, Left, Space Before: 0 pt, After: 0 pt, Line spacing: single Formatted: English (Australia) Formatted: English (Australia)	303	each of the three decades (FigFigure 54). In the period 1988 to 1998, vegetation clearingdeforestation	$\mathcal{N}$	Formatted: Font: (Default) Times, 12 pt, Not Bold
<ul> <li>the north and south of the city. However, in the last decade from 2008 to 2018, vegetation loss</li> <li>accelerated in the distal regions with urbanization. However, there was also some vegetation gain over</li> <li><b>Formatted:</b> Normal, Lett, Space Before: 0 pt, After: 0 pt, Line spacing: single</li> <li><b>Formatted:</b> English (Australia)</li> <li><b>Formatted:</b> English (Australia)</li> </ul>	204		$\langle \rangle$	Formatted: English (Australia)
306       accelerated in the distal regions with urbanization. However, there was also some vegetation gain over       Formatted: English (Australia)         Formatted: English (Australia)				<b>Formatted:</b> Normal, Left, Space Before: 0 pt, After: 0 pt, Line spacing: single
	505	the norm and south of the city. However, in the last decade from 2008 to 2018, vegetation loss		Formatted: English (Australia)
307 the three decades (FigFigure 54, Table 344) predominantly in the northern part of the city.	306	accelerated in the distal regions with urbanization. However, there was also some vegetation gain over		Formatted: English (Australia)
	307	the three decades (FigFigure 54, Table 344) predominantly in the northern part of the city.		



			Period		•
Period		1988-1998	1998-2008	2008-2018	
Whole Area	Vegetation loss	22,231	19,250	20,178	
	Vegetation gain	15,538	15,838	12,591	•
	Net loss	6,692	3,412	7,587	•
Golf courses	Vegetation loss	68	27	40	•
	Vegetation gain	219	92	43	•
	Net gain	152	64	4	•

Calculation of changes within the golf courses and in the whole area (Table <u>344</u>) showed that the

major urban area of Perth experienced a net loss in vegetation cover. Though vegetation compensation

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occurred together with <u>vegetation clearingdeforestation</u> over 30 years of urbanization, the vegetation
 loss was always much larger than vegetation gain with the largest net vegetation loss occurring in the
 last decade. However, the golf courses showed a different trend where the net gain of vegetation cover

happened over three decades and the largest gain was between 1988 and 1998.

335 <u>3.3</u> Analysis of connectivity components of green space networks

336 Results of the MSPA analysis indicate that the reduction in vegetation cover over the last thirty years 337 has led to a decline in connectivity (Table 55). Among the two types of landscapeMSPA classes that 338 are important for connectivity (core and bridge), the total area of core class decreased by about 10% 339 over three decades while the bridge class was maintained at around 37,000 ha, but the proportion of 340 this class per total vegetation cover area (VCA) increased due to the reduction of vegetation cover 341 over time (Table 455). This analysis also shows the fluctuation in the areas of the rest of the MSPA 342 classes including islets, loops, edges, perforations, and branches which do not contribute to 343 connectivity in the landscape. The proportion of these classes increased through time from 24% in 344 1988 to 30% in 2008 and 2018.

Figure 65 shows that the core area was distributed mostly in the northern part of the city and their areas decreased significantly in later years. In 1988, the bridge class covered a large area of the city's central region but this decreased over time. In recent years, most of the vegetation cover in the central region of the city belongs to the islet, loop, edge, perforation and branch classes, illustrating that isolation became more serious in the central region of the city over the three decades.

Figure 65. Results of the Morphological Spatial Pattern Analysis (MSPA), for the Perth
 regionMSPA-from 1988 to 2018analysis,

The vegetation cover within golf courses also contributes to connectivity. The proportion of core area within golf courses fluctuated between 12% and 27%. Moreover, the largest proportion of vegetation in golf courses was classified as bridge but it experienced a downward trend from 52% to 41% in three decades. Of the remaining classes which do not contribute to connectivity, the edge and loop classes accounted for a higher proportion with each of them contributing 7% to 16% of total vegetation cover. Formatted: Font: (Default) Times, 12 pt

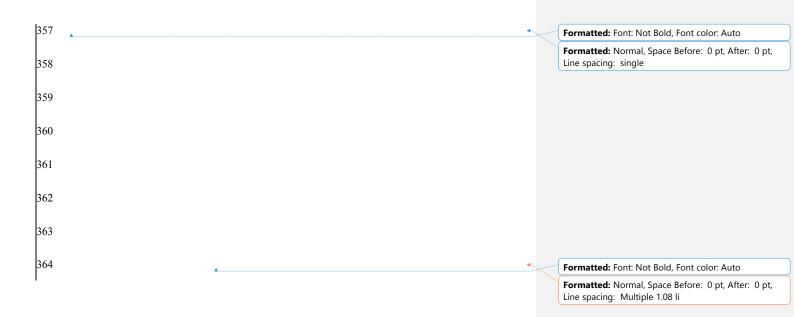
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# 375Table 554. Results of Morphological Spatial Pattern Analysis (MSPA)376connectivity of Perth's vegetation from 1988 to 2018.

Landscape type	Year			Within go	lf courses	
		Area	Proportion of total	Area	Proportion of	
		(ha)	VCA (%)	(ha)	total VCA (%)	
Core	1988	32,012	32.6	325	23.2	
	1998	20,607	22.5	171	12.7	
	2008	22,251	25.3	230	16.7	
	2018	18,101	22.5	383	27.3	
Bridge	1988	37,127	37.9	738	52.6	
	1998	39,412	43.0	814	60.2	
	2008	37,902	43.1	732	53.1	
	2018	37,503	46.7	588	42.0	
Islet	1988	10,396	10.6	31	2.2	
	1998	16,436	17.9	78	5.8	
	2008	12,922	14.7	15	1.1	
	2018	12,349	15.4	37	2.7	
Perforation	1988	1,099	1.1	3	0.2	

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Landscape type	Year	Perth Metr	opolitan Region	Within go	olf courses	•
		Area (ha)	Proportion of total VCA (%)	Area (ha)	Proportion of total VCA (%)	
	.1998	486	0.5	(na) -	_	_
	2008	834	1.0	-	_	•
	2018	406	0.5	6	0.4	4
Edge	1988	7,430	7.6	162	11.5	
	1998	4,814	5.3	95	7.0	
	2008	4,986	5.7	147	10.7	-
	2018	5,218	6.5	230	16.4	•
Loop	1988	5,670	5.8	112	8.0	-
	1998	6,295	6.9	146	10.8	•
	2008	5,607	6.4	209	15.2	•
	2018	3,669	4.6	129	9.2	•
Branch	1988	4,361	4.5	32	2.3	•
	1998	3,619	4.0	47	3.5	-
	2008	3,491	4.0	43	3.2	•
	2018	3,117	3.9	29	2.1	

### 378 379

#### 380 4 Discussion

381 We used Landsat imagery to characterize the patterns of vegetation change, habitat connectivity and 382 the role of golf courses in maintaining green spaces and connectivity in an urban landscape. We found 383 that vegetation elearingdeforestation led to a reduction in habitat connectivity in the Perth Metropolitan Region. However, golf courses can play an important role in maintaining vegetation and 384 385 supporting biodiversity connectivity in urban landscapes. Prior workPriviousPrevious study ies has 386 have documented the increase in the urban footprint of Perth using multi-temporal urban expansion 387 statistics derived from Satellite imagery [58]; -However, this studytheir work did not address the 388 issues of vegetation dynamics, nor the biodiversity and structure of the vegetation and habitat

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389	connectivity in the Perth Metropolitan Region. Therefore, our study have worked to filladdresses this	
390	gap	Formatted: Font: Not Italic
391	4.1 <u>Vegetation clearingDeforestation</u> and urbanization	Formatted: Font: (Default) Times, 12 pt
392	The vegetation dynamics in the major urban areas of Perth reflect the pattern of urbanization over	Formatted: Font: (Default) Times, 12 pt, Not Bold
393	time. The reduction in green space found in this study can be explained as a close relation to the	
394	process of development in this city. Over the last three decades, urban development in Perth has taken	
395	place at an unsustainable rate [42]. In the early 1990s to 2006, Perth's population grew by around	
396	1.8%, but the figure has nearly doubled since then [59]. Also, this study indicated that, from 1988 to	
397	2018, Perth's urban footprint increased from $74_{,376}$ - <u>thousand</u> to $92$ - <u>thousand</u> , 243 ha (Table 223) and	
398	is consistent with previous research in urban growth in this region [58]. In addition to expansion, the	
399	city has become denser due to the construction of new residential dwellings in urbanised areas. In the	
400	last 20 years, on average, 740 ha/yr of urban and urban deferred zoned land was consumed by	
401	subdivision, and 830 ha/yr was consumed by construction in the Perth metropolitan area and nearby	
402	Peel region [60]. In addition to this expansion, the city has become denser with the construction of	
403	new residential dwellings in urbanised areas. Though vegetation gain occurred in some places as a	
404	result of natural increase in canopy cover as urban vegetation grows through the conservation efforts,	
405	vegetation offset from development projects (e.g. mining), the plantation programs of the government	
406	taking place in bare soils in some suburbs, and efforts to increase green spaces from private land	
407	owners, the vegetation loss associated with urbanization has been more significant.	
408	The difference in spatial patterns of vegetation loss are also related to the urban plans of this city. Our	
409	results show that between 1988 and 1998, there was significant vegetation loss in the central region of	
410	the city which can be linked to The Corridor Plan [61]. Historically, Perth's development pattern from	Formatted: Font: Not Italic
411	1970s to 1990s was based on linear corridors stretching out from the city's core, with large non-urban	
412	wedges between each of these corridors [61]. However, from 1998 to 2008 and from 2008 to 2018,	
413	vegetation clearingdeforestation was more significant in the outer subregions of the north-west and	
414	south-west of the city due to the adoption of METROPLAN-Metroplan [62], Perth recently has been	Formatted: Font: Not Italic
415	divided into subregional areas, rather than corridors for planning purposes. The two coastal subregions	

418	Originally the region was covered by woodlands dominated by eucalypts and banksias and coastal	
419	heath interspersed with chains of wetlands. Perth is home to a rich biodiversity, with more than 1,700	
420	species of flowering plants and iconic species of threatened fauna in the region [64]. Therefore, such	
421	vegetation elearingdeforestation for urbanization has resulted in the devastating loss of significant	
422	natural habitats in this biodiversity hotspot city, leading to the designation of as an endangered	
423	ecological community by the Australian Government [41].	
424	<u>4.2</u> Connectivity of green space networks in urban landscapes	Foi
425	The MSPA analysis indicates that the loss of area of vegetation as a consequence of urban expansion	Foi
426	has led to a marked reduction in connectivity of green space networks in the Perth urban landscape. In	
427	the MSPA analysis, As only cores (the stepping stones between forest habitat patches) and bridges (the	
428	structural corridors to link core areas) can contribute to the connectivity between the habitat areas in	
429	the landscape_[65],-tThe reduction of these areas areas in Perth our studassociated with urbanization	
430	throughout the time y indicates the high impact of urbanization urban development on habitat	
431	connectivity <sub>z</sub> through the loss of core areas, which act as stepping stones between forest habitat	
432	patches, and the loss of bridges that act as structural corridors to link two or more core areas-[65]. This	
433	analysis also shows the increase in proportion of islets, which are totally isolated patches, and other	
434	classes (perforations, loops, branches, edges) that cannot reach a new core habitat area for originating	
435	the potential movement [65]. Clearly, expansion of Perth city has fragmented the remaining blocks of	For
436	natural habitat and increased isolation of natural habitats. This may reduce population and gene flow	
437	among patches and may disrupt the connection between subpopulations and a large regional	
438	population [66] and thus threaten the long-term viability of relict populations	For
439	The fFragmentation process was obvious in the central region of the city and in recent decades it has	Foi Coi
440	become more serious in the outer parts of the city. This is critical as Perth is within a globally	
441	recognised biodiversity hotspot, which is home to rich biodiversity found nowhere else in the world.	
1.10		

(the North-West and South-West) included in our study have consistently achieved higher rates of

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population growth under Metroplan [63].

442 The connectivity in the major urban area of Perth is not only critical for the linkage of habitats within

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443 the Swan Coastal Plain but also for the connection of these coastal habitats to a large regional 444 biosphere in south-western Australia. 445 The results also illustrated that a 'Core' area and a network of 'Bridge' types exist in the central and outer subregions of Perth. This is the consequence of early conservation efforts of the government 446 447 which created protected areas such as Kings Park, Bold Park and other significant areas. Very few 448 cities in the world have such large areas of natural bushland in the centre of a big city [67]. However, 449 future urban growth will continue to put pressure on the biodiversity. If current policies (Perth and 450 Peel@3.5million) are fully implemented, existing stocks of urban and urban deferred land would be 451 consumed by about 2075 [68]. The challenge for urban planning to preserve urban forests and 452 biodiversity is thus increasing, and it is clear that planning for future expansion should also include 453 large protected areas. -454 Our MSPA output with spatial distribution of seven classes provides fundamental information for 455 future urban planning. There is a need to maintain important green spaces which are classified as cores 456 and bridges in the city, especially in the central region where most of the natural vegetation exists as 457 islands. Also, the MSPA branch classes can be used to identify candidate ecological restoration areas. 458 The branch class can be thought of [69] as a foundation of a potential corridor that could, if 459 revegetated, connect two spatially disjunct core areas to improve connectivity in the larger region. 460 Although other analyses, such as functional connectivity, should be taken into account in landscape Formatted: Left, Space Before: 0 pt, After: 0 pt, Line spacing: single 461 connectivity assessment [32], the structural connectivity analysis in this study will be useful for 462 determining the priority protection level and critical areas of the connecting corridor, informing 463 conservation strategies at a variety of scales, especially when the biodiversity values of this region are 464 suffering from various threats including land clearingdeforestation, feral animals, weed incursions, 465 more frequent fires through arson and tree disease [64]. 466 <u>4.3</u> The role of golf courses in maintaining urban forest Formatted: Font: (Default) Times, 12 pt Formatted: Font: (Default) Times, 12 pt, Not Bold 467 Our study indicates that golf courses account for a significant proportion of the urban area of Perth.

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This category of land use has been vital in maintaining green space in urban areas over the past thirty

468

years. In contrast to the overall decline in urban green space, golf courses have preserved green spaces
within urban settings and even created a net gain of vegetation cover over time. The highest net gain
was seen in the period between 1988 to 1998 when some golf courses were established resulting in the
planting of trees.

473 In the green 'matrix' of Perth, golf courses with their significant area of vegetation cover have

474 contributed considerably to the connectivity in the urban landscape. A significant proportion of their

475 green space was classified as core or bridge categories. The proportion of vegetation within golf

476 courses classified as bridges was higher than in the whole study area. Golf courses with large areas of

477 native vegetation provide "links" to other large natural patches of urban vegetation.

478 Although there are concerns with the environmentally negative impacts of golf courses as a source of

pollution through pesticide and fertiliser usage [22], habitat modification [25] and high water usage

480 [70], previous studies provide evidence about the biological values of golf courses, such as providing

481 refugial habitat for urban-avoiding wildlife [24, 71-79]. Our study indicates that golf courses in urban

482 settings have been maintaining large green-area habitats and played an important role in biodiversity

483 connectivity in the city.

#### 484 <u>4.4</u> Monitoring urban forest dynamics

In this study, we utilized medium-resolution satellite remote sensing data to identify land use classes, characterise vegetation dynamics and connectivity. The data maps the spatial and temporal patterns of land use types characterizing a consistent, detailed vegetation dynamic of the city [58, 80]. Clearly, the biophysical elements of urban landscapes are well-reflected through physical features (NDVI) derived from remote sensing data with an accuracy of up to 89%.

490 Despite these kinds of data, it is hard to describe the detailed information of ecosystem such as species

491 composition and forest structure. However, they show their advantage in mapping land cover

492 dynamics across large areas of big cities over time when high resolution imagery is not available. For

493 monitoring urban forests in big cities, the large scale and long temporal datasets are more

494 advantageous compared with datasets that focus only on discerning a specific land use type in a

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Formatted: Font: (Default) Times, 12 pt Formatted: Font: (Default) Times, 12 pt, Not Bold relatively small area [27, 81, 82]. This is because it allows spatially detailed identification of changes associated with development over time. Therefore, this-the approach described in this paper method provides baseline information for sustainable urban planning and development. In addition, the MSPA analysis can further evaluate the dynamic of vegetation cover by the describing the spatial configuration of ecosystems at the pixel level, detecting changes of habitat connectivity over time [32].

501 5 Conclusions

502 With rapid urban expansion, the most meaningful question to address is how to balance urban 503 development and urban forest preservation. Urbanization requiring vegetation elearingdeforestation is 504 inevitable in many cities worldwide. Our study found a significant loss of vegetation cover in a 505 biodiversity hotspot over three decades of urbanization, which led to a reduction in habitat 506 connectivity in the urban landscape. A lesson learned from the experience of urbanization in Perth is 507 that any future urban growth following the patterns observed over the past three decades will continue 508 to put pressure on maintaining urban forest ecosystems and biodiversity conservation. As cities 509 continue to grow in response to socio-economic development, considering all opportunities for urban 510 biodiversity conservation is important. Urban conservation strategies must therefore consider not only 511 the protected areas, but also the off-reserve sites. 512 Our study indicates that golf courses in urban settings have been maintaining green-area habitats and 513 have played an important role in biodiversity connectivity in the city. Potentially, urban golf courses 514 could become more purposefully managed for biodiversity conservation and the improvement of 515 critical ecosystem services in urban areas. In the rapidly urbanizing biodiversity hotspots like Perth, 516 where fragmentation is one the biggest threats to biodiversity, the way that golf courses contribute to 517 increase the connectivity in the intervening urban matrix should not be underestimated. Therefore, it is 518 important for government authorities and golf courses owners to pay more attention in maintaining 519 ecosystem health in urban golf courses.

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Comment	Response
Page 1, row 26 (abstract): consider being	Agreed and edited:
specific (last three decades, 1988-2018)	"last three decades, 1988-2018"
Page 1, row 29 and 30 (abstract): I	We have clarified this in the text. In Australia and other
wonder if due to their specific land use	parts of the world, many golf courses include significant
golf course are somewhat non conductive	non-play areas, which comprise plantations or natural
to habitat suitability?	vegetation. Those are shown to be suitable for habitat of
	wildlife and biodiversity in previous studies and
	government policies:
	- Hodgkison, S. C., Hero, J. M., & Warnken, J.
	(2007). The conservation value of suburban golf
	courses in a rapidly urbanising region of
	Australia. Landscape and Urban Planning,
	79(3), 323-337.
	doi:https://doi.org/10.1016/j.landurbplan.2006.03
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### 2. Reviewer #1

	<ul> <li>Hudson, MA. R., &amp; Bird, D. M. (2009). Recommendations for design and management of golf courses and green spaces based on surveys of breeding bird communities in Montreal. <i>Landscape and Urban Planning</i>, 92(3), 335-346.</li> <li>Tanner, R. A., &amp; Gange, A. C. (2005). Effects of golf courses on local biodiversity. <i>Landscape and Urban Planning</i>, 71(2), 137-146. doi:<u>https://doi.org/10.1016/j.landurbplan.2004.02</u>. .004</li> </ul>
I am not too sure about your last statement in the Abstract that suggest "we need to consider before clearing for urban development". An already developed area becomes a fair game in my opinion and you may need to qualify that statement. Will check how you substantiated this?	We have edited this section of the Abstract to: "Our findings suggest that for future urban expansion, urban planning needs to more carefully consider factors that affect connectivity in the landscape such as preserving functional forest remnants and encouraging reforestation."
Page 2, row 44 (Introduction): suggesting	This takes into account the circumstances where urban areas expand into forested areas, or where reforestation occurs on previously deforested land. Our paper clearly shows that remnant forests dispersed across urban areas are essential for biodiversity conservation. Agreed and edited
of replace "delivered" by "derived: Page 2, row 47 (Introduction): While there are few publications about these topics, most of them tend to be rather tenuous at best. The general idea of large urban environments being non conductive to healthy lifestyle is well founded but maybe beyond the amount of green?	This is now deleted
Page 2, row 49 (Introduction): "natural disasters" Floods for example?	Have modified: "some kinds of natural disaster for example food"
But they me be conductive to other risks and hazards too? Page 2, row 55 (Introduction): "Fragmentation": This is almost always inevitable	Have edited: Therefore, urban development that requires clearing of vegetation, due to reduction in vegetation cover, habitat loss and fragmentation is a threat to biodiversity

Page 3, row 84: REF 29 is not correct? Look for Tucker, Huete, Myneni, Prince, for an NDVI reference	The Reference: 29 is deleted and the reference Tucker 1979 and Myneni et al 1996 are now added for NDVI analysis.
Page 3, row 88: "Then"	Deleted
Page 3, row 88: "Then" Page 4, row 104 "Study area": You need to expand this section a bit more to create a anchor for the motivations and objectives? Not sure what else to say, but things like what is so special besides the nmbr of golf courses? how it is biodiverse? what do you hope to achieve? are there any plans to change things? etc.	<ul> <li>In the Introduction, the background of the study area has been involved the information about why we choose this study area. Because it lies within a rapidly urbanizing biodiversity hotspot in Australia and has important role in regional biodiversity connectivity, which is linked to the aims, motivation, objectives of this study.</li> <li>Additional text added to the study area section:</li> <li>"The study area belongs to the Perth Metropolitan region covering four sub-regions (North West, Middle Central, Inner Central and South West). Perth has a Mediterranean-type temperate climate with a hot and dry summer, and a cold and rainy season occurring between May and October [32]. Under future climate-change scenarios, this area is projected to experience a lower annual rainfall [33].</li> <li>Perth belongs to the Australia's southwest corner, which is recognized as a global biodiversity "hotspot" with outstanding natural environments. Our study area occurs on the Swan Coastal Plain which is part of the southwest of Australia which in turn has the highest concentration of rare and endangered species). More than 6,000 species of native plants and 100 native mammals, birds, frogs and reptiles occur in this region, making it a biodiversity "hotspot" [31, 34].</li> <li>Perth has retained a significant area of natural vegetation which has conservation significance thanks to the introduction of legislation and policies aimed primarily at protecting biophysical environmental values. This includes the Western Australian Environmental Protection Act 1986 [35]; the Federal Government's Environment Protection and Biodiversity Conservation Act 1999 [36]; and more recently, Bush Forever [37, 38], a policy which took a whole-of-government approach to identify and protect biologically significant bushland and wetlands within the Perth metropolitan area. However, Perth has experienced extensive urban development since the 1980s [39]. The expansive growth of the Perth metropolitan footprint has contributed to the loss of b</li></ul>

Page 4, row 108: what does unsustainable	" unsustainable rate" is now deleted and the sentence has
mean here?	been edited.
Page 4, row 123: Please correct, it is the Earth Resources Observation and Science Center (EROS).	It is now corrected
Page 4 and 5: Landsat data and pre- processing There are issues with the classification based on images from the month of December only (Summer). There was little in the way of what exact dates, what data, how did you remove clouds, etc This is critical since it will impact the change detection which is based on NDVI, which is very sensitive to noise in the data and the time the data came from? You will need to elaborate on your exact methods and data analysis here.	More details of the input data sets for the classification and analysis are added to the text . We chose all the free cloud images or at least cloud-free at the study area, so there is no requirement for removing cloud.
Page 5, rows 127-133: USGS now distributes fully research ready data (fully atm. corrected using standard and sophisticated methods that surpasses DOS) There was hardly any useful information on how the Atm. Correction was carried. You need to clarify this further so readers can replicate and or understand better.	<ul> <li>The best atmospheric correction varies on each object (Yusuf et al. 2018). We used dark object subtraction (DOS) to correct atmospheric scattering as this method is still approved appropriate and reliable one, which is consistent with previous studies:</li> <li>Mohajane, M., Essahlaoui, A., Oudija, F., Hafyani, M. E., Hmaidi, A. E., Ouali, A. E., Teodoro, A. C. (2018). Land Use/Land Cover (LULC) Using Landsat Data Series (MSS, TM, ETM+ and OLI) in Azrou Forest, in the Central Middle Atlas of Morocco. <i>Environments</i>, 5(12), 131.</li> </ul>
	<ul> <li>Dewi, E., &amp; Trisakti, B. (2017). COMPARING ATMOSPHERIC CORRECTION METHODS FOR LANDSAT OLI DATA. International Journal of Remote Sensing and Earth Sciences (IJReSES), 13, 105. doi:10.30536/j.ijreses.2016.v13.a2472</li> <li>Cui, L., Li, G., Ren, H., He, L., Liao, H., Ouyang, N., &amp; Zhang, Y. (2014). Assessment of atmospheric correction methods for historical Landsat TM images in the coastal zone: A case study in Jiangsu, China. European Journal of Remote Sensing, 47(1), 701-716. doi:10.5721/EuJRS20144740</li> </ul>
	Gilmore, S., Saleem, A., & Dewan, A. (2015). Effectiveness of DOS (Dark-Object Subtraction) method and water index techniques to map

	<ul> <li>wetlands in a rapidly urbanising megacity with Landsat 8 data. <i>CEUR Workshop Proceedings</i>, <i>1323</i>, 100-108.</li> <li>Nazeer, M., &amp; Nichol, J. (2014). Selection of atmospheric correction method and estimation of Chlorophyll- A (Chl-a) in coastal waters of Hong Kong. <i>3rd</i> <i>International Workshop on Earth Observation</i> <i>and Remote Sensing Applications, EORSA 2014 -</i> <i>Proceedings</i>, 374-378. doi:10.1109/EORSA.2014.6927916</li> </ul>
	Yusuf, F. R., Santoso, K. B., Ningam, M. U. L., Kamal, M., & Wicaksono, P. (2018). Evaluation of atmospheric correction models and Landsat surface reflectance product in Daerah Istimewa Yogyakarta, Indonesia. <i>IOP Conference Series:</i> <i>Earth and Environmental Science</i> , 169, 012004. doi:10.1088/1755-1315/169/1/012004
Page 5, row 138: Reword the caption. This is a processing pipelines or flowchart.	We use the term flowchart as we suggest it is more appropriate
Page 5, row 140: Why here?	It is now deleted
Page 5, row 149: For Landsat we usually list the actual band numbers to avoid any confusion?	The equation is edited
Page 6, row 153: The first reason for high NDVI is that RED is consumed by chlorophyll to drive photosynthesis.	This is now edited
Page 6, row 156: "three classes", that are?	Three classes are added
Page 8, row 212: Grammar error	It is now corrected
Page 8, row 230: where did this nmbr come from?	The number is now corrected
I suggest you improve the captions of all figures - Elaborate on caption and make them read better?	We have edited the captions
Page 10, row 243, suggestion f or the title of table 3.	It is now edited
The concept of vegetation cover gain in urbanized areas is a bit of a misnomer, as how would that happen? is it urban abandonment? or other mechanism? Please clarify.	We have added text to describe this in the first paragraph of Sect 4.1.
For the sake of clarity and completeness I highly suggest you define these terms (Core, Bridge, etc.) and what they capture	Agreed and all of those terms are redefined in Table 1 in the Methods section.

and mean?	
The reference is great but forces the reader to read another paper, where a simple short definition may suffice. I also find the reference to " Golf courses" as a fully functional and reliable habitats a bit confusing considering their high traffic and human impacts? Please clarify.	We have added to the Introduction: Golf courses are established for recreational purposes. The whole area of golf courses are a mix of bushland, fairways and infrastructure. Though they are not fully ecologically functional as with a natural parks. Several studies investigated the condition of vegetation inside the golf courses and indicated that those natural areas are significantly important to biodiversity conservation. Therefore, together with the natural reserves, golf courses can play some roles as off-reserve
Page 10, 256: Is it necessary to abbreviate	sites for biodiversity conservation in urban landscapes. Yes it is, we did abbreviate "Vegetation cover area
here?	(VCA)" for short title of Table 5.
Page 12, row 293: These terms must be	I have added the definition of those terms in the new
defined for clarity.	Table 1
Page 13, row 315: "74 to 92 ha": Thousand?	Agreed and corrected
Page 14, row 342: "Cores and bridges" this needs to be defined for the sake of a general audience.	Agreed and all of those terms are redefined in the table in the Method section.
Page 15, row 368: "2075": That is assuming an ever increasing numbers?	Agreed.
Page 16, Row 392-397: I wonder due to their specific and heavy use could golf course really be paralleled to natural veg. cover?	As mentioned above, previous studies about the golf courses in Australia and other counties have shown that the non-playing areas in many golf courses are the planted vegetation or natural bushes, which are suitable as habitats in urban landscapes.
Generally the manuscript is well written and easy to read and understand, but it lacked critical technical information and clarift in some key areas (Data analysis, Habitat analysis). I suggest you address these shortcoming.	Agreed, We have edited and bolstered the data analysis and habitat analysis components.

## 3. Reviewer #2

Comment	Response
This study do not intend to explain the	Agreed.
'dynamic'- nets effect of many factors	

such as climate, abiotic environment,	The title is edited: "Vegetation trends associated with
biotic interaction, disturbance history etc.	urban development: The role of golf courses."
In vegetation cover over Perth	
metropolitan, but seek to describe 'only'	
the spatio-temporal land use change	
pattern associated with urbanization in	
the area. Hence, the title should be	
reframe to capture only this aspect.	

## 4. Reviewer #3

Comment	Response
Kindly improve the map resolution of all figures	It is improved
The accuracy assessment of the classification is not exit the manuscript, it is needed to be added.	It is added in the table 3
Kindly add the lat/long, scale, and north arrow on the border of layout.	It is added

## 5. Reviewer #4

Comment	Response
Golf courses have potential in habitat but	Agreed. See response to Reviewer 1, above.
to think they are superior in habitat	
protection than natural areas is the	
problem I have.	
I also think you kept moving forward and	
back on the focus of the study. Please	
refer to my comments attached.	
Page 1, line 58: "urban matrix": I guess	Agreed and edited
you mean urban vegetation matrix	
Line 206 "in their surrounding regions.":	Changed from "surrounding regions" to "surrounding
Have to be clear on the specific	green spaces"
surrounding regions. Natural or builtup	
Line 210, 212-213, "Land use": There is	Agreed and edited
differences between land use and land	
cover. What you have is cover rather than	
use	
Line 214-215, "However, the urban	Agreed and edited: increased 10% from 1988 to 2018

	Г
footprint of built up and bare land area	
had increased 10% by 2018.	
215": Increased from 1988 or 1998	
Line 218-219, "Accuracy assessment": It	Agreed and edited
should come first before the results so we	
know the results we are dealing with	
Line 226, Figure 3: After seeing Figure 3.	We have added a new figure 4, which shows the details
Am a bit sceptic about the results for the	of underlying Landsat data and classification at the fine
Golf Course? Reflecting back on the	scale for one of the golf courses.
methodology used to derive Golf Course	Ũ
in line 180-183. Do you think Landsat	
image of 30*30m or 15*15 for Landsat 8	
did a good job of classifying a small	
zones like the park. There is	
generalisation when the study area is big	
which is acceptable but when zoomed in	
to a local scale the generalisation will be	
too high. You can try mapping it with the	
google earth but the problem is the golf	
courses are too many. So try mapping a	
few to make your point	
Line 253 "Two types of landscape that	Agreed and edited to "two MSPA classes"
": types of landscape matrix or	Agreed and edited to two WSFA classes
index?	
Line $306 - 307$ "not address the issues of	
	Agreed and edited: the writing was not clear here and
vegetation dynamics, nor the biodiversity	may have caused the confusion:
and structure of the vegetation and habitat	A previous study has documented the increase in the urban
connectivity": If the work did not then	footprint of Perth using multi-temporal urban expansion
what is the golf course play a part in	statistics derived from satellite imagery (MacLachlan,
biodiversity connectivity meant for.	Biggs, Roberts, & Boruff, 2017); However, their work did
Is biodiversity connectivity and habitat	not address the issues of vegetation dynamics, nor the
connectivity highly mutually exclusive?	biodiversity and structure of the vegetation and habitat
	connectivity in the Perth Metropolitan Region. Therefore,
	our study has worked to fill this gap. We have now pointed
	this out in the first paragraph of the Discussion.
	ans out in the first paragraph of the Discussion.
Line 343-345, "The reduction	Agreed and edited to remove this issue:
of these areas in our study indicates the	-
2	"As only cores (the stepping stones between forest
high impact of urbanization on habitat	habitat patches) and bridges (the structural corridors to
344	link core areas) can contribute to the connectivity
connectivity	between the habitat areas in the landscape [63], the
345":	reduction of these areas in Perth associated with
How do you reconcile line 344 to 345 and	urbanization throughout the time indicates the high
306-307?	impact of urban development on habitat connectivity