

**EXTENT, RATE OF INVASION AND CONDITIONS FAVOURING  
OCCUPANCY AND DOMINANCE OF *TYPHA LATIFOLIA* IN  
SELECTED WETLANDS OF HARARE, ZIMBABWE**

**By**

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## ABSTRACT

*Typha latifolia* is a global aggressive invader of wetlands. It is now one of the major threats to wetland ecosystems in Harare. Factors that promote its establishment and dominance are still poorly understood. The present study aimed at determining conditions that favour *T. latifolia* establishment and dominance in selected wetland sites of Harare. It also sought to establish the species present distribution and predict its future areal extent in the city's wetland sites. Google Earth satellite imagery was used to map Harare wetland sites. Rate of areal expansion of *T. latifolia* occupied sites was determined from aerial images acquired from Google Earth dating back some 10 years (2008-2018). MaxEnt software (version 3.3.3k) was used to predict future distribution of *T. latifolia* in Harare. A comparison of historical and current images showed that there has been significant change in *T. latifolia* patch sizes within the largest three wetland sites, namely Prospect (176.3 ha), Monavale (159.1 ha) and Tynwald (655.5 ha). Results indicated a marked increase in the spread of *T. latifolia* within Monavale wetland from 2008 to 2018. The area covered by *T. latifolia* increased from 0.12 ha to 1.83 ha during this period, indicating a 93% increase. Area occupied by the species in Prospect wetland expanded from 1.53 ha in 2011 to 5.40 ha in 2018, indicating a 72% increase in areal distribution. That of Tynwald wetland increased from 0.59 ha in 2008 to 4.49 ha in 2018, indicating an 87% increase. The MaxEnt species distribution model predicted a future spatial distribution of *T. latifolia* in areas with suitability greater than 0.38 in proximity to water course. Soils from the twelve wetlands differed with respect to pH, but had similar moisture content, phosphorus, nitrogen and carbon. To establish the relationship between plant morphological and edaphic characteristics, a multi-linear regression analysis was carried out. The results showed significant relationships between nitrogen and shoot height. Significant differences in mean nitrogen concentration within vegetative parts of *T. latifolia* collected from the twelve sites during the study period were observed. No significant differences in vegetative parts of *T. latifolia* in terms of phosphorus and carbon contents were observed from the twelve wetland sites. The study identified soil carbon and nitrogen to be significant environmental variables that explained nutrient concentrations in vegetative parts. It is concluded that *T. latifolia* is indeed invading most of the wetlands of Harare, and major contributing variables to *T. latifolia* invasion were found to be pH, soil moisture content, and soil nitrogen and carbon. Water availability is critical in facilitating *T. latifolia* encroachment. This implies that other than high nutrient levels, the expansion of *Typha* stands in Harare wetland areas will largely be governed by moisture availability. It can be concluded that the primary drivers of invasion are high soil nutrient status and moisture. Hence, management of this noxious species must focus on controlling nutrient loading and managing the hydrologic dynamics of the wetlands.



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# CHAPTER ONE

## 1 INTRODUCTION

### 1.1 General introduction

Wetlands are lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water (Guo *et al.*, 2017; He *et al.*, 2011). They act as sponges, absorbing water during periods of high runoff, and gradually releasing it during dry periods. Wetlands also recharge ground water resources, and this benefits the surfacebiotic community by providing a stable flow of water to the surface. Wetland systems are an integral part of the socio-economy of communities as they support fisheries, pasture and agriculture (Zedler& Kercher 2004). They also provide water for irrigation, power generation and transportation. Much of the southern African region depends on wetlands for dry season farming. Frost (1996) noted that wetlands covered 4.6% of Zimbabwe's land surface, with vleis covering some 3.6% of the land area (Zanamwe 1997).

Wetland plant invasive species are occurring much more frequently and occupying greater areal extent than ever before (Simba *et al.*, 2013). They exert extreme pressure on wetland ecosystems, resulting in degradation. One common wetland invasive species is *Typha latifolia*. Genus *Typha* includes rhizomatous, perennial macrophytes that occur in seepage areas and swamps over a wide latitudinal range (Simba *et al.*, 2013). A preliminary assessment showed that most of Harare's wetlands have been invaded by *T. latifolia*. The species is encroaching at a very fast rate, thereby threatening all open water spaces. *T. latifolia* is commonly associated with habitat disturbances that result in altered hydrology (Tuchman*et al.*, 2009) and/or elevated phosphorus and nitrogen nutrient levels (Shih& Finkelstein 2008; Tuchman *et al.*, 2009). The species is commonly considered as a weed in Zimbabwe which needs careful management as it seriously impacts on biodiversity

(Tuchman *et al.*, 2009). The species builds up large amounts of biomass soon after occupying a site. Dry biomass, together with competition for light and nutrients, eventually impedes the growth of associated species (Funk 2008; Herr-Turroff & Zedler 2007). This has immense impacts on macroinvertebrate, mammal, reptile and bird communities. As the accumulated biomass degrades; it transforms the soil texture, composition and depth (Herr-Turroff & Zedler 2007). Over time, these changes often create drier conditions suitable for invasion by such other species as *Phragmites australis* (Fritz *et al.* 2018). These changes may permanently alter the wetlands into dry ecosystems (Jespersen *et al.*, 2017).

Mapping is an important tool in management of plant invasions as this allows for tracing the history and pattern of invasion. Estimation of the extent and distribution of wetlands in different areas has been made through different broad-scale approaches such as GIS and remote sensing (Lavergne & Molofsky 2004). GIS and remote sensing has become a common tool in wetland inventories (Guo *et al.*, 2017; He *et al.*, 2011). The present study aimed at determining conditions that favour *T. latifolia* establishment and dominance, establishing its current distribution, and predicting its future areal extent in selected wetland sites of Harare.

## **1.2 Statement of the problem**

Studies on *T. latifolia* invasion on wetlands of Harare are limited. The ecology of the species is well documented elsewhere (Anderson *et al.* 1993; Daehler, 2003; Hinsinger, 2001), but very little is known of conditions that favour its establishment in Zimbabwe. *Typha latifolia* forms dense stands attributed to its strong vegetative propagation. It often excludes most other wetland species, but within limits of clearly defined stand margins. These drastic changes may irreversibly alter wetland ecosystems (Bellavance & Brisson 2010). It needs to be established whether *T. latifolia* occupancy and dominance are associated with pre-existing

conditions or result from habitat transformation by the species. The present study sought to understand the conditions that favour *T. latifolia* establishment and dominance, and determine the areal extent of invasion of the species in selected wetland sites of Harare, while at the same time, predict its future invasion pattern by way of remote sensing.

### **1.3 Justification of the study**

This study contributes to the understanding of species invasion and urban wetland ecology in Harare. The primary focus of the study was to analyse changes that have occurred on some wetland sites of the city due to exotic plant invasion. These changes are considered to be of detrimental effect to wetland ecosystem functioning in and around the city. This is also considered as having negative impacts on floristic and faunal compositions (Jespersen *et al.*, 2017) in the wetlands.

### **1.4 Main Objective**

The primary objective of the present study was to determine the extent and rate of invasion of *T. latifolia* in wetland areas of Harare, and establish conditions that favour its occupancy and dominance.

#### **1.4.1 Specific Objectives**

The specific objectives of the study were:

1. To establish the extent and rate of invasion of *T. latifolia* in selected wetland sites of Harare.
2. To assess morphological plasticity of *T. latifolia* across different sites.
3. To determine soil nutrient content (nitrogen, phosphorus, carbon) on sites occupied by *T. latifolia*.
4. To assess whether nutrient concentrations in vegetative parts of mature *T. latifolia* provide an indication of soil nutrient status on sites that it occupies.

## **1.5 Research Questions**

The study attempted to answer the following questions;

1. How is *T. latifolia* distributed, and what is the rate of its invasion on wetland sites of Harare?
2. Does *T. latifolia* exhibit morphological plasticity in response to soil nutrients and pH?
3. Do sites invaded by *T. latifolia* differ in soil nutrient status?
4. Does nutrient concentrations in vegetative parts of *T. latifolia* provide an indication of soil nutrient availability?

## **1.6 Research hypotheses**

The hypotheses for this study were:

1. Extent and rate of invasion of *T. latifolia* differ from one site to another.
2. *T. latifolia* exhibits morphological plasticity in response to soil characteristics.
3. Soil characteristics vary on sites occupied by *T. latifolia*.
4. Nutrient concentrations in rhizomes of mature *T. latifolia* provide an indication of soil nutrient availability.

## **1.7 Thesis structure**

The thesis is structured into five chapters as follows.

### *1.6.1. Thesis introduction*

### *1.6.2 Extent and rate of invasion by T. latifolia in selected wetlands of Harare*

The aim of this Chapter was to estimate the extent and rate of invasion of *T. latifolia* in selected wetlands of Harare.

### *1.6.3 Morphological plasticity of T. latifolia in response to edaphic differences in selected wetlands of Harare*

The aims of this Chapter were to assess morphological plasticity of *T. latifolia* in selected wetlands in Harare and to determine soil nutrient content on sites occupied by *T. latifolia*.

1.6.4 Relationship between nutrient concentrations in vegetative parts of mature *T. latifolia* and soil nutrient content on sites that it occupies.

The aim of this Chapter was to assess whether nutrient concentrations in vegetative parts of mature *T. latifolia* provides an indication of soil nutrient status.

1.6.5 General synthesis/discussion/conclusion

This chapter provides a general synthesis of the findings and recommendations.

### 1.8 Study Area

The study was conducted on 12 wetland sites in Harare indicated in Figure 1.1. Wetlands with large, well defined *T. latifolia* patches were selected for the study.

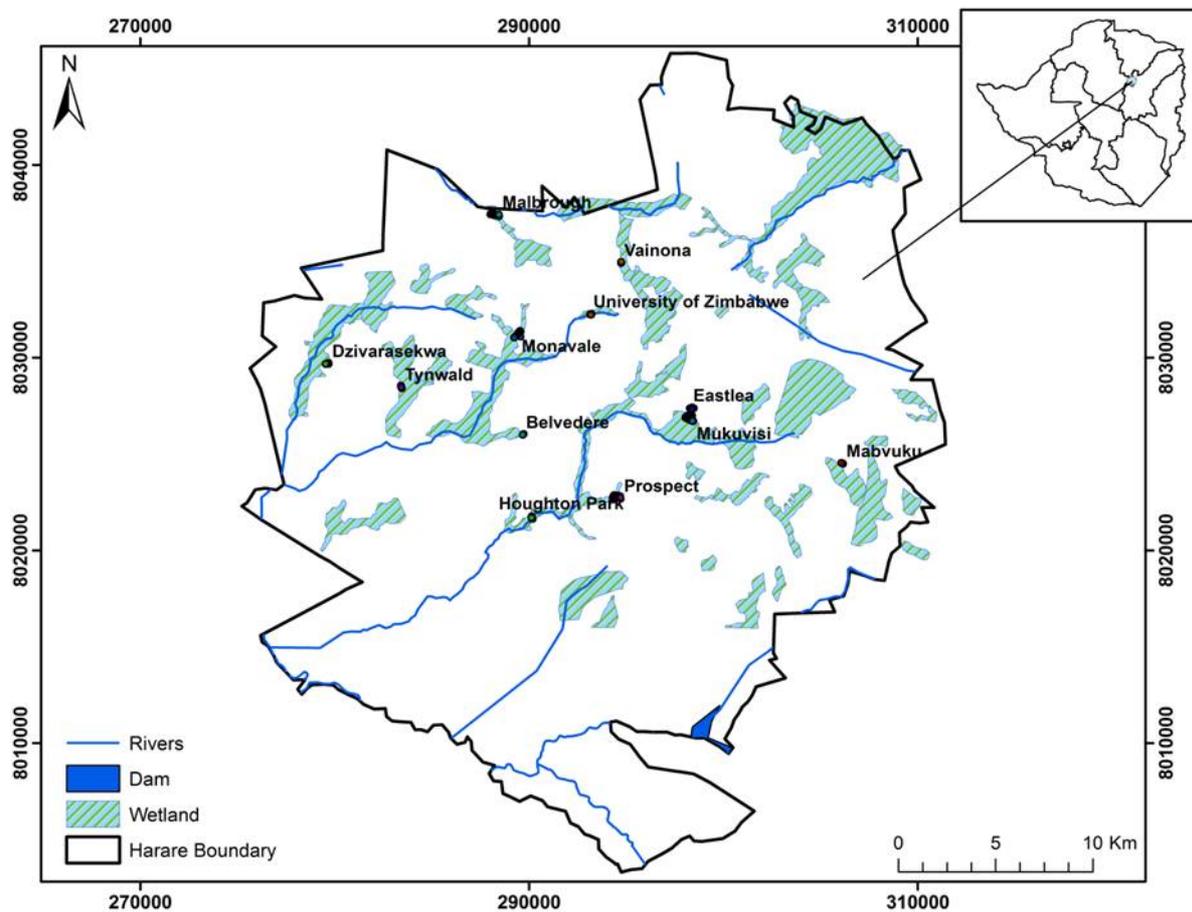


Figure 1.1: Map showing the boundary of the City of Harare and the 12 wetland sampling sites

The study was conducted on wetland sites within suburban areas of Harare, the capital city of Zimbabwe. Twelve sites were selected in the following residential areas: Mabvuku, Dzivarasekwa, University of Zimbabwe campus, Eastlea, Prospect, Tynwald, Mukuvisi railway area, Marlborough, Houghton Park, Belvedere, Vainona and Monavale. In all these sites, *T. latifolia* occupied large patches within wetlands. The geographic coordinates of the sites are shown in Table 1.1.

Mabvuku wetland occurs along the Harare-Mutare road near the Mabvuku turn off. This wetland is used for sewage processing (using open ponds), subsistence farming and water abstraction.

The second site was in Monavale. Part of the Monavale wetland is under protection, whilst adjacent areas are used for subsistence farming and residential houses. The third site is in Belvedere wetland area where much of the wetland is occupied by residential stands, with only minor areas left as open space.

The fourth site is in Prospect vlei. Much of the area is under cultivation, and refuse is dumped along the river channel and sewage inflows enter the wetland. The fifth site was in Marlborough vlei area which is a seasonal wet grassland area that supports a rich diversity of flora and fauna. This wetland forms an important part of the water catchment of Lake Manyame, which together with Lake Chivero catchment area, is threatened by cultivation, sewer overflow and refuse dumping.

The sixth site was in Houghton Park. Much of this wetland is under cultivation and illegal settlement. The seventh site was in Dzivarasekwa wetland which is mostly cultivated land with some church buildings erected in its environs.

The eighth site occurs on either side of a railway line near Mukuvisi woodland to the east of the city. The wetland is located along the Old Mutare Road in Msasa Park. Adjacent to it is

the ninth site which is in Eastlea near Rhodesville Police Station and Cresta Hotel. This wetland is mostly under cultivation.

The tenth site is in Tynwald running alongside Bulawayo Road. This site showed evidence of sewage and waste disposal. The eleventh site is in Vainona along the Gwebi River. This site is threatened by cultivation and refuse dumping. The last site was within the University of Zimbabwe campus by Churchill Avenue and Upper East Road. The wetland is sited at the source of Marimba River.

Table 1.1: GPS coordinates of the 12 wetland sites

<b>LOCATION</b>	<b>36K</b>	<b>UTM</b>
Tynwald	283397	8028533
Mukuvisi railway	298449	8026717
Marlborough	287880	8037436
Monavale Vlei	289471	8031012
Prospect Park	294848	8022648
Houghton Park	290132	8021769
Eastlea	298317	8027208
Vainona	294732	8034900
University of Zimbabwe	293187	8032057
Belvedere	290158	8025793
Dzivarasekwa	279714	8029529
Mabvuku	306290	8024615

The city of Harare is located in the middle veld at an elevation of 1 488 m above sea level. The city is surrounded by granite from which greyish brown sandy loams and coarse textured sandy soils are derived (Anderson *et al.*, 1993). In the upland areas and on vleis, such as Borrowdale and Belvedere, deep black and reddish brown clay vertisols soils are found (Anderson *et al.*, 1993). Andosols, which are dark silt loam and grey soils, are all found in other parts of Harare (Anderson *et al.*, 1993).

Harare has a subtropical upland climate (Love *et al.*, 2010). The high altitude results in cooler and drier climate than a typical tropical or subtropical climate. There are three main seasons: a warm, wet season from November to March/April; a cool, dry season from May to August (corresponding to winter in the Southern Hemisphere); and a hot, dry season in September/October. Rainfall is seasonal and shows inter-annual variability. Daily temperature ranges are about 7–22 °C in July (the coldest month); 15–29 °C (59–84 °C) in October (the hottest month) and about 16–26 ° (61–79 °C) in January (midsummer) (Love *et al.*, 2010). The climate supports a natural vegetation of open woodland. The most common tree of the local region is the Msasa (*Brachystegia spiciformis*). Various species of *Brachystegia*, a hardwood tree up to 90 feet high with pale reddish brown wood are dominant (Mudimu 2006). Other common species include the mohobohobo (*Uapaca kirkiana*, a medium-size tree with large spade-like leaves and the thorn tree (*Acacia* sp.), (Henkel 1931; Wild, 1955; Boughey, 1961; Wild & Barbosa, 1968). Introduced species in the area include the *Jacarandamimosa* (from South America) and the Flamboyant tree (*Delonix regia*), from East Africa and Madagascar (Wild & Barbosa, 1968; Lawton, 1982; Frost, 1996). Harare residents engage in different human activities such as settlement development, industrial activities and agriculture (Simba *et al.*, 2013), especially on open land such as wetlands.

## CHAPTER TWO

### EXTENT AND RATE OF INVASION OF *T. LATIFOLIA* IN SELECTED WETLANDS OF HARARE

#### 2.1 Introduction

Wetlands are susceptible to bio-invasions (Zedler & Kercher 2004), and are highly sensitive to changes associated with plant invasions (McCary *et al.*, 2016). The major threat associated with invasive non-indigenous wetland plant species is the impact on native diversity and its effects on ecosystem processes and functions (Theoharides & Dukes 2007). *Typhalatifolia*, an aggressive invader of wetlands (Shih & Finkelstein 2008; Tuchman *et al.*, 2009), was first observed in Harare wetlands in the past few decades. It is now one of the major threats to wetland ecosystems in of the city as it forms dense, mono-specific stands (Zedler & Kercher 2004) due to its strong vegetative propagation (Paradis *et al.*, 2011). *T. latifolia* raises the pressure on Harare wetlands which are already under threat from cultivation, housing construction, solid waste dumping and siltation (Gumindoga *et al.*, 2014; Kibena *et al.*, 2014).

The city's wetlands are headwaters of the Manyame/ Marimba/Gwebi rivers catchment area from which the city of Harare relies (Zanamwe 1997). The catchment area in turn feeds into two downstream impoundments, Lakes Chivero and Manyame, two main sources of Harare's drinking water. The city is situated in the watershed from which the three rivers emerge. This presents ecological challenges as Lake Chivero, becomes a closed loop, where upon drinking water is drawn while at the same time, effluent is discharged into the same lake. Thus the disruption of ecological processes within the catchment, especially wetland functioning, poses water treatment challenges (Nhapi 2004; Makado & Hoko 2011). The catchment is a primary water source for half of the population of Zimbabwe. Thus, it is critical that wetlands of Harare be preserved. A fall in water surface area has already been observed for Lake

Chivero catchment due to land use and land cover changes during the period 1986-2014 (Tendaupenyu *et al.*, 2017). Cultivation, a major threat to Harare wetlands (Whitlow 1990, Zanamwe 1997) has been linked to changes in ground water recharge and discharge, flood regimes, nutrient and sediment retention and stream flow (Dixon & Wood 2003). *T. latifolia* is likely to increase the threat of lowered water table, thereby increasing water stress to the city. It is, therefore, paramount that the three-components of a wetland, namely hydrology, physio-chemistry and biota (Mitsch & Gosselink 2000) be maintained, as they are central to supply and quality of water (Gumindoga *et al.*, 2014; Kibena *et al.*, 2014; Mhlanga *et al.*, 2014).

*Typha latifolia* is native to North America and Europe (Grace 1986). It is a cosmopolitan species occurring in wetlands throughout most temperate zones in North America, Europe and Asia and many subtropical areas (CABI 2018). Its ability to dominate wetlands and create large biomass (CABI 2018) poses challenges to wetland management. The species is increasingly displaying invasive characteristics, including in countries where it is native (Shih & Finkelstein 2008; Olson *et al.*, 2009).

*T. latifolia* has spread beyond its native range (CABI 2018), and has become naturalised in Zimbabwe (Catarino & Martins 2010). It is, however, only recently that it was categorised as noxious as it appears to be spreading rapidly into sites where it was not previously recorded (Lofgren *et al.*, 2002). The species presence in Harare wetlands was only recorded recently. This observation needs to be confirmed by way of mapping its current distribution in relation to areas that it occupied in the last decade. This information will assist in *T. latifolia* management in Harare. Information relating to the species distribution within the city environs is scant. The understanding of a species invasion chrono-sequence requires accurate spatial-historical reconstruction of the dynamics of the invasion (Walker *et al.*, 2010). This

can be achieved through Geographic Information Systems (GIS) and remote sensing technology (Guo *et al.*, 2017). Plant species invasions can be detected directly from reflectance properties of vegetation in certain portions of the electromagnetic spectrum (Guo *et al.*, 2017; He *et al.*, 2011). Such approaches have been widely used in mapping land use and land cover changes in wetlands (Walker *et al.*, 2010). Likewise, remote sensing and GIS have also been used to map wetland loss (Guo *et al.*, 2011) where Landsat Thematic Mapper (TM) images and Landsat enhanced Thematic Mapper Plus (ETM+) images for a defined period are used to map wetland changes using set reference years. Wetland mapping has also involved the observation of such biophysical parameters as soil, water and vegetation. Modelling of invaded sites has been carried out based on GIS and remote sensing, providing specific details on location, structure and species composition of vegetation (Guo *et al.*, 2017).

It is also critical to model the future distribution of *T. latifolia* in Harare wetlands using species distribution modelling. Species distribution models (SDMs) are tools used in assessing and predicting impacts of climate change on flora and fauna (Farrer & Goldberg 2009; Tuchman *et al.*, 2009; Lishawa *et al.*, 2010). SDMs can be used to determine relationships between species and the environment, and predict their distribution from occurrence (presence only or presence/absence) data. Understanding of factors influencing species distribution is imperative for ecological research (Angeloni *et al.*, 2006). Selecting the most suitable modelling algorithm and relevant data sets is a major challenge in species distribution modelling. SDMs dealing with presence-only data are advantageous over presence/absence modelling methods, conditional to the suitability of the study. Maximum entropy (MaxEnt) is a general purpose machine learning method applied in producing species distribution maps using presence-only data (Wilcox *et al.*, 2008). MaxEnt is a bioclimatic

model that is widely used in predicting species distribution in combination with Generalized Linear Mixed Models (GLMMs).

This chapter sought to establish the spatial distribution of *T. latifolia* and determine its rate of spread within selected wetland sites of Harare. The future distribution of *T. latifolia* was modelled from MaxEnt. The chapter addressed the following questions:

1. How is *T. latifolia* distributed within twelve selected wetland sites of Harare?
2. At what rate is the species spreading?
3. How will it be distributed in future?

## **2.2 Methods and Materials**

An initial reconnaissance survey established that twelve wetlands of Harare were extensively invaded by *T. latifolia* (Figure 1.1, Chapter 1). A subsequent survey determined the pattern of the species distribution on the twelve wetlands.

### ***2.2.1 Determination of extent of Typha latifolia establishment in twelve wetlands***

Wetland mapping was based on coordinate points recorded from a GPS receiver. Wetlands were delineated by moving around and demarcating wetland extent, and recording the coordinates. A series of points were recorded around sites where *T. latifolia* occurred as a way of delineating the sites. The GPS data were loaded into ARCGIS and overlaid on most recent satellite imagery (base map). A new, empty polygon shape file was created, and features added through on-screen digitizing and tracing of sequence points (Tchoukanski, 2008).

### ***2.2.2 Determination of *T. latifolia* rate of establishment in selected wetlands of Harare***

Rate of invasion of *T. latifolia* was determined from aerial images acquired from Google Earth dating back some 10 years (2008-2018) drawn from September for all years to allow for comparison and to reduce the effects of variability in image quality brought about by seasonality, sun angles and atmospheric conditions. Current extent of establishment of *T. latifolia* was recorded from GPS location data. Characteristic shape, colour and texture of *T. latifolia* invaded sites formed the basis for establishing historical occurrence and extent of *T. latifolia* occupied sites. A trained interpreter delineated patches in each historical aerial image, beginning with the most recent; to determine the location and size of *T. latifolia* stands in each image at a specified period across the wetland complex. The interpreter digitized the perimeter of contiguous stands of *Typha* within each image in succession, creating year-specific *Typha* extent polygons. Differences in texture and colour, as compared to the surrounding ground cover, allowed for delineation. The rate of establishment was estimated in terms of distance per year, and calculated as hectares according to Gilbert & Leibhold (2010).

### ***2.2.3 Accuracy assessment and interpretation refinement***

An accuracy assessment test was conducted. This was done to find errors and to improve interpretation of *Typha* delineation. Interpretation confidence levels for each *Typha* polygon were classified: a value of 1 was given to areas where the interpreter was highly confident that the vegetation was *Typha*; a value of 2 represented moderate confidence; and a value of 3 represented low confidence and was assigned to polygons with some variability in texture or colour. Randomly located points (RLPs) were generated within all polygons using the 'Generate Random Points' tool in ET Geo Wizards (Tchoukanski, 2008) within ARCMAP. A stratified random sample of RLPs from each confidence category was selected for field

ground-truthing. Twenty-five per cent of the RLPs from each confidence category were loaded onto a hand-held GPS unit and visited in the field. A one-metre square vegetation plot was established at each point, and *Typha* presence or absence, per cent cover, and stem density were recorded. The accuracy of interpretation was assessed for each confidence category and for each site. Using information gained from the accuracy assessment, particularly incorrectly assigned *Typha* stands, polygon delineations were refined and manual interpretation of digital images was improved through examination of subtle differences in colour and texture between *Typha* and native vegetation types.

#### ***2.2.4 Plant distribution modelling of T. latifolia in wetlands of Harare***

MaxEnt software (version 3.3.3k)(Phillips *et al.*, 2006) was used to predict the distribution of *T. latifolia* in selected wetlands. The MaxEnt (version 3.3.3) used in this study was obtained from <http://www.cs.princeton.edu/schapire/MaxEnt/> and can be downloaded freely for scientific research. MaxEnt, which is a contraction of the phrase maximum entropy, has been demonstrated to perform as well or better than other models (Vanagas 2004). A literature search was used to identify variables which have been implicated in reported encroachment problems of *T. latifolia* elsewhere in the world. These include: increased water depth; constant water level or a reduction in water level fluctuations and high nutrient levels or an increase in nutrient supply, particularly of nitrogen and phosphorus (Angeloni *et al.*, 2006). A Species Distribution Model (SDM) was built as a function of pH, soil moisture, phosphorus, nitrogen, carbon and location. Species distribution models (SDMS) mainly use distribution data of species (presence or absence) and environmental data to algorithmically estimate species' niches, and then project those niches onto the landscape, reflecting species habitat preferences in the form of a probability (Blach-Overgaard *et al.*, 2010; Cao & Tang 2014). The results can be explained as the probability of species presence and species richness.

### 2.2.6 Maximum entropy (MaxEnt) model

In this study MaxEnt software (version 3.3.3k) was used to predict future species distribution of *T.latifolia* in wetlands in Harare. The MaxEnt software is based on the maximum-entropy approach for modelling species niches and distributions. From a set of environmental grids and geo-referenced occurrence localities, the model expressed a probability distribution where each grid cell has a predicted suitability of conditions for the species. Under particular assumptions about the input data and biological sampling efforts that led to occurrence records, the output can be interpreted as predicted probability of presence (log transform), or as predicted local abundance (raw exponential output).The entropy was given by the formulae:

$$\mathcal{H}(\xi) = \sum_{i=1}^n p_i \log \frac{1}{p_i} = - \sum_{i=1}^n p_i \log p_i$$

The species distribution curves of each variable were calculated, and the contributions' of each variable to the Species Distribution Model (SDM) of *T.latifolia* were calculated using the software's built-in jack-knife test. Area under ROC (receiver operating characteristic curve) was also calculated (Hanley & McNeil, 1982).The software package MaxEnt used the AUC to evaluate model performance. In general, AUC is between 0.5 and 1. AUC < 0.5 describes models that perform worse than chance and occurs rarely in reality. An AUC of 0.5 represents pure guessing. Model performance is categorized as failing (0.5–0.6), poor (0.6–0.7), fair (0.7–0.8), good (0.8–0.9), or excellent (0.9–1) (Swets, 1988). The closer the AUC is to 1, the better the model performance is( Table 2.1).

/

Table 2.1: Model performance categorization (Swets, 1988)

AUC value	Model performance
<0.5	Fails to describe reality
0.5	Pure chance
0.5–0.6	Fail
0.6–0.7	Poor
0.7–0.8	Fair
0.8–0.9	Good

## 2.3 Results

### 2.3.1 Extent of *T. latifolia* establishment in twelve wetlands

Wetland size and areal extent of *T. latifolia* in the 12 selected wetlands is shown in Table 2.2 and Figures 2.1 to 2.4. Wetlands ranged from 60 ha (University of Zimbabwe wetland) to 1044 ha (Belvedere wetland). Percentage extent of *T. latifolia* establishment ranged from 0.04% (Houghton Park wetland) to 3.08% (Mukuvisi railway wetland). All twelve wetlands contained *T. latifolia*; however the extent of its establishment varied widely across the wetlands. In nine wetlands, the encroachment comprised of a single rush bed which followed the drainage line and the wettest part of the wetland (Figures 2.1, 2.2 and 2.3), while three wetlands namely, Dzivarasekwa (Figure 2.1c), Tynwald (Figure 2.3c) and Vainona (Figure 2.2a) had small, scattered beds. *T. latifolia* plants were confined to damp or constantly wet sites, on gently sloping ground, often associated with *P. australis*. The largest extent of invasion was in Mukuvisi Railway, Prospect, Marlborough and University of Zimbabwe wetlands where 3.08%, 3.06%, 1.87% and 1.40%, respectively, of the wetland had been invaded (Table 2.1).

Table 2.2: Sizes of studied wetlands and percentage extent of encroachment by *T. latifolia*

<b>Name of site</b>	<b>Total wetland area (ha)</b>	<b>Area encroached by <i>Typhalatifolia</i> (ha)</b>	<b>% Extent of encroachment</b>
University of Zimbabwe	60.72	0.85	1.40
Marlborough	66.18	1.24	1.87
Eastlea	102.31	0.42	0.41
Vainona	159.11	1.23	0.77
Monavale	169.81	0.41	0.24
Houghton Park	171.10	0.07	0.04
Prospect	176.37	5.40	3.06
Mukuvisi railway	190.40	5.87	3.08
Eastlea	102.31	0.42	0.41
Tynwald	655.49	4.26	0.65
Dzivarasekwa	655.49	0.41	0.65
Belvedere	1044.85	0.75	0.07

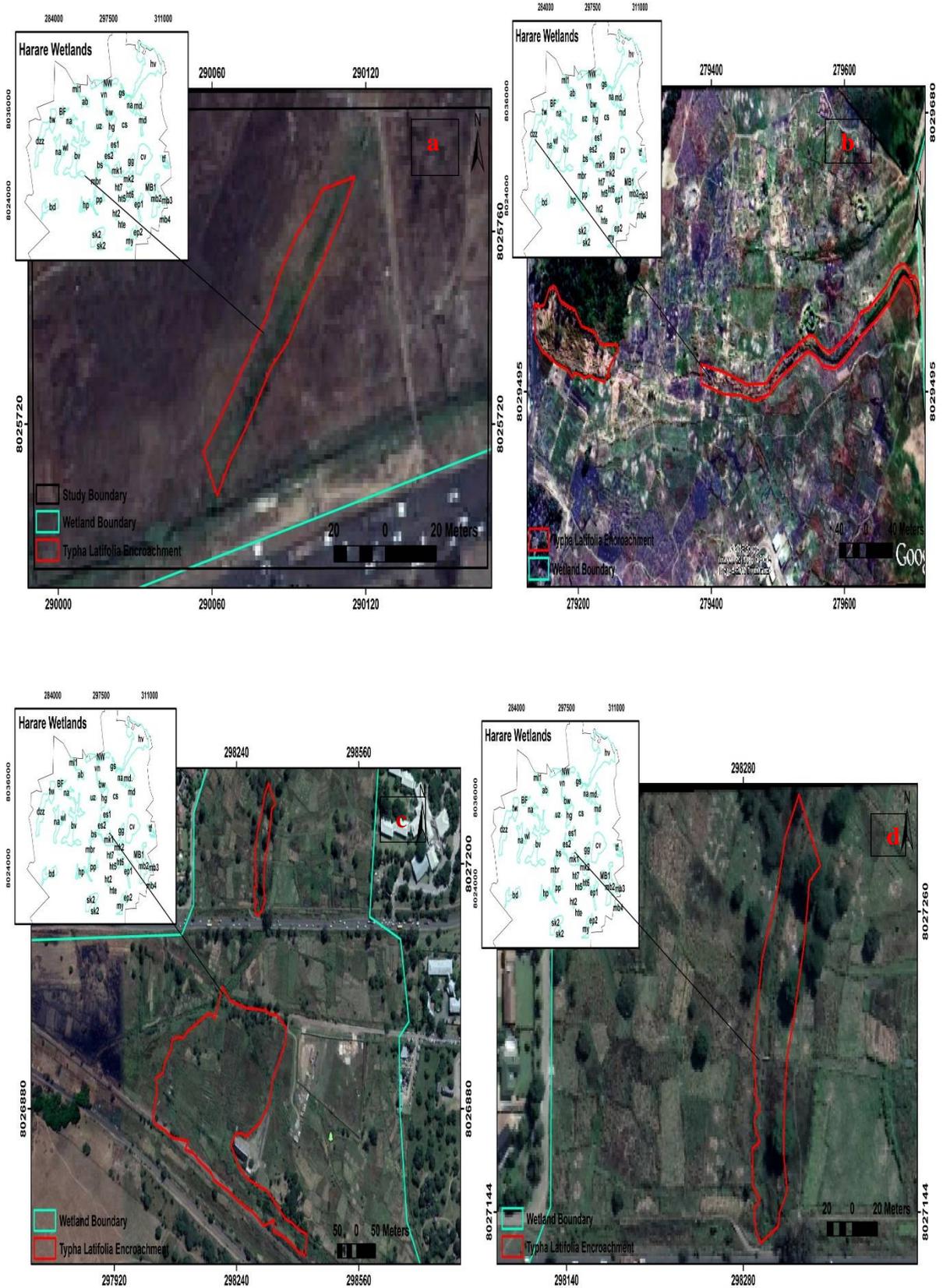


Figure 2.1: Boundary map and area covered by *T. latifolia* for (a) Belvedere 2, (b) Dzivarasekwa, (c) Mukuvisi Railway and (d) Eastlea wetlands in 2018

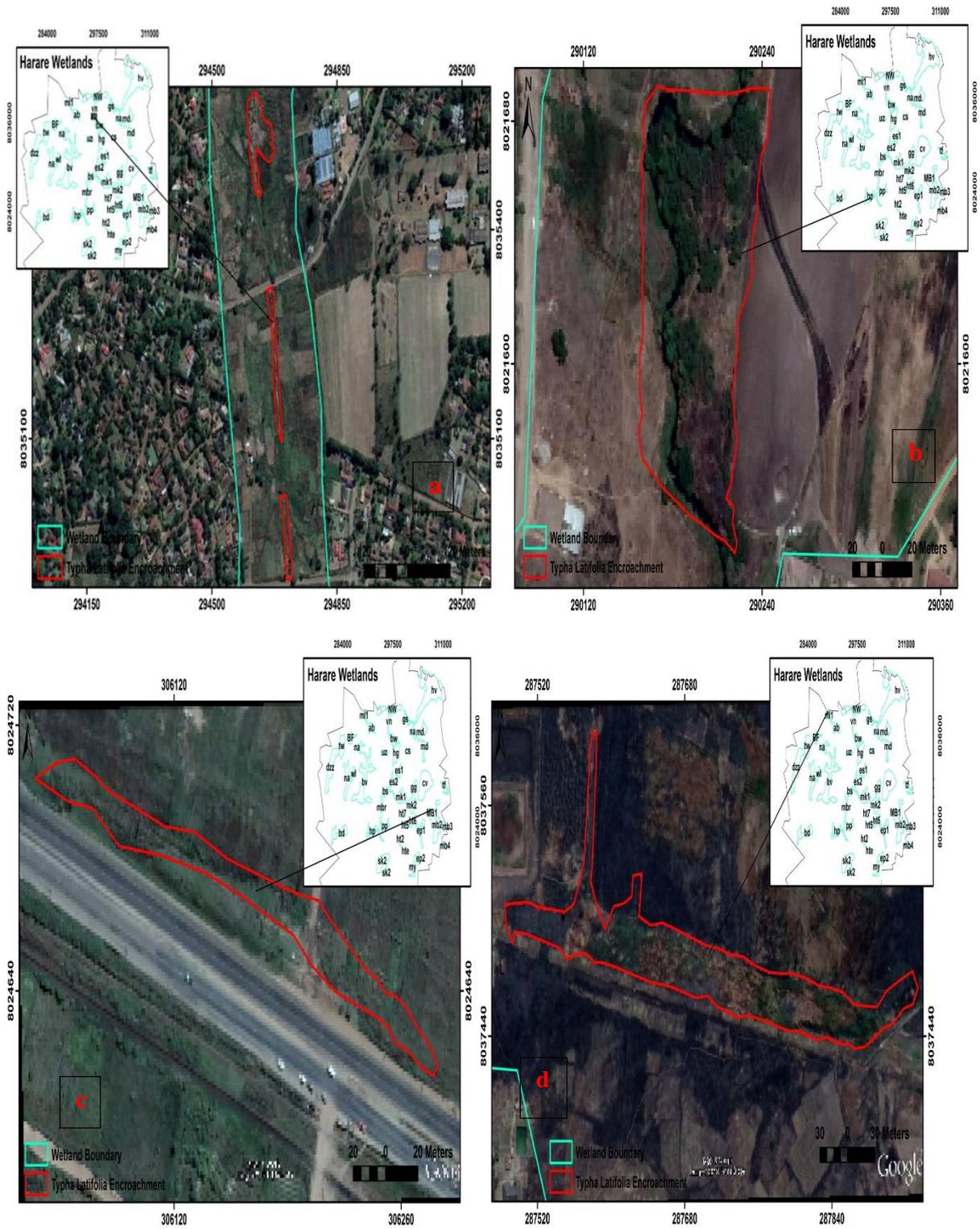


Figure 2.2: Boundary map and area occupied by *T. latifolia* for (A) Vainona, (B) Houghton Park, (C) Mabvuku and (D) Marlborough wetlands in 2018

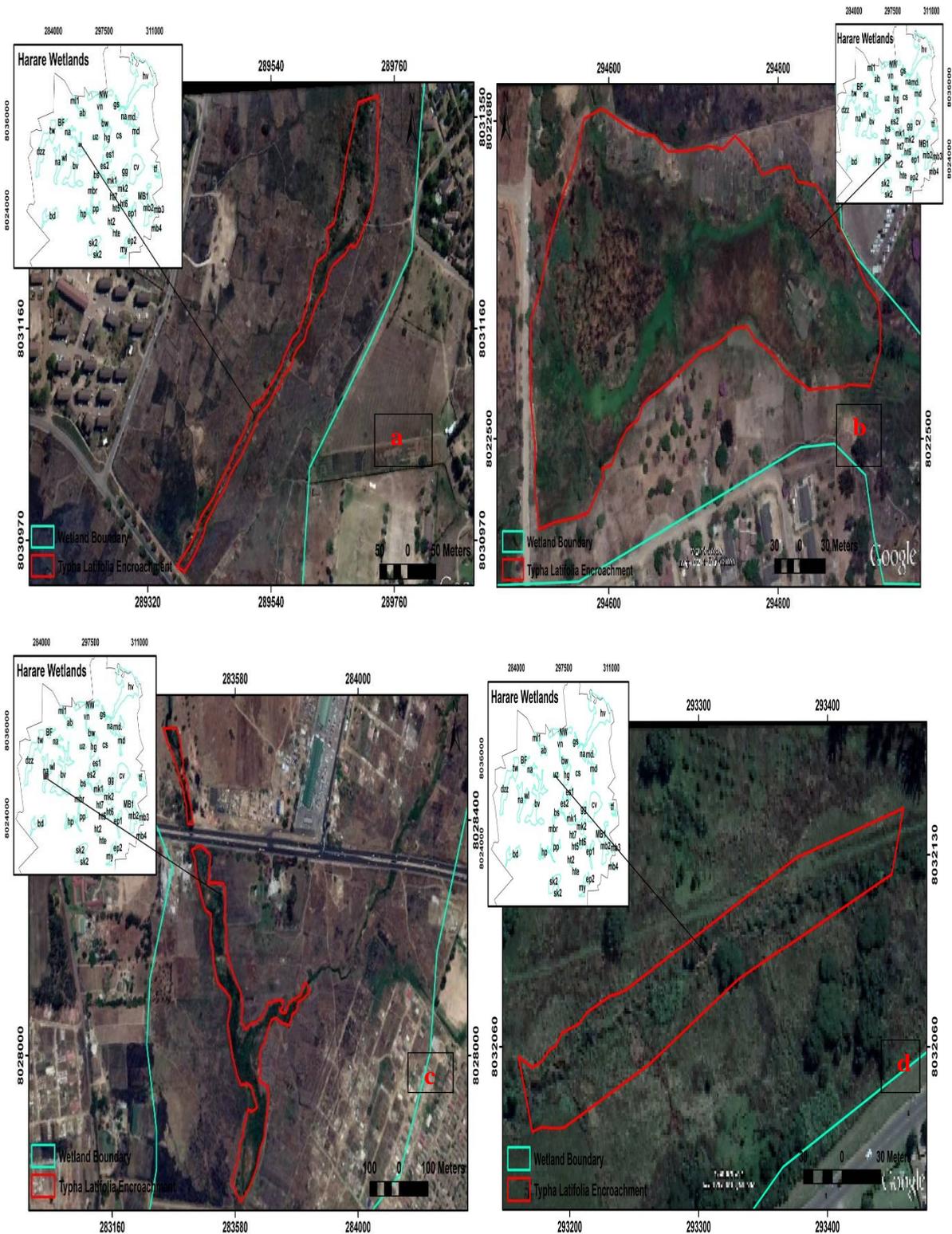


Figure 2.3: Boundary map and area occupied by *T. latifolia* for (A) Monavale 2, (B) Prospect 2, (C) Tynwald and (D) University of Zimbabwe wetlands in 2018

### **2.3.2 Rate of encroachment in Prospect, Monavale and Tynwald wetlands**

Most of the wetlands under study had small patches, hence their spectral bands could not allow for identification of *T. latifolia* occupied sites. The three largest wetlands, namely Prospect (176.3 ha), Monavale (159.1 ha) and Tynwald (655.5 ha) that had a better resolution were used in the analysis to determine the rate of encroachment. A comparison of the historical and current images showed that there had been significant change in *T. latifolia* patch sizes within the three wetlands (Figure 2.4). In all the wetlands, there was an exponential increase in the area covered by *T. latifolia* over the ten year period.

The variation in rate of *T. latifolia* encroachment among the three study sites is shown in the vegetation maps (Figures 2.5 to 2.7). In Monavale, there was marked increase in the spread of *T. latifolia* within the wetland during years 2008 to 2018 (Figure 2.5). The area covered by *T. latifolia* increased from 0.12 ha to 1.83 ha during this period, indicating a 93% increase. *T. latifolia* formed three small scattered patches of 0.12 ha in 2008 along the main drainage line (Figure 2.5). The patches had progressively increased in number to 5 by 2016, covering 1.08 ha (Figure 2.5). The fastest rate of increase of 63.9% occurred during the first 3 years after which the rate declined to 30.2% by 2018 (Table 2.2). The patches had coalesced by 2018 along the drainage line, covering some 1.8 ha (Figure 2.7).

Prospect wetland had no *T. latifolia* in 2008, but showed significant spread of the invasive plant from 2011 to 2018 (Figure 2.6). *T. latifolia* patches expanded from 1.53 ha in 2011 to 5.40 ha in September 2018, indicating a 72% increase. *T. latifolia* occurred in fragmented patches of 2.4 ha and 3.5 ha in 2014 and 2016, respectively, which had coalesced by 2018 to form a single large patch of 5.3 ha along the main drainage line. The highest rate of increase of 37.9% occurred between 2011 and 2014, but the rate subsequently declined to 33.7% in 2018 (Table 2.2).

In the Tynwald wetland, the patch size also increased from 0.59 ha in 2008 to 4.49 ha in September 2018, indicating an 87% increase (Figure 2.7). *T. latifolia* occurred in two scattered patches in 2008 which were along the main drainage line, covering 0.5 ha (Figure 2.7). The number of patches progressively increased to four in 2016 covering 3.4 ha, and had coalesced by 2018, covering 4.4 ha along most of the drainage line (Figure 2.7).

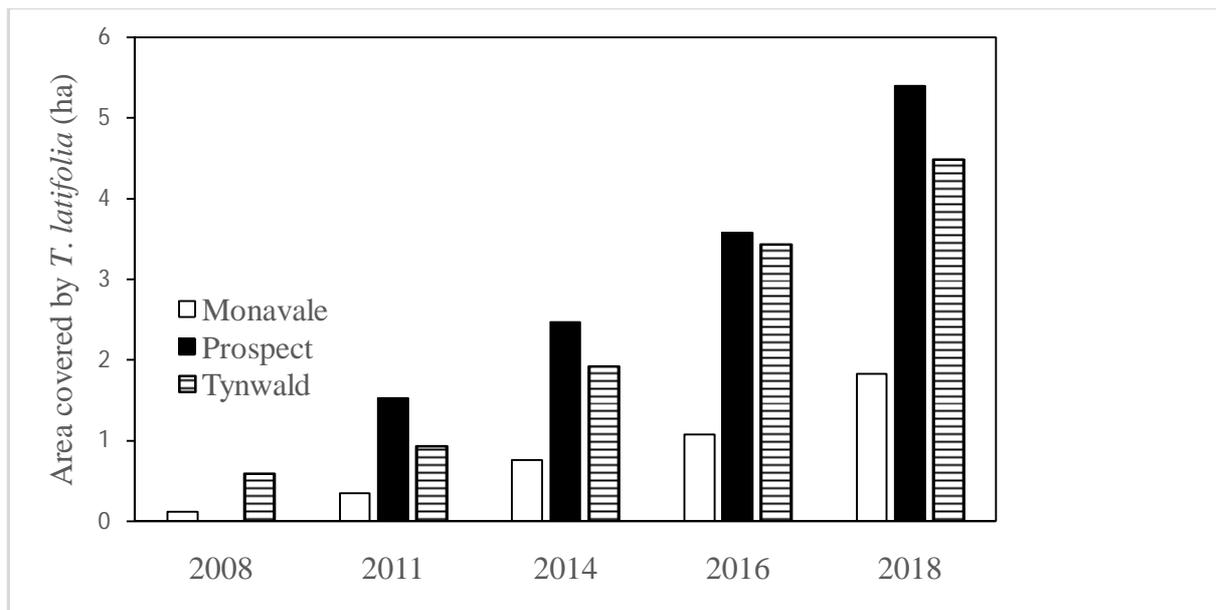


Figure 2.4: Change in distribution of *T. latifolia* in Monavale, Prospect and Tynwald wetlands over a 10 year period (2008-2018)

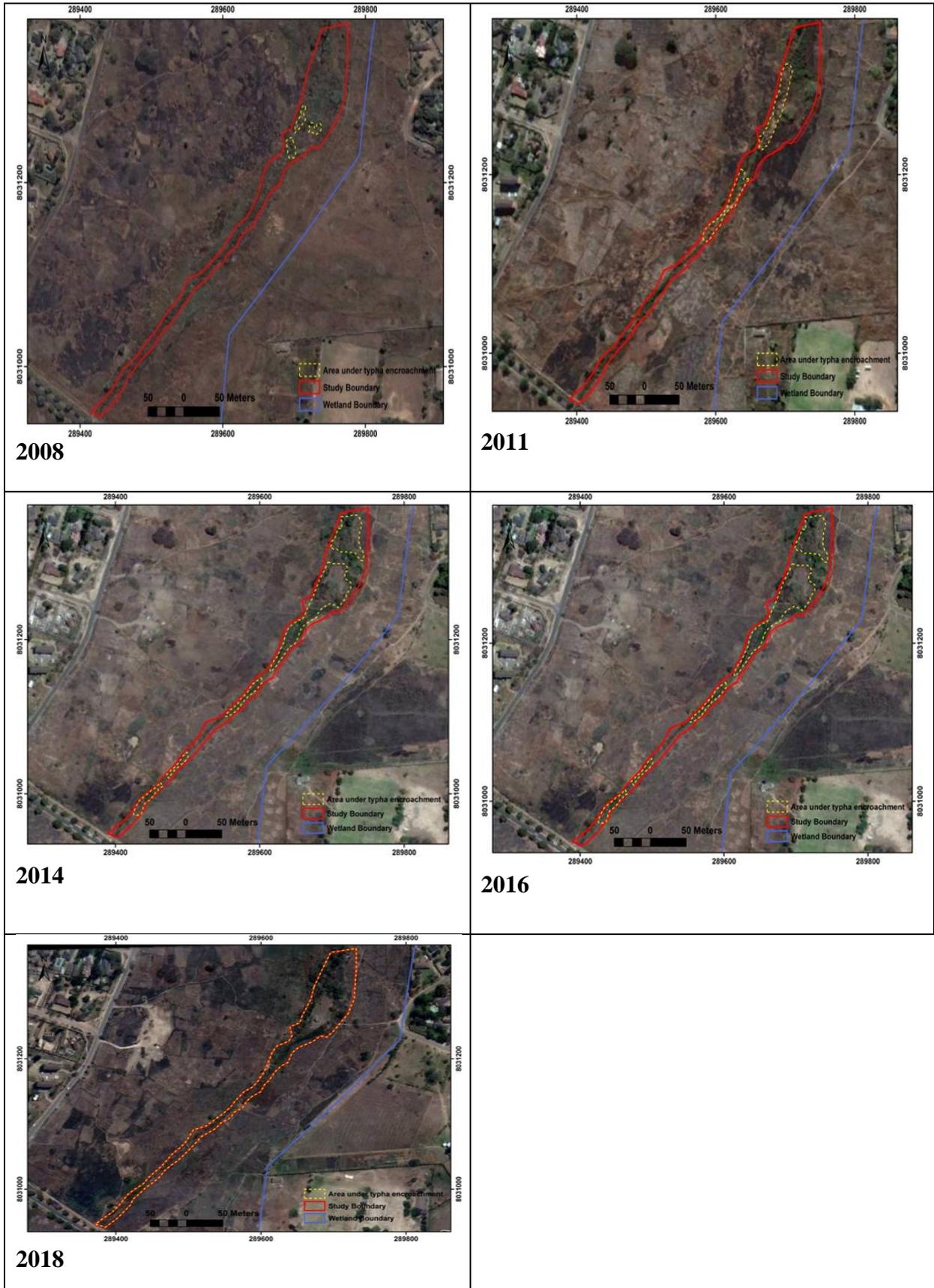


Figure 2.5: Vegetation maps showing change in *T. latifolia* occupied patches in Monavale wetland during period 2008-2018

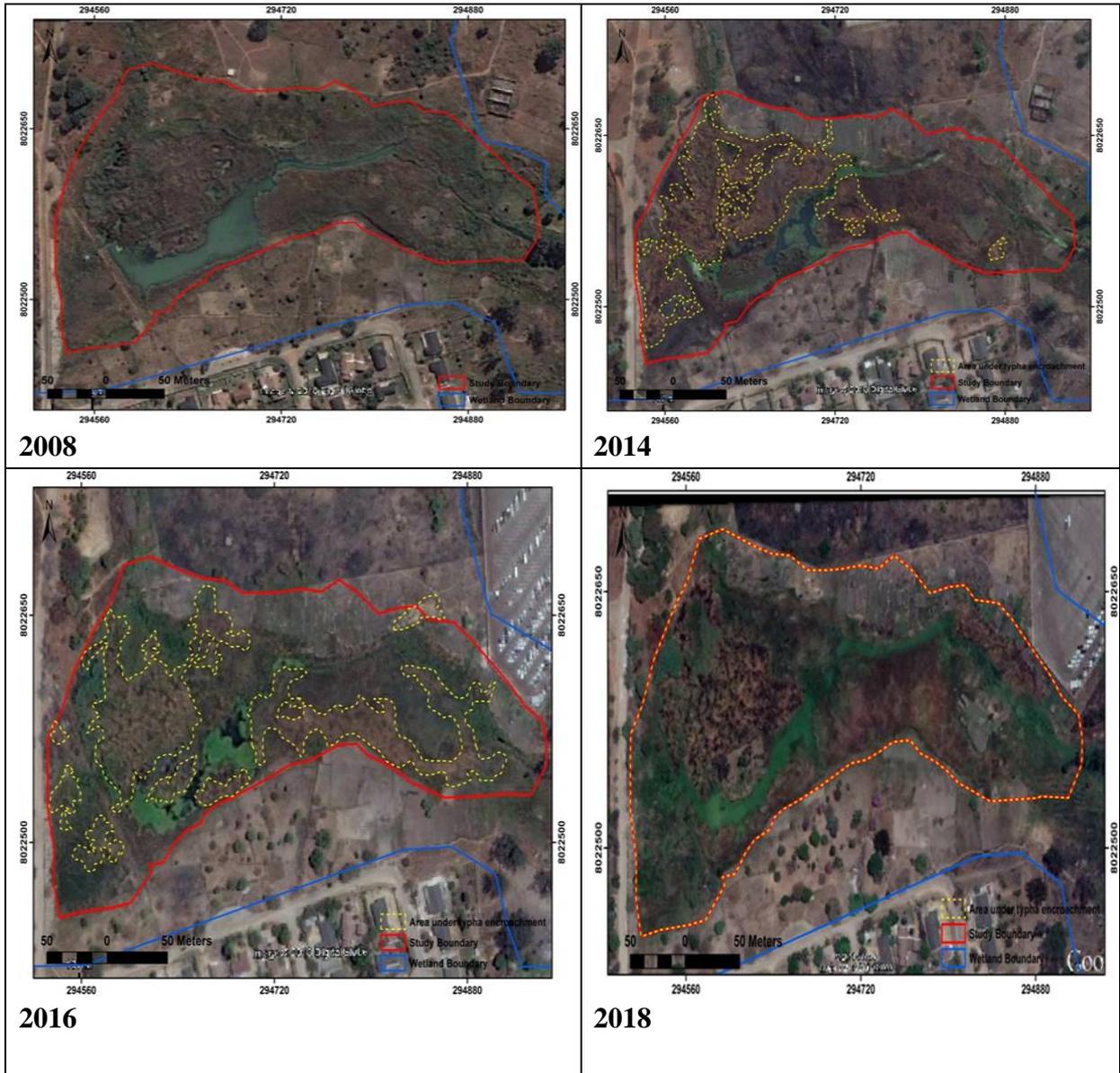


Figure 2.6: Vegetation maps showing change in *T. latifolia* occupied patches in Prospect wetland during period 2008-2018

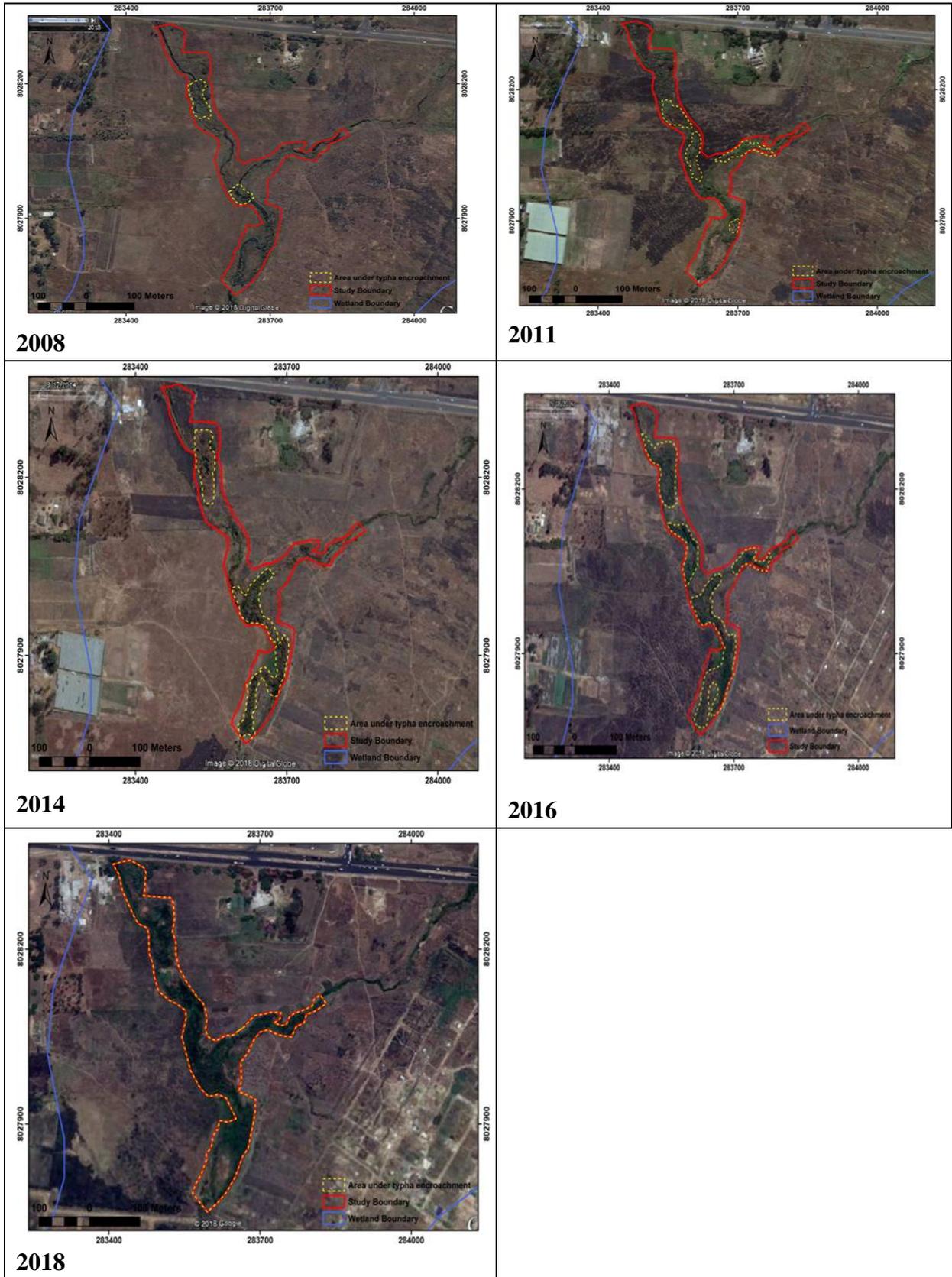


Figure 2.7: Vegetation maps showing change in *T. latifolia* occupied patches in Tynwald wetland during period 2008-2018

### 2.3.3 Species distribution modelling of *T. latifolia* in wetlands in Harare using MaxEnt species distribution model

#### 2.3.4 Model performance and variable contributions

The calculated ROC showed that the AUC value of the training dataset was 0.850 (Figure 2.8). According to the model, this is classified as satisfactory with the given set of training (Table 2.3). Results of the jack-knife test are shown in Figure 2.9. The pH and phosphorus showed gains ( $>0.5$ ) when used independently, indicating that they had greater influence between themselves than carbon, moisture and nitrogen combined. The latter three variables had lower gains when considered separately (Figure 2.10) showing that they did not contain much information on their own. Response curves show the quantitative relationship between environmental variables and the logistic probability of presence (also known as habitat suitability), and they deepen the understanding of the ecological niche of the species. The responses of 5 environmental variables to *T. latifolia* Species Distribution Model are illustrated in (Figure 2.10). According to the response curves *T. latifolia* is responsive to pH, phosphorus and carbon (Figure 2.10).

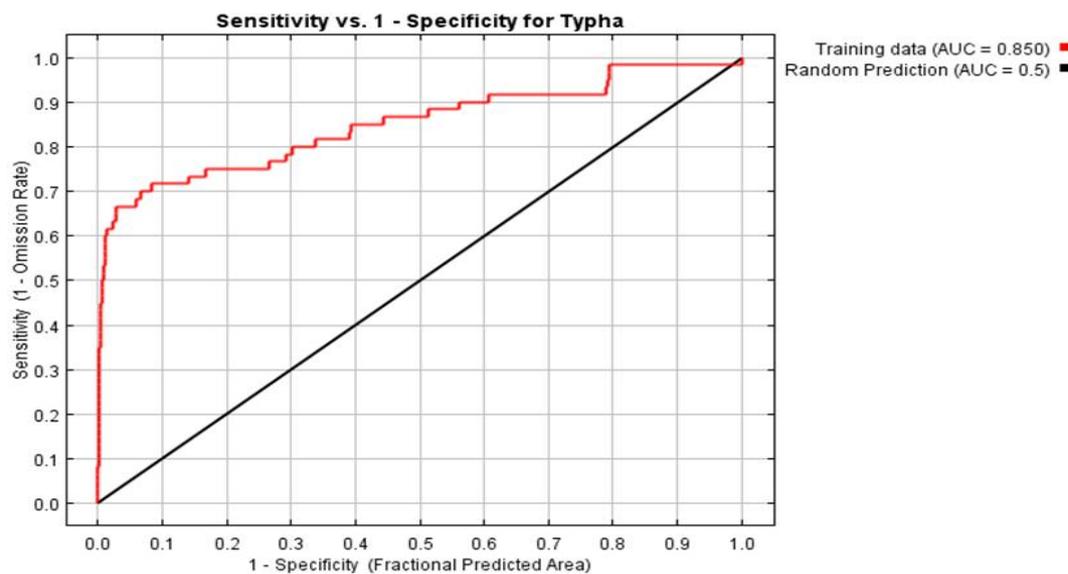


Figure 2.8: Results of the AUC curves in developing *T. latifolia* species prediction model of Harare wetlands

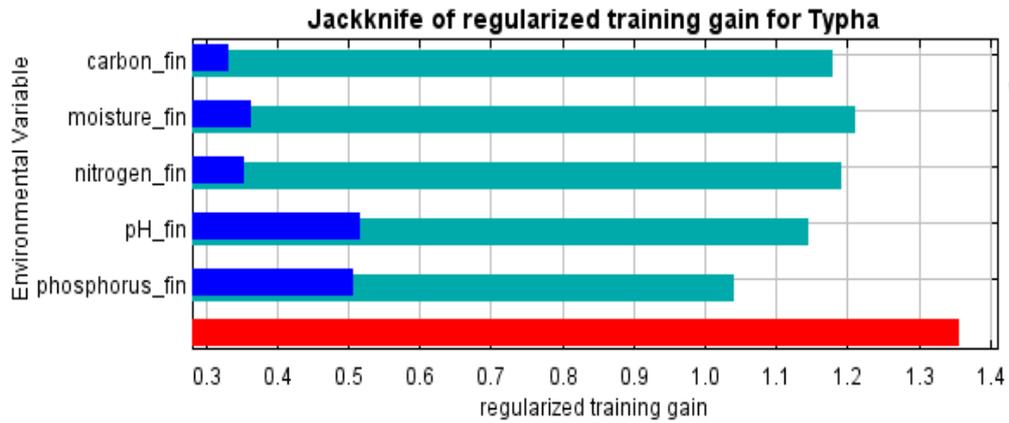


Figure 2.9: Results of a jack knife test of variables' contribution to the model of *T. latifolia* distribution

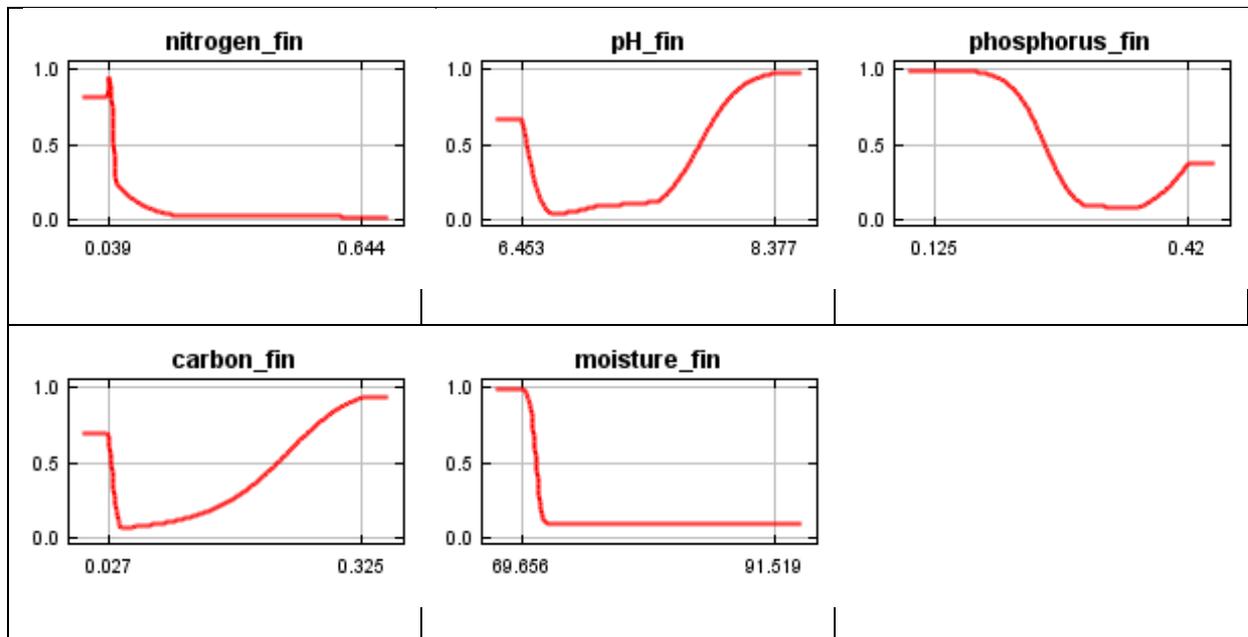


Figure 2.10: Response curves of five environmental variables in *T. latifolia* distribution model

### **2.3.5 Model application**

Figure 2.11 shows the results of the *T. latifolia* distribution simulation on Harare wetlands (model image). The simulation showed that spatial distribution of *T. latifolia* was higher in areas with suitability greater than 0.38 when the distance to the nearest water course was short. In most areas where the probability of occurrence was 0, there was no water body nearby, thus making the occurrence of *T. latifolia* highly unlikely. According to the results of the jackknife test shown in (Figure 2.9) pH and phosphorus showed gains (>0.5) indicating greater influence when modelling plant species distribution. Most of the areas in the model which recorded a value of 0.54 are water courses and wetlands. The response curves also show that *T. latifolia* is responsive to pH, phosphorus and carbon (Figure 2.10). The area in model which accounts for 50% of the projected species distribution is mostly residential areas of Harare. These areas are known to be highly eutrophic mainly because of the anthropogenic activities mentioned in Chapter 1 such as sewage discharge, urban agriculture and refuse dumping which in turn increase nutrients phosphorus and carbon thus increasing the likelihood of *T. latifolia* occurrence.

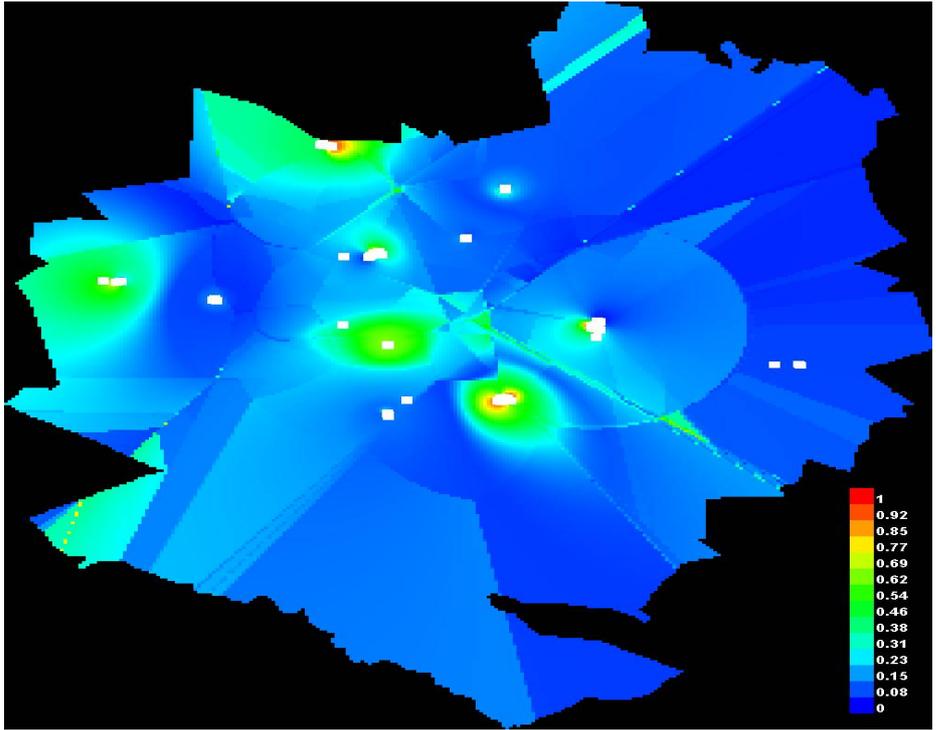


Figure 2.11: Predicted species distribution model of *T. latifolia* in wetlands of Harare according to occurrence records

## 2.4 Discussion

Results of the study show that *T. latifolia* has extended its occupation onto new sites and expanded its area of distribution on sites it occupies in Harare. This is likely to have major implications on biodiversity and ecosystem functioning of Harare wetlands. The extent of encroachment has been variable and restricted to main drainage lines or water courses.

The variation in extent of encroachment may reflect differences in duration of colonisation and levels of nutrients and moisture. Wetlands generally function as sinks, and those of Harare in particular, are subjected to eutrophication because of their landscape position (Junk *et al.*, 2013). As has been observed elsewhere, wetlands in human-dominated landscapes tend to receive nutrient-rich surface waters. Such sites are suitable for invasion by *T. latifolia* (Tsai *et al.*, 2012). All wetland areas of Harare included in the present study receive highly eutrophic surface water with high levels of nitrogen and phosphorus. It would appear that the encroachment of *T. latifolia* in Harare wetland sites is partly influenced by high water table or

moisture availability and nitrogen and phosphorus levels as already observed elsewhere (Jespersen *et al.*, 2017; Marburger & Travis 2013; Drohan *et al.*, 2006). This phenomenon was quite apparent in Prospect wetland where despite the absence of *T. latifolia* in 2008; its occupancy was followed by a dramatic expansion in area of occupancy from 1.5 ha in 2011 to 5.40 ha in 2018. This translates to a >3 times increase in size of the 2011 established patch. *T. latifolia* is known to spread rapidly from underground rhizomes, and can heavily dominate a site, contributing to up to 90% cover (Lishawa *et al.*, 2015). The species is known to spread most rapidly on wetland sites of high nutrient content (Boers & Zedler 2008). Such environment occurs on wetland sites of Harare that are characterised by high nutrient inputs associated with raw sewage flows. Previous studies have shown that wetlands in human-dominated landscapes receiving nutrient-rich surface water and groundwater flows also tend to be more heavily invaded (Simba *et al.*, 2012; Asaeda *et al.*, 2005) in part because nutrient addition promotes the growth and dominance of important invasive species over natives (Boers & Zedler 2008).

All *T. latifolia* occupied sites in the twelve wetlands included almost mono-specific stands of the species. It appears that once it gets established, *T. latifolia* alters the wetland conditions to promote its own growth and further establishment as already noted by Larkin *et al.* (2012). A thick accumulation of litter that reduces light at the soil surface (thus inhibiting establishment and growth of potentially competitive species) and ramps up internal nitrogen cycling is created (Currie *et al.*, 2014). This increases carbon storage and nutrient retention on occupied sites (Martina *et al.*, 2016). The eutrophic conditions within the twelve studied wetlands, coupled with enhanced soil nutrient status on occupied sites promotes growth and further establishment of *T. latifolia* (Jespersen *et al.*, 2017). Thus this cycle of positive feedback creates challenges for management of the species.

The largest invasions have occurred in Mukuvisi Railway, Prospect, Marlborough and University of Zimbabwe wetlands where 3.08%, 3.06%, 1.87% and 1.40%, respectively, of the wetland area has been occupied by *T. latifolia*. This reflects differences in hydrologic and eutrophic characteristics of the twelve wetlands. Mukuvisi wetland forms the headwaters of the highly polluted Mukuvisi River that falls within the Mukuvisi River Basin in Upper Manyame basin (Zaranyika 1997; Moyo & Worster 1997). The wetland receives nutrient-rich effluent from the highly polluted Mukuvisi River (Phiri 2010). Marlborough wetland, a seasonal wet grassland, regulates water flow into Gwebi River, a tributary of Manyame River that flows into Lake Manyame. The University of Zimbabwe wetland forms the headwaters of Marimba River and it has raw sewage directly discharged into it. The conditions in these wetlands are ideal for establishment of *T. latifolia*, a large-size clonal invader that best establishes on sites with high nutrient soils (Currie *et al.*, 2014; Martina *et al.*, 2016).

*T. latifolia* established itself as small patches in Prospect, Monavale and Tynwald wetlands but has since formed mono-specific stands along main drainage lines in each wetland. Marked increases in *T. latifolia* patch sizes occurred within a period of ten year (2008-2018) as shown by an exponential increase in the three wetlands. There has been a varied rate of expansion in area occupied by *T. latifolia* with the highest rate being recorded in Prospect, followed by Tynwald and then Monavale. In Tynwald, the patch size increased by > 7 times between 2008 and 2018. High soil nutrient content favours invasion by *T. latifolia*, while establishment of the species increases nutrient retention and nutrient loads (Elgersmaet *al.*, 2017). Thus a combination of eutrophication and plant invasion in Harare wetlands, can act as multiple stressors in wetland environments (Davis *et al.*, 2010). Any control measures must be focused within the first 10 years following the species establishment before any

significant decline in habitat conditions occurs (Mitchell 2011). It becomes a challenge to eliminate accumulated organic matter and re-establish the hydrological regime after 35 years (Leeds *et al.*, 2009; White *et al.*, 2008). Invaded sites have been observed to dry up after 55 years due to organic matter accumulation, leading to “terrestrializing” of invaded sites (Buffam *et al.*, 2010). Reducing nutrient inputs should be one important component of an effective management strategy for *T. latifolia* (Jespersen *et al.*, 2017). It is envisaged that eutrophication is strongly antagonistic toward efforts to control *Typha* in Harare wetlands. Thus, effectiveness of the management of the invasion by *Typha* entirely depends on the success in controlling quality of effluent discharged into Harare wetlands.

A species distribution prediction model based on maximum entropy theory was developed to evaluate and predict the potential distribution of *T. latifolia* in wetlands of Harare. The model appeared to present an accurate prediction of future *Typha* distribution in the wetland areas according to results of AUC index. Among the 5 variables selected for model construction, *T. latifolia* was primarily influenced by three variables: pH, carbon and phosphorus. Olde Venterink *et al.* (2001) also noted that *T. latifolia* patch sizes increased with increase in phosphorus and carbon in the wet meadows in North east Poland. Regions with habitat suitability greater than 0.54 are entirely located along water courses. This demonstrates that water level stability is critical in facilitating *T. latifolia* encroachment. This implies that other than high nutrient levels, the expansion of *Typha* stands in Harare wetland areas will largely be governed by moisture availability. It is concluded that the invasion of *T. latifolia* is posing one major serious threat to biodiversity and functioning of Harare wetlands, with the primary drivers of this invasion being high soil nutrient status and moisture. The challenge for Harare lies in the maintenance of low nutrient input through curtailment of raw sewage discharge in

wetland areas. Any future management of this noxious species must focus on nutrient loads and hydrologic dynamics of the wetlands.

## CHAPTER THREE

### MORPHOLOGICAL PLASTICITY OF *T. LATIFOLIA* IN RESPONSE TO EDAPHIC DIFFERENCES IN SELECTED WETLANDS OF HARARE

#### 3.1 Introduction

Obligate wetland invasives like *T. latifolia* exhibit morphological plasticity as an adaptation to environmental heterogeneity and new stress factors (Daniel & Haury 2006; Dorken & Barret 2004). Morphological changes can be induced by such environmental factors as nutrient enrichment, fluctuating water levels and exposure to transitory harmful conditions (Kutashige & Agrawal 2005; Gratani 2014). Such changes enhance the invasive capacity and dominance of the species over co-occurring species (Funk 2008; Herr-Turroff & Zedler 2007) by altering the balance of competition in a plant community (Trewavas, 2003). Phenotypic plasticity affords optimal fitness to invasive plants (Gratani 2014; Fritz *et al.* 2018), thus enhancing their growth and development over a wide range of edaphic conditions. This consequently promotes their invasion capacity under varied environmental regimes (Nunney 2016; Davidson *et al.*, 2011). A plant can respond by shifting biomass allocations from root to shoot systems (Herr-Turnoff& Zedler 2007). Key life-history traits that change morphologically include tissue elongation, new leaf recruitment and increased basal diameter (Li *et al.*, 2011).

The genus *Typha* is common in nutrient-rich wetlands (Jespersen *et al.*, 2017). One of its species, *T. latifolia*, can aggressively invade and become dominant under high light intensity, nutrient rich wetland environments (Jespersen *et al.*, 2017). Such conditions are prevalent in Harare wetland sites (see Chapter 2). The species is reportedly dominant where nutrients are abundant (Dorken & Barret,2004) as typified by Harare wetlands. It is critical to determine whether morphological plasticity confers competitive advantage to *T. latifolia* in Harare

wetland ecosystems as a way of establishing whether the species has competitive advantage over native species. It is hypothesized that morphological plasticity enhances the invasive capacity of *T. latifolia* in Harare wetlands where its range has been increasing in the last decade (see Chapter 2). The majority of studies on *Typha* have been carried out in North America and Canada (Daehler, 2003). None have been done in Zimbabwe despite the increasing predominance of *T. latifolia* under local wetland conditions.

Wetlands are susceptible to invasions which result in monotypic communities due to their landscape sink position, where disturbances are frequent and moisture and nutrients accumulate (Daehler, 2003). Studies on the relationship between plants and environmental variables can provide an understanding of the implications of anthropogenic impacts on wetland ecosystems (Lan *et al.*, 2010) especially in an urban set up like Harare. Harare experiences challenges in sewage treatment which leads to discharge of untreated sewage effluent into wetlands (Dorken & Barret, 2004). This creates elevated nutrient levels in wetlands, leading to eutrophication (Fitch *et al.*, 2009), thereby increasing vulnerability to invasions (Lavergne & Molofsky 2004). Eutrophic conditions favour invasive species due to their greater resource use efficiency than native con-generas (Daehler, 2003). As observed elsewhere, Harare wetlands act as sinks by accumulating nutrients which facilitate the growth of opportunistic species (Gratani, 2014) like *T. latifolia*. Invasive plant species can also change the soil nutrient status which further promotes their establishment (Anderson *et al.* 2014; Daehler, 2003; Hinsinger, 2001).

The morphological plasticity of shoot height, shoot diameter and number of leaves of *T. latifolia* was investigated in Harare wetlands subjected to different eutrophication levels. The aim of this chapter was to determine whether *T. latifolia* exhibited morphological plasticity as

a response to changes in soil nutrient status (N, P, and C), moisture and pH in selected wetlands of Harare. It was hypothesized that *T. latifolia* exhibits morphological plasticity in response to differences in soil nutrient concentration. This information is useful in inferring the risks posed to Harare wetlands.

The chapter addressed the following questions:

1. Does *T. latifolia* exhibit morphological plasticity in response to soil nutrients, moisture and pH?
2. Do sites invaded by *T. latifolia* differ in soil nutrient status, soil moisture, and pH?
3. Which edaphic factors influence *T. latifolia* shoot height, diameter and number of leaves in the respective wetlands?

## **3.2 Materials and Methods**

### ***3.2.1 Assessment of edaphic characteristics on sites invaded by T. latifolia***

Soil sampling was carried out in twelve wetlands. Details on the sampling sites and their locations are outlined in Chapter 1 (Figure 1.1; Table 1.1). At each wetland site, three line transects were drawn from the margin to the centre of an invaded site after which 1×1m quadrats were systematically laid at the margin and centre of each line transect. Soil samples were collected from the centre of each 1×1m quadrat to a depth of 10cm using a soil auger. The soil samples were placed in brown paper bags and transported to the laboratory for determination of pH, moisture content, carbon, nitrogen and phosphorus. Total nitrogen was measured by the Kjeldahl analysis method (Mehlich, 1953). Total phosphorus was determined by the colorimetric molybdenum blue method (Charles and Simmons, 1986). Total organic carbon was determined by the calorimetric method (Charles & Simmons 1986). Soil pH was

determined by a pH meter (WTW PH 340i). Soil moisture content was determined according to the Standards Association of Australia method (1977).

### ***3.2.1 Assessment of morphological plasticity of *T.latifolia****

Five plants were randomly selected within each 1 X 1m quadrat. Measurements were made on each plant for shoot height (cm), shoot diameter (cm) and numbers of leaves were counted.

## **3.3 Data Analysis**

Kruskal-Wallis tests ( $p < 0.05$ ) were carried out to test for differences in edaphic characteristics among sites. A nonparametric test, the Mann-Whitney U test, was therefore used to compare soil physio-chemical and morphological characteristics among the 12 sites. The computer software STATISTICA version 7 was used. A post ANOVA Duncan test at 95% confidence interval was used to separate the differences in means. Stepwise multiple regression analysis was performed to determine which edaphic factors influenced *T. latifolia* shoot height, shoot diameter and number of leaves in the respective wetlands. Multiple linear regressions were used to determine if *T. latifolia* exhibit morphological plasticity in response to soil nutrients, moisture and pH.

## **3.4 Results**

### ***3.4.1 Edaphic characteristics on sites invaded by *T. latifolia****

Table 3.1 and Figure 3.1 below summarise mean values of soil physico-chemical properties of the soil in 12 wetlands during the time of study. Soils in all wetlands were acidic (Table 3.1). Mean soil pH ranged from 6 to 7.7. Mean percentage moisture content was above 70% in all wetlands. The highest mean percentage moisture content of 88.1% was recorded in the

Mabvuku wetland. Mean carbon was very low and it was below  $0.05 \text{ mg l}^{-1}$  in nine wetlands. Slightly higher carbon levels were recorded in Marlborough, Monavale and Belvedere wetlands (Figure 3.1). Mean phosphorus was below  $0.41 \text{ mg l}^{-1}$  in all wetlands except Mabvuku. The lowest phosphorus was recorded in Mukuvisi wetland (Figure 3.1). Nitrogen was below  $0.10 \text{ mg l}^{-1}$  except in Dzivarasekwa, Marlborough, Tynwald and Eastleawetlands . The site which recorded the least nitrogen content was Mukuvisi railway wetland . There was no significant difference in percentage moisture content, phosphorus and nitrogen among the sites (Figure 3.1). Marlborough and Vainonawetlands accounted for most of the variation in carbon mean values and very little variation amongst the other ten sites (Figure 3.1). Based on the results in Table 3.2 for Kruskal-Wallis tests only nitrogen and pH values are significant with p-values of 0.032 and  $<0.001$  respectively (  $p < 0.05$ ). Soil moisture content, phosphorus (P), carbon content were not significantly different among on the twelve wetland areas of Harare. A pairwise Mann –Whitney analysis also showed nitrogen and pH values are significant with p-values (  $p < 0.05$ ).

Table 3.1: Mean values for soil physico-chemical properties of the soil in 12 wetlands during the time of study (C, N, and P are in  $\text{mg l}^{-1}$ , moisture is %)

Site	C		N		P		Soil moisture		Soil pH	
	Mean	Stdev	Mean	Stdev	Mean	Stdev	Mean	Stdev	Mean	Stdev
Dzivarasekwa	0.04	0.004	0.15	0.07	0.24	0.08	75.7	3.7	7.3	0.18
Marlborough	0.27	0.15	0.25	0.28	0.36	0.06	73.3	9.89	7.5	0.42
Monavale	0.22	0.16	0.06	0.01	0.28	0.03	73.9	24.4	7.1	0.4
Vainona	0.04	0.01	0.05	0.02	0.36	0.04	71.6	18.4	6.5	0.14
Mabvuku	0.04	0.02	0.09	0.06	0.41	0.11	88.1	1.48	6	0.75
UZ	0.05	0.01	0.07	0.03	0.32	0.06	76.6	7.15	6.9	0.73
Tynwald	0.07	0.01	0.21	0.26	0.34	0.06	79.6	6.45	7	0.38
Eastlea	0.05	0.01	0.16	0.05	0.32	0.11	78.6	7.68	6.8	1.39
Mukuvisi railway	0.03	0.00	0.09	0.06	0.20	0.09	73.5	22.5	7.1	0.45
Houghton Park	0.04	0.01	0.07	0.01	0.31	0.03	82	3.48	6.9	0.43
Belvedere	0.10	0.16	0.08	0.01	0.30	0.01	81.5	6.12	7.7	0.14
Prospect	0.04	0.01	0.06	0.02	0.29	0.06	83.8	8.36	6.5	0.17

Table 3.2: Kruskal-Wallis ANOVA and Mann-Whitney post hoc tests for significant differences in soil physico-chemical characteristics of 12 wetlands in Harare during the time of study. Significance was tested at  $p < 0.05$

Variable	H value	P value	Pairwise Mann-Whitney p-value
P	17.7	0.087	0.09
N	21.2	<0.001	<0.001
C	18.5	0.069	0.07
Ph	32.4	<0.001	<0.001
Percentage soil moisture	15.4	0.163	0.20

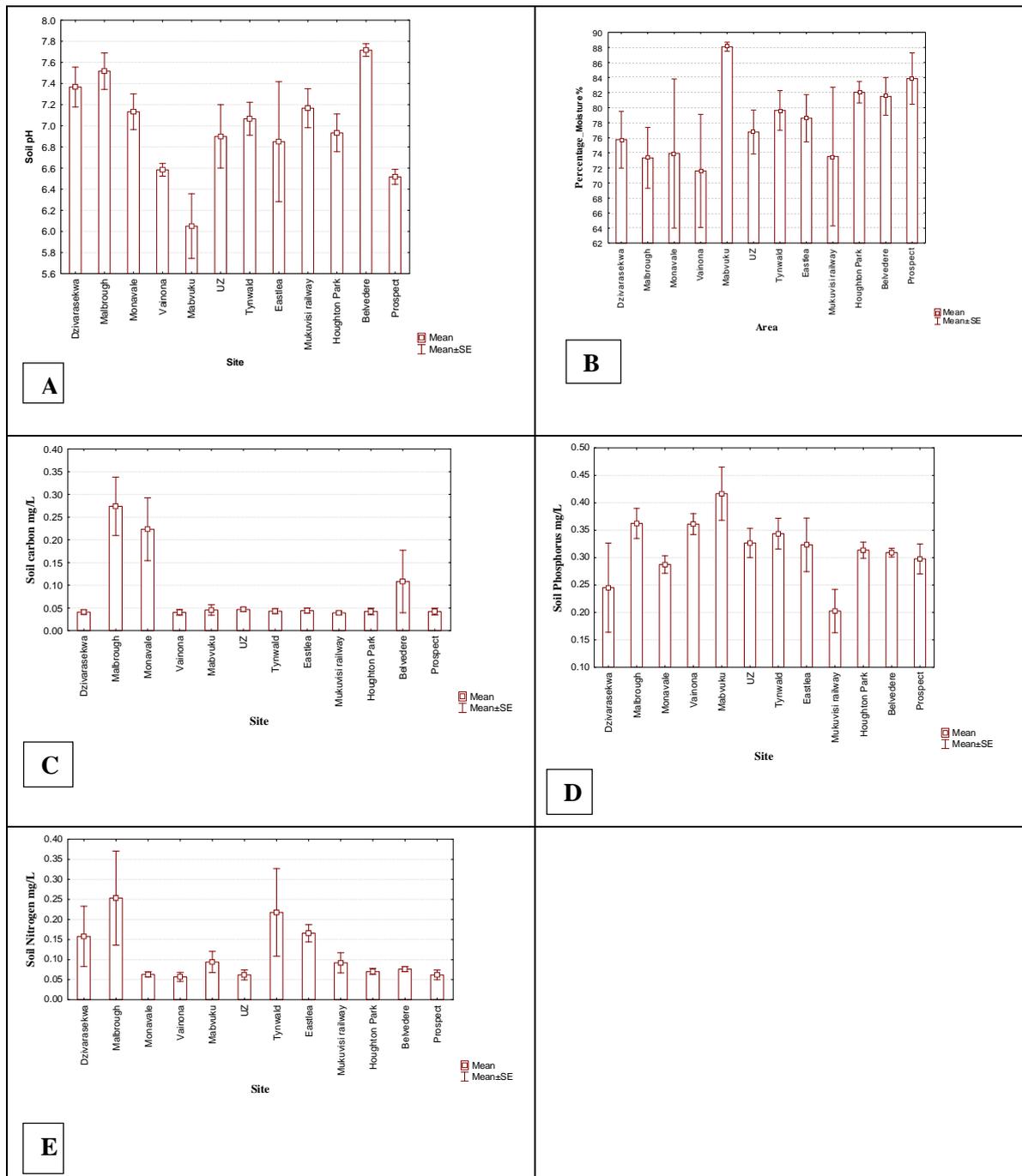


Figure 3.1: Means of the edaphic characteristics (a) pH (b) % moisture content (c) carbon (d) phosphorus and (e) nitrogen in sites invaded by *T. latifolia*

### ***3.4.2 Morphological plasticity of T. latifolia***

Table 3.3 and Figure 3.2 below summarise the mean values of morphological plasticity for 12 wetlands during the time of study. This included shoot height, shoot diameter and number of leaves. The differences in mean shoot diameter, mean shoot height and mean number of leaves was very apparent for plants from University of Zimbabwe, Dzivarasekwa and Mukuvisi railway wetlands (Table 3.2). Low mean shoot heights of 1m, low shoot diameter of 1.2 cm and lowest number of leaves of 4 were recorded on plants in Mukuvisi railway and Prospect wetlands. The highest shoot diameters of 11.5cm, shoot height of 4.5 cm and the highest numbers of leaves of 15 were recorded on plants in Dzivarasekwa and University of Zimbabwe wetlands (Figure 3.2). According to the Kruskal-Wallis Anova test there were significant differences ( $p < 0.05$ ) among the sites for plant shoot height, shoot diameter and number of leaves (Table 3.3). A pairwise Mann-Whitney analysis also showed significant differences ( $p < 0.05$ ) among the sites for plant shoot height, shoot diameter and number of leaves (Table 3.3)

Table 3.3: Mean values of morphological features of *T. latifolia* for 12 wetlands during the time of study

Site	Shoot height (cm)		Shoot diameter (cm)		Number of leaves	
	Mean	Stdev	Mean	Stdev	Mean	Stdev
Dzivarasekwa	3.94	0.23	5.17	1.21	10	0.80
Marlborough	3.6	0.24	4.5	1.47	8.6	1.29
Monavale	2.49	0.20	2.12	0.31	7	0.41
Vainona	2.5	0.15	2.84	0.62	7.7	0.82
Mabvuku	1.64	0.26	2.78	0.29	7.7	0.61
UZ	2.17	0.63	5.71	3.20	10.1	1.97
Tynwald	2.94	0.49	3.11	1.07	7.2	0.60
Eastlea	2.48	0.42	4.61	1.78	7.93	0.78
Mukuvisi railway	1.54	0.14	2.22	0.43	6.5	0.39
Houghton Park	2.02	0.88	3.58	1.73	8.1	1.22
Belvedere	2.20	0.33	3.6	0.73	8.1	0.75
Prospect	1.78	0.33	2.63	1.15	6.5	1.17

Table 3.4: Kruskal-Wallis ANOVA and Mann-whitney post hoc tests for significant differences in morphological features of *T. latifolia* of 12 wetlands in Harare during the time of study. Significance was tested at  $p < 0.05$

Variable	H value	P value	Pairwise Mann-Whitney test p-value
Shoot height	50.4	<0.001	<0.001
Shoot diameter	37.7	<0.001	<0.001
Number of leaves	18.5	<0.001	<0.001

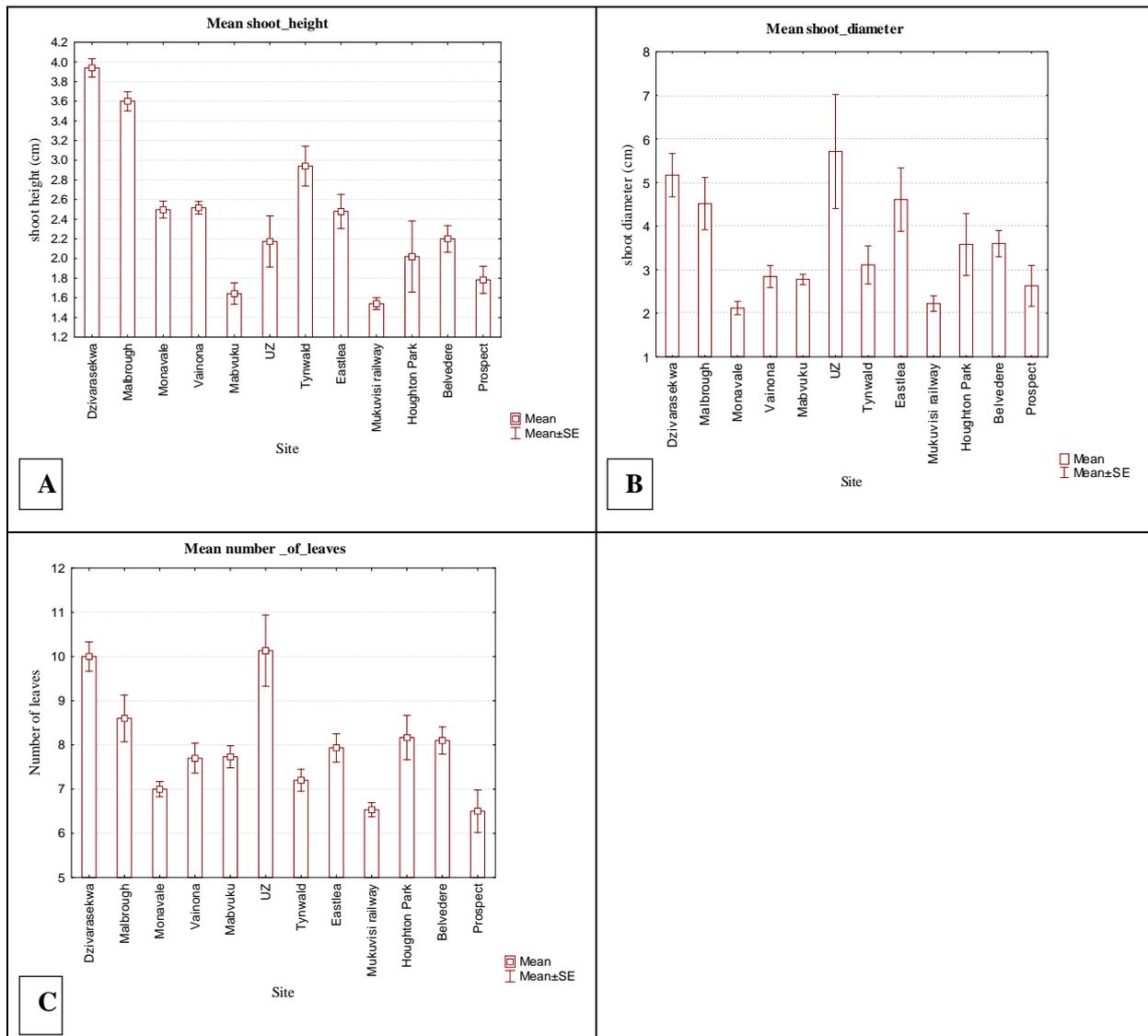


Figure 3.2: Means of the plant morphological characteristics (a) shoot height, (b) shoot diameter (c) number of leaves of sites invaded by *T. latifolia*

### 3.4.3 Relationship between plant morphological and edaphic characteristics

Stepwise regression analysis was used to determine the importance of selected environmental variables contribution to shoot height, shoot diameter and number of leaves (Table 3.5). Each independent variable (edaphic characteristics) was tested. Using mean values for pH, soil moisture, C, N and P showed very few significant relationships between predictor variables and shoot height. Phosphorus concentration showed the best correlation with shoot diameter in Marlborough and Mabvuku wetlands with  $R^2$  values of 0.94 and 0.99 respectively. A

significant relationship was also noted for nitrogen in Marlborough wetland with an  $R^2$  value of 0.94. Prospect and UZ wetlands also showed significant relationships with pH as a predicting variable of shoot height with  $R^2$  values of 0.96 and 0.86 respectively. Percentage moisture was also a significant predicting variable in Mabvuku wetland with an  $R^2$  value of 0.99.

Results from Table 3.6 revealed that moisture produced a significant effect on shoot diameter for plants in Prospect wetland, with a positive and significant parameter. The Belvedere wetland test result was indifferent ( $p$ -value =0.05). Soil carbon(C) produced a positive and significant effect to shoot diameter in Vainona wetland whilst in Dzivarasekwa wetland it had a negative significant effect. Soil nitrogen (N) had a positive and significant effect on shoot diameter in Dzivarasekwa wetland only. Soil pH had a positive and significant effect on shoot height in Dzivarasekwa wetlands, whilst in Prospect wetland the effect was negative and significant.

A summary of stepwise regression analysis carried out to determine independent variable contribution of soil nutrient variables per site to number of leaves is given in Table 3.7. There were very few variables which were significant in predicting shoot diameter amongst the sites. Soil carbon(C) has a positive and significant effect on number of leaves in Tynwald wetland. Soil carbon has a negative significant effect on number of leaves in Mukuvisi railway wetland. Soil moisture had a positive and significant effect on number of leaves in Tynwald wetland only. Soil pH had a positive and significant effect on number of leaves for plants in Vainona and Mukuvisi railway wetlands.

Table 3.5: Summary statistics of independent variable contribution to shoot height per wetland site

Variables	Model1 β(Partial p- value)	Model 2 β(Partial p- value)	Model 3 β(Partial p- value)	Model 4 β(Partial p- value)	Model 5 β(Partial p- value)	Model 6 β(p-value)	Model 7 β(Partial p- value)	Model 8 β(Partial p- value)	Model 9 β(Partial p- value)	Model 10 β(Partial p- value)	Model 11 β(Partial p- value)	Model 12 β(Partial p- value)
Intercept	1.69	1.36	0.55	0.40	-2.68	0.23	2.02	0.59	-	-	-	1.67
Moisture					2.34( <b>0.01</b> )	0.86(0.18)		1.69(0.08)	-	-	-	0.40(0.08)
Soil C			-0.13( <b>0.04</b> )	0.82(0.19)			4.09(0.06)		-	-	-	-
Soil P		0.28( <b>0.02</b> )			-0.37( <b>0.005</b> )							0.18(0.26)
Soil N		-0.06( <b>0.05</b> )	0.82(0.20)					1.21(0.20)	-	-	-	
Soil pH	0.27(0.16)					-0.16( <b>0.01</b> )	0.32(0.22)	0.19(0.19)	-	-	-	1.62( <b>0.02</b> )
Full modelR <sup>2</sup>	.41	.94	.83	.37	.99	.39	.75	.86	-	-	-	.95
Full model p-value	0.16	0.01	0.06	0.19	0.01	0.18	0.11	0.18	-	-	-	0.6

Model 1=Dzivarasekwa, Model 2=Marlborough, Model 3=Monavale, Model 4 =Vainona, Model 5 =Mabvuku, Model 6=UZ, Model 7=Tynwald, Model 8= Eastlea, Model 9 =Mukuvisi railway, Model 10 =Houghton Park, Model 11= Belvedere, Model 12=Prospect

Table 3.6 Summary of statistics determining independent variable contribution to shoot diameter per wetland site

Variables	Model1 β(Partial p- value)	Model 2β(Partial p-value)	Model 3 β(Partial p-value)	Model 4 β(Partial p- value)	Model 5 β(Partial p-value)	Model 6 β(Partial p- value)	Model 7 β(Partial p-value)	Model 8 β(Partial p- value)	Model 9 β(Partial p- value)	Model 10 β(Partial p-value)	Model 11 β(Partial p- value)	Model 12 β(Partial p- value)
Intercept	0.69	0.25	-	1.30	-	1.86	-	-1.08	-1.51	-	1.01	-2.10
Moisture			-	0.22(0.06)	-	3.88(0.12)	-	3.00(0.18)	-0.06(0.31)	-	0.56( <b>0.05</b> )	0.53( <b>0.01</b> )
Soil C	-3.22( <b>0.01</b> )		-	3.90( <b>0.02</b> )	-	-	-	-5.4(0.34)	1.78(0.18)	-	-0.05(0.34)	
Soil P			-	0.22(0.06)	--		-			-		
Soil N	0.21( <b>0.02</b> )	0.25(0.17)	-		-		-			-		0.65(0.08)
Soil pH	0.84( <b>0.003</b> )		-		-	1.49(0.23)	-	0.75(0.18)		-	1.14(0.07)	-1.59( <b>0.01</b> )
Full model R <sup>2</sup>	.99	.40	-	.96	-	.59	-	.75	.58	-	.95	.99
Full model p-value	0.05	0.17	-	0.04	-	0.25	-	0.34	0.24	-	0.07	0.01

Model 1=Dzivarasekwa, Model 2=Marlborough, Model 3=Monavale, Model 4 =Vainona, Model 5 =Mabvuku, Model 6=UZ, Model 7=Tynwald, Model 8= Eastlea, Model 9 =Mukuvisi railway, Model 10 =Houghton Park, Model 11= Belvedere, Model 12=Prospect

Table 3.7 Summary of statistics determining independent variable contribution to number of leaves per wetland site

Variables	Model 1β(Partial p-value)	Model 2β(Partial p-value)	Model 3β(Partial p-value)	Model 4 β(Partial p-value)	Model 5β(Partial p-value)	Model 6β(Partial p-value)	Model 7 β(Partial p-value)	Model 8 β(Partial p-value)	Model 9 β(Partial p-value)	Model 10 β(Partial p-value)	Model 11 β(Partial p-value)	Model 12 β(Partial p-value)
Intercept	-	-	-0.45	1.46		-	-0.17	-	-1.74	1.40	0.31	-2.90
Moisture	-	-	0.06(0.33)		0.80(0.15)	-	0.52( <b>0.0004</b> )	-			0.72(0.13)	
Soil C	-	-				-	2.21( <b>0.0005</b> )	-	-2.07( <b>0.0008</b> )	3.46(0.15)	0.12(0.34)	-2.2(0.31)
Soil P	-	-	0.65(0.08)		0.26(0.19)	-	0.55( <b>0.0006</b> )	-				
Soil N	-	-		0.34(0.38)	0.70(0.19)	-		-				
Soil pH	-	-		2.67( <b>0.004</b> )	-0.20(0.22)	-		-	0.20( <b>0.0002</b> )			1.60(0.28)
Full model R <sup>2</sup>	-	-	.67	.95	.97	--	.99	-	.99	.44	.66	.75
Full model p-value	-	-	0.18	0.009	0.22	-	0.0009	-	0.0004	0.15	0.19	0.13

Model 1=Dzivarasekwa, Model 2=Marlborough, Model 3=Monavale, Model 4 =Vainona, Model 5=Mabvuku, Model 6=UZ, Model 7=Tynwald, Model8=Eastlea, Model9=Mukuvisi railway, Model10=HoughtonParkModel11=Belvedere, Model12=Prospect

### 3.4.3 Relationship between plant morphological and edaphic characteristics

Table 3.8 summaries the results of a multiple linear regression model showing the relationship between shoot height, shoot diameters and number of leaves and edaphic characteristics during the time of the study. The model identified nitrogen content in the soil as the only significant variable influencing shoot height ( $p < 0.5$ ) (Table 3.8). Other variables like shoot diameter and number of leaves had no significant relationships with edaphic parameters. A p value of 0.80 and 0.26 respectively was recorded for shoot diameter and number of leaves indicating a very weak correlation between shoot diameter and number of leaves to edaphic characteristics during the time of study (Table 3.8).

Table 3.8: Multiple linear regression model results showing the relationship between shoot heights shoot diameter and number of leaves and edaphic characteristics

Variables	Shoot height(Partial p-value)	Shoot diameter(Partial p-value)	Number of leaves β(Partial p-value)
Intercept	1.15	2.07	5.53
Moisture	0.004(0.56)	0.006(0.71)	-0.01(0.28)
Soil C	1.51(0.08)	1.71(0.39)	-1.87(0.25)
Soil P	0.24(0.79)	0.31(0.87)	2.58(0.13)
Soil N	1.42( <b>0.03</b> )	0.31(0.87)	0.10(0.93)
Soil Ph	0.20(0.13)	0.29(0.38)	0.42(0.09)
Full model R <sup>2</sup>	.17	.34	0.09
Full model p-value	0.02	0.80	0.26

### 3.5 Discussion

The twelve wetlands soils differed with respect to pH and nitrogen but had similar levels of percentage moisture, phosphorus and carbon. Soils in the wetlands were acidic to slightly alkaline. Soil pH has a major role in controlling nutrient bio-availability (Weidenhamer & Callaway 2010). Previous studies have also shown that plant invasion significantly increase soil pH (Chen *et al.*, 2012) which accelerates litter decomposition and thus plays a crucial role in regulating nutrient availability (Simba *et al.*, 2013). *T. latifolia* invasion in Harare wetlands is still very recent, with very little litter accumulation, such that its influence on nutrient cycling might still be minimal.

Carbon content was high in Marlborough and Vainona wetlands, but relatively uniform in other wetlands. This could be a reflection of the differences in time of invasion. *Typha* is a large, fast-growing plant with higher biomass than native species it displaces (Bellavance & Brisson 2010), thus allowing it to have a higher rate of carbon capture. Its higher rate of carbon capture is expected to increase soil organic matter concentrations via decomposition of abundant litter, as well as elevated belowground root tissue and possibly root exudates (Daehler, 2003). The larger extent of invasion in Marlborough and Vainona vlei (see Chapter 2) and longer time since invasion could be already showing impact on carbon cycling. A plant-soil positive feedback that favours *Typha* persistence occurs when *Typha* increases soil nutrient concentrations through carbon fixation (Larvenergne & Molofsky 2004). *Typha* is then able to better exploit increased nutrient availability than the native species it displaces (Chen *et al.*, 2012). It can be envisaged that in Harare wetlands as observed elsewhere both high pH and high carbon will allow *Typha* to increase nutrient availability, thereby allowing it to be a driver of its own invasion rather than being dependent on available nutrients (Nunney, 2016; Trewavas, 2003).

The highest shoot diameter, shoot height and number of leaves per plant occurred at the University of Zimbabwe and Dzivarasekwa wetlands while the lowest occurred in Mukuvisi railway wetland. Many studies have shown that invasive plants exhibit plasticity in nutrient rich wetlands as an adaptive response to change in resource availability (Simba *et al.*, 2013). There is however no general pattern between phenotypic plasticity and plant invasions (Daniel *et al.*, 2006) which might explain the lack of a clear pattern of plasticity in *T. latifolia* in Harare wetlands. This can be partly attributed to the similarities in carbon, phosphorus content and moisture content in wetland soils and relatively young invasion time. *T. latifolia* encroached Harare wetlands in the last decade, for example in Prospect wetland within a time frame of 10 years. *T. latifolia* will not have built up enough litter biomass to change soil nutrients. In this study, the morphological attributes measured did not exhibit a pattern that suggests that morphological plasticity is a driver for *Typha* invasions in the twelve wetlands under study. The slight differences in variability of the plant growth characteristics might be just a localised growth response to the localised heterogeneity of environmental conditions.

To establish the relationship between plant morphological and edaphic characteristics, a multiple linear regression model was carried out. The results showed significantly weak relationships between nitrogen and shoot height. However, the regression analyses revealed no significant relationships between total phosphorus, carbon, percentage moisture and pH and plant morphological characteristics of *T. latifolia* measured during the study. Nitrogen is a major nutrient required for plant growth (Brix *et al.*, 2002; Lan *et al.*, 2010) to promote leaves, stem and other vegetative part's growth and development (Funk, 2008). Plant nitrogen use efficiency is affected by soil pH (Fitch *et al.*, 2009; Funk, 2008; Chen *et al.*, 2012). Nitrogen use efficiency in plants is excellent at a soil pH range 6.5-7.0 (Funk, 2008), a pH range that occurred in all studied wetlands. This response is an adaptation and the adaptation

is reflected by a series of changes mainly in morphological phenotypes, decrease in stem diameter, decrease of the leaf numbers, and the increase of plant height.

To find the relationship between plant morphology of *T.latifolia*, soil nutrients (particularly total nitrogen and total phosphorus, carbon, percentage moisture), and pH per site, stepwise regression analyses were conducted. Significant relationships between pH, soil moisture content and carbon and shoot height, shoot diameter and number of leaves in most of the wetlands were established. R<sup>2</sup> values ranged between 0.40 and 0.99. Previous studies have shown that plant invasion significantly increase soil pH (Chen *et al.*, 2012) which accelerate litter decomposition and thus plays a crucial role in regulating nutrient availability (Simba *et al.*, 2013). Hence we infer that increased nutrient availability and soil moisture content during the study period led to higher soil fertility in the wetlands under study and increased plant carbon uptake translating to increased plant growth rate, and plant size (Fitch *et al.*, 2009; Chen *et al.*, 2012).

In conclusion, the study showed that *T. latifolia* did not exhibit a clear pattern of morphological plasticity because edaphic characteristics among the wetlands were generally similar except for pH and N. Differences observed with respect to plant shoot height, shoot diameter and number of leaves could be a reflection of slight localised inherent heterogeneity of the soils.

## CHAPTER FOUR

### IS VEGETATIVE NUTRIENT CONTENT IN MATURE *T. LATIFOLIA* INDICATIVE OF SOIL NUTRIENT AVAILABILITY IN SELECTED WETLANDS OF HARARE?

#### 4.1 Introduction

Plant nutrient content is an important indicator of soil nutrient availability (Roy-Bolduc, 2016). High soil nutrient availability generally translates to high plant nutrient content (Zhang, 2017). However, availability of a particular nutrient in the soil is not the single factor determining its uptake (Jacobsen & Lorbeer, 1998). Such other factors as temperature, humidity, and soil moisture and plant health variously influence nutrient uptake. Plant analysis reflects both soil nutrient availability and plant nutritional status (Roy-Bolduc, 2016). Plant nutrient content is not fixed, but constantly changes (Jacobsen and Lorbeer, 1998). It may vary monthly or even daily. Nutrient content may even differ among organs of the same plant. Frequently, there is positive correlation between plant and soil nutrient contents. Plant tissue analysis provides information on plant nutritional status and assists with visual diagnosis of deficiency/toxicity symptoms. However, it does not provide enough information to explain the reason for the nutritional disorder. Sometimes plant analysis might not be sensitive enough, since above a critical nutrient level, only a small change in plant nutrient content occurs despite significant increase in soil nutrient availability (Prasseet *al.* 2015). It complements a proven soil testing plan and helps identify ways plants use nutrients more efficiently.

*T. latifolia* is an emergent wetland plant and has a shallow-root system that often results in nutrients enrichment in surface soils through roots and rhizomes absorptions (Mitchell, 2011). The species requires nitrogen and phosphorus for growth and reproduction. Through absorption, a portion of nutrients in the water column is transferred to the plant (Jacobsen

&Lorbeen, 1998). Thus the nutrient content values can serve to illustrate the range of nutrient contents of *Typha* across various locations, thereby providing a basis for comparison with studies carried out elsewhere.

Vegetative material from mature individuals of *T. latifolia* separately collected from twelve wetland sites of Harare which were assumed to be subjected to different eutrophication levels were collected and analysed for nitrogen, carbon and phosphorus. It was hypothesized that nutrient contents of vegetative parts of *T. latifolia* are indicative of soil nutrient status of the different wetland sites occupied by the species.

The present Chapter aimed at addressing the following questions;

1. Do sites invaded by *T. latifolia* differ in plant nutrient contents?
2. Is *T. latifolia* plant nutrient content indicative of soil nutrient status?

## **4.2 Methods and Materials**

### ***4.2.1 Assessment of nutrient concentrations in vegetative parts of T.latifolia***

#### ***4.2.2 Plant sampling***

Details on the sampling sites and their locations are outlined in Chapter 1 (Figure 1.1, table 1.1). At each wetland site, three line transects were drawn from the margin to the centre of the invaded site where 1×1m quadrats were systematically laid at the margin and centre of each line transect. Vegetative material from mature *T. latifolia* were harvested from three randomly selected plants from each quadrat and pooled into a composite sample. 10g of each sample was oven dried at 60°C followed by 65°C for 24 hours to achieve constant weight. Dried plant samples were crushed and screened to a maximum particle size of 0.25 mm and analysed for phosphorus, carbon and nitrogen. Total nitrogen was determined by the Kjeldahl method (Mehlich, 1953). Phosphorus was determined by the molybdate method after

digestion (Charles & Simmons, 1986). Organic carbon was determined by the Walkely and Black wet oxidation method (Charles & Simmons, 1986).

### **4.3 Data Analysis**

Kruskal-Wallis tests ( $p < 0.05$ ) were performed to assess for differences in plant nutrient concentrations amongst sites. A nonparametric test, the Mann-Whitney U test, was used to compare difference in plant nutrient content among the twelve sites. The computer software STATISTICA version 7 was used to analyse the data. A Redundancy Analysis (RDA) was carried out to identify which nutrient concentrations in vegetative parts of mature *T. latifolia* provided an indication of soil nutrient status.

### **4.4 Results**

#### ***4.4.1 Assessment of nutrient concentrations in vegetative parts of T.latifolia***

Table 4.1 and Figure 4.1 summarise mean values of plant nutrient contents from the 12 wetlands sites. All sites recorded high levels of plant phosphorus above  $0.30 \text{ mg l}^{-1}$ . The highest phosphorus contents ( $0.40 \text{ mg l}^{-1}$ ) were recorded from plants growing at Marlborough and Vainona wetland sites and the lowest at Mukuvisi railway site ( $0.20 \text{ mg l}^{-1}$ ). Marlborough and Tynwald sites recorded the highest mean nitrogen contents ( $0.25 \text{ mg l}^{-1}$  and  $0.21 \text{ mg l}^{-1}$ , respectively). In the remaining 10 sites, nitrogen was below  $0.10 \text{ mg l}^{-1}$ . The site with the least recording was Vainona wetland site. Carbon content also varied markedly among sites. The carbon values were very low (below  $10 \text{ mg l}^{-1}$  for 10 sites), except in Marlborough and Monavale wetland sites. The lowest concentration was recorded at Mukuvisi railway site. According to the Kruskal-Wallis ANOVA test for significant differences, *T.latifolia* plant nutrient content showed no significant ( $p > 0.05$ ) differences among the sites for carbon and phosphorus. There was however significant differences in nitrogen for all sites during the time of study (Table 4.2). The Mann Whitney post hoc analysis also showed no significant ( $p$

> 0.05) differences among the sites for carbon and phosphorus. There was however significant differences in nitrogen for all sites.

Table 4.1: Mean values for plant nutrient concentrations of *T. latifolia* in 12 wetlands of Harare

Site	C (mg l <sup>-1</sup> )		N (mg l <sup>-1</sup> )		P (mg l <sup>-1</sup> )	
	Mean	Stdev	Mean	Stdev	Mean	Stdev
Dzivarasekwa	0.04	0.004	0.15	0.07	0.24	0.08
Marlborough	0.27	0.15	0.25	0.28	0.36	0.06
Monavale	0.22	0.16	0.06	0.01	0.28	0.03
Vainona	0.04	0.01	0.05	0.02	0.36	0.04
Mabvuku	0.04	0.02	0.09	0.06	0.41	0.11
UZ	0.05	0.01	0.07	0.03	0.32	0.06
Tynwald	0.07	0.01	0.21	0.26	0.34	0.06
Eastlea	0.05	0.01	0.16	0.05	0.32	0.11
Mukuvisi railway	0.03	0.00	0.09	0.06	0.20	0.09
Houghton Park	0.04	0.01	0.07	0.01	0.31	0.03
Belvedere	0.10	0.16	0.08	0.01	0.30	0.01
Prospect	0.04	0.01	0.06	0.02	0.29	0.06

Table 4.2: Kruskal-Wallis ANOVA tests for significant differences in *T. latifolia* plant nutrient content at 12 wetland sites of Harare. Significance was tested at  $p < 0.05$ .

Variable	H value	P value	Mann-Whitney post-hoc analysis p-value
P	17.7	0.0875	0.09
N	21.2	0.0312	<0.001
C	18.5	0.0690	0.07

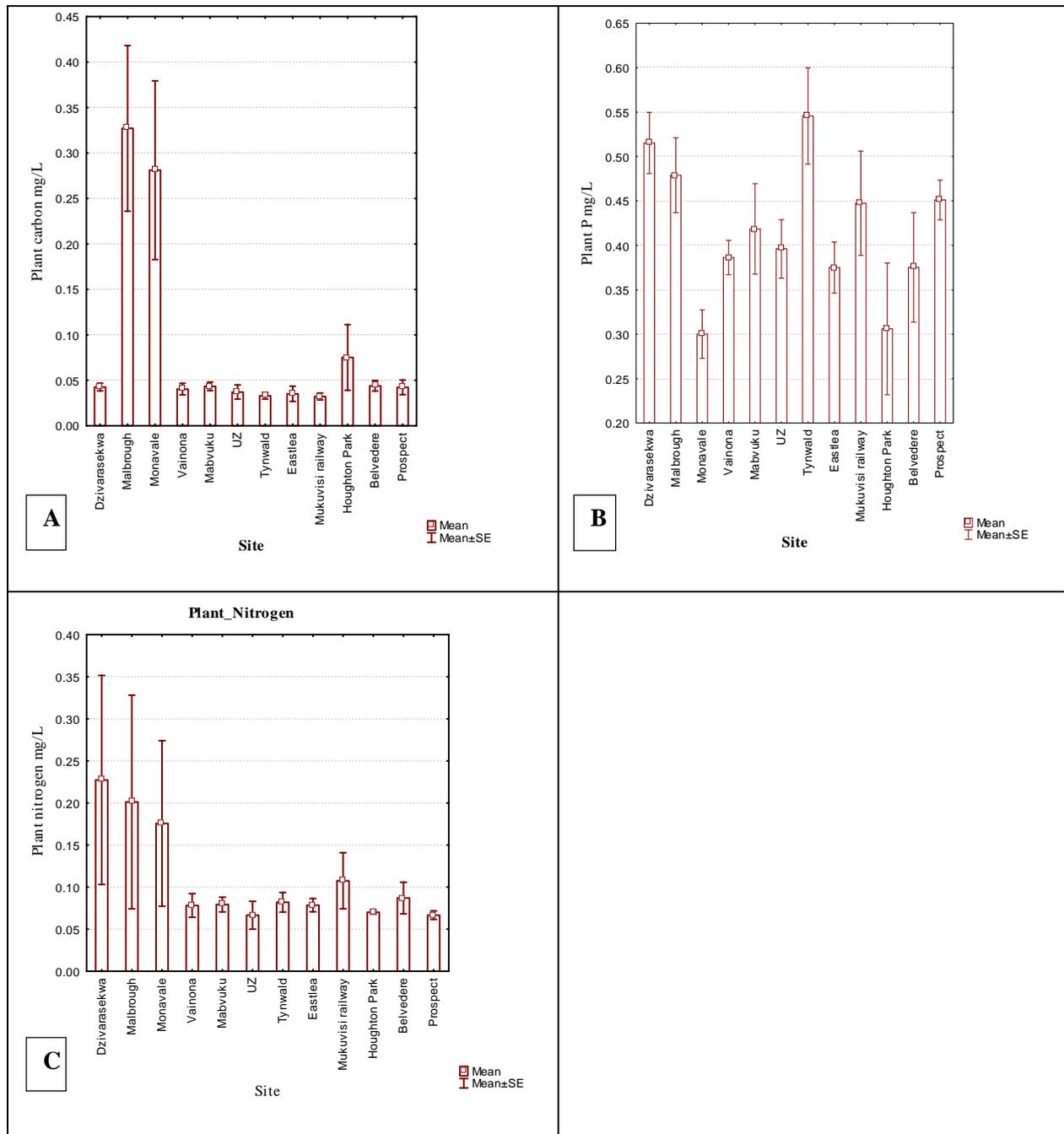


Figure 4.1: Means of *T. latifolia* plant nutrient contents, (a) carbon, (b) phosphorus and (c) nitrogen from different wetland sites of Harare

#### 4.5: Relationship between plant nutrient content of *T. latifolia* and soil nutrient status

Table 4.3 summarises the results of the Redundancy Analysis (RDA) of the associations between the measured plant nutrients and soil nutrients at twelve wetland sites. Using forward selection (Monte-Carlo permutations), the study identified soil carbon (F ratio =12.347, p = 0.002) and soil nitrogen (F ratio =4.660, p = 0.018) as significant environmental variables that explain plant nutrient contents.

Table 4.3: Summary results of RDA analysis of the relations between plant and soil nutrient contents

Variables	Trace	F-ratio	P-value
Both variables together (Soil N & Soil C)	0.208	9.081	0.002
Soil nitrogen	0.062	4.660	0.018
Soil carbon	0.150	12.347	0.002

#### 4.6 Discussion

According to the Redundancy Analysis results, the high soil nitrogen and carbon contents are reflected in the plant nutrient contents. Invasive plants have high absorptive efficiency for nitrogen which is reflective of gross nitrogen mineralisation (Mark, 2011). This accounts for the high nitrogen content in vegetative parts of *T. latifolia*. The primary sources of nitrogen should be surface runoff, incorporation of detrital organic matter, and atmospheric deposition (Prasse, 2015). *T. latifolia* is an emergent wetland plant and has a shallow-root system. It is extremely productive and competitive and grows wherever standing water persists (see Chapter 2). It sequesters carbon from the atmosphere and takes up nutrients from the sediment as it grows, incorporating these components into the plant. It also utilises nitrogen and carbon for their growth and reproduction. In this way, a portion of nutrients in the

water and soil column is transferred to plants (Jacobsen and Lorbeen, 1998). Generally, a higher availability of a nutrient in the soil translates into a greater concentration of that nutrient in the plant (Zhang *et al.*, 2017). In a similar study Jacobsen and Lorbeen (1998) found a strong correlation between nutrient of standing crop (grams nutrient per square meter) and soil parameters. This is not surprising as soil quality/nutrient availability is a component of standing crop nutrient measurement (Fitch *et al.*, 2009).

Significant differences in means of nitrogen concentrations in both the soil (see Chapter 3) and vegetative parts amongst the 12 sites were observed. Nitrogen is a major nutrient requirement for plant growth, and is acquired from the soil through roots (Fitch *et al.*, 2009). Most invasive plants are known to thrive in habitats rich in nitrogen, i.e., they prefer to invest in nitrogen uptake and utilisation (Hawkes *et al.*, 2005). Nitrogen is usually obtained from the soil through plant roots, but many factors can affect the efficiency of nitrogen acquisition. First, the chemistry and composition of certain soils can make it harder for plants to absorb nitrogen. It may not be available in certain soils, or may be present in forms that the plants cannot use. Soil properties like water content, pH, and compaction may exacerbate acquisition of nitrogen in certain soils (Hawkes *et al.*, 2005).

There were no significant differences in phosphorus and carbon contents of *T. latifolia* vegetative material from the twelve wetlands sites. The soils in the 12 wetlands were also similar with respect to phosphorus and carbon. This can be partly explained by the fact that wetlands act as natural sponges which remove and process organic and inorganic materials from water and sediments and help prevent eutrophication by absorbing excess nutrients like phosphorus (Fitch *et al.*, 2009). They store these elements within the litter, sediment and plants (Hawkes *et al.*, 2005) thus explaining similarities in nutrients in plant vegetative parts of *T. latifolia* in the wetlands under study.

In conclusion nutrient contents of vegetative parts of *T. latifolia* were not indicative of soil nutrient status of the different wetland sites occupied by the species, a fact that can be attributed general similarities in moisture content, phosphorus and carbon in the twelve wetlands. This indicates that the invasion is very recent such that *T. latifolia* has not yet altered edaphic attributes to enhance its own competitiveness.

## CHAPTER FIVE

### 5 GENERAL SYNTHESIS

#### 5.1 Overall synthesis of the findings

The primary objective of the present study was to determine the extent and rate of invasion of *T. latifolia* in wetland areas of Harare, and establish conditions that favour its occupancy and dominance. *T. latifolia* distribution, its extent and rate of invasion on wetland sites of Harare was determined. A significant change in *T. latifolia* patch sizes over a 10 year period in the largest three wetland sites, namely Prospect, Monavale and Tynwald, was observed. The area covered by *T. latifolia* increased by 93%, 72% and 87% in Monavale, Prospect and Tynwald, respectively. *T. latifolia* spreads rapidly via underground rhizomes, and can dominate sites with up to 90 % cover (Lishawa *et al.*, 2015). The predicted species distribution model showed that *T. latifolia* was responsive to pH, phosphorus and carbon, and its distribution would be confined to watercourses. Dense *Typha* stands are associated with eutrophic systems (Jespersen *et al.*, 2017), and Harare wetlands are providing an ideal niche because they are known to be highly eutrophic mainly because of the anthropogenic activities which include sewage discharge, urban agriculture and refuse dumping. These activities increase nutrient loading in the wetlands thereby increasing the likelihood of *T. latifolia* occurrence. Mapping of its invasion dynamics through GIS based historical imagery is a low-cost approach that can be used to further understand its invasion ecology within Harare wetlands. The traditional aerial photography interpretation methods utilized in this study proved to be highly accurate for determining its extent over a period of 10 years.

*T. latifolia* morphological attributes measured during the study did not exhibit a pattern that suggests that morphological plasticity as a driver for *T. latifolia* invasion in the twelve wetlands under study. The initial assumption was that the wetlands were of different eutrophic

status. This was proved contrary. Instead, the twelve wetlands soils only differed with respect to pH and nitrogen, but had similar levels of percentage moisture, phosphorus and carbon. Thus understandably *T. latifolia* only exhibited slight differences in variability of the plant growth characteristics, probably responding to minor localised heterogeneity of edaphic conditions. The results showed significant relationships between nitrogen and shoot height. Significant relationships among pH, soil moisture content, carbon and shoot height, shoot diameter and number of leaves was observed in most of the wetlands. *Typha* has a wide degree of environmental tolerance, and can grow under a variety of substratum types, primarily pH and soil moisture levels (Lishawa *et al.*, 2015). For this reason, it is unlikely that these factors would influence the morphological plasticity of the plants. Although nutrient availability plays an important role in plant growth, as most of the wetlands visited were similarly nutrient enriched, it was difficult to evaluate the effect of differences in trophic status on plant morphology. It can be inferred that nutrient rich surface affluent waters discharged into Harare wetlands have altered the nutrient content of wetland soils as they primarily discharge into downstream reservoirs.

This study also investigated whether nutrient concentrations in vegetative parts of *T. latifolia* reflects soil nutrient availability. Only soil carbon and nitrogen were identified to be significant environmental variables that explain nutrient concentrations in vegetative parts of *T. latifolia*. Previous studies have shown that plant nutrient content can be used as effective indicators of soil nutrient availability (Roy-Bolduc, 2016). In this study, vegetative parts did not clearly reflect soil nutrient availability, a fact that can be attributed to similarities in edaphic characteristics among sites and recent invasion of *T. latifolia*.

## **5.2 Prediction of future invasion pattern**

Variables which have been implicated in enhancing the encroachment problems of *T. latifolia* elsewhere in the world include increased water depth, constant water level or a reduction in water level fluctuations and high nutrient levels or increase in nutrient supply, particularly of nitrogen and phosphorus (Simba *et al.*, 2013). A Species Distribution Model (SDM) based on maximum entropy theory was developed to predict the existence and potential spread of *T. latifolia* in Harare wetland environs. The results presented in Chapter 2 support observations that water level stability and availability influences the establishment and potential spread of *T. latifolia* in Harare, showing that expansion of *Typha* stands is presently largely governed by the water availability.

## **5.3 Management and control strategies**

Encroachment and development of mono-specific *Typha* stands can be reduced by creating an environment in which *Typha* growth is stressed. Studies performed in other parts of the world, have shown that the creation of germination sites, water stabilisation and eutrophication are three factors which promote invasion and encroachment (Fitch *et al.*, 2009; Chen *et al.*, 2012; Simba *et al.*, 2013; Roy-Bolduc 2016). Their elimination should therefore inhibit these processes.

Leaving a community of *Typha* stands to develop to its full potential increases the subsequent cost of control as well as problems associated with the plant stands. *Typha* alters wetland functions in ways that promote its own invasion (Farrer & Goldberg 2014). Early identification and treatment of potential problem areas is recommended. Wetland managers should be made aware that *Typha* is not indigenous. It decimates native plant communities and alters the organic content of wetland soils (Martina *et al.*, 2016), and should be controlled in areas where dense stands are undesirable as soon as shoots appear.

#### **5.4 Conclusion and recommendations**

*Typha latifolia* is indeed encroaching into most of the wetlands of Harare with the major contributing factor being pH, soil moisture, nitrogen and carbon. The use of environmental variable data and species presence data under GIS application can enable researchers to generate invasive species distribution models with longer historical perspective and higher temporal resolution than is possible from aerial imagery alone. This approach can provide a wealth of high-resolution data about relatively recent invasions by wetland macrophytes. The information can improve the understanding of invasion dynamics of a species, thereby enhancing the spatial and temporal scope of invasive species research and management.

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