Ecological restoration of papyrus wetlands at Lake Naivasha, Kenya: social and ecological considerations

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by

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Abstract

Papyrus swamps form ecological buffer zones at the land-water interface, protecting lake shallows from sedimentation and reducing the risk of eutrophication in open water. Many communities living near papyrus swamps, particularly in East Africa, derive socioeconomic benefits from these highly productive ecosystems. Loss of the buffering capacity of papyrus at Lake Naivasha, Kenya, explains much of the observed increase in the lake's trophic state. Multiple authors have called for Naivasha's wetlands to be restored; however, the social and ecological factors that would need to be considered before doing so have received insufficient attention. Case studies of recent restoration programmes at Lake Victoria illustrate the means by which degraded wetlands can be rehabilitated. Analysis of attitudes towards papyrus at Lake Naivasha reveals a general lack of awareness surrounding the benefits of local wetlands, forming a potential barrier to successful restoration there. An assessment of the lake's riparian zone demonstrates that both anthropogenic and natural pressures present significant challenges for the survival of lake-fringing wetlands, highlighting changes that have occurred within the ecosystem over the last few decades. Potential means of addressing both the social and ecological limitations to papyrus restoration are offered, with explicit linkages to the benefits of doing so made clear. Floating islands are shown to be the most appropriate reference for ecological restoration at Lake Naivasha, which can be replicated through artificial technology. The establishment of a consumptive use value for harvested papyrus at Naivasha would help to raise stakeholders' awareness of wetlands; a novel means of producing biomass briquettes was met with positive responses from local residents and may be used to encourage community participation in restoration. A vision for wise use of this internationally renowned Ramsar site is set out, with recommendations made as to how papyrus wetlands could be managed sustainably over the long term.

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Contents

Acronyms

AFI	Artificial Floating Island
BMU	Beach Management Unit
CERP	Comprehensive Everglades Restoration Plan
CUV	Consumptive Use Value
EAA	Everglades Agricultural Area
GRN	Global Restoration Network
HELP	Hydrology for the Environment, Life and Policy
ITCZ	Intertropical Convergence Zone
KWS	Kenya Wildlife Service
LNGG	Lake Naivasha Growers' Group
LNRA	Lake Naivasha Riparian Association
MA	Millenium Ecosystem Assessment
MIT	Massachusetts Institute of Technology
NEA	National Ecosystem Assessment
OWSHG	Okana Wetland Self-Help Group
PES	Payment for Environmental Services
RQ	Research Question
SER	Society for Ecological Restoration International
SQS	Site Quality Score
TEK	Traditional Ecological Knowledge
TN	Total Nitrogen
TOKS	Table of Known Services
TP	Total Phosphorus
TQ	Thesis Question
UNESCO	United Nations Educational, Scientific and Cultural Organization
VIRED	Victoria Institute for Research on Environment and Development
WHO	World Health Organization
WRMA	Water Resources Management Authority
WTP	Willingness To Pay

The endemic papyrus gonolek, *Laniarius mufumbiri* (from Mwinami et al. 2010, used with permission).

Chapter 1. Introduction

Chapter 1. Introduction

1.1. Outline

Natural resources, particularly vegetation found in local environments, are increasingly recognised for their contributions to rural livelihoods in Africa and beyond (Rönnbäck et al. 2007; Shackleton et al. 2008; Lannas and Turpie 2009; Little and Lara 2010; Adekola and Mitchell 2011; Terer et al. 2012; Khan et al. 2013).

Cyperus papyrus, L. (hereafter 'papyrus') is no exception. The increasing number of publications on papyrus swamps[1] in recent years (Owino and Ryan 2007; Kiwango and Wolanski 2008; Morrison and Harper 2009; Osumba et al. 2010; van Dam et al. 2011; Saunders et al. 2012; Kiwango et al. 2013) reflects a resurgence of interest from natural and social scientists into the role that these wetlands play in maintaining the health of aquatic ecosystems and supporting the livelihoods of local communities.

Of particular interest are the multiple ecosystem services that are produced from well-functioning papyrus swamps (Morrison and Harper 2009) and the potential consequences of their loss for communities who are dependent upon them (Maclean et al. 2011). Only very recently have researchers begun to examine the value of ecological restoration as a response to the degradation of papyrus swamps in East Africa (van Dam et al. 2011; Kiwango et al. 2013).

This thesis seeks to identify and analyse the social and ecological factors that will be critical to the successful restoration and sustainable management of wetlands at Lake Naivasha in Kenya. Lake Naivasha was a declared a Ramsar site in 1995 (Harper et al. 2011), a 'Wetland of International Importance' as designated by the Ramsar Convention on Wetlands (Ramsar, Iran, 1971). Despite having won the Ramsar Conservation Award in 1999 (Ramsar 1999), which saw Naivasha heralded internationally as an early example of successful community-based management of a Ramsar site, the principles of 'wise use' of wetland resources are not yet evident (Harper et al. 2011).

'Wise use' of Ramsar sites is defined as:

[1] Papyrus wetlands are generally referred to as 'swamps' in East Africa (Thompson 1976); the two terms are used interchangeably throughout this thesis.

"the maintenance of their ecological character, achieved through the implementation of ecosystem approaches, within the context of sustainable development" (Ramsar 2010, p.16).

The 'ecological character' of Ramsar sites refers to:

"the combination of the ecosystem components, processes and benefits/services that characterise the wetland at a given point in time" (Ramsar 2010, p.14).

The Ramsar Convention recognises that wetland restoration programmes can lead to favourable human-induced changes in ecological character (Annex to Resolution VI.1, 1996) and are a key aspect of wetland management interventions (Ramsar 2010). Kenya does not yet, however, have a management plan for the 'wise use' of wetlands at Lake Naivasha that has been agreed upon by all stakeholders (Harper et al. 2011). A commitment to formulating a management plan with the involvement and input of all stakeholders has been made by Kenya as a Contracting Party to the Convention (Ramsar 2010) and is critical to Lake Naivasha's continued designation as a Ramsar site.

The overall objective of this thesis is therefore to address the question:

How can wise use of wetlands at Lake Naivasha be achieved?

Repeated calls have been made for the ecological restoration of papyrus wetlands at Lake Naivasha (Zalewski and Harpr 2001; Hickley et al. 2004; Morrison and Harper 2009), an action that is regarded as critical to the future sustainability and wise use of the ecosystem (Jones and Humphries 2001); however, as yet, a nuanced understanding of the ecological and social limitations to restoration is lacking. The primary objective above is thus informed by a secondary objective, forming the focus of empirical research conducted in this thesis, which seeks to address the question:

What is the potential for restoration of Lake Naivasha's papyrus wetlands?

This question is drawn from guidance provided by Ramsar (2010b), which outlines criteria necessary to describe in detail the ecological character of wetlands, towards designing management plans for the wise use of Ramsar sites. Seven criteria for evaluating features of the ecological character of wetlands are listed; data pertaining to the first 6 of these (size;

biological diversity; naturalness; rarity; fragility; typicalness) were included as part of the original designation of Lake Naivasha as a Ramsar Site in 1995 (S. Higgins, personal communication). The final criterion, *"Potential for improvement and/or restoration"* (Ramsar 2010b, p.38), has been added since that time and remains to be addressed.

Ramsar (2010) recognises that, beyond 'ecological character',

"most sites will contain other features of equal importance, for example, cultural, socio-economic, geological and geomorphological features, landscape and palaeo-environmental features. It is important that these features be given appropriate attention… evaluation should focus on the values and functions, goods and services provided by the wetland in support of human well-being and on the presence of cultural features" (Ramsar 2010b, pp. 38–39).

This thesis correspondingly takes an interdisciplinary approach – using methods employed by natural scientists, social scientists and economists – to address its main objectives, responses to which frequently oscillate between human and environmental perspectives.

The objectives above are addressed using 5 thesis questions (TQs), which guide the research:

- Why should papyrus wetlands at Lake Naivasha be restored from a sociological perspective? (**TQ1**)
- What are the key social factors at Lake Naivasha that might hinder successful wetland restoration? (**TQ2**)
- Why should papyrus wetlands at Lake Naivasha be restored from an ecological perspective? (**TQ3**)
- What are the key ecological factors at Lake Naivasha that might hinder successful wetland restoration? (**TQ4**)
- How can the successful restoration and sustainable management of wetlands at Lake Naivasha be achieved? (**TQ5**)

Chapter 2 provides a review of relevant literature and sets out the case for ecological restoration at Lake Naivasha; a recognition of previous shortcomings helps to guide the thesis by identifying a number of knowledge gaps to be addressed by the research.

Chapter 3 sets out the different methods employed, corresponding to a total of 25 research questions (RQs), which are used to address the 5 thesis questions. Responses to TQs 1+2 are presented in Chapter 4; responses to RQs 3+4 in Chapter 5 and to RQ 5 in Chapter 6.

Chapter 4 examines the key social factors to be considered in the restoration of papyrus wetlands: Part 1 investigates the use, misuse and rehabilitation of papyrus by local communities around Lake Victoria; Part 2 forms a comparative analysis with local communities at Lake Naivasha, analysing stakeholder perceptions of wetland services at and between the two lakes.

Chapter 5 examines the key ecological factors to be considered in the restoration of papyrus wetlands: Part 1 quantifies the productivity and nutrient uptake capacity of wetlands at Lake Naivasha; Part 2 describes in detail the plant communities of Naivasha's riparian zone and identifies the nature and extent of current impacts on wetland development around the lake.

Chapter 6 draws on the findings of preceding chapters and presents the results of two shorter studies; together these reveal how the data collected during this thesis could be used to guide the successful reinstatement of wetlands at Naivasha, with recommendations as to how they might be sustainably managed using existing community institutions and concepts.

Chapter 7 provides a concise summary of the key findings as they relate to the main thesis objectives, as well as some reflections on the nature of interdisciplinary research.

1.2. Study areas

The research presented herein takes as its focus Lake Naivasha, but makes frequent reference to Kenya's Lake Victoria region (Fig. 1.1). During an initial visit to Lake Naivasha, it quickly became apparent that minimal interactions between local communities and wetlands were occurring (E. Morrison, personal observation). Lake Victoria was chosen since earlier studies (e.g. Balirwa 1995; Gichukki et al. 2001) indicated that local communities there use papyrus wetlands to support their livelihoods; generating a detailed understanding of this was deemed critical to defining what 'wise use' (Ramsar 2010) of papyrus at Naivasha might therefore entail. Both sites are described according to their defining characteristics below.

Lake Naivasha (0° 45' S, 36° 20' E) is Kenya's second largest freshwater body (surface area c. 140 km^2, max. depth c. 8 m) lying at an elevation of 1,890 m above sea level (m.a.s.l.) in the Rift Valley province, with a surrounding catchment area of around 2,150 km^2 (Harper et al. 2011). The lake is unusual in being one of only two freshwater bodies (the other being Lake Nakuru to the north: Fig. 1.1) in a system of otherwise alkaline-soda lakes (Harper and Mavuti 2004), making it an extremely valuable resource for humans and wildlife in this semi-arid region of Kenya (Morrison and Harper 2009). This freshwater system is used for drinking, washing and livestock watering by >600,000 people (Kenya National Bureau of Statistics, KNBS 2012) living throughout the Naivasha catchment. The lake water also supports a geothermal power plant (generating c. 15% of Kenya's total output, projected to rise to c. 39% by 2014: Afara Global 2012) and supplies the irrigation needs of a commercial vegetable and flower growing industry. The latter is Kenya's top foreign-exchange earner and makes the Lake Naivasha ecosystem a critical component of the national economy (Harper et al. 2011). The extent of papyrus wetlands throughout the entire catchment was estimated at 17.7 km^2 in 2006 (Onywere et al. 2012), although the size of wetlands within the main lake is known to vary considerably over time and has generally exhibited a downward trend since the mid-1970s (Harper et al. 1995; Boar et al. 1999; Boar 2006; Morrison and Harper 2009).

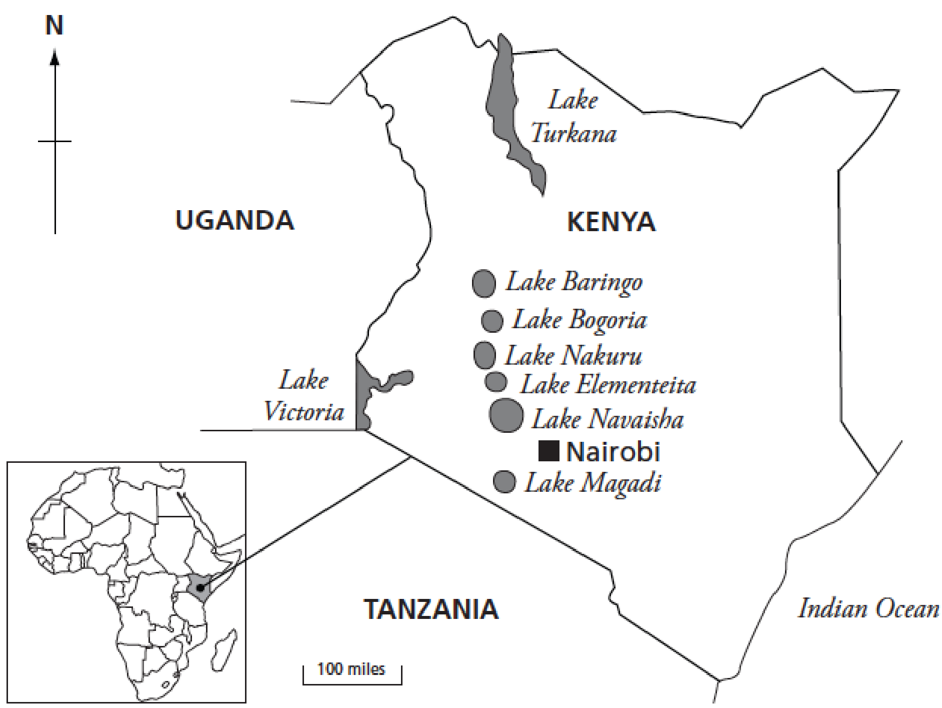

Fig. 1.1. Kenya and the lakes of the Rift Valley (from Harper et al. 2011, used with permission).

Lake Victoria (1° 0' S, 33°, 0' E) is the world's second largest freshwater body (surface area c. 68,500 km^2, max. depth c. 84 m) lying at an altitude of 1,133 m.a.s.l., with a surrounding catchment area of some 185,000 km^2 (Balirwa 1995). The Kenyan part of Lake Victoria, roughly 6% of its total surface area, fringes Nyanza province with a population of around 5 million people (KNBS 2012). In addition to fishing (the principal source of protein for the region's population), subsistence agriculture and local craft industries, Nyanza's natural resources support textile and paper mills, sugar refineries, leather tanneries, cement plants and agrochemical factories (Kairu 2001; Loiselle et al. 2006). The spatial extent of papyrus growing along the entire (international) shoreline of Lake Victoria has yet to be satisfactorily determined, although wetlands found within the Kenyan portion of the lake are known to be appreciably larger than those at Lake Naivasha; one site, the Nyando wetland, has between 30–50 km^2 of papyrus alone (van Dam et al. 2011).

Despite differences in scale and economic functions, both lakes depend on papyrus wetlands to help regulate the health of the aquatic environment and provide essential ecosystem services to local, regional and international populations (Harper et al. 1990; Harper et al. 2002; Loiselle et al. 2006; Odada et al. 2009; Harper et al. 2011) as described in detail in the following sections.

Chapter 2. Literature review

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2.1. Ecological restoration

Ecological restoration is "the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed" (Society for Ecological Restoration International, SER 2004, p.3). The practice of doing so has arguably existed in one form or another for centuries, yet the concept has only recently begun to receive widespread attention as a potential means of integrating the social, economic and cultural aspects of our use of natural resources (Palmer et al. 2006; Comin 2010). Restoration activities are typically targeted towards the improvement of degraded ecosystems, but they are ultimately conducted to fulfil society's wider (ecological, socioeconomic, cultural and personal) values (Clewell 2000).

It is an inherently dynamic field, yet its practitioners are unified by published definitions of terms and concepts (SER 2004) and evolving guidelines on best practices (Clewell et al. 2005; Clewell and Aronson 2007, 2013). The applied aspects of ecological restoration are supported by a scientific foundation in its sister discipline of restoration ecology, which ideally provides clear concepts, models and methodologies to support the practice of restoration (Howell et al. 2011). Restoration projects to date have been directed towards many different ecosystem types around the world, including pine savannas in southeastern USA (Cox et al. 2004); temperate forests in Chile (Little and Lara 2010); Mediterranean steppe in France (Jaunatre et al. 2012); *shola* grasslands in India (Srinivasan 2012); subtropical thickets in South Africa (Mills and Cowling 2006) and tropical rainforests in Brazil (Brancalion et al. 2012). Until very recently, however, little attention (cf. Kiwango et al. 2013) has been paid to the restoration of papyrus wetlands in East Africa.

One of the largest ecological restoration efforts to date has centred on the degradation of the Florida Everglades in the southeastern USA (Maltby 2009). The Everglades were once a vast wetland (34,000 km^2: Mitsch and Gosselink 2011) with extremely low nutrient levels (phosphorus concentrations <.01 mg P l^{-1}: Keddy 2010). A steady flow of water produced a distinctive sedge-dominated plant community adapted to wet, infertile conditions, characterised by sawgrass, *Cladium jamaicense* (Sklar et al. 2005). Humans have heavily impacted the region since the mid-twentieth century; the construction of canals in the 1960s, intended to drain the Everglades and supply water to Florida's rapidly expanding cities, drastically altered the hydrology of the wetlands (Mitsch and Gosselink 2011). At the same time, the sugar cane industry began to exploit the Everglades' freshwater; intensive agriculture led to increasing nutrient loads entering the wetlands, which in turn caused the replacement of native sawgrass with plant communities dominated by invasive species such as cattail, *Typha domingensis* (Keddy 2010). Almost half of the original Everglades have now been lost to the expansion of the Everglades Agricultural Area (EAA) to the north and urban development to the south (Light and Dineen 1994). The changes caused by human impacts on the Everglades include a reduction in the spatial extent of wetlands, lower water levels, an increased frequency of droughts, a 90% decline in water birds, increasing populations of exotic species and a reduction in characteristic landscape features such as islands of *Cypress* trees (Keddy 2010).

The Comprehensive Everglades Restoration Plan (CERP), involving all major federal and state environmental organisations, as well as the US Army Corps of Engineers, aims to address, *inter alia*: nutrient loading from agricultural runoff (with a specific aim of reducing the phosphorus concentrations within the Everglades to <.01 mg P l^{-1} inside 'stormwater treatment areas'); loss and fragmentation of different habitats caused by urban and agricultural development; the spread of *Typha* and other invasives and hydrological changes caused by drainage and river channelization (Maltby 2009). At the same time as reducing environmental degradation, restoration efforts must provide for access and restoration, accommodate the multiple uses of conservation areas, support and maintain the EAA and meet the demands of an increasing human population (Oyola-Yemaiel 1999). Overall, the CERP is projected to cost over $8 billion, with work planned for the next 20 years or more (Mitsch and Gosselink 2011).

The success of ecological restoration projects such as the CERP is often qualified by increases in biodiversity and the provision of ecosystem services (Aronson et al. 2007). A meta-analysis by Benayas et al. (2009) of 89 project reports published prior to 2008 found that, whilst restoration actions increased biodiversity and ecosystem services across the different projects by an average of 44 and 25% respectively, values remained lower in restored versus intact reference ecosystems. Of particular relevance to this thesis was an additional finding that only 3 of the 89 projects had attempted to address eutrophication in water bodies, each of which focused on only one ecosystem service (nutrient removal) at the expense of many others (e.g. harvesting of plant fibre, fisheries support, aesthetic qualities) (Benayas et al. 2009). The authors maintained, however, that ecological restoration offers the potential of a 'win-win' solution in terms of combining conservation goals with socioeconomic development objectives. A separate meta-analysis suggested that this is rarely the case; Aronson et al. (2010)

analysed 1,582 reports on the results of restoration projects published from 2000–2008 and found that only c. 3% of these explicitly addressed the socioeconomic outcomes (or lack thereof) of the restoration actions taken. A significant gap that was identified was the paucity of these reports that devoted resources to interviewing people, as well as a failure to make clear the evidence of the benefits of restoration as a worthwhile investment for local communities (Aronson et al. 2010).

When local communities are excluded from restoration projects, questions as to whether an ecosystem should even be the subject of restoration may unexpectedly arise, contrary to the expectations of those advocating for it. Shore (1997) described a project in suburban Chicago designed to restore remnants of degraded prairie grasslands. An unforeseen 'public relations disaster' led to angry protests from neighbouring landowners, who felt that they had not been informed about the project and its objectives or who otherwise opposed the restoration methods being used. The project was abruptly brought to a halt, to the collective disbelief of thousands of long-term volunteers, through the issuing of a politically motivated moratorium on all restoration activities (Shore 1997). A more recent study into the restoration of pine forests in the southwestern United States identified related social conflicts over restoration 'meanings and values' across multiple projects, as well as insufficient funding and a lack of accounting for benefits of projects lacking a market value (Hjerpe et al. 2009).

Similar conflicts of interest emerged in response to the CERP: the indigenous Miccosukee tribe, for example, claimed that their livelihoods within the Everglades were threatened by the increasing number of uses made of the wetlands; land developers, seeking to construct properties on the margins of the Everglades, raised concerns about restrictions imposed upon them in the form of permit limitations; utilities companies demanded assurances from the CERP concerning water supplies to urban areas and raised issues of flood protection (Oyola-Yemaiel 1999). Those planning and managing restoration projects therefore face the complex task of attempting to satisfy the oft-competing needs and interests of different groups, whilst at the same time striving to improve environmental conditions (Comin 2010).

The engagement of local stakeholders from the very beginning of restoration projects has, for many years, been considered paramount to their long-term success (Clewell et al. 2005); However, the concept of explicitly linking restoration activities to their immediate beneficiaries (i.e. local communities) has only recently entered the science and practice of ecological restoration (Goldstein et al. 2008; Galatowitsch 2009; Aronson et al. 2010; Clewell and Aronson 2013). A recent meta-analysis suggests that the restoration community is now beginning to take heed of its earlier shortcomings concerning stakeholder engagement. Hallett et al. (2013) examined a total of 203 reports on restoration projects conducted in 54 countries published within SER's 'Global Restoration Network' (GRN 2013) up to May 2012. Almost 60% of these projects discussed goals related to social values, which variously included: (1) the economic potential of restoration; (2) educational outreach opportunities; (3) community engagement in restoration activities; (4) governance issues arising from project results and (5) cultural values associated with the restored ecosystem (Hallett et al. 2013). Looking more closely at the reports, however, only around 25% examined elements of (1), (2) and (3) and less than 10% addressed social goals related to (4) and (5) (GRN 2013).

Thus, on the one hand, the inclusion of social goals in the majority of GRN projects suggests that practitioners are increasingly aware that social and ecological systems are interlinked (Hallett et al. 2013). On the other hand, however, the paucity of projects explicitly linking restoration objectives to issues of governance and, in particular, the lack of restoration objectives derived from an analysis of cultural values, implies that significant gaps need to be addressed before the field can be considered an "elixir to resolve socioeconomic problems", as has previously been claimed (Clewell and Aronson 2007, p.5). This is of particular relevance to restoration programmes within Ramsar sites, such as Lake Naivasha, where efforts to improve the ecological character of wetlands must occur alongside 'wise use' by the stakeholder community, with the socioeconomic benefits of doing so established from the outset (Ramsar 2010, 2010b, 2010c). Despite the shortcomings outlined above, the contributions of ecological restoration are increasingly widely recognised, particularly for its potential to reinstate the delivery of ecosystem services from degraded sites (Benayas et al. 2009; Comin 2010; Woodworth 2013).

2.2. Ecosystem Services

The Millennium Ecosystem Assessment (MA) defined ecosystem services as "the benefits people obtain from ecosystems" (MA 2005, p.49) and divided these into 4 categories: supporting, regulating, provisioning and cultural ecosystem services. Supporting services essentially underwrite all others; examples of these foundational processes include nutrient cycling, water cycling and soil formation. Examples of regulating services include climate regulation, water purification and pollination. Provisioning services can be thought of as the material benefits or products obtained directly from ecosystems, including food, fibre and fuel. Cultural services are conversely the non-material benefits derived from healthy ecosystems, which include spiritual and religious values, aesthetic qualities and recreational values (MA 2005).

The MA (2005) classification is deliberately general, insofar as it was aimed at promoting public understanding about the services and benefits that well-functioning ecosystems provide to humans (Costanza et al. 1997; Daily 1997). Turner et al. (2011) argued that, whilst it provides a useful context for discussion, the MA (2005) definition falls short of an 'operative definition' that would allow for more meaningful comparisons to be made across different scenarios. Turner et al. (2011) proposed an alternative, more functional definition of ecosystem services, drawing on the work of environmental economists such as Boyd and Banzhaf (2007) and Wallace (2007), as "the aspects of ecosystems consumed and/or utilized to produce human well-being" (Turner et al. 2011, p.5).

There may be no single classification system appropriate for use in all cases (Fisher et al. 2009). However, the definition of Turner et al. (2011) is used in this thesis in relation to papyrus swamps in East Africa, where links between 'consumption' of the biotic and abiotic components of wetlands and improved local livelihoods are well documented (Bugenyi 2001; Gichuki et al. 2001; Maclean et al. 2003; Loiselle et al. 2006; Maclean et al. 2011; Kiwango et al. 2013). The MA (2005) classification nevertheless remains instructive in its ability to convey the complexity of ecosystem characteristics within 4 easily understood categories. Papyrus wetlands produce ecosystem services within each of these, e.g. biodiversity (supporting); water purification (regulating); plant fibre (provisioning) and wildlife tourism (cultural), as set out in further detail below.

Whilst scientists and policy-makers are increasingly applying the concept of ecosystem services to ecological restoration, the demand for ecosystem services (i.e. the needs of beneficiaries) and the relative ranking of different services by local communities have received only limited attention (Lamarque et al. 2011). Consulting communities on proposed restoration projects is crucial if one is to understand people's perceptions, values and needs in relation to the ecosystem being restored (Johnson and Pflugh 2008; Menzel and Teng 2009). Few studies, however, have explicitly addressed the identification or perception of different ecosystem services by local stakeholders (cf. O'Farrell et al. 2007; de Chazal et al. 2008; Pieroni and Giusti 2009; Quétier et al. 2010; Lamarque et al. 2011; van Riper et al. 2012; Hutchinson et al.

2013) and only one study has thus far attempted to investigate people's perceptions of papyrus wetlands specifically (Bikangaga et al. 2007).

2.3. Ecology of papyrus

Papyrus, an emergent macrophyte, is a giant member of the sedge family (reaching 10 m at high altitude sites: Thompson et al. 1979). It typically out-competes coexisting wetland species, forming vast monotypic swamps in wet parts of central, eastern and southern Africa (van Dam et al. 2011). Papyrus wetlands in Kenya occur along the shores of Lake Victoria (Balirwa 1995), around the inflowing rivers of Lake Naivasha (Harper 1992) and within smaller freshwater bodies of the Rift Valley (Terer et al. 2012).

Fig. 2.1. Papyrus swamp at Lake Naivasha, Kenya (photo: E. Morrison)

Papyrus swamps (Fig. 2.1) form ecological buffer zones at the land-water interface, protecting lake shallows from sedimentation (Kansiime et al. 2007) and allowing excess nutrients arriving from the catchment to be efficiently assimilated and recycled into plant biomass (Gaudet 1977), thereby reducing the risk of eutrophication in open water (Hickley et al. 2004). Jones and Muthuri (1997) calculated the net primary productivity of a papyrus swamp at Lake Naivasha to be >6 kg dry weight m^{-2} yr^{-1}, making it one of the most productive natural ecosystems on record.

High productivity in papyrus wetlands is supported by a number of characteristics, including: utilisation of the efficient C_4 photosynthetic pathway (Jones and Milburn 1978); a closed canopy structure intercepting >90% of photosynthetically active radiation (Jones and Muthuri 1985) and a high nutrient use efficiency (Boar 2006). The presence of C_4 photosynthesis is unexpected in wetlands, being a trait more often associated with vegetation growing in hot and dry environments (Doliner and Joliffe 1979). Indeed, papyrus is one of a very small group of freshwater emergent macrophytes that possess the C_4 pathway (Jones and Muthuri 1984), whose highly efficient use of radiation, water and nitrogen is considered to have a significant impact on the functioning of ecosystems in which they occur (Knapp and Medina 1999).

Much research on papyrus over the last 30 years (e.g. Gaudet 1977; Thompson et al. 1979; Jones and Muthuri 1984; Jones 1987; Harper 1992; Boar et al. 1999; Jones and Humphries 2002; van Dam et al. 2007) has explored in great detail the ecology of these wetlands in relation to processes operating within the freshwater ecosystems of which they are a functional component. Comparatively few socioeconomic studies (cf. Gichuki et al. 2001; Maclean et al. 2003; Terer et al. 2012) have been made, on the other hand, with the studies that do exist rarely examining the context and drivers of local papyrus use and knowledge.

2.4. Human interactions with papyrus

Papyrus forms a readily renewable source of plant fibre because it is fast growing and high yielding, something upon which humans have long capitalized since ancient Egyptians began to make the first forms of paper c. 5,000 years ago (Bell and Skeat 1935). Today, many communities living near papyrus swamps, particularly in East Africa, continue to derive socioeconomic benefits from these highly productive ecosystems. Stems are harvested for the production of mats, baskets and furniture (both for subsistence and for sale); the nutritious umbels are fed to livestock during dry periods when grazing opportunities are limited and the wetland habitat as a whole is prized for hunting opportunities and as a store of traditional medicines (Gichuki et al. 2001; Maclean et al. 2003; van Dam et al. 2011; Terer et al. 2012b).

Previous studies have cited the use of papyrus as a domestic fuel by local communities living throughout the plant's geographic range: along the banks of the Nile in times of ancient Egypt (Gaudet 1998); within the Hula wetland of Israel prior to drainage in the 1950s (Cohen-Shacham et al. 2012) and around the shoreline of East Africa's Lake Victoria in the present day (Gichuki et al. 2001). However, being of low density, large volumes of papyrus are required to produce sufficient heat for cooking, a factor that contributes to overharvesting of local wetlands (Owino and Ryan 2007). Furthermore, users complain of the production of excessive amounts of smoke and ash (Maclean et al. 2003), with serious implications for human health.

Jones (1983) outlined attempts to produce biomass 'briquettes' (densified fuel pellets) from papyrus in East Africa. Although a pilot factory was established in Rwanda, the project did not succeed. Precise reasons for this remain unclear, although it appears that insufficient funding and failure to create a product acceptable to potential end-users combined to frustrate the venture. That said, "the time is ripe for another attempt to revive the idea" (M. Jones, pers. comm.): public interest in biofuels is currently high (Cacciatore et al. 2012), whilst the production of wood charcoal, a key driver of deforestation, remains one of the largest sources of domestic energy in East Africa (Arinaitwe et al. 2012). An experiment to produce briquettes made from carbonized papyrus is described in Chapter 3, the results of which are presented in Chapter 6 in relation to wise use of wetlands at Lake Naivasha.

Because of their potential to provide fuel and other products that support local livelihoods, papyrus swamps are often sites of anthropogenic degradation (Gichuki et al. 2001; Owino and Ryan 2007; Maclean et al. 2011). Man-made threats to papyrus swamps arise from: the pressures of population growth (Balirwa 1995); unsustainable rates of harvesting (Osumba et al. 2010); ineffective management strategies (Hartter and Ryan 2010) and drainage in favour of agriculture (Maclean et al. 2011); over the long term they are also likely to suffer from human-mediated climate change (Odada et al. 2009). The future of papyrus swamps in East Africa, as with many other wetland types around the world (Schuyt 2005; Mitsch 2010), is therefore highly uncertain (van Dam et al. 2011; Saunders et al. 2012).

The loss of papyrus around Lake Victoria, for example, has frequently been attributed to over-harvesting and conversion of wetlands to cultivated fields (Balirwa 1995; Kairu 2001; Swallow et al. 2010). Owino and Ryan (2007) recorded nearly 50% habitat loss within 3 important papyrus wetlands of Lake Victoria over 3 decades, as a result of conversion to agriculture, increasing demand for papyrus products and a general lack of clear policy on wetland conservation. Kiwango and Wolanski (2008) concluded that the future state of the lake and the welfare of its human population are both "highly related to the future of its papyrus wetlands" (p.95), prompting the authors to call for certain sites to receive full protection and others to be designated sites of sustainable harvesting. Precisely what constitutes 'sustainable harvesting' of papyrus wetlands is unclear, however.

2.5. Harvesting papyrus

Several authors (Muthuri et al. 1989; Kariuki et al. 2001; Thenya 2006; Osumba et al. 2010) have measured rates of regeneration in papyrus wetlands that have been subjected to experimental harvesting, with estimates of biomass recovery time varying markedly, from 3.5–24 months. Terer et al. (2012b) recently arrived at a minimum recommended harvesting interval of 12 months (i.e. a single annual harvest) based on their research at Lake Naivasha, employing a similar methodology to previous studies, in which all aboveground biomass within experimental plots was completely removed, or 'clear-cut'.

Critically however, previous studies have shown that there are significant differences between different age-classes[2] of papyrus with respect to their relative mineral concentrations (Gaudet 1977b) and contributions to total biomass within a given area (Thompson et al. 1979). Based on this information, clear-cutting approaches (involving removal of all aerial material, irrespective of age-class) to estimates of sustainable harvesting intervals are likely to be flawed, in that:

1. Removing stems of younger age-classes (I and II), which contain higher concentrations of nutrients essential for growth (e.g. N, P) than older (age-classes III and IV) stems (Gaudet 1977b), is likely to reduce the wetland's regenerative capacity and is an exaggeration of 'normal' disturbance conditions.

2. Harvesting all available papyrus fulfils only one of the multiple ecosystem services of these wetlands (i.e. provision of plant fibre), at the expense of many others (e.g. biodiversity support, local climate regulation, aesthetic values, etc.).

[2] The morphology of papyrus swamps is often described with reference to culms (stems) belonging to 4 different 'age-classes'. These are: age-class I (unelongated culms with closed umbels); II (young culms elongate but with umbels just opening); III (mature culms with open umbels) and IV (senescing culms with achlorophyllous umbels) (Gaudet 1977b).

3. Crucially, the approach is unlikely to represent the practices of papyrus harvesters themselves (to whom the results of regeneration experiments are nominally directed), who are more likely to remove only tall, mature stems in order to maximise returns in biomass from harvesting effort.

Clear-cutting papyrus is thus likely to be an ineffective means of estimating the harvesting potential of any given wetland. It would seem logical that the majority of harvesters would preferentially remove only bulkier stems – seeking, in a rational way, to minimize their efforts whilst maximizing their returns in biomass. A selective harvest, solely of stems belonging to age-classes III and IV, might provide a more accurate estimate of the extent to which papyrus wetlands can be exploited. Defining sustainable limits of harvesting is critical at Lake Naivasha, where the restoration and subsequent 'wise use' (Ramsar 2010) of papyrus is considered to be of "prime management importance" (Jones and Humphries 2001, p.43) for the future of the ecosystem. Before considering Naivasha's future, however, it is important to understand the social and ecological history of the lake, a summary of which is set out in the following sections.

2.6. Lake Naivasha: recent human history

Maasai pastoralists occupied the Lake Naivasha basin until they were removed from the area under the terms of a treaty with the British colonial government in 1904 (Morgan 1969). Colonial land expropriation in Kenya resulted in a division of land between blacks and whites, as elsewhere on the continent (Mackenzie 1988; Nelson 2010). The Naivasha basin became part of the so-called 'white highlands' – large swathes of the central uplands of Kenya with high agricultural potential – where only European settlers were allowed to own land. Extensive, white-owned cattle ranches occupied the bottom of the Rift Valley (Morgan 1969).

The land around Lake Naivasha itself was subdivided by the colonial government and sold to Europeans (Becht et al. 2005). In addition to land expropriated for the establishment of white agriculture, a 'colonial conservation estate' (Murombedzi 2010) was created at Naivasha; all of the land surrounding the lake passed into private ownership, except for a few 'lake corridors' retained in government control for livestock watering. The exact number of these access points is uncertain, but it was understood to have been around 15 (Harper et al. 2011). Part of this thesis seeks to address this knowledge gap at Lake Naivasha as it relates to public access to sites where papyrus grows; a mapping exercise is described in Chapter 3, the results of which are presented in Chapter 6.

After Kenya won independence in 1963, farms once owned by Europeans were sold to government, subdivided and sold to members of the Kikuyu tribe (Morgan 1969). Land ownership in the bottom of the valley remained largely unchanged, however, with most of the land around the lake still owned by Kenyans of European origin (Becht et al. 2005). The lake water at this time was used to support a small number of farms, growing citrus fruits, alfalfa and fattening cattle (Harper and Mavuti 2004). The expansion of a commercial flower-growing industry, beginning in the early 1980s, led to a rapid rise in Naivasha's human population as people immigrated from surrounding regions in search of employment opportunities (Harper et al. 2011).

The lake basin now supports other economic activities besides floriculture, including a large domestic water supply, a commercial fishery, a geothermal power plant, livestock rearing, smallholder farming and wildlife tourism (Abiya 1996; Billgren and Holmén 2008). The intensity of land use in the immediate vicinity of the lake has increased over the last few decades (Mekonnen et al. 2012). The population of the wider basin has grown at the same time, resulting in a proliferation of small-scale agriculture and the cultivation of steep slopes and riverbanks, with associated increases in erosion (Everard et al. 2002; Harper and Mavuti 2004).

2.7. Lake Naivasha: recent ecological history

The lake receives drainage from two perennial systems, the Malewa (drainage area 1,730 km^2) and Gilgil rivers (420 km^2: Harper et al. 2011). Smaller, ephemeral systems drain hills and escarpments closer to the lake (Everard et al. 2002b). Despite having no surface outlet, freshness is maintained by dilute inflows, biochemical and geochemical sedimentation and underground seepage (Gaudet and Melack 1981). The freshness of the water and natural fluctuations in lake level once gave rise to species-rich community of aquatic plants arising from successional processes on wet mud at the water's edge (Gaudet 1977; Harper 1992). There were also high diversities of birds and mammals, including a large population of hippopotamuses and many terrestrial species grazing along its shoreline, such as buffalo, zebra and several species of antelope (Harper and Mavuti 2004; Harper et al. 2011).

The major component of the vegetation was papyrus, which once formed fringing wetlands along nearly the entire length of the lake's shoreline (Gaudet 1977). The largest area of papyrus occurred as an extensive floating swamp around the inflow of the Malewa and Gilgil rivers, a region described by Gaudet (1979) as the 'North Swamp' (Fig. 2.2). Permanent papyrus wetlands at the land-water interface regulate the health of aquatic environments by acting as a "giant filter" for sediment and a "nutrient sieve" (Thompson 1979, p.189). Layers of peat accumulated beneath the floating structures of papyrus and fine organic particulate matter was slowly released into the main lake, helping to maintain clear water and oligotrophic conditions (Gaudet 1979; Gaudet and Muthuri 1981; Harper 1992).

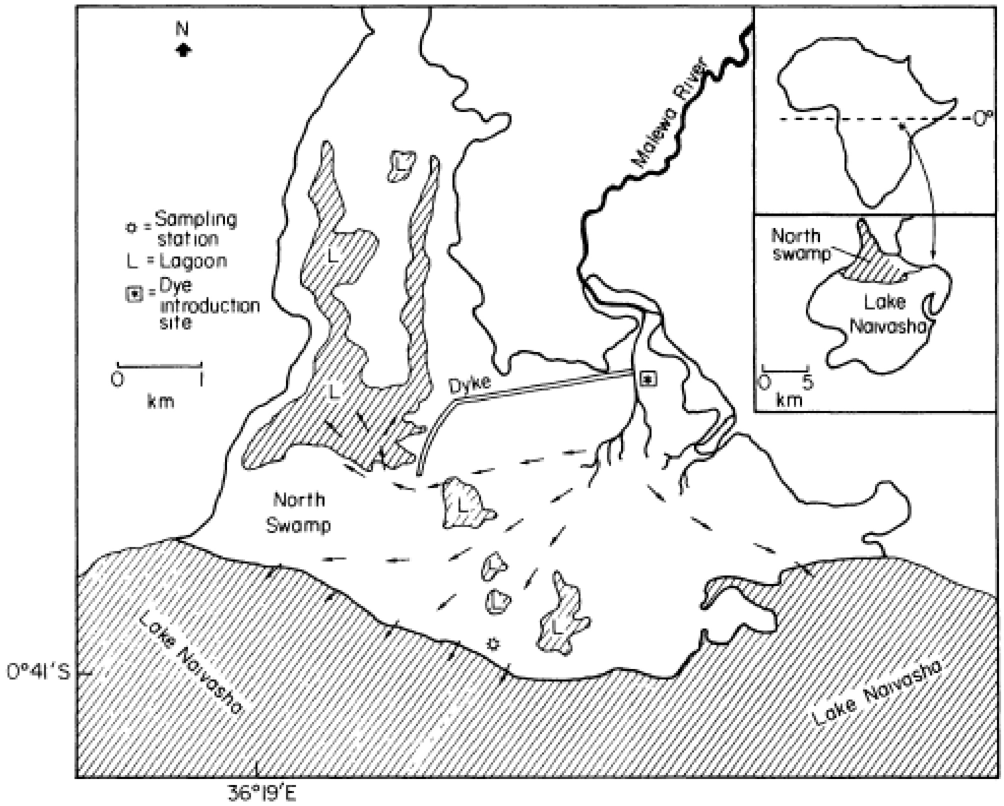

Fig. 2.2. The erstwhile North Swamp of Lake Naivasha (from Gaudet 1979, used with permission).

Beds of floating-leaved water lilies (*Nymphaea caerulea*) and submerged plants (*Ceratophyllum* and *Potamogeton* spp.) were characteristic of the lake shallows until 1974 (Gaudet 1977; Harper 1992). The deliberate introduction of the Louisiana crayfish (*Procambarus clarkii*) in 1970, intended for export to international markets, had a dramatic effect on the ecosystem through its total elimination of floating-leaved and submerged plants within a few years (Harper et al. 1990). The ecology of the lake has been almost completely restructured since that time, in part due to the arrival (accidental or otherwise) and subsequent impacts of additional alien species, notably water hyacinth (*Eichhornia crassipes*) and common carp (*Cyprinus carpio*), the effects of which have been described in detail by Harper et al. (2011).

Papyrus wetlands now occupy only c. 10% of their former area. The causes of lake-wide degradation of papyrus were demonstrated by Morrison and Harper (2009) and are set out in detail in Chapter 5 (section *5.7.2.1*). Loss of the buffering capacity of papyrus, particularly around the inflowing rivers, can explain much of the observed increase in Naivasha's trophic state (Harper et al. 1993; Kitaka et al. 2002; Stoof-Leichsenring et al. 2011) as sediments and soluble phosphorus now freely enter the system (Boar et al. 1999; Harper and Mavuti 2004). Calls have been made for over a decade for the ecological restoration and sustainable utilisation of papyrus at Lake Naivasha (Zalewski and Harper 2001; Harper and Mavuti 2004; Hickley et al. 2004; Morrison and Harper 2009; Terer et al. 2012b).

Restoration efforts are justified from an ecological perspective in light of the wide array of ecosystem services derived from healthy, functioning wetlands. Intact papyrus swamps, at a minimum: (1) act as land-water buffer zones (ecotones), protecting lake shallows from sedimentation by trapping suspended solids within their extensive rhizome and root structures; (2) efficiently assimilate and recycle excess nutrients carried down from the catchment by virtue of their high productivity, thereby helping to mitigate enrichment of lake water and (3) provide valuable habitat for wildlife, including mammals, fish, birds and invertebrates, amplifying biodiversity and improving food chain support (Gaudet 1979; Gaudet and Muthuri 1981; Harper 1992; Harper et al. 1995; Kyambadde et al. 2004; Maclean et al. 2006; Kansiime et al. 2007; Morrison and Harper 2009).

Wetland restoration now seems possible, given the support of local and national governance agencies as well as international donor assistance (Harper et al. 2011). However, the social and ecological factors that would need to be considered before embarking on restoration activities have not, until now, received sufficient attention.

2.8. Social considerations

A total of 207 publications arising from research conducted at Lake Naivasha over the last half-century (1961–2013), compiled by P.R. van Oel (unpublished), were categorized into broad fields of interest: a search was performed for 12 different keywords (shown in the first column of Table 2.1) within the titles of the publications and the percentage of papers corresponding to each was calculated (Table 2.1). The results reveal the relative contribution to our knowledge of the Lake Naivasha ecosystem from different scientific disciplines. Research into fish and fisheries management has predominated over this period – accounting for 16% of all publications – reflecting the significance of fish both as a commodity and for the regulatory control exerted by certain species on lake ecology (e.g. bottom-feeding behaviour of carp: Britton et al. 2007). Studies into lake and river chemistry accounted for a similar proportion of total research effort (14%), commensurate with growing concern surrounding eutrophication and its consequences for ecosystem health (Harper et al. 1993).

Table 2.1. *Summary of publications (n = 207) arising from scientific research at Naivasha from 1961–2013*

Rank	Field	Research interests	%	Example
1	Fish and fisheries	Fish biology; population changes; fisheries management	16	Britton et al. 2007
2	Lake chemistry	Nutrient cycling; sediment analyses; water pollution	14	Gaudet and Melack 1981
3	Past hydrology	Palaeoclimatic changes; limnological responses; environmental variability	12.5	Verschuren et al. 2000
4	Botany	Swamp ecology; macrophyte assemblages; food web structures	12	Gaudet 1977
5	Avifauna	Breeding behaviours; waterbird counts; population fluctuations	9.5	Harper et al. 2002b
6	Geology	Rifting and tectonics; structure and evolution of lake; mineral assemblages	7	Bergner et al. 2009
7=	Recent hydrology	Water availability and balance; basin morphology; catchment attributes	6	Ojiambo et al. 2001
7=	Phytoplankton	Diversity of and turnover in communities; nutrient controls on; ecosystem controls of	6	Hubble and Harper 2002
8	Zooplankton	Distributional profiles; implications for fisheries; *Daphnia* ecology	5	Mavuti 1990
9=	Invertebrates	Population studies; invasive species ecology; taxonomy	4.5	Smart et al. 2002
9=	Socioeconomics	Resource management; anthropogenic impacts; land use and change	4.5	Harper et al. 1990
10	Mammals	Population studies; biodiversity values; grazing effects	3	Kisia et al. 2002

Research along socioeconomic, cultural and political lines has been comparatively limited, however, accounting for just 4.5% of published output (Table 2.1) and revealing an important gap in our understanding of the Lake Naivasha basin. Studies that have been conducted (e.g. Harper et al. 1990; Becht and Harper 2002; Otiang'a-Owiti and Oswe 2007) have generally framed human activities in relation to the natural environment somewhat reductively as different sets of 'threats' or 'negative pressures' (over-abstraction, soil losses, habitat degradation, etc.). What is often missing from these works is a more nuanced understanding of the underlying (demographic, cultural, political, economic) factors that produce environmentally damaging behaviours. More 'socially robust' (Jones and Paramor 2010) environmental research acknowledges that social and natural science data "represent two halves of a whole human-environmental interaction" and, crucially, attempts to "treat them with equal weight" (Strang, 2006, p.8). This assessment highlights the need to integrate concepts and methodologies from the social sciences into ecological research in order to 'overcome the gap' separating its practitioners from the multiple sociological interactions critical to more integrated water resources management (Hiwasaki and Arico 2007; Lemos et al. 2007).

The body of scientific research created from studies at Lake Naivasha has nevertheless helped to establish the basin as an example of 'good practice' in water resources management. In addition to becoming Kenya's second Ramsar site, scientific achievements at Naivasha have been recognised by UNESCO (United Nations Educational, Scientific and Cultural Organization) who declared Lake Naivasha a 'HELP' (Hydrology for the Environment, Life and Policy) basin and most recently an 'Ecohydrology Demonstration Site' (Harper et al. 2011).

Hiwasaki and Arico (2007), however, contend that:

"…the trend of past activities conducted under UNESCO… shows that emphasis placed on social and cultural factors has been insufficient. An important aspect that has yet to be fully addressed… is the one related to people's relationship to water and the surrounding environments" (p.4).

Lake Naivasha is a case in point. Despite repeated calls for their ecological restoration, a nuanced understanding of the attitudes of local people towards papyrus wetlands is currently missing; this scenario supports the recent findings of Hallett et al. (2013) that the majority of restoration efforts to date have failed to explicitly link restoration objectives to 'cultural values' in relation to the ecosystem being restored. As Clewell et al. (2005) attest to: "local residents... need to know how the restored ecosystem can benefit them personally... if they are unaware of the restoration and its public benefits, they may vandalize or otherwise disrespect it" (p.11). A principal aim of this thesis is to attempt to overcome this important knowledge gap, using the 'language' of ecosystem services to identify local communities' values and beliefs in relation to papyrus – towards the successful restoration and future wise use (Ramsar 2010) of Naivasha's wetlands.

2.9. Ecological considerations

Another critical step in planning a restoration project is to provide an ecological description of the designated site (SER 2004). Each project must have an 'ecological reference': "a representation from nature that guides all aspects of project planning and implementation" (Clewell and Aronson 2013, p.137). Ecological references can take different forms and may be prepared from both primary and secondary sources of information. Key primary sources include actual ecosystems, termed 'reference sites'; in some cases, these may be remnants of the same ecosystem that survived impairment. Secondary sources include any other information that adds to one's understanding of the ecosystem prior to impairment. The ecological reference represents the future condition, or target, on which restoration is designed and which will serve later as a basis for project evaluation (Clewell et al. 2005; Clewell and Aronson 2013).

Despite repeated calls for wetland restoration at Naivasha, only two attempts have so far been made to provide details as to where restoration should take place and how it should be done in practice. Zalewski and Harper (2001) submitted the first of these, proposing that papyrus be restored either side of the Malewa river at a location in the midst of the former North Swamp. The project consisted of 3 interconnected wetlands, with water channeled into each via a series of sequential weirs along the course of the river. These were to be designed to channel flash, seasonal and infrequent (El Niño-type) floodwaters respectively into shallow horseshoe excavations to stimulate germination of dormant papyrus seeds. The second proposal, submitted by Githaiga (2008), described a project to dam the Gilgil river to the west of the Malewa, near to the northern limit of the former North Swamp. The proposal was to construct a levee running perpendicular to the course of the Gilgil to divert water into its former floodplain. A network of shallow channels would distribute water across this area, stimulating papyrus germination on small islands created by earthworks to produce a mosaic of wetland patches.

Both proposals advocated for papyrus restoration within Naivasha's 'riparian zone', a term strictly defined by some authors as "an area in close proximity to a stream or river" (Bren 1993, p.278) drawing on its Latin roots in *ripa* meaning 'bank' (of a river). The word riparian is applied in a broader sense at Lake Naivasha to describe "the zone of direct interaction between terrestrial and aquatic environments" (Swanson et al. 1982, p.267) and is legally defined as all land lying below the 1908 water level at Lake Naivasha of 1,892 m.a.s.l. (Harper et al. 2011). From an ecological perspective, this region is more accurately referred to as an ecotone, a zone of transition "between two ecological systems, having sets of characteristics uniquely defined by space and time scales and by the strength of interactions between the adjacent ecological systems" (Holland 1988, p.48). In tropical freshwater ecosystems, maximal vegetation community variability or 'activity' is centred within ecotones since these areas are particularly sensitive to environmental perturbations (Bugenyi 1991, 2001). Through processes of succession, a pattern of zonation develops in these transitional habitats, which "tends to indicate in space what is likely to happen over time in the wetland itself" (Maltby 2009, p.6).

Fig. 2.3. Drawdown at Naivasha reveals bare wet mud, soon to be colonized by seedlings (photo: R. Fox).

Herein lies a significant knowledge gap. It has been more than 35 years since Gaudet (1977) published his comprehensive description of Lake Naivasha's 'drawdown zone' – the region of the shore exposed as lake levels decline and upon which successional changes occur (Fig. 2.3), often resulting in the formation of papyrus swamps. Since that time, despite becoming a well-studied lake, few researchers, if any, have re-examined the plant communities of Naivasha's riparian zone during and after a period of hydrological drawdown. Since (1) this region has sets of characteristics uniquely defined by space and time (Holland 1988) and (2) analysis of changes within ecotones can be used to detect changes through time over much larger regions

(Holland et al. 1991), it is imperative to revisit the plant communities of the riparian zone prior to attempting any restoration of wetland habitat therein. Based on a description of its current ecological state and the nature of impacts upon it, one can assess the appropriateness of using papyrus growing there as a 'reference' for ecological restoration.

2.10. Links to thesis objectives

Information generated by addressing the knowledge gaps highlighted above will be used to guide responses to the main thesis objectives. For example, conducting an in-depth exploration of the socioeconomic attributes of papyrus from the perspectives of local stakeholders (section *2.8*), allied with a detailed examination of processes that influence the growth and distribution of plant communities within the drawdown zone (section *2.9*) will directly contribute to addressing the secondary objective, framed by the question, '*What is the potential for restoration of Lake Naivasha's papyrus wetlands?'*

Linking the findings generated from empirical studies conducted as part of this research (described in Chapter 3) with the results of previous studies conducted in different settings will, in turn, contribute to addressing the overall objective, framed by the question, '*How can wise use of wetlands at Lake Naivasha be achieved?'* It is hoped that the information presented in this thesis will ultimately be used to help guide the sustainable management and wise use of the ecosystem, towards the continued designation of Lake Naivasha as a Wetland of International Importance under the Ramsar Convention (1971).

By employing an 'ecosystem services approach' (Turner et al. 2011) to describe the different processes and functions of papyrus wetlands, this thesis, in a case-specific scenario, reflects wider contemporary efforts to draw attention to the benefits of natural resources *sensu* the Millenium Ecosystem Assessment (MA 2005). More recently, the National Ecosystem Assessment (NEA 2011) adopted a similarly broad, interdisciplinary approach to that of the MA (2005) in an effort to raise awareness of the importance of the UK's ecosystem services – both those delivered from the natural environment of the UK and those imported from other nations – for the well-being and economic prosperity of its citizens.

One of the key findings of the NEA was that approximately 66% of the UK's annual water demand is met by overseas sources in the form of embedded ('virtual') water, three quarters of which is due to the import of agricultural biomass (NEA 2011). Mekonnen et al. (2012) found that the UK market accounts for 18% of the total export of virtual water from Naivasha in the form of cut flowers that have been grown using lake water; moreover, the total export of virtual water from the ecosystem has shown significant growth in recent years, increasing from 11 Mm^3 in 1996 to 21 Mm^3 in 2005 (Mekonnen et al. 2012). The analysis and quantification of potential improvements to the delivery of ecosystem services from papyrus wetlands at Lake Naivasha can therefore be seen as having both local and international ramifications in terms of defining 'wise use' (Ramsar 2010).

2.11. Summary of literature review

- Papyrus swamps are highly productive habitats that provide a multitude of ecosystem services, including the ability to purify water, support biodiversity and provide plant fibre that can be harvested by local communities for socioeconomic gains. These wetlands are often subject to environmental degradation through misuse; the extent to which they can be sustainably harvested has not yet been satisfactorily determined.

- Ecological restoration has the potential to improve biodiversity and ecosystem service delivery, yet only a handful of studies have targeted eutrophic waters and these have focused exclusively on nutrient removal. The restoration of papyrus wetlands in East Africa has so far received very little attention.

- Many restoration projects have fallen short of explicitly addressing the benefits of ecological restoration for local communities and have specifically failed to devote resources to interviewing stakeholders; in some cases this has resulted in unforeseen barriers to restoration.

- There have been only limited attempts to quantify ecosystem services from stakeholders' perspectives; this is critical to the long-term success of restoration projects where enhancement of ecosystem services is a primary objective. Only once has this been attempted with respect to papyrus wetlands.

- Scientific research at Lake Naivasha has predominantly focused on aspects of aquatic ecology, with comparatively little effort spent on studying socioeconomic aspects of the ecosystem; calls for the ecological restoration of papyrus at Naivasha present an ideal opportunity to attempt to address some of these shortcomings.

Chapter 3: Methodology

Chapter 3: Methodology

3.1. Philosophical contexts

Typically I look upon research problems from a positivist epistemological perspective (Smith et al. 1996), adopting a hypothetico-deductive approach borne out of my education in the physical sciences. Some of my research questions (e.g. *What is the rate of primary production in papyrus wetlands at Lake Naivasha?*) required studying phenomena (e.g. biomass accumulation under different levels of disturbance) in 'natural' settings, testing hypotheses generated by earlier studies under comparable conditions; I therefore approached these aspects of my thesis as an objectivist (Rand 1990).

Other research questions (e.g. *Do people's perceptions of papyrus wetlands vary significantly between Lake Naivasha and Lake Victoria?*) required me to attempt to generate, rather than test, hypotheses (e.g. surrounding the significance of consumptive use values). When doing so, I recognised that the 'reality' of the situation was rather more subjective, being created by individuals, their values and behaviours; I therefore approached these aspects of my thesis more as an interpretivist (Weber 2004).

In short, my philosophical perspective – and thus my methodological approach – changed throughout my thesis apropos the task in hand, reflecting the frequently dynamic nature of interdisciplinary research. Indeed, the pursuit of holistic solutions to complex problems arguably benefits from multi-strategy or mixed methods approaches (Creswell 2009) and thus an underlying degree of philosophical flexibility. As Einstein (quoted in Feyerabend 2010, p.2) wrote:

"The external conditions, which are set for [the scientist] by the facts of experience do not permit him to let himself be too much restricted in the construction of his conceptual world by the adherence to an epistemological system."

3.2. Methods

The different methods used to address TQs 1–5 are summarised according to the research questions (RQs) to which each corresponds in Table 3.1. Each method is then set out in detail in the subsections that follow, presented according to the chapters to which they relate for ease of reference.

Table 3.1. *Summary of the main methods and the research questions to which each corresponds*

	Thesis questions	*Research questions*	*Methods*	*Results*
How can wise use of wetlands at Lake Naivasha be achieved?	**TQ1:** Why should papyrus wetlands at Lake Naivasha be restored from a sociological perspect	**RQ1**: What are the demographic characteristics of papyrus users? **RQ2:** What do they use papyrus for and how important is it to their livelihoods? **RQ3:** What are the negative aspects of livelihoods based on papyrus? **RQ4:** How can these negative aspects be addressed?	• Questionnaires (RQ1–4) • Semi-structured interviews (RQ1–4) • Focus group discussion (RQ1–4)	*Chapter 4, Part 1*
	TQ2: What are the key social factors at Lake Naivasha that might hinder successful wetland restoration?	**RQ5:** What are the demographics of stakeholders at Lakes Victoria and Naivasha? **RQ6:** Do people's perceptions of papyrus vary significantly between the two lakes? **RQ7:** If they do, which demographic characteristics might explain this variation? **RQ8:** Which wetland services do stakeholders value the most and why? **RQ9:** Does awareness of their values have an impact on local wetlands?	• Semi-structured interviews (RQ5–9) • Survey instrument (TOKS) (RQ5–9) • Statistical tests (RQ7+9) • Focus group discussions (RQ8) • Habitat surveys (SQS) (RQ9)	*Chapter 4, Part 2*
	TQ3: Why should papyrus wetlands at Lake Naivasha be restored from an ecological perspective?	**RQ10:** What is the rate of primary productivity in papyrus wetlands at Lake Naivasha? **RQ11:** How does this change under different harvesting strategies? **RQ12:** How does the concentration of N and P vary between age-classes? **RQ13:** Does the concentration of these nutrients vary between sites? **RQ14:** How do nutrient concentrations in papyrus compare to other common plants? **RQ15:** How much N and P would be removed from 1 m^2 of harvested wetland?	• Experimental plots (RQ10+11) • Field surveys (RQ12–14) • Laboratory analyses (RQ12–15) • Statistical tests (RQ12–14)	*Chapter 5, Part 1*
	TQ4: What are the key ecological factors at Lake Naivasha that might hinder successful wetland restoration?	**RQ16:** How many plant species are found in the riparian zone? **RQ17:** What is the distribution of these species during and after a drawdown event? **RQ18:** How does their number and distribution compare to Gaudet (1977)? **RQ19:** What are the ecological characteristics of the most common species? **RQ20:** Which factors influence the number and type of species in the riparian zone? **RQ21:** What factors influence papyrus swamp development in the riparian zone?	• Experimental transects (RQ16–17) • Field surveys (RQ16–17) • Statistical tests (RQ18) • Desk study (RQ18–21)	*Chapter 5, Part 2*
	TQ5: How can the successful restoration and sustainable management of wetlands at Lake Naivasha be achieved?	**RQ22:** What would constitute a more appropriate reference state for restoration? **RQ23:** Where should restoration efforts be focussed? **RQ24:** How can public support for papyrus restoration be increased? **RQ25:** How can the management of restored wetlands be made sustainable?	• Desk study (RQ22+25) • GPS/GIS mapping (RQ23) • Briquette trials (RQ24) • Laboratory analyses (RQ24)	*Chapter 6*

3.2.1. The natural capital of papyrus wetlands (Chapter 4, Part 1)

Survey design

An initial visit to Kenya's Lake Victoria region was made in January 2010 to discuss survey tools and potential study sites with local research assistants under the facilitation of VIRED (Victoria Institute for Research on Environment and Development). A comprehensive survey instrument (Appendix 1) was subsequently compiled, which sought to generate a detailed understanding of the demographic, historical and economic attributes of individual papyrus harvesters within the Nyando river basin of Kisumu District (Fig. 3.1). A questionnaire was chosen since, once carefully designed and tested, it could be efficiently distributed to a large number of respondents. Research assistants were fully trained in the appropriate use of this instrument. The questionnaire was piloted at Dunga beach, a site outside the Nyando basin where local communities had participated in previous studies (e.g. Aseta and Ong'ang'a 2003), prior to dissemination. Dunga beach was chosen as it was considered by VIRED to represent as far as possible the broad array of human-wetland interactions around Lake Victoria; it was felt that knowledge gained there would thus be illustrative of the potential range of responses likely to be received from communities elsewhere in Kenya, including Lake Naivasha.

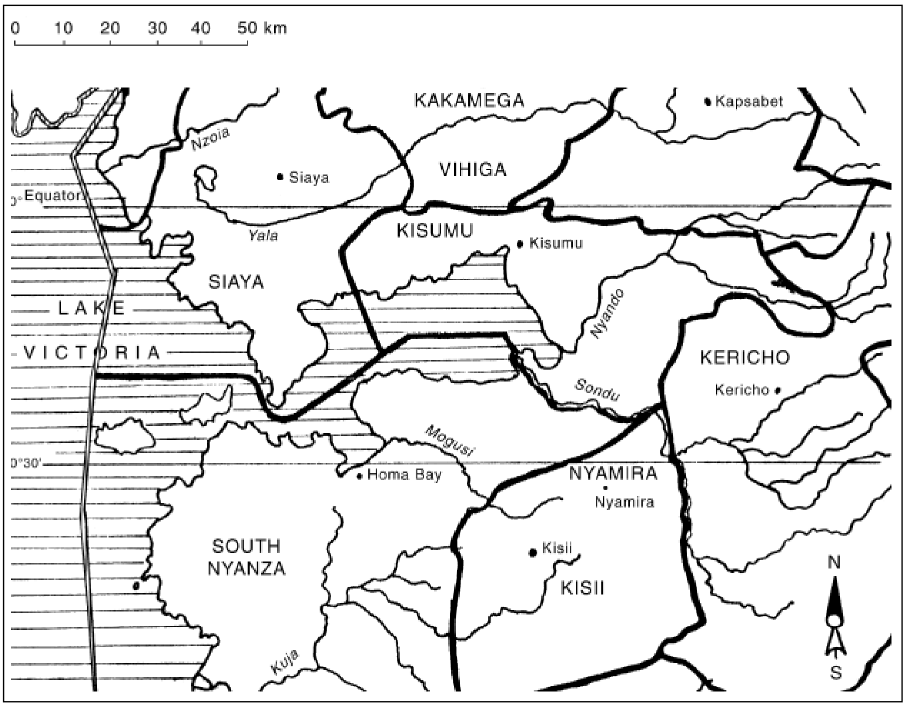

Fig. 3.1. Kisumu District in Nyanza Province, showing the Nyando river (centre right) entering Lake Victoria (from Kairu 2001, used with permission).

Thirty-three villages (Fig. 3.2) within 7 sub-locations[3] throughout Kisumu District were subsequently visited in May 2010. These villages, where papyrus harvesters were known to reside, were chosen by VIRED on the understanding that local residents had not participated in earlier studies, increasing the likelihood of generating some novel insights. A stratified random sample of all villages within Kisumu District was not chosen since it would have yielded fewer useful results (owing to the great divergence of livelihood strategies pursued throughout the region) within the time available; the objective was to gather information from papyrus harvesters specifically.

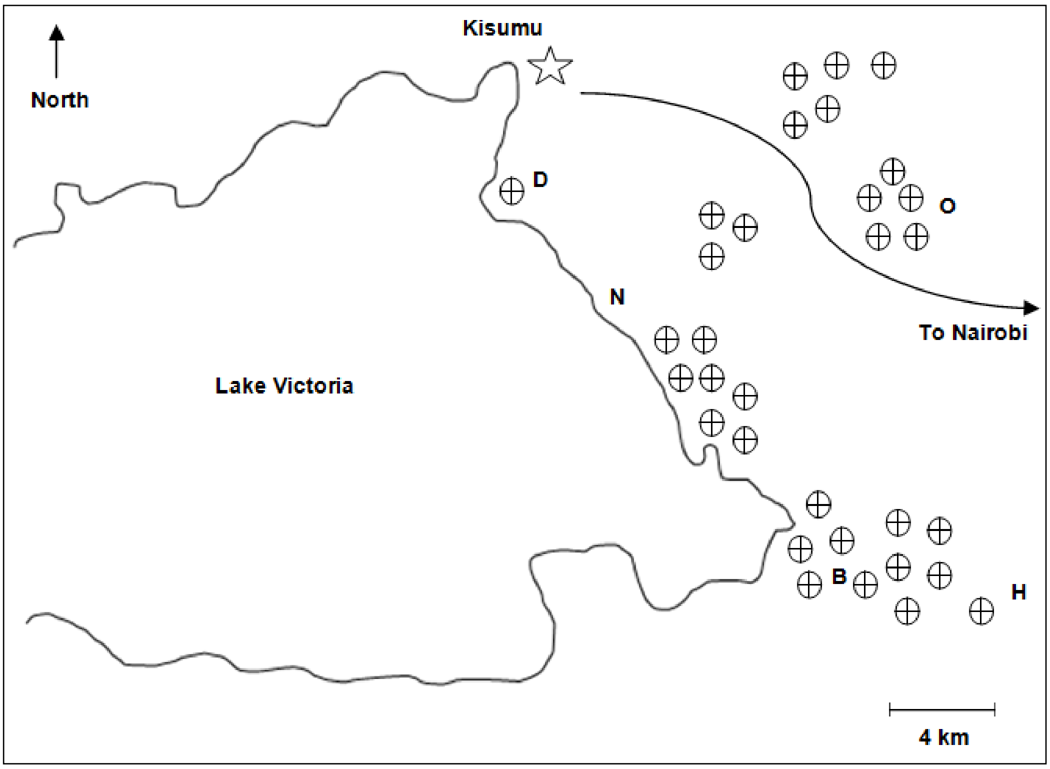

Fig. 3.2. Sketch map showing approximate locations of the 33 villages (circles with crosses) visited, as well as other sites mentioned in the text (B = Bugo; D = Dunga; H = Harambee; N = Nyamware; O = Okana).

Data collection

The approval of an area chief, senior village elder or other well-respected figure from each site was sought prior to any data collection and, in several cases, a dedicated visit was made in a preceding day. This individual was asked to appoint a member of the local community known to be a papyrus harvester who would be willing to complete the survey in the first instance; he/she was then asked to nominate another. This 'chain-referral' (Beauchemin and González-

[3] A sub-location is the smallest administrative unit in Kenya; these are, in turn, part of a division, a district and a province (Francis 2000).

Ferrer 2011) system was maintained until a total of 110 questionnaires had been completed (typically taking 30–45 min. each), by which time it was felt that a point of saturation in the responses being received had been reached.

Several key informants (e.g. village elders, teachers, traditional healers, etc.), nominated by area chiefs, participated in semi-structured interviews (typically lasting 30 min. each) conducted at the villages of Bugo and Harambee (Fig. 3.2), selected by VIRED on the basis they had not participated in earlier studies. Semi-structured interviews were chosen to provide more flexibility for respondents to express their opinions and insights than the questionnaires allowed for, creating a more in-depth exploration of, for example, issues connecting papyrus harvesting with commodity production and marketing.

Finally, a focus group discussion was held at Okana (Fig. 3.2), lasting c. 90 min. and attended by 8 members of the community. Okana was selected for its known contact with VIRED, who had worked with the community over the preceding decade to restore papyrus swamps that had been lost to overharvesting and mismanagement. The Chairman of the Okana 'self-help group', a community-based management forum created to govern use of Okana's wetland resources, was asked to nominate participants. A focus group discussion was chosen to provide participants the freedom to express their opinions in a context or sequence different to that offered by the questionnaires or semi-structured interviews.

Recordings of the interviews and focus group discussion were made and later transcribed and translated into English where necessary. Analysis of numerical data proceeded through the coding of qualitative findings to facilitate identification of key themes, which were subsequently tested for significance (χ^2) using SPSS 20.0 (IBM Corp. 2011).

Study limitations

The limitations of the different methods employed were considered fully. The utility of questionnaires, for example, is inherently limited to the questions asked; important issues omitted from their design will therefore not feature in later analysis. Crucially, all data derived from a questionnaire will reflect respondents' selective memories as well as the designer's own biases; they also limit opportunities for in-depth responses and deeper exploration of certain issues. The researcher must also consider the effects of fatigue induced by lengthy questionnaires and possible misinterpretations of complex questions (Adams and Cox 2008). The chain-referral (or 'snowballing') approach taken to the selection of respondents suffers from being limited to individuals with close ties to their communities, who would otherwise not be the subjects of referral (Beauchemin and González-Ferrer 2011).

Some of the more open-ended questions in the initial survey tool elicited longer and more detailed responses than expected when piloted at Dunga beach, confirming some of the limitations of this approach as highlighted above. A decision was therefore made to conduct semi-structured interviews in addition to the questionnaire, which ultimately allowed for more flexibility and detail in the way that participants responded, thereby facilitating more in-depth expression of participants' own views and perspectives. The pilot study also identified questions not previously considered during the planning stages, which were therefore included in the questionnaire, some of which also helped to guide focus group discussions. Interviews and focus group discussions have their own constraints. For example, one risks creating potential imbalances in gender or age representation brought about by biases in the selection of participants, suffering from language issues and asking leading or restrictive questions (Adams and Cox 2008).

Many of these limitations would have been particularly problematic had a single research method been employed. By taking a mixed methods approach (Creswell 2009), it was felt that the weaknesses of any one method were mitigated as far as possible, with the resultant dataset including both wider scale quantitative materials, drawn from multiple respondents across the 33 villages, in addition to more in-depth qualitative data from key informants. All of the methods were submitted to and approved by the University of Leicester Committee for Research Ethics.

3.2.2. Public perceptions of papyrus (Chapter 4, Part 2)

Survey design

All 'known' human welfare benefits associated with papyrus wetlands in East Africa were listed following an extensive literature review and then grouped into similar sub-sets. The resulting table formed the basis of a survey instrument designed to assess peoples' perceptions of papyrus wetlands. A pilot study was then conducted at Dunga beach (Fig. 3.2) in order to ascertain the completeness of this table, as well as to provide a training opportunity for research assistants prior to data collection. The pilot study revealed the existence of several benefits attributed to papyrus that had not been identified from the literature review; these were therefore added to the list. The final table (Appendix 2) thus consisted of 27 sub-sets of benefits organized into 4 groups, corresponding to the major categories of ecosystem services (provisioning, regulating, cultural and supporting) as defined by the MA (2005), with between 6–8 sub-sets in each category.

Data collection

Semi-structured interviews were subsequently conducted at 8 different sites along the shoreline of Lake Victoria during August 2011 over the course of one week, from 07:00–14:00 hours. August was chosen since riparian communities are particularly active at this time between Kenya's long and short rains, after which many wetland sites become inaccessible due to flooding. Each site was randomly selected from a list of locations with known public access to wetlands that had been compiled by field assistants.

Individuals encountered within the riparian zone (defined for the purposes of this study as land lying between the lake edge and up to 500 m inland) were then approached at each site. Willing participants were asked open-ended questions such as *"do the papyrus wetlands here hold any value for you?"* or *"do you think the swamps are important for the environment in any way?"* and responses written down verbatim. Demographic (e.g. gender, age, highest level of formal education) and life history data (e.g. sources of income, duration of residence around the lake, frequency of visits to the wetlands) were also collected in an attempt to situate different perceptions of wetlands within explanatory social and cultural contexts. One of the objectives of this study was to generate data on the demographic characteristics of the wider stakeholder community at each lake, in contrast to Part 1 of this chapter where the focus was solely on papyrus harvesters.

It was felt that a point of saturation in the responses being received had been reached after 118 interviews. A further 118 interviews were subsequently conducted, at 8 different sites randomly selected in the same manner, along the shoreline of Lake Naivasha the following week during the same time of day.

Responses provided by participants were assigned to appropriate sub-sets of services within the table described above (hereafter 'TOKS': Table Of Known Services) upon returning from the field. For example, if a respondent stated that he/she valued papyrus for its perceived medicinal properties, that citation would be assigned to the sub-set entitled "source of biochemical resources", under provisioning services. Each of the 236 interviews could thus be allocated an individual TOKS 'score' (the theoretical maximum being 27, should all sub-sets be cited), serving as an initial quantitative representation of stakeholders' responses for the purposes of statistical comparison between sites. The relative percentage weighting (by citation) of each sub-set was then calculated in order to reveal which services might be assigned priority from a management perspective.

Focus group discussions (lasting between 30–45 min. and attended by 5–8 individuals) were also held at two sites chosen at random (Ramula, Lake Victoria and Kamere, Lake Naivasha), with efforts made to ensure a balanced representation of gender and age. These sessions allowed for greater depth of expression and insight than the one-on-one interviews alone and contributed important information to the study, particularly concerning values associated with heritage, spirituality and other such 'cultural' services.

Finally, papyrus wetlands at each of the 16 sites were allocated a 'site quality score' on a scale of 1–10. Starting from a hypothetical score of 10 ('pristine' wetland), a point was then deducted for any of the following disturbance characteristics: evidence of clearance from burning or over-harvesting; signs of uprooting; habitat patchiness; stunted growth; missing umbels (flower heads); signs of trampling; presence of large numbers of livestock and proliferations of climbing weeds. Each site was surveyed in a systematic fashion for each of these characteristics, using the checklist shown in Appendix 3, prior to the collection of qualitative data. These scores were compared with TOKS scores in order to discern what relationship, if any, existed between local habitat quality and levels of environmental awareness.

Statistical comparisons between the different datasets for each lake were then made employing a variety of tests (*F*-test; *z* test; one-way ANOVA; Mann-Whitney *U*-test; Spearman Rank Correlation Coefficient and χ^2) using SPSS 20.0 (IBM Corp. 2011).

Study limitations

The same limitations described in section *3.2.1* in relation to the use of semi-structured interviews and focus group discussions apply to this study as well.

The potential weaknesses of assigning numeric values to qualitative descriptions (i.e. creating TOKS and site quality scores) were considered fully. In particular, the TOKS scores reflected the number of different ecosystem services recognised as important by the respondents, but they were not indicative of economic or other quantitative aspects of value attributed by me or by participants to different services. The values assigned to, and the valuation of, ecosystem services – especially with reference to cultural services and to economic/non-economic valuation – is currently an issue of much debate and contention (Gómez-Baggethun and Ruiz-Perez 2011; Potschin and Haines-Young 2011; Busch et al. 2012). For the current study, the TOKS data represented an initial indication and point of comparison as to the nature and range of important ecosystem services at and between the two lakes.

3.2.3. Productivity and nutrient uptake in papyrus (Chapter 5, Part 1)

Productivity

Two hundred culm-units[4] (50 from each age-class) were selected at random within an undisturbed stretch of papyrus at Fisherman's Camp along the southern shoreline of Lake Naivasha (0°82' S, 36°34' E). The girth of each culm-unit was measured to the nearest 0.1 cm at a point just above the tip of the tallest sheathing scale leaf (C: Fig. 3.5) using a pair of dial callipers. Each stem was subsequently cut at that same point with a machete and labelled according to its age-class and girth. All material was set out to dry in the sun until a constant weight was recorded on a set of digital scales, measuring to the nearest 1 g.

Estimates of biomass were then determined from a linear regression fitted to the relationship between culm-unit dry weight and girth derived from these samples after Jones and Muthuri (1985). To test the accuracy of the linear regression against known (weighed) values, all living material within 7 x 1 m^2 quadrats (distributed at random throughout the same wetland) was removed, dried and weighed in the same way as above.

Biomass replacement rates in response to different selective harvesting strategies were determined from a further 16 x 1 m^2 quadrats. These were established at random, beginning 5 m inside the wetland and spaced at least 5 m apart, marked using plastic poles and nylon string. Four different harvesting intervals – monthly, quarterly, biannually and annually – were assigned, with 3 replicates and 1 control for each. The number of stems in each quadrat was counted and their individual dry weights estimated using the linear regression. Culm-units belonging to age-classes III and IV were then removed, save the controls.

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[4] The term 'culm-unit' refers to a single culm with an intact umbel (Jones and Muthuri 1985).

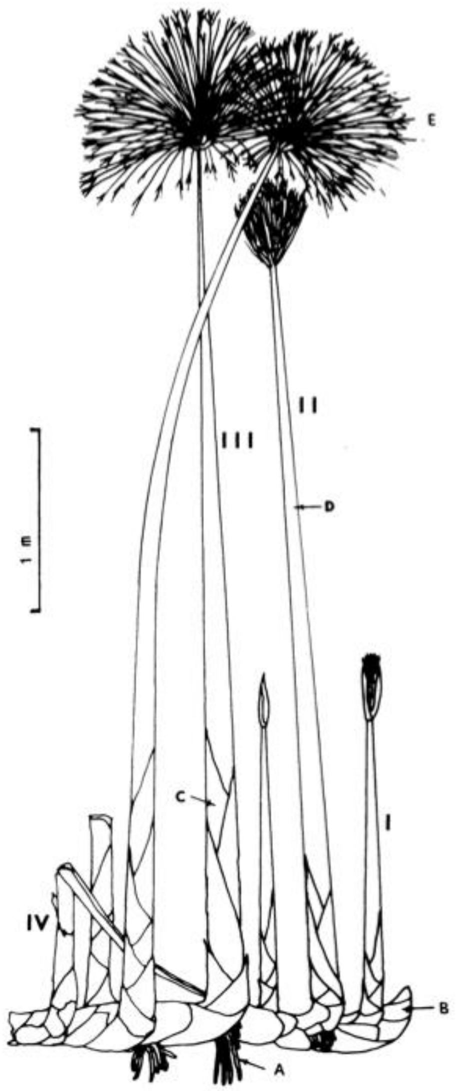

Fig. 3.5. Morphology of a papyrus swamp, revealing appearance of stems in age-classes I–IV; also showing roots (A), advancing tip of rhizome (B, age-class '0'), tallest sheathing scale leaf (C), culm (D) and umbel (E) (from Gaudet 1977b, used with permission).

Nutrient uptake

Seven culms from each age-class (I–IV) were selected at random from 2 neighbouring sites of mature fringing wetland along the lake's southern shoreline – Fisherman's Camp and Carnelley's Camp – in order to assess within-site variations in nutrient concentration. Papyrus at the former site was flooded but not at the latter. Both wetlands were in a state of low disturbance with high 'site quality scores' (Chapter 4, Table 4.6). Culms were cut with a machete at a point above the tip of the tallest sheathing scale leaf, individually labelled and taken to the laboratory.

Seven culms belonging to age-class I were selected at random from 4 further sites around the lake to measure between-site variation. These were: Marula Estate at the northern end of the Malewa river's deltaic wetlands; the mouth of the Malewa river at the southern end of the deltaic wetlands; fringing wetlands below the settlement of Kasarani to the northwest and floating islands inside Crescent Island lagoon to the east. In addition, one site within the middle catchment (at 2008.6 m.a.s.l.) was sampled, a wetland along the course of a tributary of the Gilgil river known as the Little Gilgil. Two locations were chosen to compare nutrient concentrations in natural wetlands with constructed treatment wetlands receiving wastewater from flower farms, one recently established (<1 year: Flamingo Farm) and one long established (>5 years: Kingfisher Farm). Since primary productivity in papyrus proceeds uninterrupted throughout the year, with minimal temporal variation in culm density, age-structure and standing biomass (Gaudet 1977b; Květ et al. 1998), the effect of seasonal variation in nutrient concentrations was assumed to be negligible and was not investigated, with all culms harvested at the same time (during August 2012).

Samples of *Azolla africana*, *Cyperus dives*, *Eichhornia crassipes*, *Hydrocotyle ranunculoides*, *Ludwigia stolonifera*, *Salvinia molesta* and *Typha latifolia* were also collected from inside 3 x 1 m^2 quadrats at various locations to compare nutrient concentrations in papyrus with other plant species commonly found in the lake or along the shoreline. Only aboveground (stem) tissues were sampled for *Cyperus dives* and *Typha latifolia* (as with *Cyperus papyrus*); whole plants (roots and floating structures) were collected for all other species.

Laboratory analyses

Sections of *Cyperus papyrus*, *C. dives* and *Typha latifolia* culms 20 cm long were cut away, thoroughly washed in distilled water to remove any detritus and then blotted dry. The equivalent mass of 1 m^2 of the remaining species was pooled from the 3 quadrats and treated in the same way. All material was placed on a sheet of tarpaulin and left out in the sun to dry for 2–3 days, then placed in an oven at 80 °C until a constant weight was returned after a further 2–3 days. Each sample was subsequently ground and passed through a 850 μm standard testing sieve (Fisher Scientific Company, USA, No. 20). These ground, dry samples were used for the analyses of total nitrogen and total phosphorus, which were performed in the laboratories of Harvard Forest, Massachusetts, with the assistance of Manisha Patel in November 2013. Nitrogen and phosphorus were chosen for analysis since (1) both nutrients have been shown to regulate productivity in papyrus and (2) their availability is a predominant limiting factor in the eutrophication of freshwaters (Muthuri and Jones 1997; Kipemboi et al. 2002).

Total Nitrogen

Subsamples of ≥0.2 g were ground a second time within 10 ml steel vials loaded with ball bearings for 10 min. using a SPEX Sample Prep 8000 M Mixer/Mill (Spex CertiPrep Group, NJ, USA) to produce a homogenous, very fine powder. This powder was then transferred to labelled polyethylene vials and stored in a drying oven at 65 °C prior to analysis. Duplicates of approximately 5 mg (exact weights were recorded for calculations) were weighed into individual tin boats on a microbalance and then loaded into an automated C:N analyser (vario MICRO cube, Elementar Analysernsysteme GmbH, Germany). The samples were combusted at 950°C to measure elemental nitrogen in its gaseous state. Total nitrogen (recorded as % dry weight N) was determined from the area under the curve of the peak using a first order calibration fit with a set of acetanilide (10.36% dry weight N) in high (1.5–4.0 mg) and low (0.2–1.5 mg) weight ranges ($r^2 = 0.999$).

Total Phosphorus

Total phosphorus was determined by flow injection analysis (FIA) following a modified version of QuikChem Method 13-115-01-2-B (Lachat Instruments, CO, USA) on a Lachat FIA Series 8500 (Fig. 3.5). Subsamples of approximately 0.4 g of the sieved material were weighed on a microbalance into ceramic crucibles and ashed in a muffle furnace (Thermolyne 30400, Labotal Scientific Equipment, Israel) at 500 °C for 4 hours. Crucibles were cooled overnight before being removed from the furnace.

The following day, 50 mL of 1 M hydrochloric acid (HCl) solution was added to each crucible with a re-pipet to dissolve the ash and the solution transferred to a labelled polyethylene vial. The dissolved ash was injected into a 1 M HCl carrier stream, which was then merged with a molybdovanadate solution. This solution reacted with orthophosphate in the sample to form a molybdovanadophosphate complex, the absorbance of which was measured at 420 nm. Absorbance was proportional to total phosphorus concentration in units of mg P l^{-1} (later reported as % weight = [mg P l^{-1} x mL 1 M HCl/g sample]/10,000), determined from the area under the curve of the peak using a second order calibration fit with a set of standards (60–0 mg P l^{-1}; $r^2 = 0.999$).

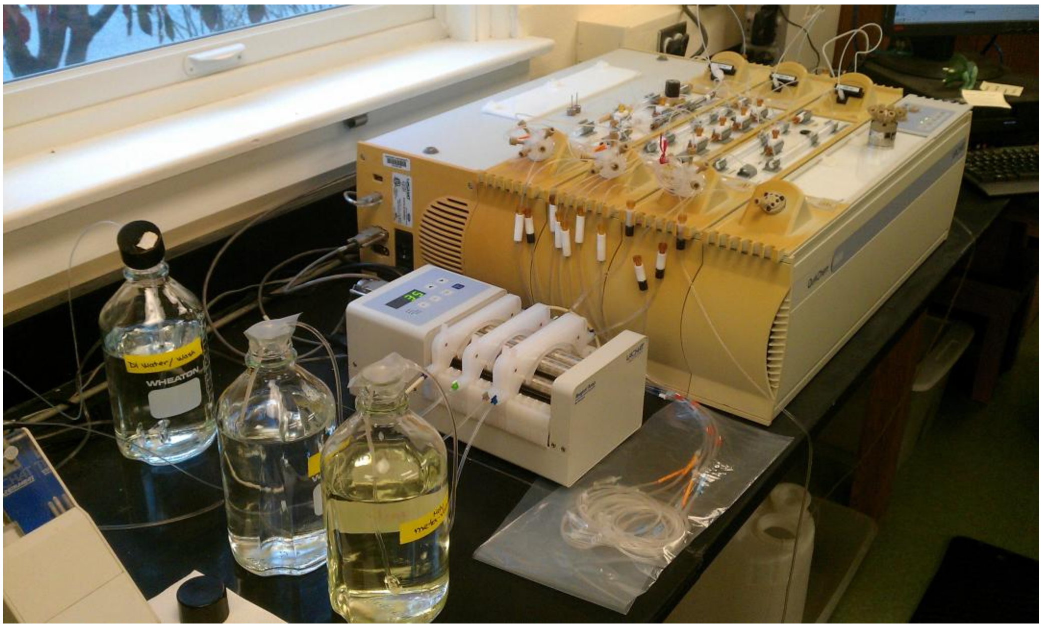

Fig.3.6. Lachat FIA Autoanalyser with manifold for total phosphorus analysis (photo: E. Morrison).

Preparation of solutions

1. Molybdovanadate solution. Exactly 16.5 g of ammonium molybdate (VI) tetrahydrate $[(NH_4)_6Mo_7O_{24}\cdot 4H_2O]$ was dissolved in 400 ml hot deionized (DI) water then set aside to cool. Under a hood, 0.6 g of ammonium metavanadate (NH_4VO_3) was dissolved in 250 ml hot DI water, which was then cooled before adding 58 ml concentrated HCl. While gradually stirring, the molybdate solution was added to the vanadate solution, transferred to a 2 litre volumetric flask and then diluted to the mark with DI water.

2. HCl (1 M) solution. Approximately 700 ml DI water was added to a 1 litre volumetric flask, followed by 83 ml concentrated HCl, then diluted to the mark with DI water and inverted to mix. Four litres of this solution were prepared: one for the carrier, one for the standards and two for diluting ashed samples.

3. Stock solution: 1000 mg P l^{-1}. In a 1 L volumetric flask, 4.396 g of potassium dihydrogen phosphate (KH_2PO_4) was dissolved in approximately 500 ml DI water, to which 83 ml of concentrated HCl was added before diluting to the mark with DI water then inverting to mix. From this stock solution, 7 standards (60, 40, 20, 10, 5, 2.5 and 0 mg P l^{-1}) were prepared and used to calibrate the Autosampler.

All glassware and crucibles were acid washed in a 25% HCl solution and rinsed with DI water to minimize contamination.

The significance of any variance in concentrations of total nitrogen and total phosphorus between stems of different age-classes, as well as in stems of age-class I between different sites and in different plant species was tested (one-way ANOVA and Tukey tests) using SPSS 20.0 (IBM Corp. 2011).

Study limitations

The mineral concentration of leaves is often used as an indicator of the availability of nutrients to the plant (Allen and Pearsall 1963; Garten 1978). In papyrus, however, mineral concentrations of the sheathing scale leaves tend to be the lowest of all aerial material (Muthuri and Jones 1997). Whilst concentrations of N and P tend to be higher in the roots and rhizomes (Gaudet 1975; Muthuri and Jones 1997; Boar 2006), sampling this material is often difficult and doing so will reduce the plant's regenerative capacity. I therefore chose to sample stems belonging to age-class I, which typically have highest concentrations of N and P among all age-classes (Gaudet 1977b; Muthuri and Jones 1997) and which serves as a less damaging means of assessing nutrient availability between sites.

3.2.4. Flora of the riparian zone (Chapter 5, Part 2)

Two sites were selected around the lakeshore. The first (1: Fig. 3.3) was that sampled by Gaudet (1977), at that time described as 'Armstrong's Jetty' but which is nowadays the site of the abandoned 'Drifters Restaurant' (although part of the original jetty remains). The land there was grazed both by pastoralists' livestock and wild animals (including buffalo, zebra, waterbuck and hippopotamus at night), but was otherwise undeveloped. The second site, close to the informal settlement of Kwa Muhia to the south of the lake (2: Fig. 3.3), was chosen since access to the water's edge at Site 1 was impossible over extensive wet mudflats on the gently sloping land (Fig. 3.4). The steeper gradient at Site 2 permitted easier access to the water's edge and therefore identification of any species growing there that would have been excluded from the transects at Site 1. The land at Kwa Muhia was grazed by a small herd of domestic cattle but was otherwise undeveloped.

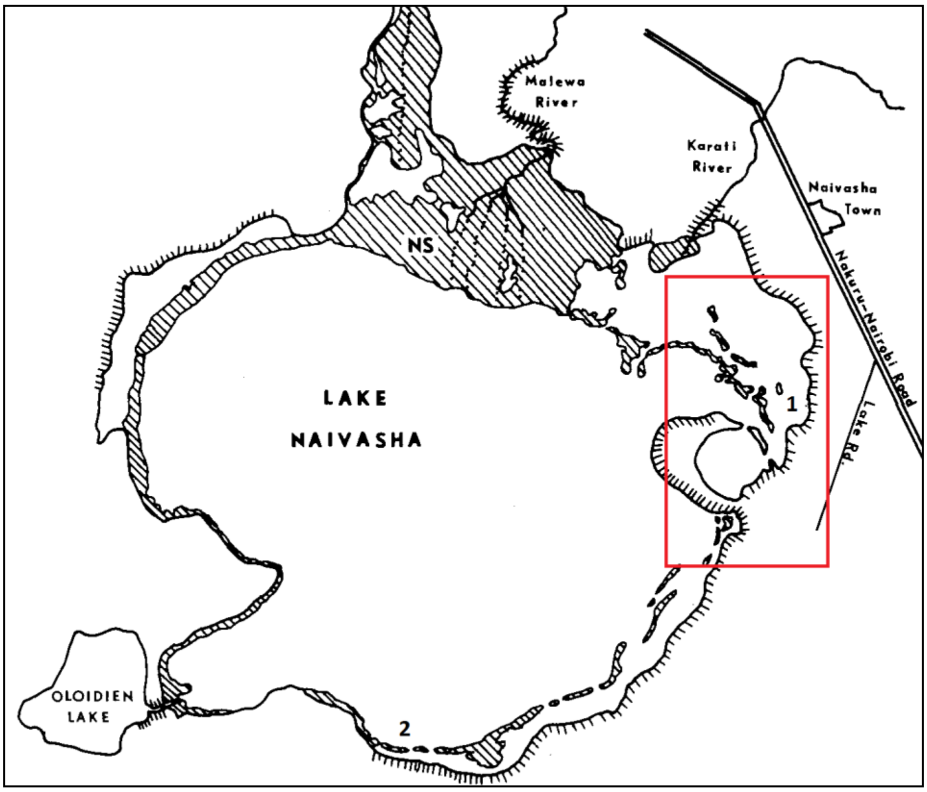

Fig. 3.3. Sketch map showing locations of study sites: 1, Drifters Restaurant; 2, Kwa Muhia. Hatched areas indicate the extent of papyrus swamps in the mid-1970s, most evidently within the former North Swamp (NS). Red box indicates area enlarged in Fig. 3.4 (from Gaudet 1977, modified with permission).

Data were collected from each site on two occasions: (1) in November 2009 following a sustained period of drawdown (2008–09) and (2) in April 2010 as the lake level began to recover following heavy rains throughout December and January. Three transect lines were established at random at each site, running perpendicular to the lakeshore, beginning at the treeline and moving towards the water's edge. Each transect was separated by a distance of 50 m. The majority of plant species were identified *in situ* using the field guide of Agnew and Agnew (1994); where insufficient material was available, specimens were collected, labelled and preserved for later identification in collaboration with taxonomists at the National Herbarium in Nairobi.

Fig. 3.4. Satellite images showing appearance of Lake Naivasha's eastern shoreline under 'normal' lake level conditions (3rd June 2001, left) and during an extended period of drawdown when wet mudflats were exposed (3rd June 2009, right). White circle indicates approximate location of transects at Site 1 (Drifters Restaurant); red line is for orientation only (with kind permission from J. Gaudet).

Data were collected at Site 1 along 450 m of transect before swampy conditions made further data collection impossible. At Site 2, the longest such transect was only 40 m, owing to the steeper shoreline there. Markers were left to assist identification of the original transect lines during the second visit. The rise in lake level following heavy rains throughout December and

January had entirely flooded Site 2 by April 2010 and had reduced the sample area at Site 1 by more than 50%. Searches of the riparian zone were conducted between site visits, making for a more complete comparison with the results of Gaudet (1977), who included in his study taxa not recorded along transects but rather known from previous collections housed in herbaria.

Measurements of abundance were made following Barbour et al. (1987). Percentage cover was estimated inside 0.5 m^2 quadrats placed at 10 m intervals along each transect. Mean percentage cover from 5 quadrats was calculated within successive 50 m sections of each transect to demonstrate the change in species abundance as one moved from the treeline to the water's edge (reduced to 10 m sections at Site 2). Frequency (percentage of quadrats containing at least one individual of a given species) was calculated to illustrate the change in distribution of species throughout the riparian zone. Relative abundance (cover of a given species/cover of all species x 100%) was also calculated, with species present >5% highlighted in the results to distinguish them from less abundant taxa.

The total number of species identified was counted and compared with the results of Gaudet (1977) and the significance (χ^2) of any variance tested. The distribution of plants was described according to the relative abundance of different families encountered along transects following Gaudet (1977). Patterns of distribution and successional changes during and after drawdown were then compared with Gaudet (1977). Possible reasons for the differences between the two studies were described from a desk study into the ecological characteristics of the most common plants identified and the anthropogenic and hydrological stressors on the riparian flora in the present day relative to the 1970s.

Study limitations

Gaudet (1977) calculated the importance value (after Phillips 1959) of different species from the sum of relative density, percentage frequency and percentage cover – with relative density determined by counting the number of individual plants rooted within 0.25 m^2 quadrats spaced 5 m apart over a distance of 115 m. This would have been a very time-consuming and laborious task in the present study, which used 0.5 m^2 quadrats spaced 10 m apart over a distance of 450 m (reflecting the greater extent of drawdown). The larger quadrat was chosen because of the visible abundance of grass at Site 1 (dominated by the creeping *Pennisetum clandestinum*), which it was felt would bias measurements of species richness had a smaller sample frame been used. I therefore provided an estimate of 'importance value' by highlighting the more abundant taxa (i.e. where relative abundance >5%) and conducting a review of the literature on the ecological characteristics of each. In spite of these differences, I am confident that drawing comparisons between the two studies is valid, not least since the location of the main study site was identical, with data collected during and after a drawdown event in both cases.

3.2.5. Public access to the shoreline (Chapter 6)

A composite sketch map of 20 locations around Lake Naivasha believed, either in the present day or within living memory, to provide public access to the shoreline was created from a series of informal interviews with a range of stakeholders, including pastoralists, fishermen, flower farmers, hoteliers, land surveyors and local residents.

Each of the 20 locations ('access points') identified by interviewees was subsequently visited during August 2012 using the sketch map as a guide. A GPS (Global Positioning System) device was used to mark the location of each access point. The length of shoreline below access points that were found to be open was recorded using the 'Waypoints' feature.

The GPS data were then imported into GIS (Geographic Information System) software (ArcGIS 10.1: ESRI 2012) and the location of each access point overlaid on a base map of Lake Naivasha. Interpretation of these data was used to determine the extent of public versus private access to the shoreline.

3.2.6. Fuel potential of papyrus (Chapter 6)

Carbonizing process

Bundles of dried culm-units harvested for the productivity experiments (section *3.2.3*) were carbonized using a methodology developed by the Massachusetts Institute of Technology's (MIT) D-Lab (2012); the experiments described below were performed with the assistance of Amy Banzaert from MIT. The method employs a c. 200-litre oil drum that has been converted into a carbonizing kiln. A large hole in the top of the drum and several smaller holes in the base promote airflow during the initial stages of combustion (Fig. 3.7).

The kiln, containing the equivalent mass of 1 m^2 of cut, sun-dried culm-units, was placed on three stones to raise it c. 30 cm off the ground (allowing air to flow through the drum) and the biomass ignited from beneath. The kiln was sealed once the culm-units had reached carbonization temperature (approximately 450 °C) to create an anaerobic environment resulting in the production of charcoal fines; the stones were removed from underneath and a metal sheet placed over the top hole, with sand used to seal any remaining gaps.

Fig. 3.7. Oil drum converted into a carbonizing kiln; holes in the base provide airflow (photo: V. Lafford).

The carbonized papyrus (Fig. 3.8) was removed once the kiln had cooled and crushed into a fine dust on a sheet of tarpaulin using a wooden mallet. A binding material – cassava (*Manihot esculenta*) flour (5–10% by weight of the carbonized papyrus) – was introduced to approximately 3 litres of cold water and then heated to a viscous paste. This binder was added to the carbonized papyrus to create a porridge-like mixture, which was subsequently formed into individual cuboid briquettes using a simple press made locally from scrap metal. A second type of press (a wooden lever design) was also tested, producing cylindrical briquettes with a central hole. The above procedures were repeated 7 times and a record kept of the number of briquettes produced from each run; all samples were dried overnight in an oven at 70 °C or until a constant weight was recorded.

Fig. 3.8. Carbonized papyrus fines ready to be crushed and mixed with binding agent (photo: V. Lafford).

Quantitative evaluation

The individual mass, volume, and density of each briquette was recorded once dry using a pair of dial callipers and a microbalance, measuring to the nearest 0.01 g. Single samples (of both 5% and 10% by weight of binder) of the cuboid briquettes were subsequently analysed by Columbia Analytical Services, AZ, for total moisture, volatile matter and calorific value alongside samples of dry papyrus stems, local wood charcoal, local firewood and other types of briquettes (all oven dried at 70 °C) as follows:

1. Total moisture was determined using a TGA 701 Thermogravimetric Analyzer (LECO Corporation, MI, USA), following method ASTM (American Society for Testing and Materials) D3173-11. Samples were dried in an open ceramic crucible at 105 °C for 1–2 hours and moisture loss reported on a % weight basis.

2. Volatile matter (dry weight basis) was determined on the same apparatus following method ASTM D3175-11. After the moisture step (above) was complete, lids were placed on the ceramic crucibles and samples heated to 950 °C in a nitrogen atmosphere. Volatile substances were driven off and reported according to % weight loss.

3. Gross calorific value (higher heating value; units of MJ kg^{-1}) was measured by combusting samples in a vessel charged with oxygen using an AC 600 Semi-Automatic Isoperibol Calorimeter (LECO Corporation, MI, USA), following method ASTM D5865-12.

Qualitative evaluation

Thirty-two households were selected at random from within two nearby settlements (Karagita and Mirera) and each provided with either 10 (smaller, cuboid) or 5 (larger, cylindrical) briquettes. Participants were asked to use the briquettes in the same way as wood charcoal for cooking their evening meal, before completing a short survey (Appendix 4) designed to determine their attitudes towards the briquettes. Questions sought to discover users' perceptions of: how much smoke the briquettes produced, how much heat they generated and how favourably they performed as fuel relative to wood charcoal. Responses were offered on a basic Likert scale of nominal categories, e.g. when asked *"How much smoke does this fuel produce compared to regular charcoal?"*, participants were asked to choose 1 of 5 statements that best matched their opinion, namely *"much less; slightly less; about the same; slightly more; much more"*. The survey tool contained further questions relating to the size of each household, the number of briquettes they would estimate consuming in a typical day, their willingness to pay (WTP) for the briquettes (if at all) and how much they spent on wood charcoal in a typical month.

Variance in the mass, volume and density measurements between the 4 different types of briquettes was tested for significance (one-way ANOVA) using SPSS 20.0 (IBM Corp. 2011). No statistical tests could be performed on the results of the combustion analysis, which was based on single samples. The variance in the number of households that offered responses in each nominal category for the 2 different types of briquettes was tested for significance using χ^2 values.

Study limitations

I acknowledge the limitations of basic Likert scales; a full Likert scaling, wherein groups of items are statistically tested to determine the extent to which they measure the same phenomena (Aiken 1996) would have been preferable. However, given the limited time available for this study, I was satisfied that a basic scale (as employed by the majority of researchers: Aldridge and Levine 2001) would provide a useful initial representation of households' perceptions of the briquettes.

Chapter 4: Social considerations

- Portions of Part 1 of this chapter have been previously published as:

Morrison EHJ, Upton C, Odhiambo-K'oyooh K, Harper DM (2012) Managing the natural capital of papyrus within riparian zones of Lake Victoria. Hydrobiologia 692:5-17.

- Portions of Part 2 of this chapter have been previously published as:

Morrison EHJ, Upton C, Pacini N, Odhiambo-K'oyooh K, Harper DM (2013) Public perceptions of papyrus: community appraisal of wetland ecosystem services at Lake Naivasha, Kenya. Ecohydrology & Hydrobiology http://dx.doi.org/10.1016/j.ecohyd.2013.03.008.

Chapter 4: Social considerations

This chapter attempts to provide a detailed understanding of the reciprocal relationship between human societies and papyrus wetlands at Lakes Victoria and Naivasha.

The material presented in this chapter seeks to address the following thesis questions:

- Why should papyrus wetlands at Lake Naivasha be restored from a sociological perspective? (**TQ1**)
- What are the key social factors at Lake Naivasha that might hinder successful wetland restoration? (**TQ2**)

Outline of Chapter 4:

Part 1: The natural capital of papyrus wetlands

1. Uses of papyrus by people living close to wetlands at Lake Victoria are investigated.
2. Limiting factors associated with livelihoods based on wetlands are assessed.
3. A case study of community-led wetland restoration is described, highlighting the importance of papyrus as a source of natural capital.

Part 2: Public perceptions of papyrus

1. The wider values of papyrus are examined from the perspectives of stakeholders at Lakes Victoria and Naivasha.
2. A contrast is revealed between the ecosystem services that are most widely recognised at each lake.
3. Possible reasons for the variance in perceptions are discussed in relation to differences in demography and geography.

- A summary of findings relating to RQs 1–4 and 5–9 is given at the end of each of Parts 1 and 2 respectively.
- Responses to TQ1 and TQ2 and are then provided at the end of the chapter.

Part 1: The natural capital of papyrus wetlands

4.1. Research questions

RQ1: What are the demographic characteristics of papyrus users?

RQ2: What do they use papyrus for and how important is it to their livelihoods?

RQ3: What are the negative aspects of livelihoods based on papyrus?

RQ4: How can these negative aspects be addressed?

4.2. Results

4.2.1. Demographic characteristics of papyrus users (RQ1)

The ratio of women to men in the survey pool was approximately 2:1. The summary demographic data in Table 4.1 describe the profile of a 'typical' papyrus user in Kisumu District: a Luo[5] female >46 years of age, out of formal education since primary school, who has been resident in her village for >10 years and making a living from papyrus for most of her adult life. She harvests papyrus every other day from a wetland >5 ha in size, which is located <0.5 km from her homestead, along with >100 other people. Her efforts provide financial support to dependents both within and outside of her own household of around 6 people.

As one moves up from the level of the individual to that of the community, it is apparent that older females (>45 years) play major roles in each of the three key activities – harvesting, production and marketing – that characterise livelihoods based on papyrus. Indeed, their level of involvement had not changed significantly over the last 10 years and remains the highest of all age-sex cohorts in the present day (Table 4.2). The equivalent male group had, on the other hand, declined in terms of its involvement in each activity, particularly so in terms of harvesting effort – a highly significant [χ^2 (1, Yates' correction, n = 110) = 7.122, p <.01] reduction of around 30% (Table 4.2).

[5] There are at least 40 tribes in Kenya. Districts lying at the edge of the belt of highlands running northwest from Nairobi are considered the home area of the Luo people (Francis 2000); every participant in this study happened to be a Luo.

Table 4.1. *Summary demographic data (n = 110: 72 ♀; 38 ♂) of the survey pool*

	Age	Education	Resident	Size	Distance
Min.	16-25	None	2	<1	<0.5
Max.	>46	College	>10	>5	>3
Mode	>46 (0.49)	Primary (0.65)	>10 (0.90)	>5 (0.89)	<0.5 (0.23)
95% CI	+0.10/-0.10	+0.10/-0.09	+0.05/-0.07	+0.05/-0.07	+0.09/-0.07

	Years	Household	Dep. in/out	Harvests	Users
Min.	1	1	0/0	4	4
Max.	65	18	12/8	28	420
Mean	18	6	3/2	17	114
95% CI	±2.52	±0.60	±0.54/±0.36	±1.09	±21.60

Key to Table 4.1. Age, of respondent; Education, highest level of education; Resident, years resident in village; Size, of wetland used (ha); Distance, of residence from wetland (km); Years, harvesting papyrus; Household, size of household; Dep. in/out, dependents supported within/outside household; Harvests, number of harvests per month; Users, number of others using same wetland. 95% confidence intervals (CI) are given for modes (expressed around proportions) of nominal data (top panel) and means of numerical data (bottom panel).

The participation of men aged 18–44 had also declined, albeit to a lesser extent; for example a reduction in harvesting effort of 10% over the decade, which is not statistically significant. The harvesting effort of women aged 18–44 had increased significantly ($\chi^2 = 5.203$, $p <.05$) over 10 years by around 25%. Younger women (<17 years) were the least involved in each activity among all cohorts, although their efforts in the marketing of papyrus appeared slightly greater in 2010 than in 2000 (a rise of around 6%). Similarly, the youngest group of males (<17 years) was the least active of all men, although their involvement had also risen slowly over the last decade, particularly so in terms of commodity production (Table 4.2).

Table 4.2. *Changing trends in different age-sex cohorts' involvement in harvesting, producing and marketing papyrus over the period 2000–2010, collated from questionnaire respondents (n = 110)*

	Harvesting		Trend	*Production*		Trend	*Marketing*		Trend
Cohort/Year	**2000**	**2010**		**2000**	**2010**		**2000**	**2010**	
♂ >45	70.0	41.8	↓	54.5	39.1	↓	20.9	17.3	↔
♂18–44	64.5	54.5	↘	45.5	36.4	↘	25.5	23.6	↔
♂ <17	14.5	17.3	↔	7.3	15.5	↗	(6.4)	(12.7)	↗
♀ >45	**72.7**	**71.8**	↔	**88.2**	**85.5**	↔	**87.3**	**86.4**	↔
♀ 18–44	45.5	70.0	↑	75.5	80.9	↗	76.4	77.3	↔
♀ <17	(4.5)	(4.5)	↔	(6.4)	(10.9)	↔	(6.4)	(12.7)	↗

Key to Table 4.2. Values are percentages, for example 70% (*n* = 110) of respondents agreed that 'men over 45 did the harvesting 10 years ago'. Arrows illustrate relative change over the decade on an arbitrary scale in which: horizontal = little change (±0–5%), sloping = moderate change (±5–15%), vertical = larger change (±15–30%). The cohort with the greatest involvement in each activity is shown in bold, that with the least in parentheses.

4.2.2. Uses of papyrus and significance to livelihoods (RQ2)

Questionnaire respondents identified multiple uses of papyrus. Different parts of the plant are used in different ways, e.g. freshly cut umbels are fed to livestock; stems are cut and dried for producing mats, baskets and more sophisticated commodities and the ash of the inner pith is valued for its medicinal properties (Table 4.3). All parts of the plant are used as a cooking fuel, the stems and rhizomes especially (Fig. 4.1). Around two thirds (66/110) of the survey pool stated that papyrus provides >50% their total household income, the remaining third somewhat less (Fig. 4.2).

Table 4.3. *Uses of papyrus identified during this study and the plant structures from which they are made*

Structure	Uses and notes
Flower head (umbel)	Fed to livestock (cattle, sheep and goats) Used as fuel For making brooms As decorations
Outer stem (culm)	Used as fuel; for making fish traps and cooking utensils; made into *kayamba* or 'raft rattles' (musical instruments); building *odeso* (small rafts); for roofing material (thatch); making ropes used in construction and for tethering boats and livestock; fashioned into hats and boxes for storage *Mats*: for sleeping or sitting on; drying grains and small fish (*omena*); as racks in market places; window blinds; ceiling board; flooring; doors; constructing granaries and walls of houses and kiosks (shops); fencing homesteads *Baskets*: many shapes and sizes, typically used for carrying goods to/from market places and for storage in homestead *Furniture*: chairs, settees, tables, picture frames, murals and table mats[6]
Inner pith	Chewed to quench thirst when working (*sensu* sugar cane); coiled into a soft support when carrying loads on head; used as a mosquito repellent *When burned*: used as fertiliser; smeared on walls of traditional houses; as a herb for cooking vegetables ('soda ash'); for preserving fish; as a remedy for oral infections (also for treating 'epilepsy' and mental health problems)
Rhizomes	Used as fuel

[6] In addition to the items of furniture listed here, 'value-added' papyrus goods (combining use of metals, paints, dyes, etc.) such as beds, shelves and lampshades were found on sale in Kisumu town.

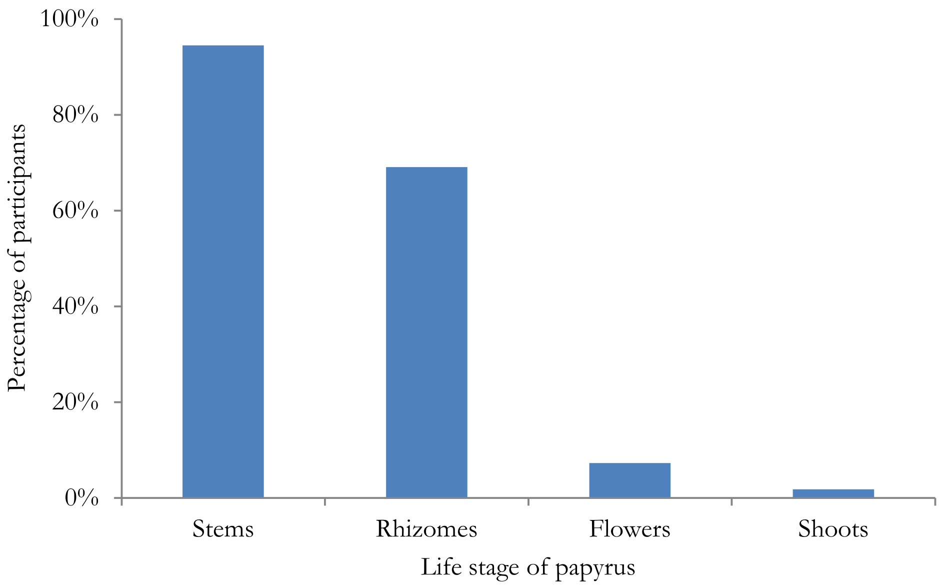

Fig. 4.1. Percentage of participants (*n* = 110) who used mature stems (culms), rhizomes, 'flowers' (umbels) and young shoots for fuel.

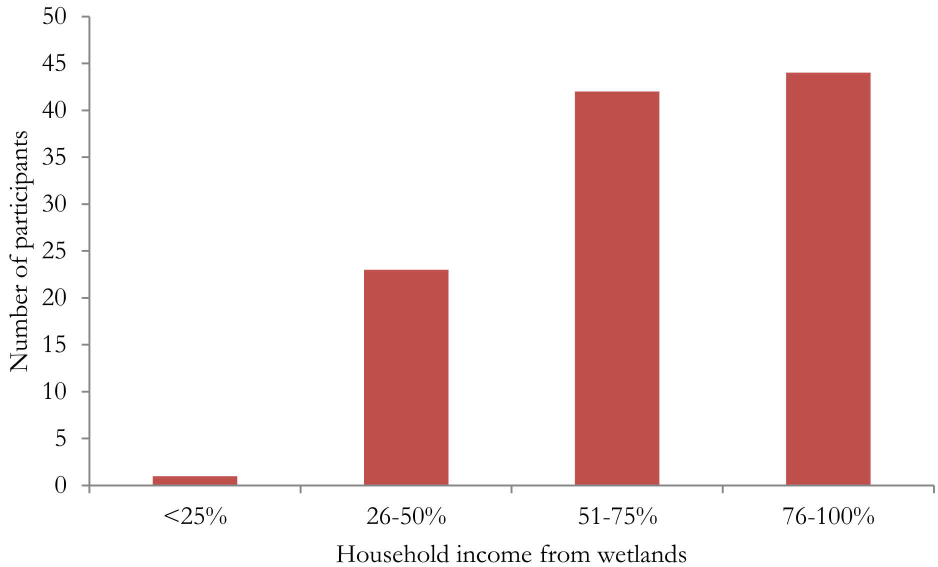

Fig. 4.2. Number of participants (*n* = 110) for whom papyrus constituted <25%, 26–50%, 51–75% and 76–100% respectively of total household income.

4.2.3. Negative aspects of wetland livelihoods (RQ3)

Almost two thirds (65.4%) of the survey pool believed that the size of local wetlands had decreased over the last decade; more than a quarter (27.3%) reported an increase, whilst the remaining 7.3% considered there to have been no change (Fig. 4.3). Of those who reported a decrease in the size of local wetlands, >50% cited smallholder farming as the principle cause; <10% blamed fishermen for the degradation, whilst only 4/110 people considered that papyrus harvesters were responsible. The remainder cited natural causes, mostly related to changes in lake level and inter-annual variations in rainfall.

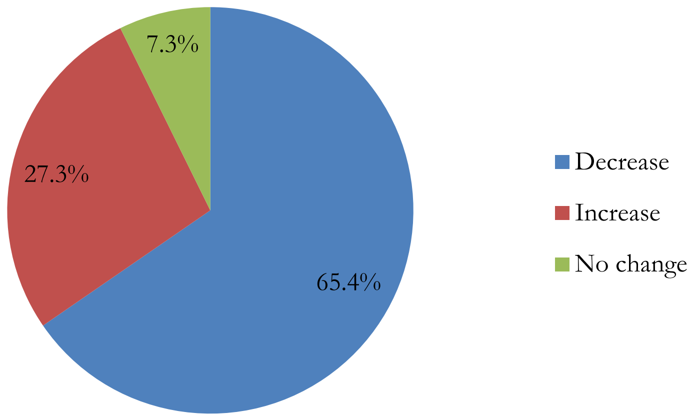

Fig. 4.3. Percentage of the survey pool that perceived local wetlands to have increased, decreased, or remained the same in size over the period 2000–2010.

Focus group discussions revealed multiple constraints, or limiting factors, to livelihoods based on papyrus. Common complaints included: high rates of infection from waterborne diseases and other human health risks; fluctuating market prices for papyrus commodities; a physically demanding working environment and frequent accidents. Means of addressing each of these constraints were also offered. Some respondents called for support from external groups; others cited the need for enhanced cooperation among harvesters themselves (Table 4.4).

Table 4.4. *Common constraints to livelihoods based on papyrus and suggested means of addressing them*

Box	*C.F. (%)*	*Constraints identified*	*Means to address constraints*
1	**15.6**	Waterborne diseases (malaria; bilharzia; sleeping sickness; cholera) from long hours spent harvesting in standing water; diarrhoea and pneumonia	Spraying of swamps with insecticide, provision of mosquito nets, anti-malarial drugs and other medication (no indications of assumed responsibility)
2	**13.3**	Bites from snakes, leeches, red ants and other insects	Spraying of swamps; removal of snakes by Kenya Wildlife Service
3	**12.7**	Limited marketing opportunities; price fluctuations; poor transport infrastructure	External support (e.g. from NGOs) in developing marketing skills; road improvements
4	**10.9**	Difficult working environment; operating barefoot, often naked; physical demands of job (e.g. carrying heavy loads long distances) resulting in backache, leg injuries; minor accidents	Recognition of need for other sources of income; general calls to "government" to make secondary education free; desire for cheap supply of gumboots
5	**10.9**	Flooding reducing access and harvesting potential; unpredictable conditions in lake;	Channels to be dug for controlling movement of water during rainy seasons

		risk of drowning	
6	**8.9**	Cuts from papyrus, accidents with *panga*s (machetes) and processing tools (e.g. needles); chest problems, asthma-like breathing difficulties; sun-blindness, eyesight damage; other work-related illnesses	Calls for cheap supply of protective clothing such as gloves; better access to medicines
7	**8.7**	Attacks from hippopotamuses, crocodiles, monitor lizards and other wild animals	Fencing to keep hippos out of harvested zones
8	**6.0**	Large number of processes involved in the trade, length of time demanded; boredom	Need for product diversification; external sources of training
9	**5.8**	Low profit margins; exploitation by brokers, agents or middle-men/women	As above, marketing skills necessary to "cut out" agents; small loans scheme for extra capital during times of low demand
10	**3.7**	Competition with other wetlanders; theft of harvested papyrus stems; competition from weeds (*mboha*)	Formation of cooperative societies to enhance sales; greater security, stores for harvested material
11	**2.5**	Conflicts with fishermen and farmers (e.g. deliberate/accidental fires; swamp drainage)	Introduction of rules such as no smoking within the wetlands
12	**1.0**	Marital issues (adultery; sexual underperformance; divorce) caused by long absences and physical fatigue; incidences of rape in isolated parts of swamp	Need for more lucrative sources of income requiring less physical effort; working in groups for safety

Key to Table 4.4. Responses provided by participants during focus group discussions when asked *'what factors constrain livelihoods based on papyrus?* and *'how can these can be overcome?'*. Limiting factors are grouped into boxes of similar attributes and are presented in decreasing order of citation frequency, C.F. (= number of citations/total citations, expressed as a % value).

4.2.4. Okana: an example of wetland restoration (RQ4)

The Victoria Institute for Research on Environment and Development (VIRED) has worked in collaboration with the Kenya Wildlife Service (KWS) since the late 1990s with the community of Okana, a settlement located inland from the lake c. 17 km southeast of Kisumu town (Chapter 3, Fig. 3.2). A focus group discussion held at Okana during the course of this thesis sought to discover how and why the community became in engaged in wetland restoration and what the results of the project were; the following information is a summary of findings from this discussion.

Okana's population once had access to an extensive area of swamp from which they harvested papyrus, arrowroot and medicinal herbs and hunted wild animals such as sitatunga (*Tragelaphus spekii*). The vast majority of the wetland had been lost by 1999, following a prolonged period of unregulated harvesting and the gradual conversion of the swamp to cultivated fields. Elder members of the community began to realise that they no longer had adequate supplies of papyrus for the production of mats, baskets, ropes and other uses made of the plant's fibre.

It was decided that the erstwhile wetland should be restored after a period of consultation facilitated by VIRED and KWS. Around 80 community members subsequently collected living papyrus material (rhizomes bearing young shoots) by hand from Nyamware, a site approximately 14 km from Okana close to the lakeshore (Chapter 3, Fig. 3.2). This material was placed in a makeshift nursery (a region of swampy ground) until it was considered ready for transplantation to the original site, located on the outside meander of a river that seasonally floods. Having initially re-established approximately 2 ha of papyrus in 2000, the restored area (Fig. 4.4) in 2010 was estimated at >7 ha.

Members of the community proceeded to form a 'self-help group' as the papyrus began to successfully regenerate. The primary motivation for doing so was to coordinate and cooperate on wise use of the wetland they had recently toiled to restore. Today, the 'Okana Wetland Self-Help Group' (OWSHG) consists of 38 individuals comprising a democratically-elected Chairman, Vice-Chairman, Treasurer and Secretary, as well as Voting Members who are organized into sub-committees of common interest groups, such as aquaculture and apiculture (although sustainable management of the wetland remains priority).

Fig. 4.4. Papyrus growing in the restored wetland at Okana (photo: E. Morrison).

Focus group participants remarked on the resurgence of a wide variety of wildlife around Okana (including waterbuck, sitatunga, mongoose, snakes, egrets and weaverbirds), which they attributed to the restored wetland. Young children are reportedly seeing many of these animals for the first time and are "learning to appreciate the value of the wetland from elder generations" (OWSHG Chairman, pers. comm.). Indeed, elder residents of Okana appeared to be particularly engaged with the project, likely as a result of having experienced the near total loss of the wetland's benefits. They are now teaching younger generations the skills necessary to produce essential crafts and commodities from harvested papyrus, which once again plays a significant role in the social and economic functioning of the community.

Funding for VIRED, which was used to facilitate the Okana restoration programme, came in large part from UNESCO (K. Odhiambo, pers. comm.). Whilst during the period of data collection (mid-2010) clear efforts were being made towards achieving 'wise use' of the restored wetland, the present situation at Okana (mid-2013) is unclear. Future efforts should, in the first instance, revisit the site to ascertain whether the OWSHG remains functional and to assess the extent to which sustainable management of Okana's restored wetland has been achieved. This is critical to understanding the long-term success of community-led restoration programmes in rural areas once initial sources of funding have been exhausted. The longitudinal analysis of changes generated by conducting repeat follow-up visits could usefully inform restoration efforts elsewhere, including Lake Naivasha.

4.3. Discussion

4.3.1. Characteristics of wetland livelihoods

A recent study by Akwetaireho and Getzner (2012), working along the Ugandan shoreline of Lake Victoria, found that willingness to pay for the conservation of papyrus wetlands was significantly higher among female respondents. The authors attributed this to the fact that women received only a small share of household income derived outside wetlands. Whilst division of household income was not investigated in the present study, a similar trend may explain why women >45 years, followed closely by women aged 18–44, were the demographic cohorts most involved in each of the 3 key activities (harvesting, production and marketing) that characterise wetland livelihoods. Mwakubo and Ikiara (2008), working at the nearby Yala Swamp, found there to be no taboos against women working with papyrus, whereas traditional beliefs discouraged women from fishing. This could explain the predominance of women in the present study, both within the survey pool (men might have been engaged in fishing activities during periods of data collection) and in the perceptions of respondents as to which community members were most active in the wetlands.

Papyrus patently has a high socioeconomic value, manifest in its multiple nutritional, medicinal, cultural, agricultural and practical uses (Table 4.3). Wetlands clearly provide significant livelihood support to rural communities living close to them, with over three quarters of respondents generating 50% or more of their total household income from papyrus alone (Fig. 4.2). Indeed, the significance of papyrus wetlands to the maintenance of local livelihoods has been attested to at multiple sites around Lake Victoria in recent studies (Gichuki et al. 2001; Thenya et al. 2006; Owino and Ryan 2007; Kiwango and Wolanski 2008; Osumba et al. 2010). All of the uses identified by respondents in this study were 'consumptive use values' (Turner et al. 2011) characterised by direct utilisation of papyrus itself, e.g. for processing into marketable handcrafts, for feeding to livestock or for burning to provide cooking fuel and ash for fertiliser. This observation finds broad agreement with the research of Kangalawe and Liwenga (2008), working in the Kilombero valley of Tanzania, who found that local wetlands contributed significantly "to both total family consumption needs and total cash income" (p.971).

This is not to say, however, that papyrus should be regarded as a more favourable means of generating income over other alternative livelihood strategies. On the contrary, the relatively meagre returns in cash income generated from harvesting papyrus stems (Maclean et al. 2003) suggest that rural communities who depend on wetlands for their survival do not necessarily do so out of choice, but rather because of a lack of better alternatives (Swallow et al. 2009). The long list of constraints that papyrus harvesters face when working in papyrus wetlands, which include serious risks to human health, difficult working conditions and frequent conflicts with others (Table 4.4) suggest that, given the availability of more lucrative alternatives, far fewer people at Lake Victoria would harvest papyrus than is currently the case.

Societal dependence on the 'natural capital' (Cairns 1993) of these wetlands comes at a cost. Indeed, the burden of physical, financial and social constraints associated with livelihoods based on papyrus was expressed recurrently during the interviews held at Bugo and Harambee. The rise in harvesting effort over the preceding decade among women aged 18–44 years, for example, was frequently attributed to the deteriorating health (from physical exertion in the wetlands) of men >45 years, whose own harvesting efforts had as a consequence declined significantly. In other words, as "older men grew tired and weak" (Anon., pers. comm.), younger women (often their wives or children) had increased their relative efforts in order to maintain the (frequently very high) proportion of household income derived from wetlands. Such actions further testify to the significance of papyrus to local livelihoods.

4.3.2. Impacts on wetlands

This high level of dependence is likely to have contributed to the general decline in the availability of papyrus through over-harvesting, as has been reported at other sites around Lake Victoria (Owino and Ryan 2007; Osumba et al. 2010). However, harvesting papyrus is not the only means of generating an income (nor the only driver of wetland degradation) within the riparian zone – with fishing, livestock rearing and subsistence farming being common alternative livelihood strategies (Loiselle et al. 2006; Swallow et al. 2009).

Questionnaire respondents often accused fishermen of destroying wetlands by uprooting papyrus to catch mudfish that take shelter beneath it, as well as when clearing areas of fringing swamp to facilitate boat access to the main lake. Herdsmen were said to routinely cut the flowering heads (umbels) of papyrus to feed their livestock, especially during the dry season when wetlands become an important source of fodder. At the same time, subsistence farmers reportedly clear swamps (through cutting or burning) from land they regard as contiguous with their plots during low lake levels, when previously flooded soils become accessible. These observations support the findings of Scoones and Cousins (1994) who, based on their research into the *dambo* wetlands of Zimbabwe, concluded that the intensity of individual efforts to maintain control over *dambos* increases during periods of drought, when wetland resources become especially important to local livelihoods

A common cause of degradation by papyrus harvesters appears to be the exploitation of wetlands for fuel (Gichuki et al. 2001), either on a daily basis, or when charcoal, firewood or other options (such as kerosene) are unobtainable: every participant in this study revealed that they use papyrus in this way for at least part of the year. The vast majority (95%) used the culms. In some cases this represented waste material discarded during the production of handcrafts; in others plants were harvested explicitly for fuel. A large proportion (69%) also used the rhizomes (favoured for being woodier and thus burning more efficiently), the removal of which greatly impairs the wetland's regenerative capacity (since below ground structures grow much more slowly than culms: Kiwango et al. 2013). A similar trend was described by Maclean et al. (2003) working at Lake Bunyoni in Uganda, where the collection and sale of papyrus for fuel was considered one of the most important uses of local wetlands.

However, despite the apparent ubiquity of the practice, papyrus was regarded as a poor quality fuel – cited as being hard to light, difficult to keep lit, and producing excessive amounts of smoke and ash. Having to burn the very same resource on which you rely for cash income is stark illustration of the 'poverty-environment trap' that Swallow et al. (2009) argue is widely responsible for the simultaneous degradation of ecosystems and human well-being throughout the Lake Victoria basin. The use of papyrus wetlands as a source of fuel is considered further in Chapter 6.

4.3.3. Wetland restoration at Lake Victoria

The case study of Okana illustrates that, from an ecological perspective, restoring papyrus wetlands can be achieved in a relatively straightforward fashion and at a minimal cost. From a sociological perspective, a large degree of the success achieved there can be ascribed to Okana's small, homogeneous community, which had a traditional history (and embedded knowledge) relating to the use of papyrus – a resource that had *a priori* value to them. The long-term partnership with VIRED and KWS appears to have guided the success of the 'bottom-up' approach to restoration that was taken, supported by the democratic leadership of the self-help group that was established. I propose the example be used as a model of wetland restoration for wider dissemination around Lake Victoria (and potentially beyond) given the straightforward, inexpensive and yet seemingly highly effective method employed.

Besides community participation, much, of course, depends upon the availability of water. Okana's wetland was situated along the bank of a river, allowing pulses of floodwater to maintain productivity. Many of the 33 villages visited during this study, however, were not. At sites not subject to flooding, suitable locations would need to be identified where the water table is high enough to permit shallow excavations to fill with water, into which papyrus could be transplanted (Fig. 4.5). Water levels would have to be considered carefully, since papyrus is highly sensitive to soil moisture conditions (Boar 2006); a simple notched weir on the downward face could be used to control water height within the stands.

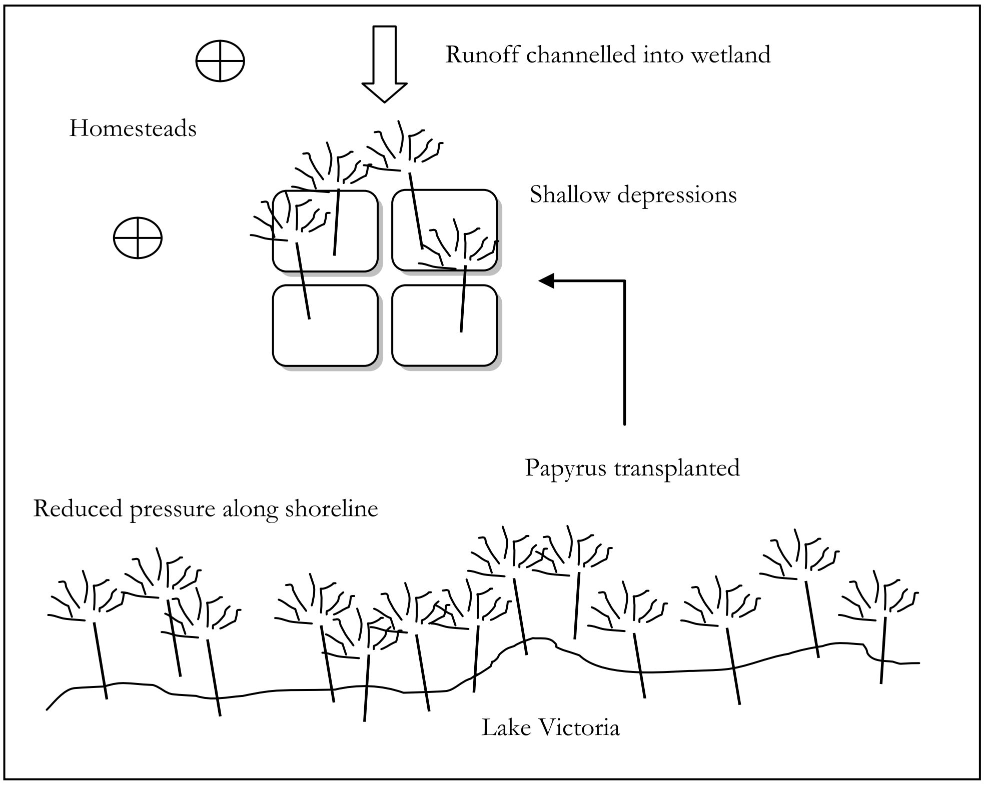

Fig. 4.5. Sketch of proposal to transplant papyrus into shallow excavations receiving surface runoff; criss-cross pathways would increase access for harvesting.

Freshness could be maintained by constructing these depressions on gently sloping land with a network of shallow rills channelling surface runoff (i.e. following rain events) into the wetlands. The four-square design and criss-cross pathways would permit easier access to the papyrus and might also serve as the basis of a harvesting strategy, whereby each quarter is cropped sequentially, allowing for a 'fallow' period in which young shoots are allowed to reach maturity before being harvested.

However, as noted in Chapter 2, what constitutes a sustainable harvesting interval for papyrus is somewhat contested. Thenya et al. (2006), based on their research at the nearby Yala wetland, advocated cutting at 14-week intervals. Other studies have suggested that cleared papyrus stands are only able to regain their original biomass after a period of 9–12 months of uninterrupted growth (Hails 1997; van Dam et al. 2007; Terer et al. 2012). The sustainability of harvesting frequencies is likely to be site-specific, related to factors such as hydrological regime, altitude, temperature and micro-climatic conditions. I tentatively support the findings of Osumba et al. (2010), who suggested a harvesting program be established at Lake Victoria based on the seasonal cycle, cutting roughly every 6 months and employing a staggered cropping regime similar to that described above.

Creating wetlands specifically for harvesting plant fibre could ease some of the constraints to livelihoods based on papyrus that are listed in Table 4.4:

- Box 1. One might expect a reduced prevalence of waterborne diseases if harvesters could access the papyrus along criss-cross pathways (Fig. 4.5), negating the need to spend hours in standing water.
- Box 4. Physical demands would be lessened if papyrus were to be transplanted closer to homesteads, minimizing the distance covered when carrying heavy loads to sites of processing.
- Box 5. Growing papyrus in dedicated stands would greatly reduce the risks to harvesters presented by flood conditions in the lake, with greater control of water levels provided by a weir.
- Box 7. Transplanting papyrus inland would reduce the risk of (at times fatal) attacks from animals active among the wetlands; hippos, for example, would be unlikely to visit the stands during the day (when harvesters are active) owing to their photosensitive skin.
- Box 10. The risk of harvested stems being stolen could be mitigated by operating closer to homesteads; competition from invasive weeds (e.g. 'mboha': *Pergularia daemia*) could be reduced by increasing access to stands along pathways – allowing the proliferation of climbing species, for example, to be more easily controlled.
- Box 11. Conflicts with others could be somewhat ameliorated, for example by negating the need to pay fishermen for use of their boats to transport bundles of stems inshore – a common expense for many papyrus harvesters.

Combining the respective citation frequencies of these factors, over half (52.3%) of all constraints identified by respondents could potentially be addressed in this way (Table 4.4). What's more, by establishing papyrus wetlands away from the immediate lake edge, human pressure along the shoreline would be reduced as harvesters concentrate their efforts farther inland, thereby helping to maintain the integrity of wetlands at the land-water interface and thus the vital regulating functions they perform (Cózar et al. 2007). Of course, putting proposals such as the above into effect would only be possible once sufficient time and effort had been spent on working with papyrus harvesters and other stakeholders to address their concerns in a more collaborative fashion, with sufficient policy and financial assistance provided in support of this. An example of how this has recently been achieved is set out below.

Kiwango et al. (2013) demonstrated that the ecological character of heavily-degraded papyrus wetlands around Lake Victoria can be restored using locally available means, in a similar way to that described at Okana and in the proposal above, whilst simultaneously providing socioeconomic benefits to local communities. Having secured the collaboration and participation of the local community after a period of consultation, formalised by the signing of a Memorandum of Understanding, simple earthworks were undertaken to create creeks supplying water to the proposed sites of restoration. Transplanted papyrus, fenced off to reduce interference from humans and wild animals, attained an aboveground biomass comparable to that of nearby pristine wetlands after a period of 2 years (Kiwango et al. 2013).

The abundance of fish larvae, juvenile fish and shrimps was shown to be higher around the restored wetlands than at sites devoid of wetlands comparable to the pre-restoration condition of the study sites. The availability of fish was a principal concern for local communities; survey data revealed that 100% (n = 87) of respondents observed an increase in fish productivity as a result of wetland restoration, which further led to rises in employment opportunities and an improvement in the site's attractiveness. The authors concluded their study by citing 4 key lessons that the project had highlighted:

1. Degraded papyrus wetlands can be readily restored to a productive state, provided that the local community is supportive.
2. Channel creation (i.e. the availability of water) is central when attempting to rehabilitate wetlands.
3. Undesirable invasive species need to be kept in check.
4. Locally available means of governance should be used to give communities a sense of ownership over the project.

In view of this last point, Kiwango et al. (2013) attributed a large degree of the project's success to the active participation, from the very beginning, of local Beach Management Units (BMUs). These community-led institutions are responsible for governance of fisheries affairs at the local level throughout the inland and coastal waters of Kenya and will be discussed further in relation to Lake Naivasha in Chapter 6.

4.4. Summary of Part 1

1. People living close to Lake Victoria use papyrus wetlands in a multitude of ways, especially older women (RQ1).

2. Local wetlands contribute significantly to income levels in Kisumu District; households strive to maintain this contribution (RQ2).

3. Livelihoods based on papyrus are beset by many limiting factors, particularly in terms of risks to human health (RQ3).

4. People harvesting papyrus, as well as those competing for resources associated with it (e.g. fish, fertile soils), can lead to wetland degradation (RQ3).

5. The use of papyrus for fuel is widespread and a potential cause of over-harvesting in local wetlands (RQ3).

6. Recognition of the benefits of papyrus, particularly its 'consumptive use values', can be a motivation for wetland restoration and subsequent wise use (RQ4).

Part 2: Public perceptions of papyrus

4.5. Research questions

RQ5: What are the demographics of stakeholders at Lakes Victoria and Naivasha?

RQ6: Do people's perceptions of papyrus vary significantly between the two lakes?

RQ7: If they do, which demographic characteristics might explain this variation?

RQ8: Which wetland services do the stakeholders value the most and why?

RQ9: Does awareness of their values have an impact on local wetlands?

Hypotheses:

H_0: There are no significant differences between Lakes Victoria and Naivasha in terms of people's perceptions of papyrus.

H_1: There are significant differences between the lakes.

H_0: Any observed variance in perceptions is due to chance (sampling error)

H_2: Variations in levels of awareness are not due to chance.

4.6. Results

4.6.1. Demographics of stakeholders (RQ5)

Lake Naivasha

The ratio of male to female respondents at Lake Naivasha was approximately 2:1 and the predominant age group 19–35 years old. There was a fairly even spread among respondents in terms of their highest level of education: 35.6% had reached primary school; 22.9% had completed secondary school; 20.3% were college graduates and 16.9% were enrolled in or had graduated from a university. Only 4.2% had received no formal education (Table 4.5).

More than three quarters (90/118) of the survey pool were residents of Naivasha, the remaining 28 being temporary visitors to the region. The majority (56/90) of residents had recently immigrated (arriving on average 9 years ago), with only 34 born in the region itself. Over half those who had immigrated had done so in search of employment, around one quarter to escape conflicts elsewhere and the remainder variously to join friends/family, with the aim of acquiring land, or for medical reasons. Most people (proportional mode 0.6 ±0.1) resided >5 km away from the wetland area where the interview took place and around one third visited the site on average once a day (Table 4.5).

Twenty stated ethnicities were recorded in the survey sample. The majority (80.5%) were Kenyans, comprising 13 different (traditionally tribal) communities; the remaining 19.5% represented 7 other nationalities[7] (American, Australian, British, Canadian, Danish, German and Zimbabwean). A total of 21 different categories of employment were recorded, ranging from flower farm workers and fishermen to teachers and tradesmen, among many others. For the majority (87.3%) of individuals, their single stated livelihood was their sole means of income.

Lake Victoria

The gender ratio of respondents at Lake Victoria was 1:1 and the predominant age group 19–35 years old. Over two thirds (68.6%) of the survey pool had left education following primary school and 14.4% no formal education whatsoever. Seventeen respondents had completed secondary school, 2 were college students and 1 was a university graduate (Table 4.5).

All respondents (*n* = 118) were local residents, the vast majority (88.1%) since birth. With only 10 individuals having immigrated to the region, the mean residence time was >35 years. One third of respondents lived close (i.e. between 0.5–1.0 km) to the wetland where the interviews took place and almost two thirds visited this site once a day (Table 4.5).

Over 99% of respondents represented the Kenyan Luo community, with just one other ethnicity (Luhya) stated. Nine different categories of employment were recorded; papyrus harvesting (39.8%) and subsistence farming (34.7%) were the most common livelihoods, followed by fishing and livestock rearing. The majority (73.7%) of respondents pursued multiple livelihood strategies by having two or more jobs.

[7] Non-Kenyans were included as 'absentee stakeholders' (Clewell and Aronson 2013) since tourism plays a role in the management of the Lake Naivasha ecosystem.

Table 4.5. *Summary demographic data of survey respondents (n = 236) at Lakes Naivasha and Victoria*

		Naivasha	Victoria
Gen.	♀	37	59
	♂	81	59
	n	118	118
Age	Min.	<18	<18
	Max.	>55	>55
	Mode	19-35 (0.7 ±0.1)	19-35 (0.4 ±0.1)
Edu.	Min.	None	None
	Max.	University	University
	Mode	Primary (0.4 ±0.1)	Primary (0.7 ±0.1)
Hist.	Res.	90/118	118/118
	Bir.	28.8%	88.1%
	Out.	71.2%	11.9%
Len.	Min.	1	6
	Max.	41	69
	Mean	9.1 (±2.1)	35.1 (±2.7)
Dist.	Min.	101-500 m	101-500 m
	Max.	>5.1 km	>5.1 km
	Mode	>5.1 km (0.6 ±0.1)	0.5–1.0 km (0.3 ±0.1)
Freq.	Min.	>1/decade	1/month
	Max.	2-3/day	2-3/day
	Mode	1/day (0.3 ±0.1)	1/day (0.6 ±0.1)

Key to Table 4.5. Gen., gender; Age (years); Edu., highest level of formal education; Hist., life history (Res., number of respondents who were local residents; Bir., % resident since birth; Out., % born outside the region); Len., length of time settled in region (years); Dist., distance of residence from wetland; Freq., frequency of visits to wetland (e.g. '>1/decade' = once every ten years or more). 95% confidence intervals are shown in parentheses for numerical means and nominal modes (expressed around proportions).

4.6.2. Perceptions of papyrus (TOKS scores) (RQ6)

The maximum 'Table Of Known Services' (TOKS) score at Lake Naivasha was 13/27 and the mean score 3.4 (±0.4). The maximum TOKS score at Lake Victoria was similar to Naivasha (15/27), yet the mean was approximately double at 6.8 (±0.6): a highly significant [F (117, 117) = 2.171, p <.01] difference (Table 4.6).

Table 4.6. *Summary of TOKS (Table of Known Services) scores and site quality scores (SQS) for each location surveyed around Lakes Naivasha (top panel) and Victoria (bottom panel)*

				TOKS score				
Rank	*Code*	*Site*	*n*	*Min*	*Max*	*Mean*	*Mode*	*SQS*
1	YM	YMCA Beach	8	0	8	4.9	Potable water *	4
2	KB	Karagita	15	1	5	4.4	Potable water	1
3	KA	Kamere Beach	24	0	8	4.3	Potable water	2
4	CV	Crescent View	8	1	5	4.0	Potable water	5
5	TB	Town Beach	15	1	13	3.5	Potable water	6
6	FE	Fish Eagle Inn	18	0	6	3.0	Biodiversity support	7
7	CA	Camp Carnelley's	10	1	5	2.4	Biodiversity support	7
8	FC	Fisherman's Camp	20	0	7	1.2	Aesthetic qualities	7
		Lake Naivasha	**118**	**0**	**13**	**3.4** (±0.4)	*** 0.4 (±0.1)**	**5** (±2)

				TOKS score				
Rank	*Code*	*Site*	*n*	*Min*	*Max*	*Mean*	*Mode*	*SQS*
1	NK	North Kabodho	15	2	15	9.6	Fibre for commodities *	5
2	NY	Nyalenda	21	4	12	8.6	Fibre for commodities	6
3	KG	Kamagaga	10	6	13	8.5	Potable water	5
4	WK	West Kabodho	12	4	12	8.0	Fibre for commodities	7
5	RA	Ramula	16	1	9	5.8	Fibre for fuel	5
6	KO	Kakola-Ombaka	16	1	10	5.4	Fibre for commodities	8
7	WK	West Kabar	16	1	8	4.1	Fibre for commodities	7
8	KM	Kamuga	12	1	9	4.0	Local climate control	8
		Lake Victoria	**118**	**1**	**15**	**6.8** (±0.6)	*** 0.9 (±0.1)**	**6** (±1)

Key to Table 4.6. Sites are ranked in decreasing order of mean TOKS score. Site codes correspond to data points in Fig. 4.8; *n*, number of respondents at each site; Mode, most frequently identified service at each site (and for the lake as a whole *); 95% confidence intervals are shown in parentheses for location means and modes (expressed around proportions).

Variance in TOKS scores reflected the number of respondents (absolute values) at each lake who cited sub-sets of services within the 4 main ecosystem service categories (Fig. 4.6), being significantly higher at Victoria in terms of provisioning [χ^2 (1, Yates' correction) = 102.696, p <.01], regulating (χ^2 = 56.021, p <.01) and supporting (χ^2 = 15.396, p <.01) services. There was no significant difference between the numbers of respondents who cited cultural services.

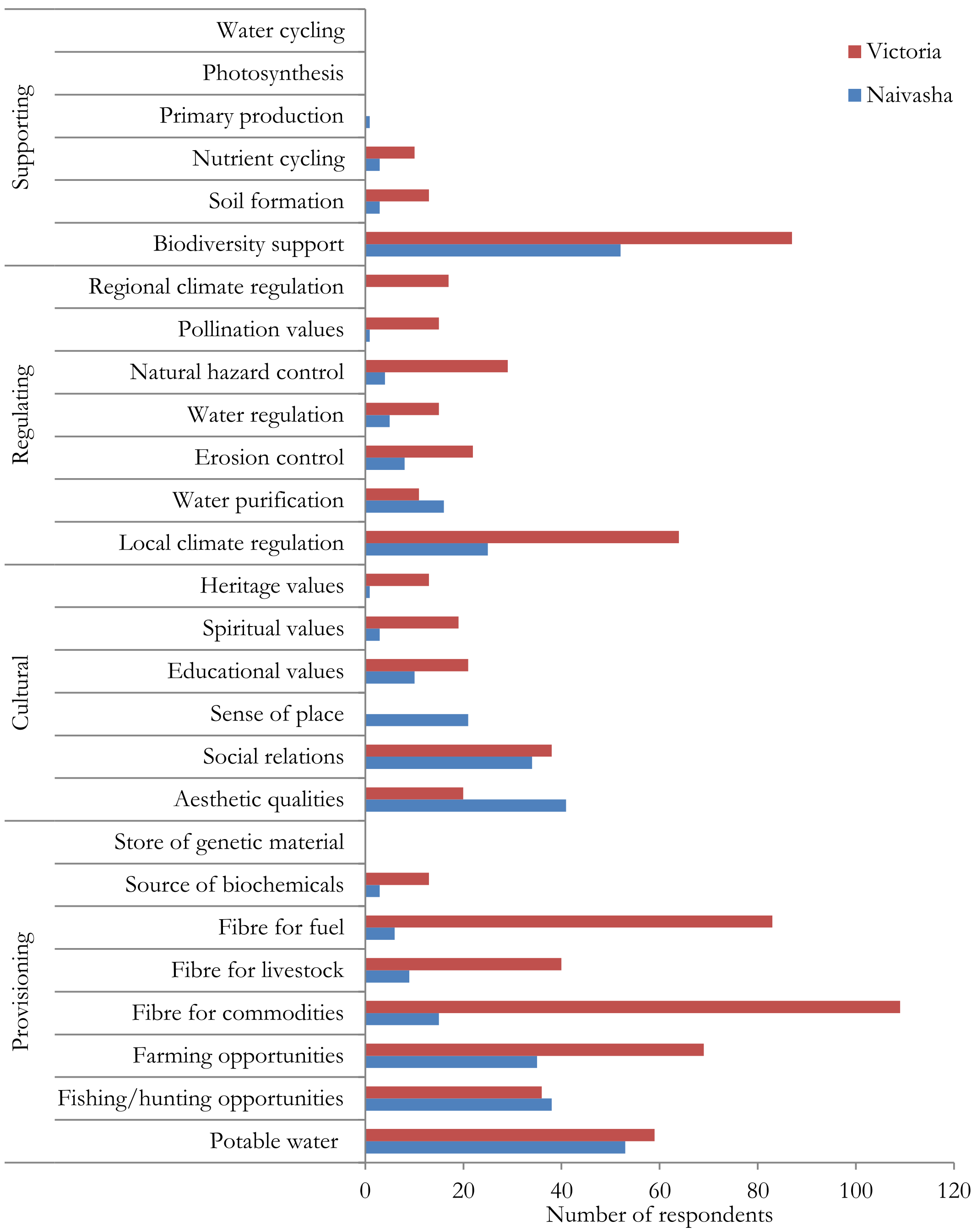

Fig. 4.6. The 27 sub-sets of services from the TOKS and the number (*n* = 236) of respondents (absolute values) who cited each at Lakes Victoria and Naivasha.

4.6.3. Statistical associations between demographic characteristics and TOKS scores (RQ7)

No significant differences (p =.05, Mann-Whitney U-test) between Lakes Naivasha and Victoria were detected with respect to variations in the number of respondents (*n*: Table 4.6) at each different site, nor their respective site quality scores; likewise no association was found between *n* and TOKS scores. There were no significant differences (p <.05) between the mean TOKS scores of men (5.2) and women (4.9).

The mean TOKS score of respondents with livelihoods centred on the riparian zone, comprising papyrus mat-makers, fishermen, coxswains, tour guides, subsistence farmers and herdsmen (mean 6.2), was strongly significantly higher (z = 6.068, p <.01) than those with livelihoods centred away from the riparian zone (mean 3.7). At Lake Victoria, 84.7% of the survey pool pursued riparian livelihoods, compared to 25.5% at Lake Naivasha.

Age had a significant [ANOVA, F (3, 232) = 3.256, p <.05] effect on scores, post hoc comparisons (Tukey HSD test) indicating that the mean score of respondents <18 years was significantly lower (mean 3.2) than those aged 36–54 years (4.9) and >55 years (6.0). At Victoria, 50.0% of respondents were aged >36 years, as opposed to 23.7% at Naivasha. There was no significant association between numbers of years settled and mean TOKS score at either lake.

Residents at Naivasha had strongly significantly (z = 6.104, p <.01) higher mean scores (4.2) than non-residents (1.8); at Victoria all respondents were residents. The difference in scores between Kenyan nationals and foreigners was strongly significant (z = 7.799, p <.01) at Naivasha, Kenyans scoring higher (4.0) on average than foreigners (1.2); there were no foreigners within the survey pool at Lake Victoria.

The difference in TOKS scores between respondents with two or more jobs and those with a single job was strongly significant (z = 10.867, p <.01), respondents with multiple jobs scoring higher on average (7.3) than those with just one (3.3). At Victoria, 73.7% of respondents had two or more jobs, compared to 12.7% at Naivasha.

Distance between respondents' homesteads and the nearest wetland had a strongly significant [ANOVA, F (5, 230) = 14.635, p <.01] effect on scores, post hoc comparisons indicating that the mean score of those residing <100 m away (8.7) was significantly different from all others. Scores tended to decrease with increasing distance from the wetland: 101–500 m (6.3); 501–1000 m (5.0); 1.1–3.0 km (5.9); 3.1–5.0 km (5.7); >5.1 km (3.0). At Victoria >60% of respondents lived <1 km away, where as at Naivasha >60% lived >5 km away.

The relationship between respondents' highest level of formal education and TOKS scores was strongly significant [ANOVA, F (4, 231) = 6.186, p <.01], those with no formal education and primary school leavers scoring higher (mean 5.6 in both cases) than those with a university education (mean 2.1). At Victoria, 83.1% of respondents comprised the former two cohorts, compared to 39.8% at Naivasha.

Frequency of visits to the wetland had a strongly significant [ANOVA, F (8, 227) = 7.554, p <.01] effect on TOKS scores, those who visited the wetland at least once a day scoring higher (mean 6.4) than those who visited 2–3 times a year (2.9) or once every 10 years or more (1.9). At Victoria 73.7% of respondents visited the wetland at least once a day, compared to 35.6% at Naivasha.

4.6.4. Priority services (RQ8)

Nullifying sub-sets of services with a relative percentage weighting <5% presents a clearer picture of which services were most widely recognised and might thus be assigned priority from a governance perspective. The most frequently identified service at Lake Naivasha was an association of papyrus wetlands with potable water, followed by support for biodiversity and appreciation for their aesthetic qualities. A different pattern emerged for Lake Victoria, where the provision of fibre for the production of commodities was of primacy, followed by biodiversity support and the provision of fibre for fuel (Table 4.7).

Both lakes had sub-sets of services not found at the other above this threshold, each group of which accounted for a similar proportion of its priority services, i.e. Naivasha (*) = aesthetic values, fishing/hunting opportunities, social relations and sense of place (combined weighting 43.8%); Victoria (+) = fibre for commodities, fibre for fuel and fibre for livestock (combined weighting 44.0%: Table 4.7).

Table 4.7. *Relative % weighting of priority services at Lakes Naivasha and Victoria; * and + indicate sub-set is uniquely recognised at that lake*

Rank	*Lake Naivasha*	%	*Lake Victoria*	%
1	Potable water	19.6	Fibre for commodities +	21.5
2	Biodiversity	17.0	Biodiversity	19.3
3	Aesthetic values *	13.3	Fibre for fuel +	14.1
4	Fishing/hunting opportunities *	12.5	Farming opportunities	12.8
5	Farming opportunities	11.5	Local climate regulation	12.2
6	Social relations *	11.2	Potable water	11.7
7	Local climate regulation	8.1	Fibre for livestock +	8.4
8	Sense of place *	6.8		

The 3 sub-sets of priority services uniquely identified at Lake Victoria (denoted by a '+' in Table 4.7) represent consumptive use values (CUVs) characterised by direct utilisation of papyrus itself – either in the production of commodities, for burning as fuel or for feeding to livestock. Each of these services was also recognised at Lake Naivasha (Fig. 4.6), although their relative percentage weighting among all citations there fell below 5%, hence their exclusion from Table 4.7.

Irrespective of locality, a strong positive correlation ($r^2 = 0.976$) existed between the number of CUVs cited by respondents (divided into 4 cohorts, consisting of those who recognised 0, 1, 2 or 3 CUVs[8]) and their respective TOKS scores (Fig. 4.7). The mean score of respondents who recognised one or more CUVs was strongly significantly higher [F (176, 58) = 3.034, p <.01] than those who recognised none at all.

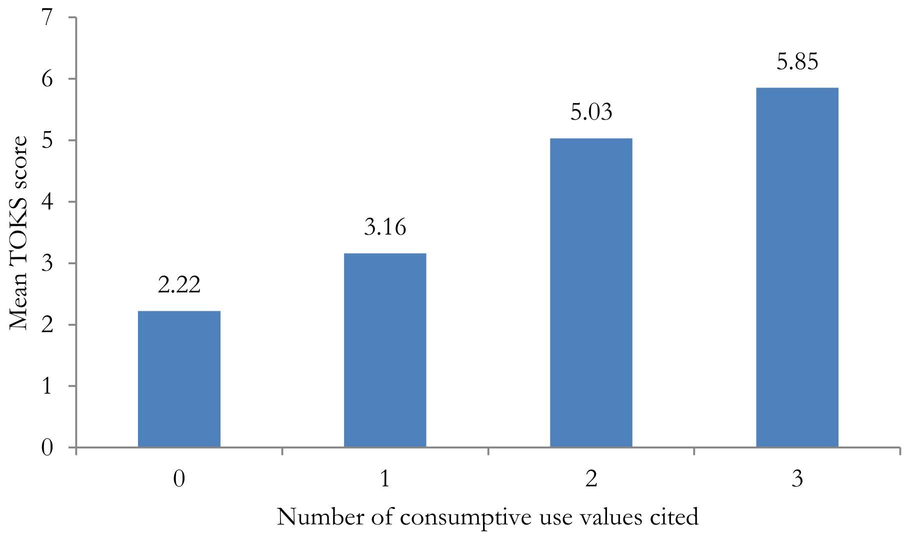

Fig. 4.7. Mean TOKS scores of respondents who recognised 0, 1, 2 or 3 consumptive use values of papyrus.

4.6.5. Impacts on wetlands (RQ9)

The average 'site quality score' (SQS, see Chapter 3, section *3.2.2*) for the 8 sites surveyed at Naivasha, rounded to the nearest whole number, was 5/10 and varied between sites from 1–7. The average SQS at Victoria was comparable at 6/10, although this varied over a narrower range from 5–8 (Table 4.6). A plot of TOKS scores against SQS (Fig. 4.8) revealed a negative correlation between the two factors at both lakes, the relationship between the data sets being stronger for Naivasha ($r^2 = 0.574$) than for Victoria ($r^2 = 0.442$), but highly significant in both cases (r_s = -.857, p =.02 for Naivasha and r_s = -.893, p =.02 for Victoria; Spearman Rank Correlation Coefficient, two-tailed test).

[8] For each record, the number of CUVs cited by an individual was discounted from their TOKS score so as not to bias the relationship, e.g. if a respondent only recognised the value of papyrus for fuel and nothing else, his/her TOKS score was treated as '0' for the purposes of the analysis.

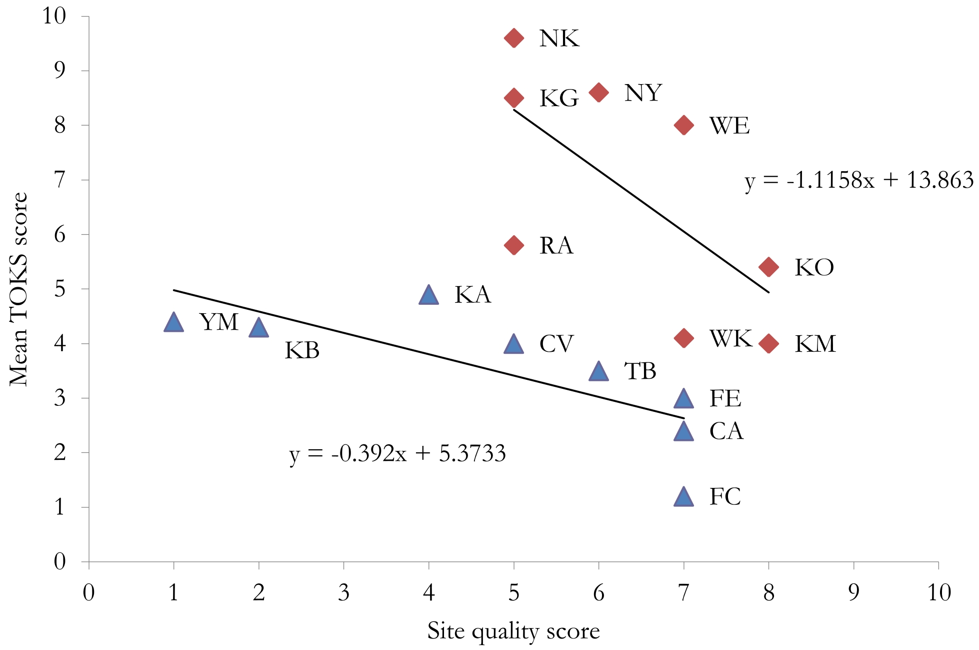

Fig. 4.8. Scatter plot of mean TOKS and site quality scores at Naivasha (blue triangles) and Victoria (red diamonds); for site codes see Table 4.6.

4.7. Discussion

4.7.1. Influence of demography on TOKS scores

The demographic data collected at Lake Naivasha describe an ethnically heterogeneous, recently settled community with a high rate of immigration, reasonably high levels of formal education and multiple livelihood strategies. Taken as a whole, respondents recognised a wide array of ecosystem services across the 4 major categories. Levels of individual awareness were generally very low, however, equating to recognition of just c. 13% of all 'known' services.

The corresponding data for Lake Victoria describe a more ethnically homogeneous and longer settled community with a lower rate of immigration, lower levels of formal education and fewer livelihood strategies. As at Naivasha, most services were recognised by the collective survey pool. However, levels of individual awareness were significantly higher, equating to recognition of c. 25% of all services.

A closer examination of the demographic data explains some of the observed variance in TOKS scores. Compared to Lake Naivasha, at Lake Victoria:

1. Over twice as many respondents were aged >36 years and had either no formal education or were primary school leavers.
2. More than 3 times as many respondents pursued livelihoods centred on the riparian zone and nearly 6 times as many had two or more jobs.
3. Over 4 times as many respondents lived <1 km from the nearest wetland and more than twice as many visited this at least once a day.

Each of these factors was shown to correlate positively and significantly with TOKS scores (section *4.6.3*), explaining the broader recognition of ecosystem services recorded at Lake Victoria. What's more, the number of people who identified one or more CUVs of papyrus (i.e. fibre for commodities, fuel and livestock) was significantly ($\chi^2 = 142.428$, $p < .01$) higher at Lake Victoria. Indeed, these 3 sub-sets constituted nearly half of all priority services uniquely identified there. At Lake Naivasha, on the other hand, all priority services (e.g. potable water, biodiversity, aesthetic qualities, etc.) corresponded to 'non-use values' (Turner et al. 2011), involving not consumption of papyrus itself, but rather utilisation of other biotic (e.g. fish) or abiotic (water) components associated with it (otherwise referred to as indirect use values: Barbier 1994).

With a greater representation of elders within the stakeholder community, lower levels of formal education and more livelihoods centred on the riparian zone, the accumulation and transfer of 'traditional ecological knowledge' (TEK) (Berkes et al. 1995) in relation to papyrus had a significant influence on people's recognition of wetland ecosystem services at Lake Victoria.

TEK has been defined as:

"a cumulative body of knowledge, practice, and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship between living beings (including humans) with one another and with their environment" (Berkes et al. 2000, p.1252).

The case study of Okana (section *4.2.4*) provides some evidence of 'cultural transmission' of knowledge and practices relating to papyrus, the focus group discussion there revealing that younger generations were learning about the benefits of wetlands, particularly in terms of their consumptive use values, from the cumulative experience of elder generations. The outcome of this learning appears to be that papyrus wetlands are valued first and foremost for their known human welfare benefits (i.e. for producing commodities, for burning as fuel and for feeding to livestock), knowledge of which ultimately leads to recognition of their wider values.

Respondents at Lake Naivasha, who had a weaker representation of elders within the stakeholder community, higher levels of formal education and a greater proportion of livelihoods centred away from the riparian zone, largely failed to identify consumptive uses for papyrus. This in turn limited their awareness of, or concern for, its wider social and environmental benefits. Naivasha has a high rate of immigration into its expanding heterogeneous communities (section *4.6.1*), wherein stores of TEK in general may have been diminished, or else are deemed less relevant to specialist livelihoods in what is, in contrast to the Lake Victoria region, arguably more of a peri-urban environment. This analysis finds broad agreement with Lannas and Turpie (2009), who compared provisioning services from a rural wetland in Lesotho with a peri-urban wetland in South Africa. The authors found that specialized livelihood strategies in the urban setting (where only 13% of households used local wetlands) contrasted with more diverse, risk-spreading livelihood strategies (Schuyt 2005) in the rural environment (where 65% of households used local wetlands).

Diverse livelihoods have been described as common in rural African societies that are heavily dependent on natural resources, where "apart from a regular wage income, it is very likely that none of the activities from which people construct livelihoods can on their own provide a secure living" (Francis 2000, p.57). Lake Victoria is typical of such scenarios (with livelihoods closely tied to papyrus), whereas the impression of Lake Naivasha is more of a society less aware of, or concerned for, the values of its local wetlands. As Clewell and Aronson (2013) recently surmised: "rural residents… are likely to be much more knowledgeable [about ecosystem services] because they are directly dependent on natural goods and services for their survival and well-being" (p.22).

However, whilst overall levels of awareness were lower at Naivasha, certain sub-sets of services were found in common at both lakes, although the extent to which they were valued at each was variable. I hypothesise that this variance can be largely explained by differences in demography and, in some cases, geography[9]. What follows is a discussion of these factors as they relate to the various priority services identified – both those common between the lakes

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9 Seasonal variations in hydrology will also have an impact on the range and value of ecosystem services from wetlands and correspondingly on the perception of these from local communities. However, having conducted the research over a 2-week period, I assume no significant differences between the lakes in this regard – all wetland sites having been in a non-flooded state.

as well as those unique to Naivasha – in an attempt to reveal reasons for the different perceptions recorded.

4.7.2. Common priority services

4.7.2.1. Potable water

It should be noted that 'potable' as used during this study refers to the relative perception of drinking water quality by local communities and is not supported by standards derived from scientific analysis. Moreover, recognition of an association of papyrus wetlands with a source of potable water (a provisioning service) does not necessarily imply recognition that papyrus wetlands are themselves responsible for improving the quality of water; this latter benefit would be listed under 'water purification' (a regulating service), which was much more poorly recognised (Fig. 4.6). Nevertheless, the most frequently identified benefit of papyrus wetlands at Lake Naivasha was their association with potable water, the possible reasons for which are set out below.

The Malewa and Gilgil rivers, which together supply the majority of freshwater entering Naivasha, are bordered for much of their lower courses by private horticultural enterprises and cattle ranches, with limited public access points (D. Kimani, pers. comm.). Visiting the lakeshore is thus the only means of collecting drinking water in the absence of municipal supplies within Naivasha's unplanned settlements (Becht et al. 2005). Furthermore, borehole water around the lake contains concentrations of fluoride up to 8 times higher than the World Health Organization (WHO) limit (1 mg l^{-1}), causing malformations and weakness in bones and teeth, whereas lake water fluoride concentrations are just below this limit (N. Pacini, pers. comm.).

A similar number of respondents cited an association of papyrus with potable water as a benefit of wetlands at Lake Victoria, yet its relative weighting among priority services was lower than at Naivasha (Table 4.7). This could be for one or more of the following reasons:

1. The Nyando and Sondu rivers, which enter Lake Victoria within Kisumu District (Chapter 3, Fig. 3.1), braid into a network of many smaller distributaries before reaching the lake, to which there is generally greater access (E. Morrison, pers. obs.), reducing the need to visit papyrus wetlands along the lakeshore to collect water.
2. Since papyrus is typically more abundant within the riparian zone (and generally more intact, with site quality scores in the range 5–8: Table 4.6), its association with potable

water may be more obscured from the perception of local communities (or, in other words, taken for granted).

3. Whilst valued for this service at certain sites, other benefits are much more widely recognised (such as the provision of plant fibre: see *4.7.3*), thereby reducing this service's priority ranking.

4.7.2.2. Biodiversity

Both lakes are renowned for their high levels of biodiversity, attracting local holidaymakers, international tourists and researchers to their shorelines (Bugenyi 2001; Harper and Mavuti 2004). The wetlands themselves provide breeding grounds and nursery refugia for fish (Hickley et al. 2004), as well as valuable habitat for mammals (e.g. hippopotamuses and sitatunga) and birds (including some papyrus endemics: Maclean et al. 2006).

Whilst forming a similar relative proportion of each lake's priority services (Table 4.7), in absolute terms a significantly ($\chi^2 = 8.821$, $p < .01$) higher number of people at Victoria recognised biodiversity support as a benefit associated with wetlands. One or more of the following factors may explain this observation:

1. The extent of wetlands at Victoria is much greater than at Naivasha and their site quality scores are generally higher, implying a higher level of biodiversity can be supported at the former lake.
2. People tended to lived closer to wetlands at Victoria than at Naivasha, a trend shown to have a significantly positive effect on TOKS scores and, by inference, levels of awareness surrounding wetlands.
3. More than 3 times as many people at Victoria pursued riparian livelihoods, thereby increasing their exposure to biodiversity associated with the wetlands.

4.7.2.3. Farming opportunities

Benefits pertaining to farming opportunities refer to the alternative value of wetlands that have been cleared of papyrus and converted to subsistence agriculture, being land of gentle gradient with good access to fresh water and soils enhanced by nutrient-rich, peat-like deposits within the wetlands (Maclean et al. 2011).

As discussed in Part 1, farmers often clear papyrus during the dry season in order to convert this productive land to agriculture (Owino and Ryan 2007). This had recently happened at one site at Lake Victoria (Ramula), where an increase in food prices had prompted local residents to clear the papyrus for conversion to rice paddies (Fig. 4.9), both in order to feed their families more cost-effectively and to benefit from the profitability of the price hike (notice the most commonly cited benefit of papyrus at that location was 'fibre for fuel': Table 4.6).

Fig. 4.9. Papyrus wetland being converted into rice paddies at Ramula, Kisumu District (photo: E. Morrison).

Indeed, a significantly ($\chi^2 = 11.133$, $p < .01$) higher number of people at Victoria cited farming opportunities as a benefit of wetlands, which may be explained by the fact that a greater proportion of respondents at Victoria (34.7% compared to 10.2% at Naivasha) were subsistence farmers themselves. Moreover, environmental laws prohibit farming in the riparian zone at Naivasha (Water Resources Management Authority, WRMA 2011).

4.7.2.4. Local climate regulation

A further shared appreciation of papyrus at both lakes concerned its regulating effects on local climate, several respondents contending that local wetlands produced more reliable rainfall compared to surrounding regions. The environment around swamps was also frequently reported as being cooler thanks to the shade of tall papyrus stands – an observation supported by Thompson (1976), who found that the air temperature at the top of the umbels can be as much as 10 °C higher than the substrate beneath.

A significantly ($\chi^2 = 17.104$, $p < .01$) higher number of people cited local climate regulation as a benefit associated with papyrus at Victoria, for which similar reasons as outlined for biodiversity (*4.7.2.2*) may be given by way of explanation, in addition to the fact that average daytime temperatures are typically higher there than at Naivasha (Åse et al. 1986; Lung'ayia et al. 2001) and thus the shade of papyrus more likely to be appreciated.

Furthermore, a number of respondents at Victoria talked of a spiritual practice linking wetlands with local climate regulation, wherein dry papyrus stems are burned in order that the "ash rising from the fire may return to the land as raindrops" (Anon., pers. comm.) encouraging the onset of the wet (growing) season. No such spiritual practice/custom was recorded at Naivasha, however.

4.7.3. Priority services unique to Lake Naivasha

4.7.3.1. Cultural services

Values relating to aesthetic qualities, social relations and one's 'sense of place' together accounted for almost one third of all priority services at Naivasha (Table 4.7). These 3 sub-sets correspond to the benefits people feel when visiting wetlands along the lakeshore to observe the natural beauty of the surroundings, interact with others during their free time, or else reaffirm their own emotional attachment with the environment in some intimate way (Kaltenborn 1998).

The unique significance of these services at Naivasha might arise from the fact that the majority of respondents worked away from the riparian zone and lived in densely populated settlements, located >5 km from the nearest wetland and set within the denuded (deforested, heavily eroded) landscape of the lake's hinterland (Becht et al. 2005) – arguably making a visit to the verdant shoreline an attractive proposition.

Significantly ($\chi^2 = 7.251$, $p < .01$) fewer people at Victoria recognised papyrus for its aesthetic qualities and none at all for contributing to their sense of place. Such values may be somewhat taken for granted there, since the majority of respondents lived much closer (<1 km) to wetlands and visited them more regularly as a consequence of their livelihood strategies. In absolute terms, however, maintenance of social relations was cited by a comparable number of respondents (Fig. 4.6), likely stemming from the fact that many people spent their days working alongside others within the riparian zone.

4.7.3.2. Fishing opportunities

The remaining priority service uniquely identified at Naivasha was fishing (and, to a lesser extent, hunting) opportunities. The physical complexity of papyrus wetlands creates ideal refugia for juvenile fish (Hickley et al. 2004), which can be easily (if illegally) caught using seine nets.

Naivasha's moderately sized commercial fishery is limited to 50 licensed fishing vessels, with further restrictions placed on crew sizes and the type of nets that may be used; what's more, following a collapse of the fishery in 2001, a closed season operates from 1st June to 31st August each year (Kundu et al. 2010). These regulations, despite being only weakly enforced, drive those who are unable (or else unwilling) to comply towards fish poaching in the lake shallows (Fig. 4.10), which may explain why fishing opportunities were often cited as a benefit of papyrus at Naivasha (V. Kinyua, pers. comm.).

Fig. 4.10. Locals fishing in defiance of Lake Naivasha's closed season on 22nd June 2012 (photo: E. Morrison).

Fishing opportunities presented by wetlands were less frequently cited at Victoria, whose vastly superior fishery compared to Naivasha permits more people to fish in the open lake. At the same time, fishermen may have simply been underrepresented within the survey pool (comprising just 11/118 respondents) precisely because they were engaged in fishing away from the riparian zone whilst surveys were being conducted.

4.7.4. Non-priority services

The following sub-sets, whilst having a relative weighting <5%, nonetheless warrant brief consideration for the sake of impartiality.

4.7.4.1. Regulating and supporting services

The wider impacts of papyrus wetlands on regional climate regulation, as well as their contributions to primary production, were uniquely recognised by respondents at Lake Victoria (Fig. 4.6). Values relating to erosion control ($\chi^2 = 6.522$, $p < .05$), natural hazard (e.g. flooding) regulation ($\chi^2 = 18.974$, $p < .01$), groundwater recharge ($\chi^2 = 5.051$, $p < .05$), nutrient cycling ($\chi^2 = 3.854$, $p < .05$) and soil formation ($\chi^2 = 6.316$, $p < .05$) were all recognised by a significantly higher number of people there than at Naivasha.

4.7.4.2. Provisioning and cultural services

The value of wetlands as a source of 'biochemicals' (i.e. traditional medicines: Table 4.3) was cited by a significantly ($\chi^2 = 6.312$, $p < .05$) higher number of people at Lake Victoria, which provides further support for the notion of TEK being an important aspect of papyrus use there.

In view of the likelihood of TEK being transferred between generations, it is perhaps not surprising that values relating to one's heritage were also recognised by a significantly ($\chi^2 = 10.363$, $p < .01$) higher number of people at Victoria.

Educational opportunities presented by wetlands were poorly recognised in general (Fig. 4.6), yet at Victoria they were identified by a significantly ($\chi^2 = 3.948$, $p < .05$) higher number of respondents. As well as learning from elder generations, this trend may be due to the efforts of environmental education organisations active in the Lake Victoria region, disseminating information related to wetlands through radio broadcasting, ecotourism and scientific research (D. Odira, pers. comm.).

Spiritual values were also recognised by a significantly ($\chi^2 = 11.683$, $p < .01$) higher number of people at Victoria. Several respondents during interviews and, more so, as part of the focus group discussion held at Ramula, made mention of a traditional belief in Luo culture concerning the practice of *nyawawa*, which is the chasing away of spirits or ghosts (*jochiende*).

The belief is that, prior to flooding, papyrus wetlands were the sites of plantations used by ancestral Luos. On occasions when deceased ancestors reappear in spirit form searching the villages for food, a great cacophony ensues (caused by the sound of clapping, drumming or the beating of pots) by members of the community fearing the dreadful moans of the *mumbo* (lake *jochiende*: Harries 2001). The sound is "intended to drive spirits away from the village toward the wetlands" (Anon, pers. comm.), which are regarded as the 'gateway' through which *mumbo* leave the living world. The papyrus is thus afforded sanctity by some members of the community who would not allow it to be cleared completely for fear of losing their means of dispelling perceived evil spirits. These data further testify to the importance of TEK in relation to papyrus at Lake Victoria. Reports of spiritual/ancestral values have also been described in relation to the sanctity of regions of the sea known as *mizimu* in southern Kenya, avoided by fishermen fearful of perceived spirit residents (McClanahan et al. 1997). Similar accounts have been described for the *dambo* wetlands of Zimbabwe (Scoones and Cousins 1994) and the 'sacred groves' of India (Gadgil and Vartak 1974).

No such belief system was spoken of during the equivalent group discussion at Kamere, nor at any of the 8 sites around Naivasha (although mention was made of baptisms being performed in the lake, this relied not so much on the papyrus as the open water). However, one shared 'cultural service' between the lakes did exist, namely appreciation of the opportunities presented by papyrus for remaining concealed when having sex with one's (or, as was often recounted, someone else's) partner – a practice known colloquially as "green lodging" (Anon., pers. comm.).

4.8. Summary of Part 2

1. The demographic data at Lake Naivasha describe an ethnically heterogeneous, recently settled community with a high rate of immigration, reasonably high levels of formal education and multiple livelihood strategies (RQ5).

2. The corresponding data for Lake Victoria describe a more ethnically homogeneous and longer settled community with a lower rate of immigration, lower levels of formal education and fewer livelihood strategies (RQ5).

3. People's perceptions of papyrus varied between the two lakes; the mean TOKS score of respondents was significantly [F (117, 117) = 2.171, p <.01] higher at Lake Victoria (6.8 ±0.6) than Lake Naivasha (3.4 ±0.4) (RQ6).

4. Variance in TOKS scores can be largely explained by differences in the following demographic characteristics: age; education; number and type of livelihood strategies; distance of residence from and frequency of visits to the nearest wetland (RQ7).

5. Broader understanding of ecosystem services at Lake Victoria may result from the transfer of traditional ecological knowledge between generations, in particular surrounding consumptive use values (RQ7).

6. At Lake Victoria, the most frequently cited benefit of papyrus was the provision of plant fibre for the production of commodities; at Lake Naivasha it was an association of wetlands with potable water (RQ8).

7. At both lakes, higher TOKS scores appeared to correlate with lower levels of wetland integrity (expressed through SQS), suggesting increased awareness of the benefits of papyrus may lead to over-exploitation (RQ9).

I reject the first null hypothesis that stated, *"There are no significant differences between Lakes Victoria and Naivasha in terms of people's perceptions of papyrus wetlands"* and conclude that the alternative hypothesis (H_1) is more likely: variance in TOKS scores between the lakes was highly statistically significant [F (117, 117) = 2.171, p <.01], the mean score at Victoria (6.8 ±0.6) being approximately twice that at Naivasha (3.4 ±0.4).

I tentatively reject the second null hypothesis that stated, *"Any observed variance in perceptions is due to chance (sampling error)"* and propose that the alternative hypothesis (H_2) seems more probable: variations in levels of awareness were not random, but related to measurable demographic characteristics of the survey population (including age, level of education, number and type of livelihood strategies, distance of residence from wetlands and frequency of visits to wetlands: *4.6.3*) in addition to knowledge of consumptive use values (*4.6.4*) and, in some cases, differences in geography.

4.9. Conclusions from Chapter 4

- Why should papyrus wetlands at Lake Naivasha be restored from a sociological perspective? (**TQ1**)

In a general sense, because of the multiple ecosystem services provided by healthy, functioning papyrus wetlands, many of which have been described in detail above. More specifically, the primary sociological motivations for restoring wetlands at Lake Naivasha are those benefits of papyrus most widely recognised by stakeholders shown in Table 4.7.

These can be categorised, after Barbier (1994), into *direct use values* (farming opportunities), *indirect use values* (potable water, biodiversity, fishing/hunting opportunities and climate regulation) and *non-use values* (biodiversity, aesthetic qualities, social relations and sense of place). Although non-use values should not be ignored, Maclean et al. (2011) argue that use values (both direct and indirect) provide a more credible basis for decision-making in wetland management, particularly in developing countries.

The most important of these in the context of Naivasha (the most frequently cited by respondents) is an association of papyrus wetlands with potable water. It should be reiterated that, whilst used by local communities for drinking, the extent to which water from the lake is considered truly 'potable' is unclear; in reality it is likely to be below WHO standards considered safe for human consumption (N. Pacini, pers. comm.). Nevertheless, a large proportion of Naivasha's population live in unplanned settlements surrounding the lake, which generally lack basic amenities including water, forcing residents to go to the lake in order to collect it (Becht et al. 2005). Not only do wetlands improve the clarity of water by encouraging sedimentation of suspended material, papyrus has been shown to improve the quality of drinking water through the retention of faecal coliforms and their associated pathogens (Kansiime et al. 2001) – a critical service at Naivasha where sewage treatment facilities are also virtually non-existent. Enhancing the ability of papyrus to purify drinking water is thus a primary sociological motivation for wetland restoration at Lake Naivasha.

A secondary motivation is the biodiversity support provided by papyrus wetlands, generating both indirect and non-use values. Indirect use values include habitat provision, such as nesting grounds for birds and cover for mammals such as hippopotamuses. Non-use values include existence value (derived from the satisfaction of knowing that wetland biodiversity exists, regardless of whether it benefits others or not) and altruistic or bequest value (knowledge that the ecosystem is enjoyed by contemporaries or will be enjoyed by future generations, respectively) (Turner et al. 2011). Indirect use values can be expressed through recreational activities such as bird watching, boating and ecotourism. Lake Naivasha itself is a tourist destination, famed for its aquatic bird diversity; the majority of tourists, however, usually only visit briefly *en route* to Kenya's more renowned destinations such as the Maasai Mara National Reserve (Harper et al. 2011). Finite tourist numbers, marginal interest in papyrus wildlife and the large number of swamps throughout East Africa limit the scope for nature-based tourism (Maclean et al. 2011). That notwithstanding, enhancing the ability of papyrus to support biodiversity remains a secondary motivation for wetland restoration at Naivasha, irrespective of whether economic (receipts from tourism) or non-market benefits (forms of existence value) are derived.

Fishing opportunities provide a third perspective on restoration. Papyrus wetlands are instrumental in the maintenance of open-water fisheries (Maclean et al. 2011). Tilapia of the genera *Oreochromis* and *Tilapia* (species of both of which are present in the Naivasha fishery: Muchiri et al. 1995) have been shown to school in waters proximal to papyrus swamps, where they feed on periphyton and detritus associated with submerged structures and in which they find refuge from predators (Chapman et al. 2002). The sediment-trapping and nutrient uptake capacity of papyrus wetlands provides further fisheries support by enhancing conditions for the growth of aquatic macrophytes and invertebrates on which other species feed (Hickley et al. 2004) – including *Cyprinus carpio* (common carp), which now dominates the Naivasha fishery (Harper et al. 2011). An association has recently been demonstrated (Kiwango et al. 2013) between rehabilitated papyrus wetlands and increased fish productivity at Lake Victoria. Enhancing the ability of papyrus to support fisheries is thus an additional sociological motivation for wetland restoration at Naivasha.

The fourth indirect use value within the list of priority services identified – local climate regulation – effectively augments the first three. Whilst the impact of wetlands on a lake's net water balance is likely to be site-specific (Saunders et al. 2007), evaporative losses from open water at Lake Naivasha were estimated to be almost two thirds higher than losses due to evapotranspiration from the papyrus canopy (Jones and Humphries 2002). Based on the calculations of Jones and Humphries (2002), the increase in the area of open water (34 km^2) created by the decline in papyrus from 1960–1995 (Boar et al. 1999) has led to a theoretical increase in water loss to the atmosphere in the order of 2.2×10^8 kg H_2O d^{-1}. Restoration of papyrus wetlands could thus enhance the water storage capacity of Lake Naivasha. This in turn would increase the quantity and quality of available drinking water, as well as provide greater fisheries and biodiversity support within a positive feedback cycle.

The only *direct* (though not consumptive) use value of papyrus wetlands assigned priority at Naivasha was their reclamation for subsistence agriculture, which would not be a motivating factor behind restoration. The Lake Naivasha Catchment Area Protection Rules (WRMA 2011) state that it is "prohibited within… riparian land… to till or cultivate, clear indigenous trees or other vegetation" (Water Act 2002, Legal Notice no. 8, Section 10:1). Not only is the conversion of wetlands to subsistence farmland thus prohibited by Kenyan law, recent evidence (Maclean et al. 2011) suggests that the economic value derived from low-intensity, multifunctional use of papyrus wetlands far exceeds the value derived from their reclamation for agriculture. Arguably, however, no significant use of wetlands at Naivasha (multifunctional or otherwise) is currently made. This will be discussed further in Chapter 6.

- What are the key social factors at Lake Naivasha that might hinder successful wetland restoration? (**TQ2**)

The results of this study indicate that, whilst the survey pool recognised a broad array of benefits associated with papyrus *per se*, the average respondent at Lake Naivasha had only a limited awareness of the wider ecosystem services of wetlands. This is in contrast to Lake Victoria, where the average respondent demonstrated knowledge of a much wider range of ecosystem services, as expressed by the difference in TOKS scores between the two lakes. The variance observed can generally be ascribed to differences in the demographic characteristics of the two stakeholder communities, as described in detail above.

Specifically, limited awareness of the benefits of wetlands at Naivasha appears to be the result of (1) a lack of known consumptive use values for papyrus, which itself arises from (2) a lack of, or inappropriate, TEK in relation to papyrus. Support for this conclusion comes from links between TEK and enhanced awareness of the values of natural resources demonstrated in previous studies conducted in, *inter alia*, forests in Canada (Turner et al. 2000); game reserves in Botswana (Phuthego and Chanda 2004); endangered species in New Zealand (Ramstad et al. 2007); wild edible foods in Japan (Cetinkaya 2009); agricultural lands in Spain (Gómez-Baggethun et al. 2010) and medicinal plants in Pakistan (Khan et al. 2013). The results of this study can be added to the list, since knowledge surrounding the consumptive uses of papyrus was shown to correlate positively with overall levels of awareness surrounding local wetlands. The implications of this in the context of wetland restoration at Naivasha (TQ5) will be discussed further in Chapter 6.

This study has highlighted a discrepancy between a detailed understanding of papyrus wetlands at Naivasha accrued from over three decades of scientific research (Gaudet 1979; Jones and Muthuri 1985; Muthuri et al. 1989; Harper 1992; Harper et al. 1995; Jones and Muthuri 1997; Jones and Humphries 2002; Harper and Mavuti 2004; Morrison and Harper 2009) and a limited awareness of the same at the community level. This suggests a weakness on behalf of researchers and policy-makers, who have failed to communicate effectively the results of their scientific research to the local community. One possible explanation for this seems to be that the majority of investigations at Naivasha have been directed towards understanding aspects of the aquatic ecology of the lake (Chapter 2, Table 2.1), at the expense of efforts directed towards understanding the uses of (and attitudes towards) the ecosystem's natural resources by different stakeholder groups. An early attempt to formulate a management plan for Lake Naivasha appears to have failed precisely because of a lack of community consultation and inclusion in the design of conservation goals (Harper et al. 2011).

Local communities arguably constitute the ultimate beneficiaries of papyrus wetlands in that their livelihoods depend, to varying degrees, on the direct and indirect benefits arising from wetland goods and services. We can therefore expect that the attitudes and behaviours of local communities will, to a considerable extent, determine the state and structure of papyrus wetlands over time (while taking due account of wider processes such as climate change). Those designing and implementing proposed wetland restoration projects at Naivasha thus require a nuanced understanding of the perspectives of these stakeholders, in order to strike a balance between enhancing the ecological state of papyrus wetlands and addressing the needs of the people who benefit from them.

A limited awareness of the benefits of papyrus is therefore the principal social factor that might hinder the successful restoration of wetlands at Naivasha. The success achieved at Okana and the recent study of Kiwango et al. (2013) both demonstrate the importance of securing public support for wetland restoration projects from the outset (Clewell et al. 2005). It has already been seen that, in the absence of genuine public support, restoration projects can experience unforeseen circumstances and socio-political barriers to achieving long-term goals (Shore 1997; Hjerpe et al. 2009) – a shortcoming of the wider restoration movement more generally (Goldstein et al. 2008; Galatowitsch 2009).

Although it was not formally assessed during this study, it became apparent from the logistics of data collection that a further cause of limited awareness of wetlands at Naivasha appears to be the restricted nature of public access to the lakeshore where papyrus grows. Publicly accessible parts of the riparian zone tended to be clustered together along the lake's eastern and southern shoreline. Many of these locations nominally charged an entrance fee, although the rule was generally not enforced. The only freely accessible site was Kamere, a 'fish landing beach' under the management of the Naivasha Fisheries Department. The extent of public versus private access to the lakeshore and its implications for wetland restoration is discussed further in Chapter 6.

Whatever the reasons for the lower levels of awareness surrounding wetlands at Lake Naivasha, the overall implication is a paucity of identifiable 'stewards' among the general public who are concerned with, or accountable for, the management of local wetlands. The results of Part 1 of this chapter indicated that papyrus harvesters at Lake Victoria constitute the *de facto* wetland managers there, since resource conservation is inherently within their (socioeconomic) interests. Whilst the sustained efforts of the Lake Naivasha Riparian Association and other local environmental organisations (Harper et al. 2011) deserve wide recognition, Naivasha's wetlands require engaged managers at the community level with vested interests in the sustainable use and management of papyrus. Again, this will be discussed further in Chapter 6.

Chapter 5: Ecological considerations

Chapter 5: Ecological considerations

This chapter attempts to determine the productivity and nutrient uptake capacity of papyrus wetlands at Lake Naivasha, as well as the present ecological status of its riparian zone.

The material presented in this chapter seeks to address the following thesis questions:

- Why should papyrus wetlands at Lake Naivasha be restored from an ecological perspective? (**TQ3**)
- What are the key ecological factors at Lake Naivasha that might hinder successful wetland restoration? (**TQ4**)

Outline of Chapter 5:

Part 1: Productivity and nutrient uptake in papyrus

1. Aboveground productivity in papyrus wetlands at Lake Naivasha is estimated from measurements of standing biomass and turnover time.
2. Concentrations of nitrogen (N) and phosphorus (P) in stems of different age-classes are analysed; between-site and interspecific variations are also investigated.
3. The amount of plant biomass and nutrients that could be removed from both clear-cutting and selective harvesting strategies is calculated.

Part 2: Flora of the riparian zone

1. The floral community of Lake Naivasha's riparian zone is evaluated and compared to the earlier work of Gaudet (1977).
2. Changes in species richness, distribution and succession relative to the baseline study are described and assessed.
3. The impacts of anthropogenic activities on the riparian flora and the effects of hydrological uncertainties on swamp development are analysed.

- A summary of findings relating to RQs 10–15 and 16–21 is given at the end of each of Parts 1 and 2 respectively.
- Responses to TQ3 and TQ4 and are then provided at the end of the chapter.

Part 1: Productivity and nutrient uptake in papyrus

5.1. Research questions

RQ10: What is the rate of primary productivity in papyrus wetlands at Lake Naivasha?

RQ11: How does this change under different harvesting strategies?

RQ12: How does the concentration of N and P vary between age-classes?

RQ13: Does the concentration of these nutrients vary between sites?

RQ14: How do nutrient concentrations in papyrus compare to other common plants?

RQ15: How much N and P would be removed from 1 m^2 of harvested wetland?

Hypotheses:

H_0: The concentration of N and P does not vary between sites at Naivasha.

H_1: The concentration of N and P varies significantly between sites.

H_0: Any observed variance in nutrient concentrations is due to chance.

H_2: Observed variance is not the result of chance.

5.2. Results

5.2.1. Rate of primary productivity (RQ10+11)

One hundred and ninety two of the 200 randomly harvested stems were usable. The linear relationship between culm diameter (range 0.65–1.96 cm) and dry weight (4.4–611.3 g) was represented by the formula: Y [dry weight of culm-unit, g] = (59.289 X) [X: culm diameter, cm] – 72.062, $r^2 = 0.974$, $n = 192$, $p < 0.001$. Estimates of biomass within the 16 quadrats, calculated using this equation, varied between 3.71–7.17 kg dry weight m^{-2}, with a mean value of 4.94 ±1.01 kg m^{-2}.

Aerial (aboveground) biomass obtained from the 7 clear-cut quadrats varied between 3.01–8.70 kg dry weight m^{-2}, with a mean value of 5.33 ±1.35 kg m^{-2}. Estimates from the linear regression were therefore deemed sufficiently similar to known values (predicting by 92.3%, or ±0.39 kg) to be reliable for measuring biomass replacement rates during selective harvesting experiments.

Average percentage weight contributions of different age-classes to total biomass m^{-2} from the 16 quadrats, calculated using the above formula, were: age-class I (5.9%); II (4.6%); III (44.1%), IV (45.4%). The ratio of mean number of stems in different age-classes (I:II:III:IV) m^{-2} was 2:1:4:4. Numbers of age-class '0' stems (= incipient culms, with only scale leaves visible: Chapter 3, Fig. 3.5, B) were also counted, appearing in the same ratio as age-class I.

Shortly after the commencement of the selective harvesting experiments, however, water levels within the wetland began to rise rapidly, flooding the quadrats (Fig. 5.1) and making data collection difficult and ultimately impossible as culms began to decompose after a period of 6–8 weeks of inundation.

Fig. 5.1. Flooded quadrat at Fisherman's Camp; edge markers (bottom-left and top-right of image) previously 1 m above water level are now submerged (photo: E. Morrison).

5.2.2. Nutrient concentrations in different age-classes (RQ12)

The mean concentrations of phosphorus in stems belonging to age-classes I and II were similar [0.23 (±.05) and 0.23 (±.04)% dry weight P respectively] and roughly twice that in age-classes III and IV, which were also similar [0.11 (±.07) and 0.10 (±.06)% P respectively] (Fig. 5.2). The variance in P between age-classes was highly significant [ANOVA, F (3, 52) = 23.328, p <.01], post hoc comparisons (Tukey HSD test) revealing that the mean concentration of P in age-classes I and II was significantly higher than in age-classes III and IV.

The mean concentrations of nitrogen in stems belonging to age-classes I and II were similar [1.02 (±.24) and 0.91 (±.17)% dry weight N respectively] and roughly twice that in age-classes III and IV, which were also similar [0.46 (±.15) and 0.44 (±.11)% N respectively] (Fig. 5.3). The variance in N between age-classes was highly significant [ANOVA, F (3, 106) = 79.750, p <.01], post hoc comparisons revealing that the mean concentration of N in age-classes I and II was significantly higher than in age-classes III and IV.

The mean concentration from all 56 stems (14 of each age-class) was 0.71 ±.31% N and 0.16 ±.08% P.

Fig. 5.2. Mean concentration of phosphorus (% dry weight) in stems of different age-classes (n = 56), showing ± standard error bars.

Fig. 5.3. Mean concentration of nitrogen (% dry weight) in stems of different age-classes (n = 56), showing ± standard error bars.

5.2.3. Nutrient concentrations at different sites (RQ13)

The mean concentration of nitrogen ([N]) and phosphorus ([P]) in each age-class was higher at Fisherman's Camp than Camp Carnelley's (Figs. 5.4 and 5.5). The variance between the two sites was significant only in terms of [N] for age-classes I [F (13, 13) = 13.880, p <.01], III (t = 7.732, p <.01; two-tailed test) and, to a lesser extent, IV (t = 2.552, p <.05) (Table 5.1).

Overall mean [N] from 28 stems (7 of each age-class) was 0.70 ±.04% at Camp Carnelley's and 0.73 ±.02% at Fisherman's Camp: a highly significant [F (56, 56) = 2.282, p <.01] difference. Mean [P] was 0.15 ±.08% at Camp Carnelley's and 0.19 ±.08% at Fisherman's Camp: a significant (z = 2.053, p <.05; two-tailed test) difference.

Table 5.1. *Mean concentration of N and P in age-classes I–IV at Camp Carnelley's and Fisherman's Camp*

Location	Nutrient	I	II	III	IV
Fisherman's Camp	% P	0.24 (±.05)	0.25 (±.04)	0.14 (±.09)	0.12 (±.06)
	% N	1.14 (±.29)***	0.95 (±.18)	0.54 (±.17)***	0.49 (±.08)*
Camp Carnelley's	% P	0.22 (±.04)	0.21 (±.04)	0.09 (±.04)	0.09 (±.05)
	% N	0.89 (±.08)	0.87 (±.16)	0.39 (±.09)	0.39 (±.11)

Key to Table 5.1. Values are percentage dry weight, ± standard deviations are given in parentheses; * = significantly (p <.05) and *** = highly significantly (p <.01) different to the other site (t-test, two-tailed).

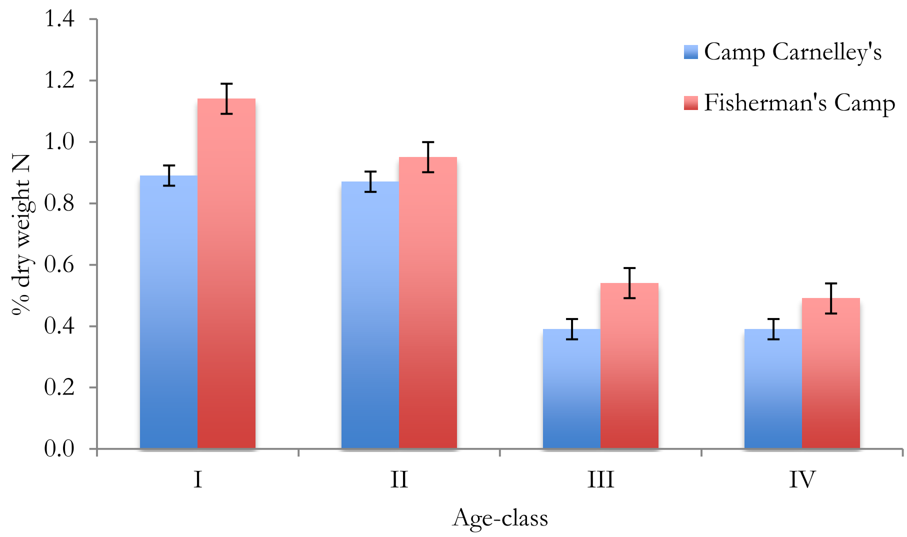

Fig. 5.4. Mean concentration of nitrogen (% dry weight) in different age-classes at two sites, showing ± standard error bars.

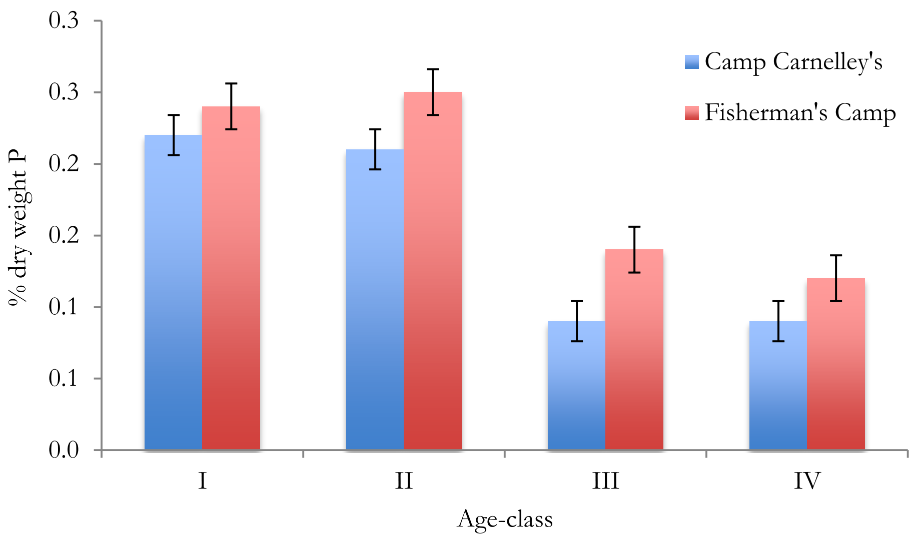

Fig. 5.5. Mean concentration of phosphorus (% dry weight) in different age-classes at two sites, showing ± standard error bars.

The treatment wetland at Flamingo Farm had the highest [N] and [P] (1.52 and 0.45% respectively) of all sites sampled (measured in stems of age-class I only), whereas the deltaic wetlands at Malewa Mouth had the lowest (0.68% and 0.06% respectively) (Table 5.2).

Table 5.2. *Mean concentrations of nitrogen and phosphorus in stems of age-class I (n = 7) at different sites*

Site	% N	% P
*Flamingo Farm**	1.52 (±.21)	0.45 (±.11)
*Kingfisher Farm**	1.28 (±.22)	0.36 (±.07)
Fisherman's Camp	1.14 (±.29)	0.24 (±.05)
Marula Estate	1.01 (±.19)	0.22 (±.03)
Camp Carnelley's	0.89 (±.08)	0.22 (±.04)
Kasarani Beach	0.97 (±.13)	0.15 (±.03)
Little Gilgil	0.79 (±.12)	0.14 (±.05)
Crater Lake	0.84 (±.09)	0.08 (±.02)
Malewa Mouth	0.68 (±.13)	0.06 (±.01)

Key to Table 5.2. Values are percentage dry weight, with sites arranged in descending order of highest concentration of phosphorus; * = constructed treatment wetlands; ± standard deviations are given in parentheses. For locations of sites see Fig. 5.7.

The variance in mean [N] between the different sites was highly significant [ANOVA, F (8, 105) = 17.486, p <.01]; the same was true for P [F (8, 45) = 28.571, p <.01]. Even when one excludes the very high concentrations recorded at the two constructed treatment wetlands, the variance between the natural wetlands remains as significant (p <.01) for both N [F (6, 91) = 12.388] and P [F (6, 39) = 26.800].

However, post hoc comparisons revealed that not all sites were statistically different from one another, e.g. [P] in stems sampled at Marula Estate was not significantly different (p <.824) from that in stems at Camp Carnelley's, but was highly significantly different (p <.01) from that in stems sampled at Malewa Mouth.

5.2.4. Nutrient concentrations in different species (RQ14)

The nitrogen content of the eight different species sampled varied between 0.39% (*Cyperus dives*) and 3.28% (*Hydrocotyle ranunculoides*). Phosphorus varied over a narrower range, from 0.04% (*Cyperus dives*) to 0.42% (*Eichhornia crassipes*) (Table 5.3).

There was significant variation between the different species in terms of mean N concentration [ANOVA, F (7, 132) = 73.467, p <.001]. Post hoc comparisons revealed that *Cyperus papyrus* was significantly lower in N than all species except for *C. dives* and *Typha latifolia*, whereas there were no statistical differences between the 3 species with the highest concentrations (*Azolla africana*, *Hydrocotyle ranunculoides* and *Salvinia molesta*).

There was also significant variation between the different plants in terms of mean P concentration [F (7, 72) = 13.395, p <.001]. Post hoc comparisons revealed no statistical differences between the 3 species with the highest concentrations (*Eichhornia crassipes*, *Hydrocotyle ranunculoides* and *Salvinia molesta*); *Cyperus dives* was significantly lower in P than all other species, whilst those in the mid-range were not statistically different from one another (all in the range 0.15–0.17% P: Table 5.3).

Table 5.3. *Mean concentrations of nitrogen and phosphorus in different plants at Naivasha*

Species	**% N**	**% P**	**Biomass (kg m^{-2})**
Eichhornia crassipes	2.24 (±.12)	0.42 (±.02)	0.16 (±.01)
Salvinia molesta	2.78 (±.05)	0.38 (±.01)	0.08 (±.001)
Hydrocotyle ranunculoides	3.28 (±.01)	0.33 (±.02)	n.d.
Azolla africana	2.77 (±.02)	0.17 (±.01)	0.04 (±.001)
*Cyperus papyrus**	0.71 (±.31)	0.17 (±.08)	4.94 (±1.01)
*Typha latifolia**	0.43 (±.14)	0.16 (±.02)	n.d.
Ludwigia stolonifera	2.58 (±.02)	0.15 (±.01)	n.d.
*Cyperus dives**	0.39 (±.06)	0.04 (±.01)	n.d.

Key to Table 5.3. N and P values are percentage dry weight in whole plants except for species marked * = in aerial structures only, with species arranged in descending order of [P]; ± standard deviations are given in parentheses; n.d. = not determined.

5.2.5. Rates of nutrient removal from harvesting (RQ15)

The mean number of stems in each age-class m^{-2} from 16 quadrats was: I (4.0); II (1.9); III (8.7) and IV (7.9). An estimation of the total amount of nitrogen (28.2 g) and phosphorus (7.0 g) that would be removed from a clear-cut harvest of papyrus stems m^{-2} at Lake Naivasha (Table 5.4) came from combining these data with the mean dry weight of stems in different age-classes and the maximum [N] and [P] in each, using mean values from Fisherman's Camp (Table 5.1).

Table 5.4. *Biomass and nutrient concentrations of stems in different age-classes at Lake Naivasha*

Factor / age-class	**I**	**II**	**III**	**IV**	*Totals*
Mean no. culms m^{-2}	4.0	1.9	8.7	7.9	**22.5**
Mean dry wt. culm^{-1} (g)	73.3	119.8	250.4	283.4	
Total biomass (g m^{-2})	293.2	227.6	2178.5	2238.9	**4938.2**
Mean [N] culm^{-1}	1.14	0.95	0.54	0.49	
Accumulation (g N m^{-2})	3.34	2.16	11.76	10.97	**28.2**
Mean [P] culm^{-1}	0.24	0.25	0.14	0.12	
Accumulation (g P m^{-2})	0.70	0.57	3.05	2.69	**7.0**

Key to Table 5.4. N and P values (% dry weight) are taken from Fisherman's Camp. Example calculation: total biomass (g m^{-2}) of age-class I (293.2) = mean no. culms m^{-2} (4.0) x mean dry weight (g) culm^{-1} (73.3). Since mean [N] culm^{-1} (% dry weight) is 1.14, total accumulation (g N m^{-2}) in age-class I (3.34) = (1.14/100) x 293.2.

5.3. Discussion

5.3.1. Primary productivity

Papyrus wetlands, alongside other emergent macrophyte communities (Westlake 1975), are one of the most productive natural systems on record, with correspondingly high rates of biomass accumulation (Jones 1983; Muthuri and Jones 1997; Loiselle et al. 2006). Approximately 60–75% of all living material is thought to be apportioned to the rhizome and root structures, with average below ground biomass estimates varying between 3.2–7.1 kg m^{-2} (Muthuri 1985; Jones and Muthuri 1997; Boar et al. 1999; Saunders et al. 2007). The majority of biomass measurements, however, have focused exclusively on above ground structures (scale leaves, culms and umbels), owing to the complexity of sampling large masses of entangled rhizomes beneath the water's surface (Saunders et al. 2007).

Multiple measurements of aerial biomass in East Africa have been made, with estimates varying widely – from a minimum of 1.4 kg m^{-2}, recorded at a flooded river valley site near Busoro in Rwanda (Jones and Muthuri 1985), to a maximum of 8.5 kg m^{-2}, measured within the Winam Gulf region of Lake Victoria in Kenya (Osumba et al. 2010). The mean estimate from a total of 4 studies (Jones and Muthuri 1997; Boar 2006; Terer et al. 2012; this study) conducted at Lake Naivasha lies close to the middle of this range at 5.2 kg m^{-2}, a figure which more than doubles when both above and below ground biomass is accounted for (mean of 10.5 kg m^{-2} from Thompson et al. 1979 and Boar et al. 1999).

Only a few researchers (Thompson et al. 1979; Muthuri et al. 1989; Saunders et al. 2007), on the other hand, have provided estimates of the *rate* of biomass accumulation over time (i.e. primary productivity) and, again, values for below ground production are often missing due to the inherent difficulties of accounting for deeply submerged rhizome and root structures. Above ground biomass, by contrast, can be measured relatively easily and non-destructively, using the general equation DW = (X G) – Y, where DW = dry weight (g), X = slope, G = culm girth (cm) and Y = intercept, derived from a linear regression fitted to the relationship between culm girth and dry weight obtained from a range of known samples (after Jones and Muthuri 1985). However, since primary productivity proceeds uninterrupted throughout the year in tropical wetlands, plant establishment, growth and mortality occur continuously and concurrently, with minimal seasonal variation in culm density, age structure or aerial biomass (Gaudet 1977b; Muthuri et al. 1989; Květ et al. 1998) – making it difficult to assign a temporal scale to papyrus swamps from which to determine rates of growth.

One solution is to make repeat visits to field sites, recording incremental increases in biomass for individually labelled culms using the equation described above. This is the approach I attempted; however flooding at Fisherman's Camp (Fig. 5.6) destroyed the control quadrats established for measuring natural productivity (RQ10), as well as those designed to measure biomass replacement rates in response to selective harvesting strategies (RQ11).

That notwithstanding, I can provide an estimate of primary productivity using 'turnover time', which is the mean length of time for which an individual culm survives or, in other words, the period over which "a papyrus community replaces its living biomass" (Thompson 1976, p.193). Turnover time can be established by monitoring a number of randomly selected culms, each labelled with a unique identifier, from their initial emergence on the rhizome, through maturity, to the point at which they reach natural mortality. Where stems belonging to age-class IV are found in an area of undisturbed wetland known to be growing in a state of dynamic equilibrium (in which biomass remains near-constant throughout the year, balanced by the interplay of mortality and regeneration: Květ et al. 1998), we can assume it has taken the length of that site's turnover time for its standing crop to accumulate. In such cases, productivity (g m^{-2} day^{-1}) can be estimated by dividing biomass (g m^{-2}) by turnover time (days).

Fig. 5.6. Flooded wetland at Fisherman's Camp showing culms beginning to decompose (photo: E. Morrison).

The wetland at Fisherman's Camp appeared to be in a state of 'dynamic equilibrium' prior to inundation, in that stems representing new growth (age-classes 0 and I) appeared in a 1:1 ratio with those that were senescing (age-class IV). Turnover time at Lake Naivasha is considered to be 150–180 days (Jones and Muthuri 1997). Since mean standing biomass (from the 16 quadrats) was found to be 4.94 ±1.01 kg dry weight m^{-2}, primary productivity can be estimated at between 27.4–32.9 g dry weight m^{-2} day^{-1}, with annual production extrapolated at >10 kg m^{-2} yr^{-1}.

This estimate of productivity is higher than that measured by previous studies, even taking the more conservative figure (27.4 g m^{-2} d^{-1}):

1. Muthuri et al. (1989) estimated 14.1 g m^{-2} d^{-1} in a wetland along Naivasha's western shore, based on monthly measurements taken over the course of 1 year, with annual production extrapolated at >5 kg m^{-2} yr^{-1}.
2. Thompson et al. (1979) recorded a mean of 17.3 g m^{-2} d^{-1} in the Upemba swamps of the Democratic Republic of the Congo, albeit the majority of measurements were made over a period of only 4 days.
3. Saunders et al. (2007) calculated a mean rate of 22.1 g m^{-2} d^{-1} in the Kirinya wetland of Uganda, based on monthly measurements taken over the course of 6 months.

The higher estimate (32.9 g m^{-2} d^{-1}) falls within the range reported by Kansiime and Nalubega (1999) for the Nakivibo swamp in Uganda (31–38 g m^{-2} d^{-1}), a site receiving high conductivity wastewater from the city of Kampala.

One explanation for the higher productivity recorded in the present study might be Naivasha's elevated trophic level relative to 1982 when the measurements of Muthuri et al. (1989) were made. The eutrophic state of the lake was recorded by Kitaka et al. (2002), who proposed that inputs from the Malewa river, particularly in terms of sediment-bound phosphorus, were sufficient to support this classification. The authors further suggested that loss of the nutrient buffering service formerly provided by papyrus (Gaudet 1979), following a decline in the area covered by the North Swamp (Boar et al. 1999), could have accelerated processes of eutrophication, although there was no empirical evidence to support this.

A recent study by Kansiime et al. (2011) found that papyrus exhibited a positive growth response (increases in both above and belowground biomass) in more nutrient-rich natural wetlands as well as in waters artificially enriched under experimental conditions. *Phragmites* spp. growing in temperate regions respond in a similar way (Szczepanska and Szczepanski 1976;

Ho 1979; Ho 1981). These findings support the possibility that the higher estimate of productivity calculated at Naivasha in the present study, compared to that recorded by Muthuri et al. (1989), could indeed reflect a greater availability of nutrients *sensu* Kitaka et al. (2002).

Nutrient availability, however, is only one of several interacting factors that govern productivity in papyrus wetlands. Rates of biomass accumulation are thought to be site-specific and related to, *inter alia*, the effects of local temperature (Thompson et al. 1979), light intensity (Jones 1987), nutrient status (Jones and Muthuri 1985) and hydrological regime (Saunders et al. 2007). In general, productivity tends to increase at higher altitudes, where lower temperatures reduce losses of carbon through respiration, allowing wetlands to maintain larger amounts of standing vegetation (Jones 1983). Sites at a lower elevation, for example the Kirinya wetland in Uganda (1,175 m: Saunders et al. 2007), may nevertheless incorporate more biomass (7.2 kg dry weight m^{-2}: Kansiime et al. 2007) than those at higher elevations, such as Lake Naivasha (1,890 m: Harper 1992; 4.9 kg dry weight m^{-2}: this study). Significant differences in other environmental controls (e.g. nutrient availability, Kirinya receiving high conductivity wastewater directly from Jinja town: Kansiime et al. 2007) may explain this.

Identifying and isolating the major factors governing productivity between sites is therefore challenging (Jones and Muthuri 1985). Indeed, even at the same site there can be ambiguity as to the exact nature of control for a particular variable; at Lake Naivasha, for example, Muthuri and Jones (1997) suggested that the availability of sulphur is most likely to constrain productivity, whereas Boar et al. (1999) favoured nitrogen limitation.

5.3.2. N and P: within-site variation

The variance in [N] and [P] between different age-classes recorded in this study agrees with earlier studies (Gaudet 1977b; Muthuri and Jones 1997). Gaudet (1977b), for example, discovered that nitrogen and phosphorus concentrations in stems of age-classes I and II (mean c. 1.5% N and c. 0.9% P) were roughly twice that found in age-classes III and IV (mean c. 0.8% N and c. 0.5% P). It seems probable that, upon reaching senescence, these mobile nutrients are translocated from older stems (age-classes III and IV), via the rhizome, towards active meristematic tissues at the base of younger stems (age-classes I and II) in order to drive new growth there. Indeed, Thompson (1976) contended that papyrus is able to maintain its high rates of primary productivity by "recycling, from old portions into its new growth, a large proportion of the carbon and nutrients which it has already 'fixed' previously" (p.196). Similar pathways have been described for species of *Typha* (Gopal and Sharma 1984; Garver et al. 1988) and *Phragmites* (Ho 1981) in temperate regions. This variance in nutrient concentrations between different age classes has important implications for defining sustainable harvesting intervals (see section *5.3.5*).

5.3.3. N and P: between-site variation

Gaudet (1977b) analysed papyrus stems from 10 different locations throughout Africa, recording a mean [N] across all age-classes of 0.73 ±.32% and a mean [P] of 0.04 ±.01%. The equivalent values recorded in this study were similar for nitrogen (0.71 ±.31%) but than 4 times higher for phosphorus (0.16 ±.08%). They were also higher than those recorded at Lake Naivasha in August 2000 by Boar (2006), based on stems collected <5 km away from the sites sampled here (0.47 ±.14% N and 0.06 ±.05% P). Values in the present study were, however, similar to those recorded at an earlier time (no date given) by Muthuri and Jones (1997) from papyrus growing along Naivasha's western shore (0.72 ±.17% N and 0.14 ±.06% P).

Since the availability of nutrients at a site affects the mineral concentration in plants growing there (Gaudet 1975), it could be that the variance in concentrations of N and P recorded at Naivasha in different studies serves as an indication of the nutrient status of the lake at the time of sampling. Ho (1981) made a similar observation based on a mineral analysis of *Phragmites australis* from 3 different Scottish lochs, finding significantly higher concentrations of nitrogen and phosphorus in plants growing in eutrophic waters. Although there is no supporting evidence, *Cyperus* spp. might exhibit the same response.

Papyrus is able to take up nutrients from waters of a very high conductivity (Thompson 1976). The variance recorded in this study appears to illustrate this, in that stems taken from the constructed treatment wetlands at Flamingo and Kingfisher Farms contained the highest concentrations of both N and P among all sites sampled (Table 5.2). These wetlands receive high conductivity wastewater from the farms' flower-packing facilities and staff canteens (J. Okumu, pers. comm.), which likely contains high levels of nitrogen and phosphorus associated with use of fertiliser and detergent respectively. The natural wetlands sampled were likely to be growing in water much lower in dissolved nutrients: Boar et al. (1999) recorded a total phosphorus (TP) concentration in the Malewa river of 0.09 mg l^{-1} TP; Muthuri and Jones (1997) recorded a value in papyrus swamp water of 0.15 mg l^{-1} TP, whereas a recent analysis (AgriQ, unpubl.) of wastewater entering the Flamingo Farm wetland cited a much higher value of 2.39 mg l^{-1} TP.

The results of a simultaneous water analysis (ibid.) in the 2 treatment wetlands indicated that the availability of nutrients was greater at Kingfisher Farm (organic nitrogen 3.57 mg l^{-1} N; total phosphorus 2.55 mg l^{-1} P) than Flamingo Farm (organic nitrogen 2.87 mg l^{-1} N; total phosphorus 2.39 mg l^{-1} P). The higher concentrations of N and P recorded in this study from the recently transplanted stems at Flamingo Farm (1.52 and 0.45 % dry weight respectively) compared to Kingfisher Farm (1.28 and 0.36 % dry weight respectively), from where they were transplanted, suggests that papyrus may respond to disturbance (i.e. nutrient losses from harvested stems) by initially increasing rates of uptake to facilitate rapid regeneration.

Fig. 5.7. Approximate locations of sites sampled to assess between-site variation in nutrient concentrations; not shown is 'Little Gilgil', which lies c. 30 km to the north of Lake Naivasha.

Stems at Marula Estate contained some of the highest concentrations of both nutrients among the 7 natural wetlands sampled (Table 5.2). This site, located at the upstream end of the lake's deltaic wetlands (the remains of the North Swamp: Fig. 5.7), receives water from the Malewa river and thus the balance of dissolved and suspended solids carried down from the catchment. Papyrus growing there is thus the first out of all the sites along the shoreline to receive plant-available species of both nitrogen (dissolved inorganic forms: mostly ammonium, NH_4^+ and nitrate, NO_3^-) and phosphorus (primarily orthophosphate, PO_4^{3-}, adsorbed on silt particles) associated with this material (Thompson 1976). This might explain the comparatively high nutrient concentrations recorded in stems at Marula Estate, as sediments settle out of the river water and papyrus and other plants growing there transform these species before they can reach other sites. It is perhaps instructive of the efficiency of papyrus in assimilating nutrients that the equivalent concentrations recorded in stems at Malewa Mouth, less than 2 km downstream, were significantly lower. Mean [P] at Marula Estate, for example, was 0.22 ±.03% whereas at Malewa Mouth it was more than 3 times lower at 0.06 ±.01% (Table 5.2). Kansiime et al. (2007) observed a similar pattern in experiments conducted at the Kirinya wetland in Uganda, where concentrations of total nitrogen and total phosphorus in water were found to progressively decrease on passing through a papyrus swamp.

Stems sampled from Fisherman's Camp were higher in both N and P than those sampled from Camp Carnelley's, <500 m away. The only major difference between the two sites was hydrological, in that the former site was in a flooded state, with rhizomes floating in open water, whereas the latter site was on dry land, with rhizomes rooted in the soil. Tanner and Headley (2011) proposed that roots protruding through the floating mat of emergent plants into open water provide a greater surface area for direct uptake of dissolved nutrients, which might explain the higher concentrations recorded at Fisherman's Camp. On the other hand, perhaps too few samples were taken to reveal an overall similarity between the two sites.

5.3.4. N and P: interspecific variation

Cyperus papyrus contained lower concentrations of both nutrients when compared to other species commonly found at Lake Naivasha (Table 5.3), but its overall uptake capacity was greater by virtue of its very high rate of biomass accumulation – with aboveground structures alone attaining 4.94 ±1.01 kg dry weight m^{-2}. *Eichhnornia crassipes* (water hyacinth), whilst containing over three times as much N and twice as much P, had a total (roots and floating leaves) biomass of only 0.16 ±.01 kg m^{-2}. *Salvinia molesta* (Kariba weed), whilst having the second highest [N] of all species, attained a biomass of just 0.08 ±.001 kg m^{-2}; *Azolla africana*, which contained a comparable concentration of N, was lower still (0.04 ±.001 kg m^{-2}).

The nutrient concentrations cited for the majority of species in Table 5.3 refer to whole plants (roots and floating structures), whereas for papyrus they represent that stored in the stems only. The rhizomes, roots and umbels of papyrus each contain up to 2–3 times the concentrations of N and P found in the culms whilst, as noted above, the majority of living material is thought to be below ground (Gaudet 1975; Muthuri 1985; Jones and Muthuri 1997; Boar et al. 1999; Saunders et al. 2007). Both factors serve to elevate overall rates of assimilation relative to the free-floating plants listed in Table 5.3 and testify to the efficacy of nutrient uptake in papyrus swamps. Stems of the 2 other emergent species investigated, *Typha latifolia* and *Cyperus dives*, both had a lower [N] and [P] than papyrus, with only *Typha* approaching its aboveground biomass, attaining c. 2.5 kg dry weight m^{-2} at low latitudes (Asaeda et al. 2005).

5.3.5. Harvesting potential

Combining the data on biomass and nutrient concentrations in different age-classes (Table 5.4) indicated that harvesting aboveground biomass (mean 4.94 kg m^{-2}) from papyrus wetlands at Lake Naivasha would remove a minimum of 28.2 g N and 7.0 g P m^{-2}. Extrapolating these data to the former North Swamp, which comprised some 11 km^2 of permanent floating papyrus (Gaudet 1979), suggests it would have held approximately 310,000 kg N and 77,000 kg P in aboveground tissues alone. This is a conservative estimate since the nutrient content of the umbels has not been taken into consideration; earlier studies (Gaudet 1975; Muthuri and Jones 1997; Boar et al. 1999) indicate that rates would be 2–3 times higher if the umbels were included in this calculation. These figures lend support to the contention of Kitaka et al. (2002) that the loss of the North Swamp's nutrient buffering capacity could have accelerated processes that led to the eutrophication of Lake Naivasha.

As noted in Chapter 2, clear-cutting approaches to estimates of harvesting potential in papyrus wetlands are likely to be flawed in that they cause excessive rates of nutrient export. This study has shown that younger stems (age-classes I and II) contain approximately twice the concentration of nitrogen and phosphorus held in older stems (age-classes III and IV), corroborating the findings of earlier studies (e.g. Gaudet 1977b). Not only would harvesting all aboveground biomass (new growth as well as old) therefore deplete accumulated stores of nutrients that might otherwise assist recovery from disturbance, removing all the umbels, where the bulk of the plant's photosynthetic tissues occur (Jones and Muthuri 1985), would act to further limit the wetland's regenerative capacity as rates of carbon fixation (and hence sugar production) decline in their absence.

Harvesting only mature stems, on the other hand, might leave a sufficient supply of nutrients within the wetland to facilitate a more rapid recovery from disturbance. Selective removal of older (photosynthetically inactive) umbels would also act to increase light availability for lower canopy, younger age-classes – in turn increasing their ratio per unit area and, by extension, overall rates of nutrient uptake (Jones 1983; van Dam et al. 2007). Muthuri et al. (1989) raised the concern that increased radiation at the water level could lead to higher levels of interspecific competition; Terer et al. (2012), however, observed no recruitment of other species within experimentally harvested plots at Naivasha. Nevertheless, the effects of altered canopy structure on microclimate and productivity warrant further investigation.

This study has also shown that 89.5% of aerial biomass m^{-2} is held in stems belonging to age-classes III and IV, with only 10.5% apportioned to age-classes I and II. Hence, by selecting only heavier, mature stems, a papyrus harvester would gain the vast majority of available biomass (a valuable provisioning service), whilst simultaneously maintaining (or even enhancing) the removal of excess nutrients from the lake (a critical regulating service). In order to accurately quantify the ability of papyrus wetlands to provide a 'bioremediation' (i.e. ecosystem enhancement) service at Lake Naivasha, one would need to calculate the relative rate of gains (in the form of plant-available nutrients arriving in the inflowing rivers) versus potential losses (the export of assimilated nutrients through harvesting aboveground material). Future research efforts should therefore aim to establish long-term monitoring of nutrient inputs from the catchment; in the absence of these data, it is impossible to provide a realistic estimate of the overall value of this potentially very useful regulating service.

Nevertheless, this study has provided a useful first step towards this: a selective harvest of older age-classes at Lake Naivasha, for example, would remove 4.42 kg dry weight (89.5% of that available) of biomass, 22.7 g (80.5%) of N and 5.74 g (81.9%) of P m^{-2} (Table 5.4). Annual rates of extraction would be double these figures should a biannual harvest prove viable in terms of maintaining productivity. It is of course impossible to say exactly how many harvests a year would be sustainable until the experiments described in Chapter 3 (section *3.2.3*) have been carried out successfully and over a sufficiently long timescale. A biannual harvest, solely of age-classes III and IV, could prove sustainable, however, given that turnover time at Lake Naivasha has been estimated at between 150–180 days (Jones and Muthuri 1997). Anecdotal support for a shorter harvesting interval than that proposed by earlier studies (frequently given as once every 12 months or more: Muthuri et al. 1989; Kariuki et al. 2001; Terer et al. 2012) comes from the activity of papyrus harvesters themselves, who typically return to the same area of wetland after a period of 3–7 months (Osumba et al. 2010; Terer et al. 2012b).

The rapidly rising lake levels that destroyed the selective harvesting experiments during the course of data collection suggest that unpredictable hydrological conditions at Lake Naivasha could rule out the possibility of biannual harvests during certain years, however. It may also prove difficult to avoid damaging young stems when traversing the wetlands in order to selectively remove older age-classes. Disturbance of this nature could, however, be somewhat mitigated by creating wetlands (designed for the explicit purpose of harvesting plant fibre) around crisscross pathways as discussed in Chapter 4 (section *4.3.3*).

5.4. Summary of Part 1

1. The rate of primary productivity in papyrus wetlands at Lake Naivasha, inferred from estimates of turnover time, is within the range 27.4–32.9 g dry weight m^{-2} day^{-1}, which is almost double the earlier estimate of Muthuri et al. (1989) (RQ10); I cannot say how rates of biomass accumulation change under different harvesting strategies (RQ11).

2. Stems belonging to age-classes I and II had approximately twice the [N] and [P] of age-classes III and IV, in agreement with earlier studies (Gaudet 1977b; Muthuri and Jones 1997), suggesting the possibility of translocation of mobile nutrients from old to new growth upon senescence (RQ12).

3. The variance in [N] between 9 different sites was highly significant [ANOVA, F (8, 105) = 17.486, p <.01]; the same was true for P [F (8, 45) = 28.571, p <.01]. Even when one excludes the very high concentrations recorded at constructed treatment wetlands, the variance between 7 natural sites remains as significant (p <.01) (RQ13).

4. *Cyperus papyrus* had a higher overall nutrient uptake capacity than any of the other species sampled by virtue of its much greater biomass. Nevertheless, nutrient concentrations in some free-floating plants (*Eichhornia crassipes*, *Ludwigia stolonifera* and *Salvinia molesta*) were higher on a % dry weight basis (RQ14).

5. A clear-cut harvest of aerial biomass would remove a minimum of 28.2 g of nitrogen and 7.0 g of phosphorus m^{-2} of wetland at Naivasha. A selective harvest, of age-classes III and IV only, would remove 22.7 g (80.5%) of N and 5.74 g (81.9%) of P m^{-2} (RQ15). It may be that the latter would be more the sustainable strategy, although empirical evidence for this is lacking.

I reject the first null hypothesis that stated, *"The concentration of N and P does not vary between sites at Naivasha"* and conclude that the alternative hypothesis (H_1) is more likely: the variance in concentration of nutrients was highly significant (p <.001) between sites in terms of both N [ANOVA, F (8, 105) = 17.486] and P [F (8, 45) = 28.571]. I cannot reasonably reject the second null hypothesis that stated, *"Any observed variance in nutrient concentrations is due to chance (sampling error)"* since measurable phenomena that might have proven otherwise (such as nutrient availability) were not recorded during this study.

Part 2: Flora of the riparian zone

5.5. Research questions

RQ16: How many plant species are found in the riparian zone?

RQ17: What is the distribution of these species during and after a drawdown event?

RQ18: How does their number and distribution compare to Gaudet (1977)?

RQ19: What are the ecological characteristics of the most common species?

RQ20: Which factors influence the number and type of species in the riparian zone?

RQ21: What factors influence papyrus swamp development in the riparian zone?

Hypotheses:

H_0: There are no differences in the number or distribution of species in the present day compared to Gaudet (1977).

H_1: There are significant differences between the two.

H_0: Any observed differences are due to chance (sampling error).

H_2: Observed differences are not the result of chance.

5.6. Results

5.6.1. Number of species in the riparian zone (RQ16)

A total of 55 taxa in 24 families was recorded, all but 3 (*Inigofera* sp.; *Panicum* sp. and *Plectranthus* sp.) identified to species level. Forty-three of these taxa were identified along transects; the remaining 12 were encountered during searches within the riparian zone and lake shallows (Table 5.5).

Twenty taxa were identified at Site 1 (Chapter 3, Fig. 3.3) in November 2009 (Table 5.6). A further 20 taxa were identified in April 2010, bringing the total there to 40. Twelve of the species recorded at Site 1 were also identified at Site 2, in addition to 6 new species (Table 5.8). Species richness decreased from inland towards the lake edge at both sites (Tables 5.6–5.8).

Table 5.5. *Total taxa (55) identified during this study*

	Site 1		Site 2	Informal
Taxa (55 in total)	Nov-09	Apr-10	Nov-09	**Surveys**
Acacia xanthophloea Benth.				*
Achyranthes aspera L.		*		
Amaranthus graecizans L.	*	*		
Amaranthus hybridus subsp. *hybridus* L.		*	*	
Azolla africana Desv.				*
Chenopodium pumilio R.Br.		*		
Cirsium vulgare (Savi) Ten.	*	*	*	
Commelina benghalensis L.		*		
Conyza hypoleuca A.Rich.	*	*	*	
Cynodon aethiopicus W.D.Clayton & Harlan	*	*	*	
Cyperus alternifolius (L.) Mant.				*
Cyperus digitatus Roxb. subsp. *auricomus* (Sieber ex Spreng.) Kük		*		
Cyperus dives Del. +	*	*	*	
Cyperus laevigatus L.	*	*	*	
Cyperus papyrus L.	*	*	*	
Cyperus rotundus L.	*	*	*	
Dactyloctenium aegyptium (L.) Willd.		*		
Dichondra repens J.R.Forst. & G.Forst.		*	*	
Dysphania ambrosoides L. (Mosyakin & Clemants) +		*		
Eichhornia crassipes (Mart.) Solms				*
Eragrostis pilosa (L.) Beauv.	*	*		
Glinus lotoides L. x *G. oppositifolius* (L.) Aug.DC. ex Hell.		*		
Hydrocotyle ranunculoides L.f.				*
Indigofera sp.	*	*	*	
Lotus corniculatus L. var. *eremanthus* Chiov.		*		
Ludwigia stolonifera (Guill. et Perr.) Raven			*	
Malva verticillata L.	*	*		
Microcystis aeruginosa Kützing				*
Nicotiana glauca Graham			*	
Oxalis corniculata L.	*	*		
Panicum sp.		*		
Pennisetum clandestinum Hochst. ex Chiov.	*	*	*	
Pistia stratiotes L.				*
Plantago major L.		*		
Plectranthus sp.		*		
Polygonum pulchrum Blume	*	*	*	
Pycnostachys deflexifolia Bak.		*	*	
Salvinia molesta D.Mitch				*
Senecio moorei R.E. Fr.	*	*	*	

Senna didymobotrya (Fresen.) Irwin & Barneby +				*
Sesbania sesban (L.) Merr.	*	*		
Setaria verticilliaris (L.) P.Beauv.		*		
Solanum incanum L.		*		
Solanum nigrum L.	*	*		
Sonchus oleraceus L. ☑		*		
Sphaeranthus confertifolius Robyns ☑			*	
Sphaeranthus suaveolens (Forsk) DC.	*	*		
Sporobolus spicatus (Vahl) Kunth.	*	*		
Trifolium baccarini Chiov.		*		
Typha domingensis Pers.				*
Typha latifolia L.				*
Verbena brasiliensis Vell.		*		
Verbena officinalis L. ☑	*	*		
Wolffia arrhiza (L.) Horkel ex Wimm.				*
Zehneria scabra (L.f.) Sond.		*		
Unique occurrences	**20**	**20**	**3**	**12**

Key to Table 5.5. Taxa highlighted in grey in the far left column represent species (21 in total) not recorded by Gaudet (1977); ☑ indicates species described by Gaudet (1977) from herbaria collections only, but which were identified *in situ* during the present study; + indicates species common between studies that have undergone taxonomic revisions; * (asterisk highlighted in grey) indicates taxa uniquely identified at that site or, in the case of the last column, during searches conducted between data collecting periods.

5.6.2. Species distribution during and after drawdown (RQ17)

5.6.2.1. Site 1: November 2009

The distribution of species along the transect lines at Site 1 in November, when lake levels were very low, could be broadly described within 3 zones corresponding to the family of plants that were most abundant in each after Gaudet (1977). These were: a Composite zone (dominated by the Compositae), a Grass zone (dominated by the Poaceae) and a Sedge zone (dominated by the Cyperaceae) (Fig. 5.8). Each zone was approximately 150 m in length, although the boundaries between them were somewhat indistinct, particularly where the Composite zone approached the Grass zone from 200–250 m (Fig. 5.8).

1. The Composite zone was dominated by two species of the Asteraceae (Compositae) with a similar percentage cover – *Cirsium vulgare* (21.7%) and *Senecio moorei* (23.8%) – followed by two species from different families, *Sesbania sesban* and *Verbena officinalis*, in lower abundance (11.9% and 16.0% respectively). Another member of the Compositae, *Sphaeranthus suaveolens* (3.4%), as well as *Cyperus dives* and *Pennisetum*

clandestinum (3.1% and 3.6% respectively) were also found there, albeit not above the threshold of 5.0% assigned to distinguish more abundant taxa.

2. *Cirsium vulgare*, *Senecio moorei*, *Sesbania sesban* and *Verbena officinalis* were also identified within the Grass zone, although their abundance there was much lower (11.2%, 8.9%, 1.7% and 3.9% respectively), this region being dominated by the grasses *Pennisetum clandestinum* (34.6%) and *Eragrostis pilosa* (21.2%) in the family Poaceae. A covering of the creeping woodsorrel *Oxalis corniculata* (5.6%) gave way to the sedge *Cyperus rotundus* (5.0%) on approaching the Sedge zone.

3. The vast majority of the Sedge (Cyperaceae) zone was composed of *Cyperus rotundus* (81.2%). *Senecio moorei*, the only species present along all points of each transect (percentage frequency 100.0%), was also found here in low abundance (5.9%). *Polygonum pulchrum* seedlings (3.7%), those of another sedge, *Cyperus dives*, the grass *Pennisetum clandestinum* and seedlings of an *Indigofera* sp. were also present, but only in scattered patches (all 2.7%: Table 5.6).

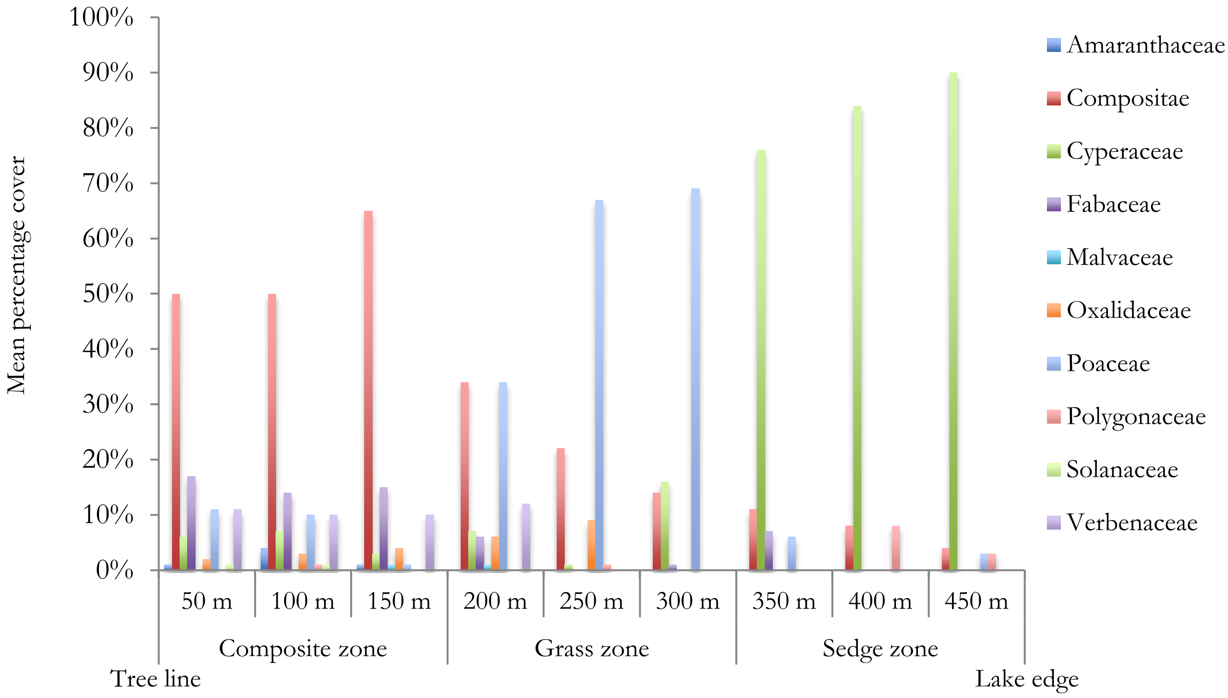

Fig. 5.8. Abundance (% cover) of different plant families within 50 m lengths of transects at Site 1 in November 2009.

5.6.2.2. Site 1: April 2010

1. By April the number of species in the Composite zone had almost doubled, increasing from 20 to 37 (Table 5.7). In contrast to November, when *Cirsium vulgare* and *Senecio moorei* were more abundant than any other species, there were no distinctly dominant taxa at this time, but rather multiple species growing in low, fairly even abundance, e.g. *Pennisetum clandestinum* (16.1%); *Verbena brasiliensis* (12.3%); *Senecio moorei* and *Sesbania sesban* (both 11.2%). The cover of *Conyza hypoleuca* had more than doubled yet remained low at 6.4% (up from 2.4% in November).

2. The Grass zone had been reduced to just c. 50 m by the rise in lake level, wherein the sedge *Cyperus dives* was now slightly more abundant (28.1%) than the grass *Pennisetum clandestinum* (25.0%). Two new arrivals in the Amaranthaceae, *Amaranthus hybridus* subsp. *hybridus* and *Chenopodium pumilio*, were both more abundant (both 9.4%) than the grass *Eragrostis pilosa*, its cover from 150–200 m reduced from 18.6% to 4.7%. Most of the *Senecio moorei* was now submerged and lower in abundance by about half, reduced from 15.2% to 7.8% An unidentified species of *Panicum* was also present here as seedlings (4.7%: Table 5.7).

3. The original extent of the Sedge zone had been flooded entirely. *Cyperus papyrus* could now be seen thriving in the shallows (Fig. 5.9), whilst *C. dives* proliferated along the shoreline, having increased in abundance within what remained of the Grass zone (which now abutted the water) from 3.3% to 28.1% (Tables 5.6 and 5.7). The formerly abundant *C. rotundus*, shorter than its relative *C. dives*, was by now completely submerged and presumably dead.

Fig. 5.9. Intermediate stage of succession: *Cyperus papyrus* now dominates the advancing Sedge zone, outcompeting its shorter relative *C. dives* (photo: R. Fox).

5.6.2.3. Site 2: November 2009

The distribution of species at Site 2 was not as clearly differentiated as at Site 1 (Table 5.8). Whilst sedges were fairly abundant (the percentage cover of *Cyperus dives*, *C. laevigatus*, *C. papyrus* and *C. rotundus* together accounting for 38.2% of the total), grass cover was heavily reduced and consisted of just 2 species – *Cynodon aethiopicus* and *Pennisetum clandestinum* – with a combined abundance of only 8.3% (cf. Site 1 where 4 species of grass together accounted for 21.9% of the total).

The zones between the different taxa were less distinct than at Site 1; indeed, two very different species – *Cyperus dives* and *Nicotiana glauca* – were found at all points along the transect lines (proportional frequency 100.0%: Table 5.8). One might thus describe the shoreline there as having a mixed, or heterogeneous, flora. No temporal changes in species richness or abundance could be described for Site 2 since flooding precluded further data collection in April.

Table 5.6. *Abundance of species (% cover) within 50 m lengths of transects at Site 1 in November 2009*

	Composite zone			Grass zone			Sedge zone				
Taxa (20 in total)	**50 m**	**100 m**	**150 m**	**200 m**	**250 m**	**300 m**	**350 m**	**400 m**	**450 m**	**PF**	**RA**
Amaranthus graecizans L.	3.3	3.3	1							33.3	0.8
Cirsium vulgare (Savi) Ten.	23.3	21.7	25	15	13.3	5				66.7	11.1
Conyza hypoleuca A.Rich.	3.3	1	3.3		1	3.3	1	1		77.8	1.5
Cynodon aethiopicus W.D.Clayton & Harlan		3.3		3.3						22.2	0.7
Cyperus dives Del.	3.3	3.3	3.3	3.3	1	1	8.3			77.8	2.5
Cyperus laevigatus L.	3.3	1		3.3						33.3	0.8
Cyperus papyrus L.		1								11.1	0.1
Cyperus rotundus L.		1				15	73.3	83.3	93.3	55.6	28.6
Eragrostis pilosa (L.) Beauv.	3.3	1		18.3	33.3	11.7	1			66.7	7.4
Indigofera sp.	1	3.3	3.3	1		1	8.3			66.7	1.9
Malva verticillata L.			1	1						22.2	0.2
Oxalis corniculata L.	1	3.3	3.3	6.7	10					55.6	2.6
Pennisetum clandestinum Hochst. ex Chiov.	8.3	3.3		11.7	33.3	58.3	5		3.3	77.8	13.3
Polygonum pulchrum Blume		1			1			8.3	3.3	44.4	1.5
Senecio moorei R.E.Fr.	21.7	23.3	31.7	15	5	6.7	8.3	6.7	3.3	100.0	13.1
Sesbania sesban (L.) Merr.	15	11.7	11.7	5						44.4	4.7
Solanum nigrum L.	1	1								22.2	0.2
Sphaeranthus suaveolens (Forsk) DC.	1	3.3	6.7	3.3						44.4	1.5
Sporobolus spicatus (Vahl) Kunth.	1	3.3	1							33.3	0.6
Verbena officinalis L.	10	10	31.7	11.7						44.4	4.8
Species richness	**15**	**17**	**12**	**13**	**8**	**8**	**7**	**4**	**4**		
Per zone		Σ20			Σ16			Σ8			100%

Key to Table 5.6. Percentage cover values >5% are highlighted in grey to distinguish more abundant taxa; PF = percentage frequency; RA = relative abundance.

Table 5.7. *Abundance of species (% cover) within 50 m sections of transects at Site 1 in April 2010*

	Composite			Grass		
Taxa (40 in total; 20 new)	**50 m**	**100 m**	**150 m**	**200 m**	**PF**	**RA**
Achyranthus aspera L.	1				25	0.2
Amaranthus graecizans L.		1	3.3		50	1.0
Amaranthus hybridus subsp. *hybridus* L.			8.3	10	50	4.4
Chenopodium pumilio R.Br.	3.3		3.3	10	75	4.0
Cirsium vulgare (Savi) Ten.	5	5	3.3		75	3.2
Commelina benghalensis L.	1				25	0.2
Conyza hypoleuca A.Rich.	13.3		6.7		50	4.8
Cynodon aethiopicus W.D.Clayton & Harlan		1			25	0.2
Cyperus digitatus Roxb. subsp. *auricomus* (Sieber ex Spreng.) Kük				3.3	25	0.8
Cyperus dives Del.	1		11.7	30	75	10.3
Cyperus laevigatus L.		1			25	0.2
Cyperus papyrus L.		1			25	0.2
Cyperus rotundus L.		10			25	2.4
Dactyloctenium aegyptium (L.) Willd.	1			1	50	0.5
Dichondra repens J.R.Forst. & G.Forst.		3.3			25	0.8
Dysphania ambrosoides L. (Mosyakin & Clemants)	1				25	0.2
Eragrostis pilosa (L.) Beauv.	1	3.3		5.0	50	1.0
Glinus lotoides L. x *G. oppositifolius* (L.) Aug.DC. ex Hell.				1	25	0.2
Indigofera sp.	1		1	1	75	0.7
Lotus corniculatus L. var. *eremanthus* Chiov.			3.3		25	0.8
Malva verticillata L.	5				25	1.2
Oxalis corniculata L.	1	3.3	3.3		75	1.8
Panicum sp.	1	3.3	3.3	5	100	3.1

Pennisetum clandestinum Hochst. ex Chiov.	13.3	21.7	15	26.7	100	18.6
Plantago major L.			1	1	50	0.5
Plectranthus sp.	1				25	0.2
Polygonum pulchrum Blume	3.3	1	1	1	100	1.5
Pycnostachys deflexifolia Bak.	3.3				25	0.8
Senecio moorei R.E.Fr.	11.7	15	8.3	8.3	100	10.5
Sesbania sesban (L.) Merr.	11.7	13.3	10		75	8.5
Setaria verticilliaris (L.) P.Beauv.			1		25	0.2
Solanum incanum L.	1			3.3	50	1.0
Solanum nigrum L.	1				25	0.2
Sonchus oleraceus L.			1		25	0.2
Sphaeranthus suaveolens (Forsk) DC.	3.3	3.3			50	1.6
Sporobolus spicatus (Vahl) Kunth.			1		25	0.2
Trifolium baccarini Chiov.	1				25	0.2
Verbena brasiliensis Vell.	11.7	15	11.7		75	9.3
Verbena officinalis L.	5		8.3		50	3.2
Zehneria scabra (L.f.) Sond.	1				25	0.2
Species richness	**26**	**16**	**20**	**13**		
Per zone		Σ37		Σ13		100%

Key to Table 5.7. Percentage cover values >5% are highlighted in grey to distinguish more abundant taxa; PF = percentage frequency; RA = relative abundance.

Table 5.8. *Abundance of species (% cover) within 10 m lengths of transects at Site 2 in November 2009*

Taxa (18 in total; 6 unique to Site 2)	**10 m**	**20 m**	**30 m**	**40 m**	**PF**	**RA**
Amaranthus hybridus subsp. *hybridus* L.	8.3	7.6	3.3		75	4.8
Cirsium vulgare (Savi) Ten.	5	3.3			50	2.1
Conyza hypoleuca A.Rich.	11.7	8.3	5		75	6.2
Cynodon aethiopicus W.D.Clayton & Harlan		3.3	6.7		50	2.5
Cyperus dives Del.	5	13.3	20	58.3	100	24.1
Cyperus laevigatus L.		3.3	6.7	10	75	5.0
Cyperus papyrus L.	21.7				25	5.4
Cyperus rotundus L.	6.7	8.3			50	3.7
Dichondra repens J.R.Forst. & G.Forst.		3.3	5	8.3	75	4.1
Indigofera sp.	8.3				25	2.1
Ludwigia stolonifera (Guill. & Perr.) Raven		6.7	26.7	21.7	75	13.7
Nicotiana glauca Graham	5	3.3	11.7	6.7	100	6.7
Pennisetum clandestinum Hochst. ex Chiov.	8.3	15			50	5.8
Polygonum pulchrum Blume	3.3	3.3			50	1.6
Pycnostachys deflexifolia Bak.	3.3	3.3	8.3		75	3.7
Senecio moorei R.E.Fr.	5	8.3			50	3.3
Solanum nigrum L.	1	1	6.7		75	2.2
Sphaeranthus confertifolius Robyns	5	6.7			50	2.9
Species richness	**14**	**16**	**10**	**5**		100%

Key to Table 5.8. Highlighted taxa represent those recorded uniquely at Site 2; percentage cover values >5% are highlighted in grey to distinguish more abundant taxa; PF = percentage frequency; RA = relative abundance.

5.6.3. Comparisons with Gaudet (1977) (RQ18)

5.6.3.1. Number of species

Only 34 species were common between the two studies; the remaining 74 previously documented by Gaudet (1977) (Appendix 5) were therefore missing. Even when the 11 species not identified *in situ* by Gaudet (1977) – but rather observed in herbaria collections (denoted by an asterisk in Appendix 5) – are excluded, the difference between the two studies remains highly significant [χ^2 (1, Yates' correction) = 19.138, p <.01], there being roughly half the number of species (55 versus 108) and families (24 versus 43) recorded in the present study.

5.6.3.2. Distribution of species

Baseline study

Gaudet (1977) described 3 different (early, intermediate and late) stages of floral succession at Site 1, initiated by a long period of low lake levels (1971–73) exposing a wide band of bare, wet mud in front of mature fringing papyrus swamps:

- A Seedling Zone[10] developed on newly exposed mudflats in the early (November) stage, populated by *Nymphaea caerulea* (water lily) seedlings. Inland from this wet mud region *Cyperus* spp. were found in large numbers, also as seedlings, growing within a narrower band of shoreline that he termed a Sedge Zone. Farther inland and closest to the papyrus swamps, species in the genera *Conyza*, *Gnaphalium* and *Sphaeranthus* (all within the family Asteraceae or Compositae) were found in flower, growing within what Gaudet correspondingly referred to as a Composite Zone.

- The lake level had begun to rise following the onset of the long rains (March/April) during the intermediate stage, such that by November most of the 3 zones had become inundated (re-flooded). The Seedling Zone had narrowed considerably and was now populated with *Sphaeranthus* spp.; the Sedge Zone had increased in area slightly but remained dominated by *Cyperus* spp., whilst the Composite Zone remained largely unchanged. The relative density of several species had decreased, although overall species richness remained near constant.

[10] To distinguish between the two classification systems, 'Zone' (capitalised) refers to the work of Gaudet (1977), whereas 'zone' refers to that of the present study.

- The region closest to the lake edge had become a *Sphaeranthus* Zone by the late stage of succession. *Cyperus papyrus* and *C. digitatus* characterised the Sedge Zone and *Conyza* and *Polygonum* spp. dominated the inland Composite Zone. At this time, Gaudet (1977) noted that *Cyperus* spp. had a very high chance of survival inside the Composite Zone (420%) but none at all within the *Sphaeranthus* Zone (0%), which he attributed to the fact that germination of sedge seed continued within the drier, inland Composite Zone right up to the time of inundation. This suggests that young *Cyperus* plants can tolerate flooding only after reaching a certain stage of development, an observation that was later supported by the experimental findings of Boar (2006).

Present study

Examination of data collected in the present study reveals the following differences from the successional processes outlined above. In the first instance, each of the 3 zones was much wider than those identified by Gaudet (1977). One reason for this is that the lake level receded farther during the drawdown of 2008–09 (c. 3 vertical m: Fig. 5.11) than during the drawdown of 1971–73 (c. 1.5 m: Gaudet 1977). The different stages of succession recorded in the present study were as follows:

- A Sedge (Cyperaceae) zone composed predominantly of *Cyperus rotundus*, a species not recorded in the baseline study, was found closest to the lakeshore in the early (November 2009) stage. No evidence of *Nymphaea caerulea*, formerly a plant characteristic of the Lake Naivasha flora (Harper and Mavuti 2004), was found, in contrast to Gaudet's description of this region (which he referred to as a Seedling Zone). A Grass zone composed of *Pennisetum clandestinum* and *Eragrostis pilosa* formed the intermediate habitat in place of Gaudet's Sedge Zone dominated by *Cyperus* spp.; indeed, no record of *Cyperus digitatus* was made and only isolated seedlings of *C. dives* (referred to by Gaudet as *C. immensus*) and *C. laevigatus* were found. The region farthest inland was termed a Composite zone in agreement with Gaudet (1977), after the Compositae found there in high abundance – the genera *Cirsium*, *Conyza*, *Senecio* and *Sphaeranthus* accounting for nearly two thirds of all species there.

- The lake level had begun to recover following plentiful short rains throughout December and January. Species richness within the Composite zone rose markedly as more seeds began to germinate by the intermediate (April 2010) stage. This is in contrast to Gaudet's (1977) account in which species richness remained near constant. The rising lake level effectively increased the extent of the Sedge zone, since much of the Grass zone was by now submerged. *Cyperus papyrus* was thriving in a dense band of new growth in the lake shallows, presumably having germinated from seed (Boar 2006); *C. dives* (*C. immensus*) dominated the shoreline, whilst the rising water had inundated *C. rotundus*.

- For around 3 months thereafter the lake level remained near constant, at approx. 1886.3 m (Fig. 5.11), during which time the new band of papyrus continued to grow. However, from August–November the lake level increased further (by c. 1 m), flooding the papyrus and covering what remained of the Grass and Composite zones entirely. Emergent structures soon began to wilt and decompose, such that by the end of 2010 the papyrus had all but disappeared (E. Morrison, pers. obs.).

5.6.4. Ecological characteristics of common species (RQ19)

5.6.4.1. Taxa unique to this study

Twenty-one taxa not listed by Gaudet (1977) were identified during this study; of these only 5 had a relative abundance (RA) >5% (Table 5.9).

Table 5.9. *Species recorded in the present study with a relative abundance (RA) >5%.*

Species	RA	Site
Cyperus rotundus L.	28.6%	1
Cyperus dives Del.	24.1%	2
Pennisetum clandestinum Hochst. ex Chiov.	18.6%	1
Ludwigia stolonifera (Guill. & Perr.) Raven	13.7%	2
Senecio moorei R.E.Fr.	13.1%	1
Cirsium vulgare (Savi) Ten.	11.1%	1
Verbena brasiliensis Vell.	9.3%	1
Sesbania sesban (L.) Merr.	8.5%	1
Eragrostis pilosa (L.) Beauv.	7.4%	1
Nicotiana glauca Graham	6.7%	2
Conyza hypoleuca A.Rich.	6.2%	2
Cyperus papyrus L.	5.4%	2
Cyperus laevigatus L.	5.0%	2

Key to Table 5.9. Species are presented in descending order of relative abundance (RA); those highlighted in grey represent taxa uniquely recorded in the present study; Site codes indicate where species attained this value.

A brief description of each of these species follows, taken from a desk study. Species are presented in descending order of highest relative abundance, with greater detail given to the more abundant species in an attempt to reveal characteristics that might explain their prominence among the riparian flora today.

1. *Cyperus rotundus* L. The herbaceous perennial sedge *C. rotundus* (purple nutsedge) is a successful invasive. With a widespread distribution (>100 countries) and known deleterious impacts on >50 agricultural crops (Rao 2000), purple nutsedge was described by Holm et al. (1977) as the "world's worst weed" (p.7). *C. rotundus* is a highly competitive species that can survive periods of environmental stress due to a prolific underground system of asexual reproductive structures – including basal bulbs, tubers and rhizomes – favouring rapid vegetative growth following disturbance (Williams 1982; Stoller and Sweet 1987; Gilreath and Santos 2005). A single tuber, for example, has been shown to give rise to >100 additional tubers in <3 months (Kim et al. 1994).

The tissues of *C. rotundus*, the tubers in particular, have allelopathic properties known to inhibit seed germination and supress growth of adjacent (notably crop) species (Jangaard et al. 1971; Holm et al. 1977; Stoller and Sweet 1987). *C. rotundus*, a C_4 plant, requires high levels of irradiation and is sensitive to shading (Stoller and Sweet 1987), which could explain its lower abundance in the more species-rich Composite zone relative to the Grass and Sedge zones, where fewer and shorter species were found. *C. rotundus* dominated the Sedge zone of Site 1 prior to inundation and had the highest RA of all species identified during the study, reaching 28.6% in November at Site 1.

2. *Cirsium vulgare* (Savi) Ten. Spear (or bull) thistle (Fig. 5.10) is a wind-dispersed biennial forb (Stace 1997); an early successional (ruderal) species that establishes as a weed in open, grazed or otherwise disturbed sites (Forcella and Wood 1986; Beck 1999). *C. vulgare* appears to be unpalatable, with no significant nutritive value for livestock – it is usually avoided by grazing animals because of its sharp spines, although goats may eat it when young (Sindel 1991; Mitich 1998). Livestock grazing of surrounding species acts to increase the competitive advantage of spear thistle; indeed, the weed may disappear altogether from areas where livestock are excluded (Klinkhamer and de Jong 1993). Seedlings are often outcompeted by tall grasses, however, which might explain its decline in abundance approaching the Grass zone of Site 1.

Fig. 5.10. Spear thistle (*Cirsium vulgare*) thriving in the Composite zone at Site 1 (photo: E. Morrison).

The litter of *Cirsium* spp. can inhibit the growth of other plants; in spear thistle, this is likely a result of nutrient immobilization during litter breakdown (Klinkhamer and de Jong 1993). Biennials tend to be uncommon or absent in late successional plant communities since they require abundant light for establishment (Forcella and Randal 1994), which could explain the decline in RA of spear thistle within the Composite zone, from 11.1% in November down to 3.2% in April, as succession advanced and competition for light increased concomitant with an increase in species richness.

3. *Verbena brasiliensis* Vell., Brazilian vervain, is a short-lived perennial herb known to displace native flora where invasive as in Kenya (Verloove 2006), thriving in riverine areas, roadsides, old fields and other disturbed sites (Hoagland and Johnson 2004). *V. brasiliensis* was recorded for the first time at Site 1 in April, where its RA within the Composite zone equated to 9.3%.

4. *Eragrostis pilosa* (L.) Beauv., soft (or Jersey) lovegrass, is a native grass known for its palatability and high grazing value (Quattrocchi 2006), preferring moist pastures as well as open, disturbed sites (Holm et al. 1997). *E. pilosa* was common in the Grass zone of Site 1 in November, although its RA among all taxa reached only 7.4%.

5. *Nicotiana glauca* Graham, tree tobacco, is native to South America but has been widely introduced throughout the subtropics, where it is regarded as a successful invasive weed of disturbed sites, forming dense colonies by virtue of a high rate of fruit and seed set (Ollerton

et al. 2012). *N. glauca* was only encountered at Site 2 (RA 6.7%), where it was found ubiquitously along the transects.

5.6.4.2. Shared taxa

The following 8 species were also identified by Gaudet (1977) and appeared in the present study with RA values >5%. Again, a brief description of each is given, presented in descending order of highest RA, with greater detail given to the more abundant species:

1. *Cyperus dives* Del. (referred to by Gaudet 1977 as *Cyperus immensus* C.B.Cl.) is a common weed of temporarily wet places throughout tropical and subtropical Africa. *C. dives* appears to be the first large sedge to germinate after lake level rises at Naivasha, becoming over-grown by *C. papyrus* after about one year (Gaudet 1977). Its ecology is otherwise poorly understood; the species has received little attention except at the taxonomic level (Verloove and Soldano 2011). *C. dives* had the second highest RA (after *C. rotundus*) of all plants identified during this study, reaching 24.1% at Site 2 where it was the only species to feature within each 10 m length of transect with a percentage cover >5%. *C. dives* is much shorter (c. 1 m) than its giant relative *C. papyrus* (c. 6 m) and appears to tolerate only shallow water, growing well along lake margins and the banks of tributary streams in Naivasha's mid-altitude catchment (E. Morrison, pers. obs.).

2. *Pennisetum clandestinum*, Kikuyu grass, is a creeping rhizomatous grass capable of withstanding high grazing pressure and forming persistent monospecific mats (Holm et al. 1977). *P. clandestinum* grows best under moist, humid conditions (although long-established mats can tolerate periods of drought: ibid.), which may explain its increased abundance in April 2010 following the December–January rains. Kikuyu grass smothers competing seedlings (supressing their growth) and is known to produce allelopathic substances that can kill adjacent species (Sanchez and Davis 1969). Gaudet (1977) described *P. clandestinum* as common only on recently exposed parts of the shoreline as well as inland, although in the present study the species was found to be widespread throughout the riparian zone, its RA reaching 18.6% at Site 1 in April.

3. *Ludwigia stolonifera* (Guill. & Perr.) Raven, a perennial creeping herb, is frequently encountered at Naivasha as a floating aquatic, forming loosely tangled mats within the littoral zone (Adams et al. 2002). Gaudet (1977) identified the species alongside emergent taxa, whereas during the present study it was found only on exposed mud at Site 2, presumably having originated from floating mats stranded on Kwa Muhia's steep shoreline (RA 13.7%).

4. *Senecio moorei* R.E.Fr., a perennial woody shrub native to Kenya (Beentje et al. 2005), is considered to be poisonous to mammals (Kamau and Mugera 1975), which could explain its continuous presence along transects through the heavily grazed land at Site 1 in both November and April: the only species with a ubiquitous distribution there (RA 13.1%).

5. *Sesbania sesban* (L.) Merr. is a native, short-lived tree that grows well under bimodal rainfall patterns, being well adapted to dry conditions punctuated by periods of flooding (Evans 1990). *S. sesban* was found only within the Composite zone farthest from the water's edge at Site 1 in the present study (RA 8.5%), whereas Gaudet (1977) encountered it both inland and on exposed mudflats.

6. *Conyza hypoleuca* A.Rich., a native woody herb listed as common in Gaudet's (1977) Composite Zone was found in low abundance within all 3 zones described in the present study at Site 1, although its RA peaked at just 6.2% among the mixed flora of Site 2.

7. *Cyperus papyrus* L. was initially found in only low abundance, with just a few seedlings scattered within the Composite zone of Site 1. A greater number of seedlings were found at Site 2, although its RA there was also low (5.4%). Once the lake level began to recover, however, papyrus thrived in the shallow water.

8. *Cyperus laevigatus* L., smooth flatsedge, described as common within Gaudet's (1977) Sedge Zone, was found in only minimal abundance beside narrow rivulets draining into the lake at Site 1 and its RA peaked at just 5.0% at Site 2.

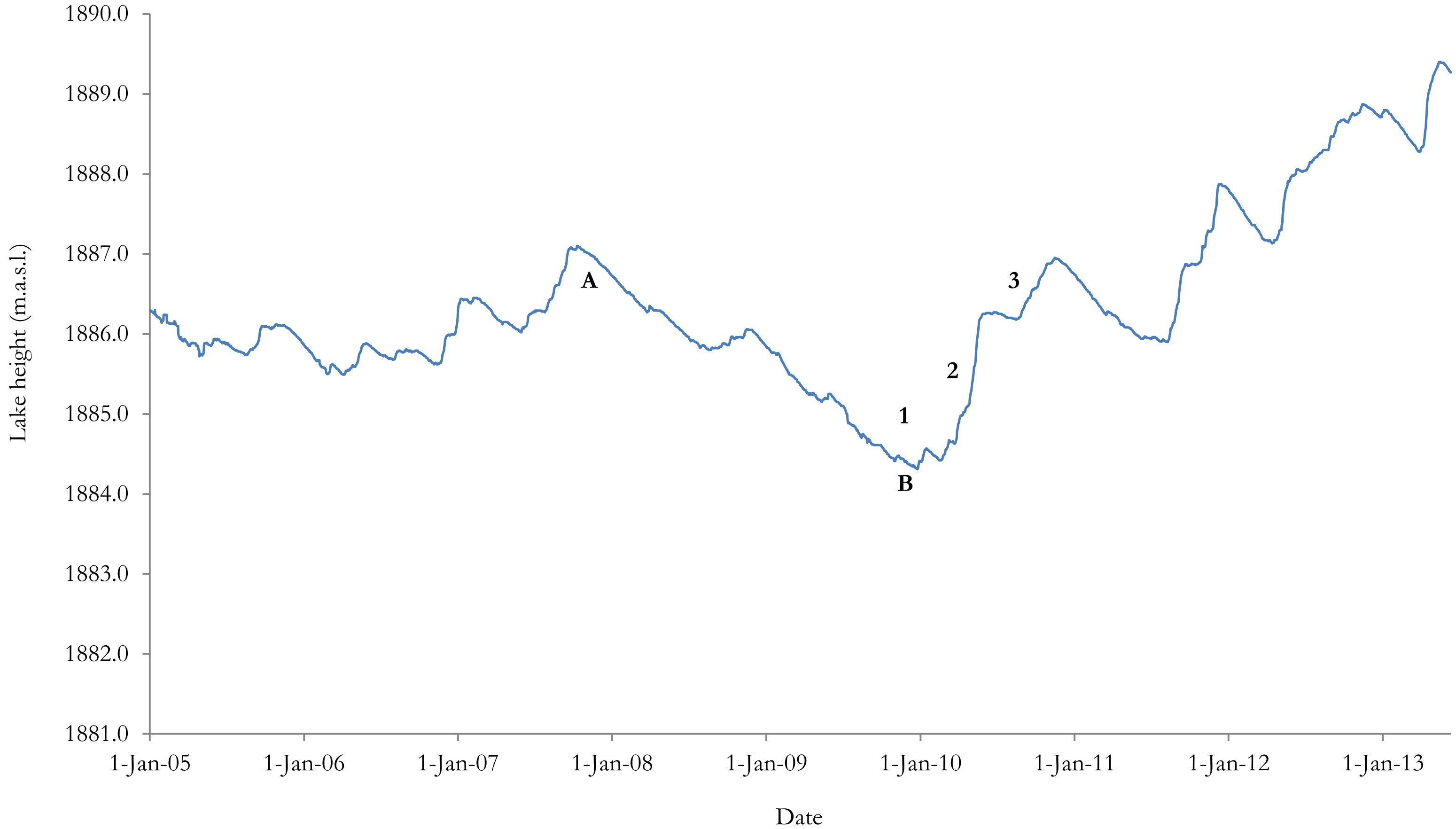

Fig. 5.11. Lake level data for Naivasha: 2005–2013. Height between points A and B reveals extent of drawdown (c. 3 m) during 2008–2009; 1 = height during data collection in November 2009; 2 = height during data collection in April 2010; 3 = point at which lake level began to rise again (July 2010). Reproduced with permission from E. Kiminta.

5.7. Discussion

There are two principal differences between Gaudet's (1977) description of Naivasha's riparian zone and that of the present study:

1. The depauperate flora of the present day: total species richness was lower by about a half (50.9%) and over two thirds (68.5%) of species were missing.

2. The lack of *Cyperus papyrus* in general and, despite its emergence as the dominant species after re-flooding, its failure to persist as a fringing swamp.

I argue that the significantly lower number of species in the present day is the result of increased anthropogenic impacts on the riparian zone relative to the 1970s and, to a lesser extent, the competitive advantages of certain taxa. This is explained in greater detail below. The subsequent section addresses the causes behind the lack of papyrus.

5.7.1. Factors influencing the number and type of species (RQ20)

5.7.1.1. Anthropogenic impacts

Not long after Gaudet's (1977) earlier study, successful experiments in the production of cut flowers around Lake Naivasha catalysed the growth of the region's commercial horticultural sector (Harper et al. 2011). Today, the irrigation of flowers, vegetables, fodder crops and macadamia nuts occupies some 4,500 ha of the lake basin, with the export of flowers alone generating >$350 million in foreign exchange for Kenya in 2005 (Mekonnen et al. 2012). The rise in employment opportunities created by the expanding horticultural industry spurred a 20-fold increase in the basin's human population relative to the early 1980s, totalling some 650,000 people in 2006 (Harper et al. 2011). In addition to the growth of Naivasha town, several 'satellite' settlements have arisen in close proximity to the flower and vegetable farms, particularly along the eastern and southern shoreline (see Chapter 6, Fig. 6.3). Roads have been tarred, schools and hospitals have been constructed and infrastructure has been improved and extended (Mekonnen et al. 2012).

Land use around the lake has intensified as a result of increased immigration to the region. Most of the lake hinterland is now under private ownership (see Chapter 6, section *6.2.1*), although certain areas have been set aside for wildlife sanctuaries and game corridors. Large parcels of land (formerly bush) immediately behind the fringing *Acacia* woodland, particularly to the east and south, have been variously cleared for commercial horticulture and energy operations, developed into hotels and staff housing complexes, or else subdivided for subsistence agriculture and cheap accommodation within informal settlements. Large swathes of land to the west and north are given over to livestock grazing as well as farming of crops such as wheat and lucerne (Becht et al. 2005).

These demographic changes would have influenced the riparian flora in one or more of the following ways:

1. Livestock densities have risen concomitant with human population growth and land development around the lake (E. Kiminta, pers. comm.), thus grazing and also trampling pressure in the riparian zone is now higher than in the 1970s. Disturbance of the flora was particularly high during the drought of 2009 when pastoralists and their herds (at least 30,000 head of livestock: ibid.) converged on the shoreline from surrounding regions. High grazing pressure gives non-palatable species (e.g. *Cirsium vulgare*) a competitive advantage over more palatable species, which could explain some of the changes in species composition observed.

2. Human encroachment into the Eburru hills to the west of Naivasha, a result of population growth in the Rift Valley more generally, has driven large herds of buffalo (*Syncerus caffer*) close to the lakeshore (counts increased 3-fold from 1995–2009 alone: Nakuru Wildlife Conservancy, unpubl.), adding further to the grazing pressure on papyrus and large grasses exerted by domestic livestock. Morrison and Harper (2009) demonstrated that degradation of *Cyperus papyrus* was due to the impacts of buffalo and cattle (discussed below) and it is conceivable that other taxa (e.g. *C. laevigatus*, which is favoured by buffalo during the late dry season: Prins 1996) would have been affected in a similar way.

3. Disturbance to riparian land (e.g. bush clearance, building construction, tillage, etc.) is likely to have reduced the range of some species, leaving a more limited seed bank for recruitment to newly exposed sediments during drawdown. For example, towards the end of 2009 when the lake level was very low, irrigation channels (in places >3 km long) were dug through the riparian land at Site 1 (Fig. 5.12) in order to reach water for pumping back to commercial holdings, impacting c. 10% of the riparian land there (E. Morrison, pers. obs.).

Fig. 5.12. One of many irrigation channels dug through the riparian zone during the low lake levels of late 2009 (photo: E. Morrison).

4. The migration of plants across geographical regions is often linked to movements of livestock, vehicles, farm machinery and plant products (Beck 1999). Increased human activity around the lake over the last few decades might therefore have been responsible for the arrival of some of the species recorded in this study that were not identified by Gaudet (1977). At the same time, movements of the general public, who frequent the riparian zone on a daily basis (seeking access to the lake for domestic water, laundry and livestock watering), may well have contributed to the loss of some of the species identified by Gaudet (1977) that were not recorded, for example through land erosion (Becht et al. 2005).

5. With more intensive land use relative to the 1970s, the number of private access roads leading to the lakeshore has increased (E. Kiminta, pers. comm.). The presence of roads has been shown to negatively impact forest ecosystems to which they grant access, through species mortality, alterations to habitat structure and the spread of exotic species (Spellberg 1998; Trombulak and Frissell 2000; Hunt et al. 2009); one might expect similar levels of disturbance in riparian zones.

5.7.1.2. Impacts of competitive species

Certain species of aquatic (e.g. *Nymphaea caerulea*) and submerged (e.g. *Potamogeton* spp.) plants once common in the lake (Gaudet 1977) have been eliminated by the arrival of Louisiana crayfish (*Procambarus clarkii*) (Harper 1992; Harper et al. 1995; Harper et al. 2011). It is conceivable that the arrival, or else increased prominence, of certain taxa has had a similar deleterious impact on the terrestrial flora. For example, many of the more commonly encountered species at Site 1 have been variously described as being highly invasive (e.g. *Cyperus rotundus*: Holm et al. 1977); capable of supressing the growth of surrounding species (*Pennisetum clandestinum*: Sanchez and Davis 1969), or else are poisonous (*Senecio moorei*: Kamau and Mugera 1975) and unpalatable to livestock (*Cirsium vulgare*: Sindel 1991) – potentially giving them competitive advantages over other species that they might have gradually displaced. However, in the absence of detailed autecological studies and empirical evidence, it is impossible to elaborate further on the impacts that certain taxa might have had on others.

5.7.2. Factors influencing the development of papyrus swamps (RQ21)

5.7.2.1. Natural drawdown and buffalo

The lack of *C. papyrus* at Site 1 in comparison to the 1970s, as elsewhere around the lake, is the result of both natural and anthropogenic causes. Morrison and Harper (2009) described how natural drawdown exposed former lakebed soils that, once dry, provided a means for buffalo and other wild animals to access the papyrus swamps. Buffalo trampled stems in order to reach the nutritious umbels, creating pathways through the wetland in the process. Other wild animals followed these pathways, grazing off young shoots that would have otherwise allowed the papyrus to photosynthesise and thus survive until re-flooded. Increased light availability encouraged the growth of climbing plants (such as *Zehneria scabra*) and creeping grasses (such as *Pennisetum clandestinum*), which eventually overgrew the remaining papyrus, transforming the wetland into open hummocky grassland (Fig. 5.13).

Fig. 5.13. Cattle grazing in the riparian zone at Site 1: the hummocky remains of papyrus are visible across the centre of the image, in front of the *Acacia* treeline (photo: E. Morrison).

Anthropogenic activity has also contributed to the loss of papyrus at Site 1, for example: (1) during the site's development into a commercial property, which would have required the owners to clear parts of the swamp in order to access the lake (Drifters Restaurant having been a floating establishment accessed via a jetty); (2) during periods of drought when herdsmen harvest the flowering heads of papyrus in order to feed their livestock and (3) during firewood shortages when stems are cut, dried and used as fuel – both latter activities have been witnessed elsewhere along the shoreline (E. Morrison, pers. obs.).

One or more of these factors might explain the lack of papyrus at Site 1 relative to the 1970s. However, its failure to persist as a fringing swamp, having regenerated in mid-2010, was solely the result of the rapidly recovering lake level (Fig. 5.11), itself a product of the unstable hydrology of Lake Naivasha. Irregular annual gains and losses in the water balance of the lake can also be attributed to natural and, to a lesser extent, anthropogenic phenomena, as described below.

5.7.2.2. Climatic controls on hydrology

The amount of precipitation that Naivasha's catchment receives is influenced by the seasonal migration of the Intertropical Convergence Zone (ITCZ), producing a strongly bimodal annual cycle of rainfall over the East African highlands, with 'long rains' falling in March/April and 'short rains' in October/November (Stoof-Leichsenring et al. 2011). The catchment receives additional rainfall from the 'Congo air boundary', with westerly to southwesterly airflow from August–September giving rise to the so-called 'September rains' (Nicholson 1996).

The North–South migration of the ITCZ (and thus the arrival of each rainy season) is in principle driven by the meeting of westerly winds over the Indian Ocean with easterly winds across the Atlantic (Becht and Harper 2002). However, significant inter-annual variability arises from changes in insolation over the Atlantic, as well as variations in precipitation and temperature over the African continent; seasonal surface temperatures in the Sahara, for example, are considered to have a strong influence on the position of the ITCZ (Biasutti et al. 2005). Further inter-annual variations in the amount of precipitation that the catchment receives are a product of East–West adjustments in the zonal 'Walker circulation' associated with the Indian Ocean Dipole and the El Niño/Southern Oscillation (Saji et al. 1999; Moy et al. 2002; Stoof-Leichsenring et al. 2011).

Increased human abstraction over the last thirty years (following the expansion of the horticultural sector in the early 1980s) has removed more water from the lake than is naturally replenished, amplifying these temporal variations in precipitation. Becht and Harper (2002) demonstrated, for example, that the lake level in 1998 was c. 3.5 m lower than would have been expected in the absence of commercial abstraction. What's more, a dam was constructed in the early 1990s on the Turasha river, a major tributary of the Malewa river, which pumps c. 20,000 m^3 day^{-1} of freshwater otherwise destined for the lake to the nearby towns of Nakuru and Gilgil (Becht and Nyaoro 2006). Such man-made deficits have hot, however, caused the vertical differences between the highest and lowest levels to exceed the range of historical fluctuations recorded from the past (Harper and Mavuti 2004). Lake Naivasha has always been hydrologically unstable, with natural lake level variability exceeding 12 vertical metres over the course of the last century (Becht et al. 2005). Verschuren et al. (2000) identified 4 periods during the last millennium when the lake nearly dried up completely, in addition to periods when water levels were significantly higher – suggesting Naivasha may have been part of a much larger lake system encompassing present day Lake Elementeita and possibly Lake Nakuru to the north (Åse et al. 1986; Becht and Harper 2002).

In its modern geomorphological setting – an endorheic lake filling a shallow basin (max. depth c. 8 m: Verschuren 1999) with gentle slopes (Becht et al. 2005) – moderate increases in Naivasha's volume result in large increases in surface area (recent fluctuations estimated in the range 100–180 km^2: Harper and Mavuti 2004; Bergner et al. 2009) and thus an extensive shallow littoral zone (Åse et al. 1986). This dynamic hydrological pattern presents certain challenges for papyrus growing along Lake Naivasha's shifting shoreline, as discussed below.

5.7.2.3. Hydrological controls on swamp development

Boar (2006) suggested that the rapid rises in water level, followed by extended dry periods, which characterise the long-term hydrology of the lake offer poor opportunities for papyrus regeneration by seedlings. In germination experiments, seedlings survived best when sediment was saturated or water level was just below the surface and poorly in sediment that was drying; seeds failed to germinate at all when sediments were flooded (Boar 2006). Observations from the present study lend support to Boar's (2006) contention that, whilst papyrus seeds are capable of germinating rapidly when sediments are rewetted, new swamps will only persist when lake level recovers slowly enough for seedling growth to keep pace with water depth.

Indeed, several drawdown events over the course of the last century (1928–29; 1934–35; 1945–46; 1951–52; 1974–75) led to the formation of new swamps at Naivasha (Gaudet 1977; Boar 2006), presumably because lake level recovered at a favourable rate. This was not the case following the 2008–09 drawdown.

5.4. Summary of Part 2

1. A total of 55 plants belonging to 24 families was recorded, all but 3 (*Inigofera* sp.; *Panicum* sp. and *Plectranthus* sp.) identified to species level. Species richness increased from the treeline to the water's edge (RQ16).

2. Species were distributed during low lake levels within 3 zones, named for the predominant plant families in each: a Composite zone (Compositae), a Grass zone (Poaceae) and a Sedge zone (Cyperaceae). Species richness increased in the Composite zone with the arrival of the short rains; the corresponding rise in lake level effectively increased the extent of the Sedge zone by flooding the intermediate Grass zone (RQ17).

3. Total species richness was lower by about a half (50.9%) relative to the baseline study; over two thirds (68.5%) of the species recorded by Gaudet (1977) were missing from the present study. A Composite zone occurred farthest inland in both studies. A Grass zone formed the intermediate habitat in place of Gaudet's Sedge Zone, which in the present study was found closest to the water's edge (both during and after drawdown), replacing Gaudet's (1977) Seedling Zone populated by water lily seedlings (RQ18).

4. Two of the most common species (*Cyperus rotundus* and *Pennisetum clandestinum*) can be summarized as highly competitive, adapted to withstand periods of environmental stress and capable of producing allelopathic substances that suppress the growth of surrounding species. The ecology of *Cyperus dives*, one of the most abundant species in both studies, is poorly understood and warrants further investigation (RQ19).

5. The number and type of species in the riparian zone are influenced by anthropogenic impacts around Naivasha. These impacts include: grazing and trampling pressure exerted by domestic and wild animals; disturbance to land through bush clearance, building construction and tillage and the migration or mortality of species caused by the movements of an increasing human population. A secondary factor could be the competitive advantages of certain taxa, although empirical proof of this is lacking (RQ20).

6. A range of factors influences the development of papyrus swamps in the riparian zone. Proximate factors are natural hydrological drawdown, the grazing pressure exerted by buffalo and domestic cattle and, to a lesser extent, deliberate human clearance. Distal factors include long-term variability in precipitation, the shifting shoreline of the lake as a result of its present geomorphology and the sensitivity of papyrus seedlings to water depth (RQ21).

I reject the first null hypothesis that stated, *"There are no differences in the number or distribution of species in the present day compared to Gaudet (1977)"* and conclude that the alternative hypothesis (H_1) is likely: the difference in the number of species between the two studies is highly significant [χ^2 (1, Yates' correction) = 19.138, p <.01], there being roughly half the number of species (55 versus 108) and families (24 versus 43) recorded in the present study. Changes in the distribution of species throughout the riparian zone were also observed, although the significance of this has not been tested.

I also reject the second null hypothesis that stated, *"Any observed differences are due to chance (sampling error)"* and conclude that the alternative hypothesis (H_2) is more probable: observed differences are not the result of chance but are related to anthropogenic impacts on the riparian zone and the competitive characteristics of certain taxa.

5.5. Conclusions from Chapter 5

- Why should papyrus wetlands at Lake Naivasha be restored from an ecological perspective? (**TQ3**)

The axiological response to this question is quite simply because of the lack of papyrus in the present day. The very low relative abundance (5.4%) of papyrus recorded in the riparian zone during this study contrasts sharply with Gaudet's (1977) account of it being the predominant species along the entirety of the lake's shoreline. Since changes within ecotonal habitats can be used to infer changes through time over larger regions (Holland et al. 1991; Maltby 2009), the ecological assessment of the sites visited during this study is likely to apply elsewhere within Naivasha's riparian zone and attests to the significant loss of papyrus recorded in earlier studies. Boar et al. (1999), for example, determined that the total area of papyrus within the wider catchment had reduced from an estimated 48 km^2 in the late 1960s to 14 km^2 in 1995. Others (Everard and Harper 2002; Harper and Mavuti 2004; Hickley et al. 2004) have described more generally an observed decline in the extent of fringing wetlands along the lakeshore over the last few decades. The reasons for the loss of papyrus were demonstrated by Morrison and Harper (2009) and have been described above (section *5.7.2.1*).

Given the paucity of papyrus recorded in the present day relative to the 1970s, restoration efforts are urgently required. This statement is justified from an ecological perspective in light of the wide array of ecosystem services derived from healthy, functioning papyrus wetlands as set out in Chapter 2. The most important of these at Lake Naivasha are arguably: (1) their role as land-water buffer zones, protecting shallows from sedimentation and (2) their ability to assimilate excess nutrients washed down from the catchment. Both services combine to mitigate processes of eutrophication in the main lake:

1. Sediment is filtered out of inflowing water as it meets the submerged parts of papyrus swamps, which act as a biophysical barrier causing suspended particles to settle out and become deposited beneath the swamp mat (Thompson 1979), thereby reducing the rate of sedimentation in the main lake and helping to improve the clarity of water.

2. Soluble reactive (dissolved inorganic) phosphorus (PO_4^{3-}) is readily taken up from the water and converted into unavailable organic forms. Even that not taken up is likely to become 'trapped' in the sediment by adsorption onto ferric hydroxide particles in lake

sediments rich in iron (Mortimer 1971), such is the case at Naivasha (Harper et al. 1993; Kitaka et al. 2002).

3. Plant-available forms of nitrogen are removed by denitrification of nitrate (NO_3^-) in the anaerobic environment beneath the swamp mat (Gaudet 1979); additional losses result from adsorption of ammonium (NH_4^+) onto particulate matter in the water column and microbial immobilization in the oxygenated root zone (Thompson 1979).

The nutrient-transforming and sediment-trapping capabilities of papyrus swamps therefore help to protect lakes from nutrient enrichment and sedimentation. What follows is an explanation as to why these supporting and regulating ecosystem services are urgently needed at Lake Naivasha.

Stoof-Leichsenring et al. (2011) analysed a lake sediment core from Naivasha for shifts in diatom assemblages and total nitrogen (TN) to infer changes in sedimentation rates and nutrient availability in the lake over the last 200 years. The variance observed between 3 distinct zones in the core was used to describe temporal changes to the lake environment:

1. Zone 1 (covering the period c. 1820–1896): environmental conditions appeared to be controlled by natural climatic variations, with minimal human influence. Bulk sediment accumulation rates (0.01 g cm^{-2} yr^{-1}), mass accumulation rates of TN (0.2 mg cm^{-2} yr^{-1}) and total phosphorus (TP) concentrations inferred from diatoms (0.05–0.09 mg l^{-1}) were relatively low.

2. Zone 2 (c. 1896–1938): a transitional period characterised by a shift from predominantly climatically controlled conditions to a period when human activities increasingly altered the lake environment, interpreted from a rapid rise in diatom-inferred TP concentrations (>0.1 mg P l^{-1}) and an increase in the abundance of diatom species (*Aulocoseira ambigua* and *A. granulata*) favouring nutrient-rich waters.

3. Zone 3 (c. 1938–2006): conditions in the lake began to reflect anthropogenic influences, manifest in higher sedimentation rates (0.08 g cm^{-2} yr^{-1}) as well as increases in TN accumulation rates and TP concentrations (reaching 0.2 mg l^{-1} in 1996), the latter inferred from a rapid shift in the diatom assemblage away from species sensitive to pollution, such as *Gomphonema gracile*, towards *Aulocoseira* spp. characteristic of more eutrophic waters (Stoof-Leichsenring et al. 2011).

One of the reasons for the increased rate of sedimentation observed within Zone 3 is the increase in human activity within the catchment over the same time period, particularly within the last few decades. Population growth in the basin has led to a proliferation of small-scale agriculture, the clearance of trees and the cultivation of steep slopes and riverbanks, with associated increases in rates of erosion (Harper et al. 1990; Everard et al. 2002; Harper and Mavuti 2004). Anomalously high rainfall between 1962 and 1964 and above average precipitation up until 1990 contributed further to the degradation of loose topsoil (Stoof-Leichsenring et al. 2011).

Loss of the buffering capacity of papyrus, following a significant decline in the area of the North Swamp at the river inflows, explains much of the increase in Naivasha's trophic state as sediments and soluble phosphorus can now freely enter the lake (Boar et al. 1999; Kitaka et al. 2002; Harper and Mavuti 2004; Harper et al. 2011). The lack of papyrus is perhaps the most serious issue for the ecosystem. In the absence of restoration efforts, Naivasha risks becoming little more than a "muddy pool" (Harper and Mavuti 2004, p.300) as rates of sedimentation and nutrient enrichment continue to rise unabated. Such a trajectory spells disaster for the lake's multiple ecosystem services and the livelihoods of the hundreds of thousands of people who depend upon them (Morrison and Harper 2009).

Mitigating continued eutrophication is thus the primary ecological motivation for wetland restoration at Naivasha.

- What are the key ecological factors at Lake Naivasha that might hinder successful wetland restoration? (**TQ4**)

The principal limiting factor to successful wetland restoration from an ecological perspective is the present state of the riparian zone itself. As has been noted, the vast majority of the once permanent floating mat of papyrus within the North Swamp has been lost. Remaining patches of wetland rooted within the riparian zone, which are generally limited to privately owned stretches of the lakeshore (Harper and Mavuti 2004; Boar 2006; Morrison and Harper 2009), are therefore the obvious choice for an 'ecological reference' on which to base restoration efforts. The results of this study have demonstrated, however, that the riparian zone would not be an appropriate reference for successful, long-term wetland restoration. As noted in guidance literature provided by Ramsar in relation to the planned restoration of degraded wetlands:

"There can be no justification for wasting resources in attempting to manage a degraded feature when the underlying reasons for the damage cannot be reversed" (Ramsar 2010b, p.38).

This is not to say that papyrus will not grow in the riparian zone *sensu stricto*. On the contrary, papyrus thrived in the lake shallows during this study when the lake level was conducive to its survival (Fig. 5.9). Harper et al. (1995) made a similar observation following an extended period of drawdown (c. 3 m) between 1983 and 1987, after which heavy rains that fell in March–April 1988 led to lake level recovery and the rapid germination of a wide band of papyrus seedlings. This germination event resulted in the formation of a fringing swamp along the majority of the lake's shoreline that persisted through subsequent small rises and falls of water level into the mid-1990s (Harper et al. 1995). Further lake level decline (beyond the lowest point reached in 1987) eventually produced the conditions described by Harper and Mavuti (2004) and later demonstrated by Morrison and Harper (2009) that led to the widespread degradation of wetlands around the lake.

It is apparent then, that whilst papyrus may survive for variable lengths of time within the riparian zone, there is no guarantee of its persistence over the long term. The ultimate explanation for this is inter-annual variability in precipitation that the basin receives, resulting in an unpredictable pattern of lake level decline and recovery, compounded by the sensitivity of papyrus seedlings to water depth (Boar 2006). Recent observations attest to this general trend, with water levels fluctuating over vertical 5 m within the last 3 years alone (Fig. 5.11).

The impacts of buffalo, other wild animals and domestic livestock add to the pressure on regenerating wetlands within the riparian zone. Human activities may exacerbate the situation further. Usually this results in only localized disturbance, such as when herdsmen harvest umbels to feed their livestock during the dry season. More rarely, widespread degradation may arise, such as during the 1983–87 drawdown when papyrus and other riparian vegetation was deliberately cleared for the cultivation of crops; this occurred along most of the shoreline such that, by the end of 1987, only an estimated 2 km^2 of wetlands remained around Naivasha (Harper et al. 1995).

Whilst the relative impacts of these different stressors will vary over space and time, a more appropriate ecological reference model on which to base restoration efforts is critical to their long-term success. This will be discussed further in Chapter 6.

That notwithstanding, from an ecological perspective there are few (if any) further limits to wetland restoration at Naivasha. Indeed, the high altitude of the lake, relatively constant climate, high levels of solar radiation and relatively nutrient-rich waters provide ideal growing conditions for papyrus (Thompson et al. 1979; Jones 1983; Everard and Harper 2002; Kansiime et al. 2007), as demonstrated by the high rate of primary productivity recorded in this study relative to other sites in East Africa.

Chapter 6: Towards restoration

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Chapter 6: Towards restoration

This chapter seeks to address the question:

- How can the successful restoration and sustainable management of wetlands at Lake Naivasha be achieved? (**TQ5**)

Research questions:

RQ22: What would constitute a more appropriate reference state for restoration?

RQ23: Where should restoration efforts be focussed?

RQ24: How can public support for papyrus restoration be increased?

RQ25: How can the management of restored wetlands be made sustainable?

Responses to these questions draw on information presented in the preceding chapters and are supplemented by the results of two studies outlined in Chapter 3, sections *3.2.5* and *3.2.6*.

6.1. What would constitute a more appropriate reference state for restoration? (RQ22)

Some of the anthropogenic impacts on the riparian zone described in the preceding chapters might be mitigated in the following ways:

1. Parts of the lake edge could be set aside for the protection of remaining fringing wetlands, with livestock excluded by fencing.
2. Flower farms could install rainwater-harvesting systems to store water during wet periods, reducing the need for large irrigation ditches through the riparian zone.
3. Hoteliers could be discouraged from clearing papyrus on their properties by educating them as to its biodiversity and economic values.
4. Local livestock owners could be trained in the cultivation of fodder grass ('zero grazing') to reduce grazing pressure in the riparian zone.
5. Nuisance exotics known to displace native species, such as *Verbena brasiliensis*, could be controlled or eradicated.

None of these measures constitute active wetland restoration, however. Instead, they are more passive attempts to preserve remaining papyrus.

The option of 'doing nothing' should also be evaluated. Drawdown events at Naivasha periodically, if unpredictably, result in the formation of papyrus swamps along the lake margins. The option therefore exists to simply wait for such an event in the hope that conditions favour the persistence of a new band of mature swamp. Gaudet (1977) noted, however, that development into a mature, functional wetland could take between 1–3 years of uninterrupted growth after suitable conditions for papyrus germination occur. Mavuti and Harper (2004) surmised "the present state of the lake no longer allows the luxury of waiting on a future lake level rise for this to happen" (p.300). Active restoration efforts are therefore critical if the paucity of wetlands at Naivasha is to be addressed successfully and sooner rather than later.

Natural climatic variability (seasonal unpredictability; episodic El Niño events; the uncertainties of climate change, etc.) and the impacts of wildlife (particularly buffalo) present significant challenges for papyrus restoration within the riparian zone. Restoration may yet be possible along privately owned stretches of the shoreline, however, where disturbance from buffalo could be prevented by digging deep ditches either side of the wetland, running perpendicular to the water's edge, across which these animals are unlikely to traverse; such ditches could include existing inlets to water pumps. The issue of unpredictable lake levels could be addressed by following the recommendations of Kiwango et al. (2013), creating spoon-shaped creeks running through the wetland along an elevation gradient, allowing rhizomes to migrate inland or towards the lake naturally as waters rise and fall. However, both of these interventions carry significant risks (e.g. flooding destroying the papyrus), would demand considerable costs (in both labour and time) and would require regular maintenance (e.g. extending creeks through the riparian land during low lake levels). Moreover, restoration on private lands necessarily excludes wider stakeholder participation, a factor shown to be crucial to the success of restoration projects (Shore 1997; Clewell et al. 2005; Hjerpe et al. 2009).

6.1.1. Floating islands

Since unpredictable lake levels and grazing pressure affect papyrus growing along the lake's shoreline, one potential solution may be to shift the focus of restoration away from the riparian zone and into the open water of the lake. The means of achieving this could be the creation of floating islands of papyrus.

Mature papyrus stands that have built up a substrate beneath the rhizome layer (formed by the products of decomposition of old culms and trapped debris) periodically break away from the littoral zone, under favourable hydrological conditions, to form free-floating islands (Fig. 6.1). The gas-filled rhizomes, which form a latticed mat with large interstitial spaces, provide buoyancy and keep the mat afloat (Kipkemboi et al. 2002). Indeed, the dominant visual feature of Lake Naivasha up until the early 1980s was numerous floating islands of papyrus, which had been lifted from their rooted locations by the rising lake level (Harper et al. 1995). These observations demonstrate that mature papyrus is adapted to flooding (Gaudet 1977) and can continue to grow and spread vegetatively while floating via the migration of rhizomes into open water (Boar 2006; Vymazal and Kröpfelová 2008).

Fig. 6.1. Natural floating island on Lake Naivasha in July 2011 (photo: E. Morrison).

Mimicking this advanced ecological state would be possible through the establishment of artificial floating islands (AFIs) on Lake Naivasha. AFIs consist of a lightweight, three-dimensional platform made from fine polymer strands. These strands are intertwined to produce a highly porous matrix, which creates an ideal growth medium for the roots of emergent aquatic plants (Stewart et al. 2008). AFIs have 4 main uses: water purification; provision of habitat for fish and birds; abatement of shoreline erosion and landscape beautification (Zhu et al. 2011). The use of AFI technology has been widely recognised for its bioremediation properties at multiple scales, from weirs and small ponds to rivers and lakes, across the world (Ahn et al. 2004): in North America (Mitsch and Jørgensen 2004), China (Zhao et al. 2012), Japan (Nakamura et al. 1999), Uganda (Okurut et al. 1999), Costa Rica (Nahlik and Mitsch 2011) and New Zealand (Tanner and Headley 2011).

The principal motivation for wetland restoration at Naivasha is the mitigation of further eutrophication by the removal of excess nutrients. The primary mechanisms of nutrient removal in any wetland are: assimilation into biomass during growth (Lee et al. 1975); microbial transformation and uptake (Richardson et al. 1997); adsorption to sediments (Sikora et al. 1995) and volatilization (Stowell et al. 1981). These processes are complex and will vary over time and according to vegetation type, temperature, pH, mineral concentrations and hydrological regime (Vymazal 2007). One of the underlying factors likely to enhance the efficacy of each mechanism, however, is the size, or more precisely the surface area, of the wetland, with larger wetlands tending to provide higher rates of nutrient uptake (Vymazal and Kröpfelová 2008). AFIs offer a distinct advantage in this regard since the thousands of individual polymer strands that make up the matrix create a large surface area for colonization by microbial films; at the same time, the roots of macrophytes planted within them pass through this matrix into the water column, favouring efficient hydroponic uptake of nutrients (Stewart et al. 2008).

Both the submerged and floating structures of AFIs provide biodiversity support. The microbial film (composed of bacteria, algae and fungi), which rapidly colonizes the matrix and roots, provides food for crustaceans. Predaceous beetles feed upon these, in turn providing prey for small fish that find refuge beneath the islands (Hwang and LePage 2011). Kipkemboi et al. (2002) found that below ground biomass in floating papyrus swamps was >40% higher than in rooted swamps, suggesting that islands would provide enhanced habitat for fish in Lake Naivasha *sensu* Hickley et al. (2004). Above ground structures provide refuge from terrestrial predators and thus secure nesting grounds for some birds, with positive effects on breeding success (Hancock 2000). This quality of AFIs offers potential support to the diversity of aquatic birdlife at Naivasha, not least for species restricted to papyrus swamps, such as the papyrus gonolek (*Laniarius mufumbiri*) and papyrus yellow warbler (*Calamonastides gracilirostris*) (Maclean et al. 2006).

The immediate advantage of AFIs at Naivasha from an ecological perspective is that they could be anchored in deeper sections of the lake, where water level fluctuations would neither flood the papyrus nor cause it to dry out. Destruction by buffalo would also be prevented since these animals tend to avoid water above shoulder height (E. Morrison, pers. obs). Islands anchored offshore may improve the visual appearance of degraded sites and would neither restrict access to the lake (e.g. for fishermen's boats), nor deny tourists a view of the open water, unlike rooted fringing swamps. The top 4 priority benefits of papyrus wetlands identified by stakeholders at Naivasha reflect the key attributes of AFIs described above, i.e. provision of potable water, biodiversity support, aesthetic qualities and fishing opportunities (Chapter 4, Table 4.7), which constitutes a solid foundation for attracting public support for their creation.

6.1.2. Practical considerations

One would first need to establish nurseries of papyrus to supply living material for transplantation into the matrices. Potential nursery sites could be the existing artificial treatment wetlands at Kingfisher and Flamingo Farms, whose managers have already developed material for restoration at their own locations (R. Fox, C. Oulton, pers. comm.). The initial growth of papyrus within the matrices would have to be restricted to dedicated ponds at the nurseries: Kadlec and Bevis (1990) reported that floating islands of *Typha* were only stable when of a certain size and once they had attained sufficient areal growth; smaller islands risk becoming top-heavy and tipping over. The development of papyrus within the islands would therefore have to be carefully monitored and controlled prior to their deployment in the open lake.

AFIs at Naivasha need not necessarily be restricted to monocultures of *Cyperus papyrus*. Nakai et al. (2008) demonstrated that *C. alternifolius* (umbrella sedge) is effective at suppressing the growth of the cyanobacteria *Microcystis aeruginosa* through the release of allelochemicals. Suppression is likely to be assisted by the effects of shading and enhancement of the zooplankton community, provided for by the structure of the floating islands (Nakai et al. 2008). *C. alternifolius*, which was recorded in this study during informal surveys, may warrant cultivation for deployment within AFIs at Naivasha since prolific cyanobacterial blooms periodically appear in the lake (Fig. 6.2), with deleterious impacts on the ecosystem and possibly harmful effects on human health (Oberholster et al. 2004). Indeed, Harper et al. (2011) and Krienitz et al. (2013) noted the progressive increase in the occurrence of potentially toxic cyanobacteria within Lake Naivasha over the last decade.

Fig. 6.2. Cyanobacterial bloom on Lake Naivasha, November 2010 (photo: E. Morrison).

Since the principal motivation for papyrus restoration at Naivasha is the removal of excess nutrients from the lake, it is essential that aerial biomass be harvested from the islands at regular intervals. Multiple studies have found that, in the absence of harvesting, nutrients taken out of solution by plants are simply recycled to water bodies upon decomposition of senescent material, nullifying their bioremediation value and the possibility of their permanent removal from the ecosystem (Gaudet 1977b; Kyambadde et al. 2004; Vymazal 2007; Kansiime et al. 2007; Zhao et al. 2012). Moreover, developing sustainable uses for harvested biomass might be used to encourage local communities to participate in the project, whilst contributing to the local economy (Kansiime et al. 2007). Future research would need consider who would be given the right and responsibility to harvest the papyrus, how they would access the islands, what incentive they might have for doing so and by what means an enabling policy environment could be created to allow them to do so legitimately and over the long term. Aspects of these considerations form the focus of the sections that follow.

6.2. Where should restoration efforts be focussed? (RQ23)

Everard and Harper (2002) argued, in light of the need to reinstate wetland habitat at Lake Naivasha, "a strategy for tackling this through community involvement is essential" (p.198). However, publicly accessible parts of the riparian zone are clustered together along the southern shoreline, as alluded to in Chapter 4 (section *4.9*), with the majority of these sites charging an entrance fee. This raises the question of where restoration activities should be focussed in order to maximize community involvement.

Discussions with various stakeholders (pastoralists, fishermen, local residents, etc.) highlighted a recurrent issue pertaining to access to the lake. The exact number of 'public access points' that were claimed to have existed within living memory varied widely between individual accounts, from a minimum of 3 up to a maximum of 20. There was thus considerable ambiguity as to how many of these putative access points existed in the present day, as well as where exactly they are, or were once, located and whether they remain freely open to the public or not. These accounts supported the assertion of Harper et al. (2011) that the precise number of 'lake corridors' originally retained in government control for access to the shoreline was unclear. The mapping exercise described in Chapter 3 (section *3.2.5*) attempted to (1) locate each of the 20 imputed access points, (2) assess their current statuses and (3) calculate the length of shoreline available to the public at each. The results of the study are presented below.

6.2.1. Results

Only 6 of the 20 access points submitted by respondents proved to be open and freely accessible to the public (i.e. without an entrance cost) at the time of data collection (August 2012). The remainder were fenced off entirely, or else access to them was controlled by a locked gateway. The 6 open access points (Fig. 6.3) were referred to locally as Central Beach (#2 in Fig. 6.3); Kihoto Estate (#3); Karagita Estate (#7); Kamere Beach (#13); Oloidien Bay (#15) and Kasarani Beach (#19).

Public access points to Lake Naivasha, Kenya

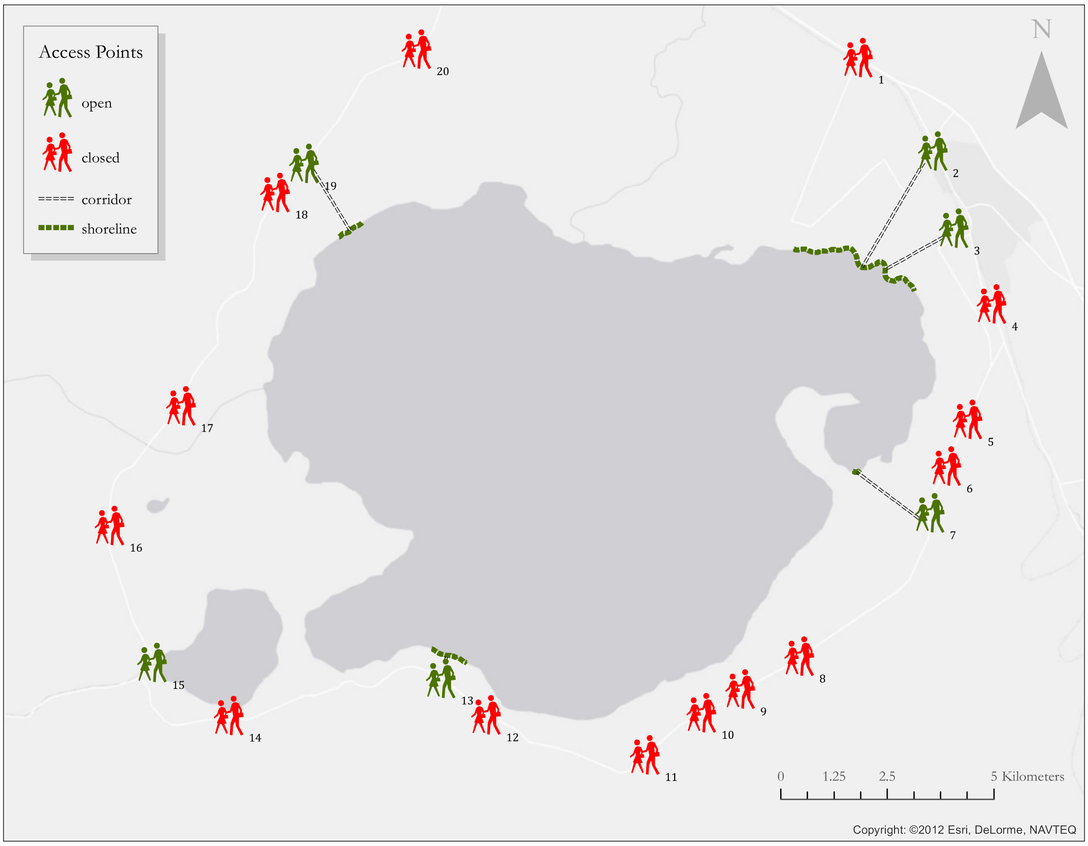

Fig. 6.3. 'Access points' (#s 1–20) visited during the study and their present statuses (green = open; red = closed). Also shown are 'lake corridors' through the riparian zone (black dashed lines) and the extent of shoreline to which each provides access (green dashed lines).

The measured length of the lake's total shoreline was 62,929 m. The sum of the lengths of shoreline to which the 5 corridors leading to the main lake[11] provided free public access was 5,451 m, or 8.7% of the total (Table 6.1). The remainder of the shoreline (91.3%) was held in private ownership, comprising commercial horticultural farms, cattle ranches, game sanctuaries, government agencies, hotels and private estates.

Table 6.1. *Public access points and length of shoreline below each*

Access point	*Shoreline (m)*	*Site code*
Kihoto Estate	2,147	3
Central Beach	1,548	2
Kamere Beach	910	13
Kasarani Beach	652	19
Karagita Estate	194	7

[11] Access point #15 was disregarded in this analysis since the corridor leads to the smaller Lake Oloidien, whose waters are not fresh (Harper et al. 1995) and do not support growth of papyrus (Harper 1992).

6.2.2. Discussion

One of the key findings of the mapping exercise – that only 30% of the access points cited in discussions with stakeholders were open – adds a quantitative dimension to the assessment of Becht et al. (2005) that "access to the lake generally has been closed" (p.290). The other key finding – that the total length of shoreline below each of these points equates to just c. 5 km of the c. 63 km shoreline – substantiates earlier reports (Harper and Mavuti 2004; Hickley et al. 2004) that almost all of the shoreline (i.e. >90%) is held in private ownership.

There are only 5 sites where the public can freely access the main lake. Two of these, below the settlements of Kihoto and Karagita (#s 3 and 7 in Fig. 6.3), are 'unofficial' in the sense that access to the lake at these sites has not been formalized through any government legislation, but has instead arisen in an informal way as a result of population growth in these unplanned settlements (E. Kiminta, pers. comm.), without the consent of the landowners (A-M. D'Olier, pers. comm.). Neither location would constitute a suitable location for restoration projects in the absence of formalized arrangements over public access.

The remaining 3 sites constitute the official 'fish landing beaches' of Lake Naivasha, where fisheries operations are monitored and regulated by members of the local Beach Management Unit (BMU). BMUs are community-level institutions registered under the national Fisheries Act (1991), which have been given the task of coordinating, developing and regulating fisheries throughout Kenya (Japp 2011). The BMU at Naivasha is divided into 3 community-elected committees, 1 for each of the 3 fish landing beaches: Central, Kamere and Kasarani (#s 2, 13 and 19 respectively in Fig. 6.3). The responsibilities of the committees are to ensure compliance with fisheries regulations at their respective beaches, resolve conflicts between fishermen and increase environmental awareness among their local communities, for example through organized 'beach clean-up' activities (Kundu et al. 2010; Kiwango et al. 2013).

6.2.3. Implications for restoration

The 'bottom-up' structure (with committee members voted for by the local community) and the nature of their responsibilities along the lakeshore lend strong support to a case for involvement of the BMU in any wetland restoration project at Lake Naivasha. Evidence for this comes from the recent study of Kiwango et al. (2013), who attributed a large degree of their success at Lake Victoria to the participation, from the very beginning, of the 'active and influential' local BMU who helped to collaboratively manage the community-led papyrus restoration project there. Moreover, given the total length of shoreline under their official jurisdiction (3,110 m: Table 6.1), which accounts for over half (57%) that available to the general public, the fish landing beaches would be one of 3 ideal sites for the establishment of AFIs at Lake Naivasha once detailed experiments have been conducted to quantify their efficacy as well as their potential (positive and negative) impacts on the environment:

1. AFIs could be anchored at fish landing beaches (at a distance to allow for drawdown and be moved accordingly) in a horseshoe arrangement. This would form a barrier to trap suspended solids being carried inshore and cause them to settle out, creating sheltered bays for the collection of clearer, cleaner water by local communities. The fish refugia created by the islands would be welcomed by the BMU, whilst birds taking advantage of nesting sites on the islands would be enjoyed by visitors to the beaches. The islands in general would add to the aesthetic appearance of these public sites and provide opportunities for education as to the benefits of papyrus.

2. The obvious site from an ecological perspective for the establishment of AFIs would be surrounding the deltas of the lake's inflowing rivers, the major point of entry of suspended solids and nutrients washed down from the catchment. AFIs could be anchored in rows parallel to the shoreline in a staggered arrangement, so as to dissipate strong currents without the risk of the islands being washed from their moorings during flood events. Such a biophysical barrier would encourage sedimentation and the assimilation of excess nutrients into biomass, reducing their availability to phytoplankton in the open lake – in effect reinstating the regulating functions provided for by the erstwhile North Swamp.

3. AFIs should be deployed within the off-take channels of flower farms to reduce the frequency of pumping equipment failures caused by the intake of sediments and debris, which result in costly interruptions to irrigation (R. Fox, pers. comm.). At the same time, a network of AFIs should be established within the multiple small dams of the middle and upper catchment (Harper et al. 2011) in order to address the issue of sediment inputs closer to point sources (e.g. at cattle watering sites) and thereby reduce the workload required of islands downstream. This finds agreement with the recommendations of Ramsar (2010c), who consider that restoration activities "should not ignore the value of upland habitats and linkages between upland and wetland habitats" and that the "minimum acceptable scale for wetland restoration planning should be at the catchment level" (p.35).

6.3. How can public support for papyrus restoration at Naivasha be increased? (RQ24)

A low level of awareness among the general public regarding the benefits of local wetlands has been cited as a principal factor hindering successful wetland management in Uganda (Wetlands Inspectorate Division 2001). Similar factors occur at Lake Naivasha, where stakeholders recognised just c. 13% of all ecosystem services known from the literature (Chapter 4).

Recognition of consumptive use values (CUVs) for papyrus was seen to correlate positively with people's awareness of wetlands at both Lakes Naivasha and Victoria (Chapter 4). The significance to livelihoods of consumptive uses for local wetlands has been increasingly documented throughout Africa over the last few years: in the Kilombero Valley of Tanzania (Kangalawe and Liwenga 2008), outside Cape Town in South Africa (Lannas and Turpie 2009), within the Niger delta wetlands of Nigeria (Adekola and Mitchell 2011) and in the Mambamba Bay area of Uganda (Akwetaireho and Getzner 2012).

Developing a novel CUV for papyrus at Lake Naivasha, supported by an appropriate educational program, may help to: (1) raise levels of awareness regarding the wider values of local wetlands; (2) generate support for restoration activities and (3) create an incentive for the sustainable management of papyrus, based on recognition of its contributions to local livelihoods. As Scoones and Cousins (1994) concluded from their research into the *dambo* wetlands of Zimbabwe, "the value of a [wetland] resource will influence the incentives to manage and control its use" (p.592).

6.3.1. Papyrus as a domestic fuel

One of the other factors shown to limit people's understanding of papyrus at Lake Naivasha was the heterogeneity of its stakeholder community and the lack of appropriate ecological knowledge relating to local wetlands therein (Chapter 4). Developing a novel CUV for papyrus based on its widespread use as a source of domestic fuel elsewhere (as discussed in Chapter 2, section *2.4*) may help to raise awareness of the socioeconomic values of local wetlands, since the need for affordable sources of energy transcends cultural inheritance and ethnic backgrounds the world over. The results of an attempt to produce briquettes made from carbonized papyrus using locally available technology (see Chapter 3, section *3.2.6*) are presented below.

6.3.2. Results

6.3.2.1. Papyrus briquettes

The amount of fully carbonized material (from 5.33 kg of feedstock, equivalent to 1 m^2 of dry papyrus culm-units) generated during the 7 trials varied between 0.98–1.40 kg (mean of 1.16 ±0.23 kg). The 4 trials of the cuboid type (Fig. 6.4), which were made using the metal press, produced a mean of 48.3 ±2.1 briquettes. The 3 trials of the cylindrical type, which were made using the wooden lever press, produced a mean of 13.8 ±1.4 briquettes.

Two different binding solutions made from cassava flour (either 5% or 10% by weight of carbonized papyrus fines) were randomly assigned to the formation of either cuboid or cylindrical briquettes. The physical properties of each of the 4 types are shown in Table 6.2, as mean values from 20 samples of each.

Table 6.2. *Mean physical properties (n = 20) of papyrus briquettes; ±standard deviations in parentheses*

Sample / Parameter	**Mass (g)**	**Volume (cm^3)**	**Density (g cm^{-3})**
Cuboid 5% cassava	24.75 (3.36)	86.86 (10.11)	0.27 (0.01)
Cuboid 10% cassava	26.06 (2.55)	95.97 (10.81)	0.29 (0.02)
Cylindrical 5% cassava	73.23 (13.73)	281.10 (49.39)	0.25 (0.01)
Cylindrical 10% cassava	92.43 (36.97)	334.32 (88.46)	0.27 (0.04)

The cuboid briquettes were significantly lower in terms of volume and mass [ANOVA, F (39, 39) = 44.711 and 93.379 respectively, p <.01], but were significantly [F (39, 39) = 2.611, p <.01] higher in density (mean 0.28 g cm^{-3}) compared to the cylindrical briquettes (0.27 g cm^{-3}). There were no statistical differences (p <.01) between cuboid briquettes produced with a 5% or 10% binding solution in terms of mass, volume or density. Cylindrical briquettes produced with a 10% solution were significantly higher in each respect [F (19, 19) = 7.250, 13.849 and 3.207 respectively, p <.01] than those made with a 5% solution.

Fig. 6.4. Carbonized papyrus briquettes (cuboid type) ready to be used (photo: V. Lafford).

Carbonizing and compressing dried papyrus culm-units into cuboid briquettes, made with a 5% binding solution:

1. Increased their calorific value, from 17.52 MJ kg^{-1} to 20.46 MJ kg^{-1}.
2. Reduced their volatile matter content, from 73.26% to 22.65% dry weight.
3. Increased their moisture content, from 7.09% to 9.07% (Table 6.3).

The mean calorific value (20.25 MJ kg^{-1}) of the 2 types of papyrus briquettes tested was around one third lower than that of local wood charcoal (32.43 MJ kg^{-1}), but slightly higher than that of local *Acacia* firewood (18.88 MJ kg^{-1}). The mean volatile matter of the papyrus briquettes (28.85%) was almost three times lower than that of firewood (79.87%) yet almost three times higher than wood charcoal (10.96%). Wood charcoal had the lowest volatile matter and moisture content and the highest calorific value of all samples. The mean moisture content of the papyrus briquettes (8.21%) was the highest of all the fuels tested (Table 6.3).

Table 6.3. *Combustion properties of different fuels tested, based on single samples of each*

Fuel tested / Combustion property	**Total moisture** (% wt.)	**Calorific value** (MJ kg^{-1})	**Volatile matter** (% wt.)
Local wood charcoal; source unknown	4.29	32.43	10.96
Carbonized papyrus, 5% cassava; cuboid*	9.07	20.46	22.65
Carbonized papyrus, 10% cassava; cuboid*	7.35	20.04	35.05
Charcoal dust, sawdust, cardboard; cylindrical*	4.89	19.21	57.40
Compressed black tea waste; cuboid*	8.16	21.96	72.69
Dry papyrus stems	7.09	17.52	73.26
Local firewood; *Acacia xanthophloea*	4.43	18.88	79.87
Sawdust, flower petals, newspaper; cylindrical*	6.53	19.82	80.34

Key to Table 6.3. Combustion properties of different fuels, presented in order of increasing percentage weight (% wt.) volatile matter; calorific value and volatile matter are based on a dry weight basis; * = briquettes.

6.3.2.2. Community appraisal of briquettes

Thirty-two households (121 people in total, mean household size 3.8 individuals) provided feedback on the briquettes; 17 households evaluated the cuboid briquettes, the remaining 15 the cylindrical type. There were no significant (χ^2, p <.01) differences in feedback regarding the amount of smoke produced, heat generated or overall performance between the 2 types. The majority (81.2%) of the survey pool stated that the briquettes produced 'about the same' or 'less smoke' than wood charcoal, whereas 18.8% believed they produced 'slightly more'. Around two thirds (65.6%) reported that the briquettes generated 'about the same' or 'more heat' compared to wood charcoal, while the remaining third (34.4%) concluded that they generated somewhat less. The majority (84.4%) declared the briquettes' overall performance as a fuel relative to wood charcoal as 'about the same' or better; 15.6% declared performance slightly less worse (Table 6.4).

Households' average monthly expenditure on wood charcoal was $12.72. Mean willingness to pay (WTP) for the briquettes was $0.21 for 10 of the cuboid type and $0.34 for 5 of the cylindrical type. The mean number of briquettes estimated to satisfy a day's fuel demand, rounded to the nearest whole number, was 28 for the (smaller) cuboid type and 13 for the (larger) cylindrical type. Extrapolating these data indicates that households' mean WTP for a month's supply of the cuboid briquettes, for example, would be $17.64.

Table 6.4. *Responses of households (n = 32) to papyrus briquettes*

Parameter / Response	**Much more**	**Slightly more**	**About the same**	**Slightly less**	**Much less**	**None at all**
Smoke produced	-	18.8 (7.0)	15.6 (6.6)	34.3 (8.5)	-	31.3 (8.3)
Heat produced	6.3 (4.2)	-	59.3 (8.8)	31.3 (8.3)	3.1 (3.1)	-
Performance	12.5 (5.9)	43.8 (8.9)	28.1 (8.0)	15.6 (6.6)	-	-

Key to Table 6.4. Responses are % values on a Likert scale, for example when asked *'How do these briquettes perform as a fuel relative to wood charcoal?'*, 28.1% of households answered 'About the same'; ±95% confidence limits are given in parentheses.

6.3.3. Discussion

The reduction in the volatile matter content of papyrus by c. 45% is of importance, particularly in developing countries, where indoor air pollution from volatile compounds (such as polycyclic aromatic hydrocarbons) has been linked to high incidences of respiratory diseases (Oanh et al. 2002). A more detailed assessment of the emissions from papyrus briquettes should be conducted in order to assess their potential impacts on human health, however.

The density of the briquettes was around three quarters that of locally available wood charcoal in Naivasha (0.38 g cm^{-3}) but double that of the original papyrus (0.15 g cm^{-3}) (E. Morrison, unpubl.). The density of the briquettes was naturally higher when combined with a 10% binding solution (Table 6.3). A trade-off must be made in practice, however, between the density of the briquettes (which generally corresponds to calorific value), emissions associated with excessive binding material (carrying possible risks to human health) and recurrent capital costs of the binding material itself (bearing in mind the need to make briquettes an economically viable use of papyrus).

A possible conflict exists with the use of cassava flour as a binding solution for briquettes in developing countries where food shortages are not uncommon. Cassava is, however, of limited nutritional value, being virtually devoid of storage protein and containing very low levels of essential amino acids (Stupak et al. 2006). Cassava was used in this study because it was cheap to acquire and less popular as a food in Naivasha than in other parts of Kenya (E. Morrison, pers. obs.). The appropriateness of binding materials is therefore likely to be site-specific. Banzaert (2013) suggested that animal manure has the potential to be an effective binding solution, with fewer complications in terms of food security.

The likelihood of carbonized briquettes becoming a novel CUV for papyrus at Naivasha can be assessed according to their quantitative, qualitative and economic potential.

6.3.3.1. Quantitative potential

The mean number of cuboid briquettes produced from 1 m^2 of dried papyrus culm-units was 48.3, so 1 hectare (10,000 m^2) of clear-cut wetland could correspondingly produce 483,000 briquettes. The average household would require c. 10,220 (i.e. 28 x 365) of these each year, thus 1 ha of wetland could satisfy the annual fuel demand of some 47 households, or around 180 individuals (since mean household size = 3.8). By the same rationale, 1 ha could produce 138,000 cylindrical briquettes, meeting the fuel requirements of some 29 households or approximately 109 individuals.

The maximum amount of fully carbonized material produced from a feedstock of 5.33 kg was 1.40 kg; if the carbon content of papyrus is 40.27% dry wt. (Wiedemann and Bayer 1983), a 100% efficiency of conversion could theoretically increase output to 2.15 kg. Such conversion rates are, however, unrealistic given the (deliberately) simplistic design of the kiln used. That said, with increased proficiency of use, I expect that the 65% efficiency achieved during this study could be improved upon and thus the number of briquettes produced from the feedstock increased.

6.3.3.2. Qualitative potential

Feedback from participating households was, on the whole, very positive: the majority of respondents stated that the briquettes produced about the same or less smoke, about the same or more heat and, crucially, performed about the same or better as a fuel compared to wood charcoal. The number of participants was low and the duration of the trials very short, but these data serve as a useful initial representation of how acceptable carbonized papyrus briquettes might be to potential end-users.

I believe that the cuboid briquettes would be better than the cylindrical for commercial production despite the lack of significant differences between households' responses to the 2 types of briquettes, for the following reasons:

1. There were no significant differences between the densities of the cuboid briquettes when using the 5% or 10% binding solution, reducing capital costs associated with their production.
2. The metal press (Fig. 6.5) used to produce the cuboid briquettes required minimal technical expertise to construct, could be made from local scrap supplies, if correctly

assembled would rarely have to be replaced and could be operated by one person, reducing labour demands.

3. The wooden lever press, on the other hand, consisted of more components that required skilful carpentry, had moving parts liable to wear and tear, would rot if not cared for, required more room to operate than the smaller metal press and demanded a minimum of two people to do so.

Fig. 6.5. Cuboid metal press (centre), with plunger (left) and ejector (right) (photo: V. Lafford).

6.3.3.3. Economic potential

An average of 48.3 cuboid briquettes were produced from 1 m^2 of dried papyrus culm-units and the mean WTP of households was \$0.21 for 10, so the sale of briquettes made in this way gives papyrus wetlands at Naivasha a theoretical market value of \$1.01 m^{-2}. Cylindrical briquettes would give the wetlands a theoretical value of \$0.94 m^{-2}. Thus, a perfunctory cost-benefit analysis (i.e. harvesting effort vs. sales revenue) suggests that production of the cuboid would be the preferred option, despite mean WTP for the cylindrical type exceeding that for the cuboid type per individual briquette. Maclean et al. (2003) found that papyrus wetlands harvested at Lake Bunyonyi in Uganda, when sold in bundles for fuel, had a value equivalent to \$0.13 m^{-2}. Prices of course fluctuate over space and time, but the results of this study suggest that processing papyrus into briquettes has the potential to increase its market value significantly – in the case of the cuboid type by a factor of 7.8.

The sale of cuboid briquettes, at a price equivalent to the current market value of wood charcoal ($0.44 per *mukebe*, roughly 2 kg: N. Chege, pers. comm.), would give papyrus wetlands at Naivasha a theoretical value of $6,546 ha^{-1}, based on a selective harvest of stems belonging to age-classes III and IV alone (as advocated for in Chapter 5). A recent estimate of the extent of wetlands throughout the entire basin (17.7 km^2: Onywere et al. 2012) confers the potential production of >7.6 x 10^8 cuboid briquettes from a single, selective harvest each year[12], satisfying the annual domestic fuel demands of 284,496 people (74,867 households), or >43% of the human population of Naivasha District (659,301 people in 2009: KNBS 2012).

This valuation is, however, highly unrealistic since it has not considered the multiple (labour, capital, transport, marketing, opportunity, avoidance) costs that would need to be included in the production of briquettes. The estimated value ($6,546 ha^{-1}) exceeds 3 earlier and more detailed valuations of papyrus wetlands in other parts of East Africa, each of which took into account multiple ecosystem services, with estimates varying between $780–$4,830 ha^{-1} (Emerton et al. 1999; Abila 2002; Maclean et al. 2003). Maclean et al. (2003) demonstrated, however, that the net present value of papyrus over a 100-year period could be much higher than this (up to $24,000 ha^{-1}) when 27–33% of a wetland is used for harvesting, which the authors defined as 'low-intensity use'. This study's valuation of $6,546 ha^{-1} assumes 89.5% of the swamp would be harvested, so a lower intensity use might correspondingly increase its value over the long term.

6.3.4. Summary

Although the sustainable limits to their production and their economic value to end-users need to be more thoroughly investigated, briquettes made from carbonized papyrus constitute a potentially significant novel use of papyrus at Lake Naivasha, not least since every participant expressed their willingness to pay for them.

The relative merits of any use of papyrus should ideally be evaluated within a trade-off scenario alongside all other ecosystem services associated with these wetlands, from global (e.g. carbon sequestration: Saunders et al. 2012) to local scales (e.g. the nutritive value of papyrus for livestock grazing: Muthuri and Kinyamario 1989), towards the establishment of best practices in wetland management. Mechansims should be established to allow transparent negotiations to take place, with different trade-offs understood and agreed upon by all

[12] If 1 ha of clear-cut papyrus can produce 483,000 briquettes, 17.7 km^2 (1,770 ha) could correspondingly produce 854,910,000. Harvesting only age-classes III and IV (89.5% of available biomass m^{-2}) within this area could produce a total of 765,144,450 cuboid briquettes.

stakeholder groups following the recommendations of the NEA (2011). Some of these trade-offs will have market values (e.g. commodities produced from harvested plant fibre), whilst others will be valued by non-monetary means (e.g. the intrinsic values of wetland biodiversity). In addition to complex trade-offs between benefits produced under different management strategies, further trade-offs will arise between different beneficiaries, which are likely to change over space and time; reconciliation of short-term (societal) goals with long-term (environmental) targets is therefore critical if the overall benefits of wetland restoration are to be maximised (Ramsar 2010; NEA 2011).

McNeely (1993) argued: "conservation measures are likely to be most successful when they provide real and immediate benefits to local people" (p.144). An increase in the supply of the 'natural capital' of wetlands should thus be a key motivation for their restoration (Clewell 2000). In the absence of a widely recognised use for papyrus, one would expect stakeholders' understanding of local wetlands at Naivasha to remain low and thus support for restoration projects limited. One must of course exercise caution when advocating for any form of wetland exploitation: the ultimate aim is of course to strike a balance between wetland restoration and *sustainable* utilisation, guided by principles of wise use (Ramsar 2010). Indeed, heightened awareness surrounding papyrus was shown to correlate negatively with local habitat quality at Lakes Naivasha and Victoria (Chapter 3, Fig. 3.5); defining sustainable limits to the consumption of papyrus is thus critical to effective, long-term management.

6.4. How can the management of restored wetlands be made sustainable? (RQ25)

6.4.1. Valuing ecosystem services

The preceding study constitutes the first attempt to place an economic value on the provisioning services of Naivasha's papyrus wetlands. This highlights a shortcoming in the efforts of the research community at Naivasha, which has failed to quantify the economic value of the basin's natural resources more generally.

Mekonnen et al. (2012) recently provided the first valuation of Naivasha's freshwater when used for the irrigation of cut flowers, estimating that Kenya generates \$8.8 m^{-3} lake water in foreign exchange earned from their export. The authors argued for the creation of a 'water sustainability premium' to be paid by international retailers of flowers grown at the lake. Not only might this help to raise awareness among flower consumers, the funds generated from the sale of these premium-price flowers could be channelled back to the farmers and used to finance measures to reduce the industry's 'water footprint' and support catchment management initiatives (Mekonnen et al. 2012).

The success of pricing water in this way remains to be seen. Whilst a 'papyrus premium' might be considered too abstract across international borders, the lack of an economic valuation for papyrus at Naivasha itself serves to obscure the full value of wetlands to the lake ecosystem and the people who depend upon it. When the wider stakeholder community begins to recognise the economic benefits of papyrus swamps, they may rationally act to maintain, or even enhance, their existence. This in turn will be contingent on an enabling policy environment at Naivasha, wherein (1) responsibilities for wetland governance and rights to access wetland resources are devolved to local communities and (2) transparent means by which the community will benefit from their participation in wetland management are established in partnership with supporting institutions. Similar arguments abound in the growing number of studies into the potential contributions of market-based instruments to conservation (Costanza et al. 1997; Landell-Mills and Porras 2002; Kosoy et al. 2007; Sovacool 2011). Among the leading instruments within this field is Payments for Ecosystem Services (PES) schemes.

6.4.2. Payments for Ecosystem Services

PES schemes have been defined as voluntary, conditional transactions over well-defined ecosystem services between at least one supplier and one user (Wunder 2005; Gómez-

Baggethun et al. 2010). PES schemes are designed to produce "more efficient environmental outcomes" (Zilberman 2007, p.1) by rewarding people for their efforts to protect and enhance delivery of ecosystem services. The idea has rapidly gained popularity as a tool for the conservation of ecosystems through the enhancement of people's livelihoods (van Noordwijk and Leimona 2010). Individuals or communities receive payment from 'buyers' for providing support to sustainable natural resource management goals. Payment may be in the form of money or in-kind contributions such as food, goods, training, jobs or improved tenure (Petheram and Campbell 2010). 'Services' are delivered by more sustainable (or reduced) use of natural resources, be the focus watershed protection (Kosoy et al. 2007), biodiversity conservation (Barton et al. 2009), carbon storage (Landell-Mills and Porras 2002) or landscape beautification (Dobbs and Pretty 2008).

The Lake Naivasha Growers' Group (LNGG), which represents the interests of the lake's commercial flower and vegetable farms, initiated a PES scheme in the Naivasha basin in 2008. The scheme was designed to address the high sediment loads carried in the Malewa river as a result of poorly managed subsistence agriculture on steeply-sloping land in the upper catchment (Harrison et al. 2010). The targeted 'sellers' of improved environmental services in this scenario were farmers whose land borders the Malewa's tributary streams within the Wanjohi and Turasha-Kinja sub-catchments, regions deemed prone to the highest risk of erosion following a feasibility study conducted in 2007 (M. Ellis-Jones, pers. comm.). The potential beneficiaries of improved services – the buyers – were identified as the downstream commercial farmers whose irrigated flowers and vegetables rely on a sustainable source of fresh, silt-free water abstracted from the lake.

Key improvements to upper catchment farming practices that the scheme encourages include the terracing of slopes with elephant grass (to hold back soil transported in surface runoff), the planting of soil-stabilising species among crop varieties (to reduce losses during storm events) and adherence to an agreement not to cultivate land adjacent to riverbanks (for the maintenance of riparian vegetation). Presently around 500 farmers are actively engaged in the PES scheme and each receives an annual payment for these services in the form of a voucher (equivalent cash value c. $17) that may be used in local stores in exchange for agricultural supplies such as tools, seeds and fertiliser (Willy et al. 2012). Focus group discussions held in mid-2011 with PES farmers in the Wanjohi and Turasha-Kinja sub-catchments (E. Morrison, unpubl.) revealed that, in terms of a working relationship between upstream and downstream users, the scheme is generally operating successfully. Indeed, the downstream buyers have recently (late 2012) agreed to continue making their payments, having visited the participating farms and been satisfied with improvements made, for example, in the terracing of steep slopes and maintenance of buffer strips.

It is difficult to say that the scheme is ecologically successful at this early stage. This is because (1) monitoring of any changes to water quality arising from the scheme is lacking, making quantification of any potential improvements impossible; (2) the significance of downstream impacts may be dwarfed by the relatively small number of farmers participating in the project; (3) the targeted sub-catchments are confined to 2 out of the total of 12 which make up the entire basin, limiting its spatial impact and (4) only a small number out of the large pool of potential buyers of these services are currently participating in the PES scheme.

Perhaps the most significant shortcoming from an ecosystem perspective is the scheme's sole focus on the services provided by agricultural landscapes of the upper catchment. With the near-total loss of papyrus around the lake, concerted efforts have to be made to direct payments towards restoration of the ecosystem services provided by wetlands, as was the original vision when scoping studies for a PES scheme were first carried out (M. Ellis-Jones, pers. comm.). Reducing diffuse sources of sediment (the objective of the current PES scheme) will only be beneficial to the wider aquatic ecosystem if the swamps – biophysical traps for all point and diffuse sources of sediment from the upper catchment – are first restored and then sustainably managed.

6.4.3. PES for wetland restoration

There is thus a good case for the existing PES scheme at Naivasha to be extended to include wetland restoration activities within the lake. The potential buyers of the ecosystem services of Naivasha's wetlands should be all the commercial users of water, including hoteliers, domestic abstractors and the horticultural industry (LNGG), since papyrus:

1. Helps to maintain the freshness of the water in the lake, which is critical to domestic use and the growing of flowers and vegetables.
2. Reduces the amount of suspended material in the water, which is critical to the flow of water through pumping equipment.
3. Helps to maintain the volume of the lake by reducing losses from open water evaporation, which is critical to long-term business.

The potential sellers in this scenario could be the committees of the Naivasha BMU, whose members are democratically elected representatives of the community responsible for, among other things, promoting environmental awareness on issues surrounding the lake. Moreover, they have vested interests in the restoration of wetlands for the same reasons as above, in addition to the direct habitat support provided to the lake's fishery by floating islands. Of course, should a novel consumptive use for harvested biomass be found (e.g. papyrus briquettes), the BMU would have an additional incentive for long-term participation in the project.

The payment in the scheme might take the form of in-kind contributions to the creation of AFIs, which could include supplying the polymer matrices as well as papyrus for transplantation from LNGG nurseries. Training would have to be provided on the creation, effective deployment and maintenance of AFIs. Participatory workshops involving the BMU should seek consultation from fishermen as to the most suitable sites for anchoring AFIs, based on their knowledge of the lake. An educational program should be designed and led by the BMU to increase awareness of the value of the floating islands among the wider stakeholder community. Once the project had been initiated, in-kind maintenance costs would have to be negotiated between the LNGG and the BMU, which might take the form of contributions to boat fuel in order that committee members could regularly visit the AFIs to maintain their functionality.

A distinct advantage of this proposal over the current PES scheme is that monitoring of any environmental changes arising from the AFIs would be relatively straightforward, with existing means of doing so already in place:

1. Experimental fish catches could be performed by committee members using their own nets to assess increases in fisheries productivity associated with the habitat provided by the islands.
2. Mature stems could be periodically harvested by the BMU for analysis of nutrients and pollutants to quantify improvements to water quality, using the laboratory services already employed by the flower farms to assess water quality parameters.

6.4.4. Carbon sequestration

The flower industry and other potential buyers may seek to pass on the costs incurred for their contributions to wetland restoration. This could take the form of a 'sustainability premium' *sensu* Mekonnen et al. (2012), although the uptake of such schemes by consumers is as yet unclear. A more plausible means of selling on the benefits of restored wetlands could be through the financing of carbon credits (Auckland et al. 2002).

Papyrus swamps may constitute a globally important carbon sink, although their efficacy as such is dependent upon prevailing hydrological conditions (Saunders et al. 2012). Jones and Humphries (2002) measured fluxes of CO_2 between papyrus swamps and the atmosphere at Lake Naivasha and found them to vary with lake levels. When detritus accumulates under water in anaerobic conditions, papyrus swamps have the potential to sequester large amounts of carbon (c. 1.6 kg C m^{-2} yr^{-1}). When water levels recede to expose organic material to aerobic conditions, on the other hand, papyrus swamps can be a net source of carbon release to the atmosphere (c. 1.0 kg C m^{-2} yr^{-1}) (Jones and Humphries 2002). AFIs offer a potential solution to the risk of carbon release, since floating islands anchored in deep water would essentially prevent detrital deposits that have accumulated beneath them from being exposed to the atmosphere, increasing the likelihood of long term carbon storage.

Tradable permits such as carbon credits are by no means necessary to the immediate restoration needs of Naivasha, but they could offer a long-term solution to financing the project in light of perceived successes elsewhere, for example in PES schemes rewarding reforestation activities in Costa Rica (Pagiola 2008) and Ecuador (Wunder and Albán 2008). Sovacool (2011), however, warns that such mechanisms often run the risk of enabling a small number of firms and/or individuals to make a profit at the expense of achieving environmental objectives; consequently, one must be wary about endorsing tradable permits as a panacea for restoration projects.

6.4.5. Sewage treatment

An alternative buyer of improved ecosystem services from restored papyrus wetlands at Naivasha is the municipal council. Efficient sewage treatment works are non-existent around the lake and the municipal council is currently seeking funds for their repair and extension (Harper et al. 2011). AFI technology, when deployed over large areas, has been shown to remove harmful bacteria and heavy metals from water bodies more cost-effectively than mechanized sewage treatment works; this is an important consideration in developing economies, where not only costs but energy demands and technical expertise are often limiting in rural regions (Zhu et al. 2011). The much-cited case of the Catskill watershed in New York showed the resultant savings that ecological restoration offered over the establishment and maintenance costs of a dedicated filtration plant to purify polluted water (Chichilnisky and Heal 1998).

Rogers et al. (1985) found that papyrus growing in constructed treatment wetlands supplied with municipal wastewater could hold up to c. 1000 kg N ha^{-1} and 150 kg P ha^{-1}. It was shown in Chapter 5 that the former extent of the North Swamp would have held approximately 310,000 kg N and 77,000 kg P in aboveground tissues alone. This was a conservative estimate as it excluded that held in the umbels, which previous studies demonstrated contain roughly twice as much P and three times as much N (Gaudet 1975; Muthuri and Jones 1997; Boar et al. 1999). A simple extrapolation of these data suggests that restored wetlands at Lake Naivasha would hold quantities of nutrients in their stems and umbels comparable to papyrus growing in municipal wastewater (c. 845 kg N ha^{-1} and 140 kg P ha^{-1}), offering a strong case for investment in restoration from the municipal council.

6.5. Summary of Chapter 6

1. Mimicking the advanced ecological state of floating islands of papyrus may constitute a more appropriate reference for ecological restoration, not least since anchored AFIs would mitigate the effects of changing lake levels and grazing by buffalo (RQ22).

2. From a sociological perspective, restoration efforts should attempt to increase public awareness of papyrus by establishing AFIs offshore from fish landing beaches, which constitute the only official sites of public access to the lakeshore. From an ecological perspective, AFIs would be most beneficial surrounding the delta of the Malewa river (RQ23).

3. Public support for wetlands could be increased through educational efforts aimed at raising levels of awareness surrounding the benefits of papyrus to local communities; the committees of the Naivasha BMU could lead this program from their fish landing beaches. Production of briquettes could be an incentive for harvesting papyrus but needs to be explored more fully (RQ24).

4. The management of wetlands at Naivasha could be underwritten by a PES scheme, with in-kind contributions from the LNGG paid to the BMU in return for their commitment to maintain the integrity and functionality of AFIs deployed around the lake (RQ25).

Chapter 7: Key findings

Chapter 7: Key findings

7.1. Summary of thesis

The key findings of this thesis can be summarized according to the 5 thesis questions that guided the research:

- Why should papyrus wetlands at Lake Naivasha be restored from a sociological perspective? (**TQ1**)

Sociological motivations (as expressed by the attitudes of local communities) for papyrus restoration at Lake Naivasha are: an enhanced provision of potable water and biodiversity, an improvement in the aesthetic appearance of wetland habitat and support for fisheries.

- What are the key social factors at Lake Naivasha that might hinder successful wetland restoration? (**TQ2**)

The factor most likely to limit public support for restoration is the lack of a widely recognised consumptive use value for papyrus itself; the underlying reason for this is the heterogeneity of its diverse, immigrant population and the lack of ecological knowledge in relation to wetlands.

- Why should papyrus wetlands at Lake Naivasha be restored from an ecological perspective? (**TQ3**)

Restoration is urgently required given the paucity of wetland habitat at Naivasha in the present day; rehabilitation of the buffering functions of papyrus swamps is needed to mitigate further eutrophication of the lake and to reinstate the wide array of ecosystem services they provide.

- What are the key ecological factors at Lake Naivasha that might hinder successful wetland restoration? (**TQ4**)

The principal limiting factor to successful wetland restoration is the present state of the riparian zone itself, which presents significant challenges to regenerating wetlands. Otherwise, environmental conditions at Lake Naivasha are highly conducive to papyrus growth.

- How can the successful restoration and sustainable management of wetlands at Lake Naivasha be achieved? (**TQ5**)

Mimicking the advanced ecological state of floating islands of papyrus through the creation of AFIs would help to overcome the ecological barriers to restoration in the riparian zone.

Community support for wetland restoration could be increased by focussing activities at public sites, raising awareness through education and explicitly linking the benefits of papyrus to stakeholders, for example through the production of briquettes. The long-term management of wetlands should involve community institutions, to which responsibilities and rights to wetland resources have been devolved. These groups should be supported by partnerships that recognise the mutual benefits of healthy wetlands for each party; market-based mechanisms such as PES might be used to encourage wise use.

7.2. Looking forward

It is important to recognise that stakeholders' perceptions cannot constitute the sole basis for improved livelihoods support, since inconsistencies are likely to arise between people's expectations of the environment and longer-term conservation goals (MA 2005; NEA 2011). At Naivasha, papyrus wetlands perform important regulating services (filtering sediments, absorbing nutrients, mitigating lake shore erosion, etc.) of great relevance to local livelihoods, whose full description and quantification remain a considerable challenge. Yet, relatively few people showed awareness of these. However, despite a bias towards economic activities and provisioning services, people's perceptions ought to be carefully considered, disclosing as they do local stakeholder needs and values, indicating which forms of environmental management will be met by a positive response from society and which forms may instead fail.

Further development of this work should be guided by the 6 conditions outlined by Denny et al. (2006) that emphasise wise use (Ramsar 2010) principles vis-à-vis their study of the potential of 'finger ponds' to enhance food security for local communities at Lake Victoria. Adapted here towards the maintenance of natural capital stocks within wetlands, these conditions require that papyrus restoration programmes be: (1) simple and willingly adopted by the community; (2) acceptable culturally and socioeconomically; (3) designed to enhance local livelihoods; (4) self-sufficient, using local resources and not overly reliant on external support; (5) acceptable environmentally, conserving levels of biodiversity and (6) defined along lines of sustainability and compliant with the Ramsar Convention's wise use philosophy (Denny et al. 2006).

Clearly there is much research still to be done and multiple questions need addressing before the proposals described in the preceding chapter could be successfully implemented: What constitutes a sustainable harvesting strategy? What will the environmental impacts of AFIs be and how can we assess these? Does a supporting legislative framework for creating new wetlands exist?

In view of the last question, it is hoped that the findings of this thesis will usefully contribute to efforts detailed within Kenya's Environmental Management and Coordination (Wetlands) Regulations (2009), in which provisions are made for the "restoration or enhancement" of certain wetlands (Section 8, Part 2c). Moreover, in 2012, the Water Resources Management Authority (WRMA) was asked to "prepare and maintain an inventory of all wetlands in Kenya" towards the development of management plans to "prevent and control degradation" of national wetlands (Section 10, Part 1). The first principle of these regulations is that Kenya's wetland resources be "utilised in a sustainable manner compatible with the continued presence of wetlands and their hydrological, ecological, social and economic functions and services" (Section 5, a). This thesis has contributed important information as to how papyrus at Lake Naivasha can be 'utilised in a sustainable manner', in keeping with its overall objective of understanding how 'wise use' (Ramsar 2010) of its wetlands can be achieved.

Looking forward, Lake Naivasha would do well to learn lessons from wetland management experiences elsewhere in East Africa. Hartter and Ryan (2010) described a similar call for the devolution of responsibilities for wetlands to local communities in Uganda where, despite some improvements in management, confusion over the exact nature of rights and responsibilities in certain areas has perpetuated exploitation and degradation of wetlands or, in other words, 'business as usual' (Hartter and Ryan 2010). Moreover, careful consideration of the specificity of proposed institutional arrangements is warranted in light of a study into wetland management strategies in neighbouring Ethiopia, where an 'entrenched political interventionist' approach to decentralisation there has, in certain cases, only served to restrict the development of local community-based institutions (Maconochie et al. 2009).

Hartter and Ryan (2010) contended that the sustainable management of natural resources must be developed from the bottom-up, "where the problems and solutions are perceived as local" (p.824). This is especially true of ecological restoration projects in developing countries, where proposals to restore degraded habitats will only find genuine support (a critical first step towards achieving wise use) "if linked to sound socio-economic research and development as well as job creation and training" (Aronson et al. 2006, p.136).

7.3. Looking back

Ramsar (2010b) recognises that formulating management plans directed towards wise use of wetlands requires interdisciplinary approaches to be taken; this necessitates close collaboration between those of different backgrounds, not least between natural scientists, social scientists and economists. Interdisciplinarity has both advantages and disadvantages; one must strive to balance time and effort equally between different fields of interest; a 'mixed methods' (Creswell 2009) researcher requires training in (and a nuanced understanding of) multiple methodologies, in order that the results of his/her research may satisfy experts within more narrowly-defined fields; at all times a holistic approach to research problems must be taken in order to capture as much relevant information as possible, without sacrificing the quality of findings from any one discipline.

At the same time, the interdisciplinary researcher benefits from having an open mind and may be in a better position to consider aspects of problems that might otherwise be discounted as too tangenital by others; with experience comes the ability to communicate effectively with those from diverse fields, which can spur collaboration and generate novel insights into research problems that had not previously been considered; at a broader scale, the increasingly more integrated nature of contemporary society and the interconnectivity of environmental issues around the world arguably demands an interdisciplinary approach, with those attempting to bridge divides between different fields of interest making important contributions to our collective understanding.

Indeed, the socio-ecological problems facing Lake Naivasha may be regarded as symptoms of much wider 'problematiques' (*sensu* Max-Neef 1995) representing, as they do, local manifestations of global issues such as water scarcity, environmental degradation, urban immigration, poverty and the uncoordinated use of natural resources. Viewed in this way, there is a need to progress beyond mere interdisciplinary research towards even closer integration of conservation efforts and so the formulation of truly *trans*-disciplinary (Jones and Paramor 2010) solutions to these problems.

Appendices

Appendix 1: Wetland Resource Use Questionnaire

These questions are designed to provide the reader with a better understanding of the ways in which people use papyrus wetlands to make a living around Lake Victoria. The answers you give will remain anonymous. Your assistance is greatly appreciated as it could help other Kenyans to use papyrus in more sustainable ways.

Enumerator: **Date**:

A: General Information

1. Tribe:

2. Gender: (a) Male (b) Female

3. District:

4. Location:

5. Sub-location:

6. Village:

7. Age group: (a) 1-15 (b) 16-25 (c) 26-35 (d) 36-45 (e) 46+

8. Highest education level of respondent:

(a) None (b) Informal (c) Primary (d) Secondary (e) College (f) University

9. Duration of residence in the village:

(a) ≤1 year (b) 2 - 4 years (c) 5 - 9 years (d) ≥10 years

B: Uses of Papyrus

1. How many years have you been making a living from papyrus?

2. Which of the following products do you make using papyrus?

2.1. Baskets *(Please circle)* (a) Yes (b) No **(Go to 2.3)**

2.2. If Yes in 2.1, what are the baskets used for? *(Please write below)*

(a) Small size baskets

(b) Medium size baskets

(c) Large size baskets

2.3. Furniture (a) Yes (b) No **(Go to 2.5)**

2.4. If Yes in 2.3, what type of furniture to you commonly make?

(a) A seat for one person

(b) A seat for two people

(c) A seat for three people

(d) A table

(e) Any other furniture (*please specify*)

2.5. Mats (a) Yes (b) No **(Go to 2.7)**

2.6. If Yes in 2.5, what are the mats used for?

(a) Uses of small mats

(b) Uses of medium mats

(c) Uses of large mats

2.7. Food for livestock (a) Yes (b) No **(Go to 2.12)**

2.8. If Yes in 2.7, which parts of the plant do you use? (*Please circle one or more)*

(a) Flower heads (b) Stems (c) Roots (d) Shoots

2.9. Please explain the reasoning behind your answer to question 2.8.

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2.10. Which animals do you feed? (*Please circle one or more)*

(a) Cows (b) Goats (c) Sheep (d) Donkeys (e) Others (*Please specify*)

2.11. When do you use papyrus to feed livestock? (*Please circle one)*

(a) During dry seasons/drought (b) During wet seasons (c) All the time

2.12. Do you use papyrus as a source of fuel?

(a) Yes (b) No **(Go to 2.14)**

2.13. If Yes in 2.12, which parts do you use? *(Please circle one or more)*

(a) Flower heads (b) Stems (c) Roots (d) Shoots

2.14. Suppose you were shown how to convert papyrus into an effective fuel, would you be willing to try it?

(a) Yes (b) No

2.15. Please give reason(s) for your answer to question 2.14.

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2.16. Please mention any other uses of papyrus that you are aware of.

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C: Source of Papyrus

1. Which wetland(s) do you normally harvest papyrus from? (*Please list their names and the total number*)

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2. How far do you live from the wetland nearest to you? (*Please circle one*)

(a) ≥0.5 km (b) 0.6-1km (c) 1.1-1.5 km (d) 1.6-2km (e) 2.1-2.5 km (f) 2.6-3km (g) >3km

3. How large is the papyrus swamp you use most regularly? (*Please circle one*)

(a) ≥1 ha (b) 1.1-2.0 ha (c) 2.1-3.0 ha (d) 3.1-5.0 ha (e) >5.1 ha

4. Has there been a change in the number of papyrus plants **in the past 10 years** within the wetland from which you regularly harvest?

(a) Yes (b) No **(Go to 7)**

5. If Yes in 4, please indicate the change that has occurred.

(a) Number of plants has increased (b) Number of plants has decreased

6. Please give the reason(s) for answer to question 5.

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7. Do other people harvest papyrus from the wetland that you use?

(a) Yes (b) No **(Go to D)**

8. If Yes in 7, how many? (*Please estimate*)

D: Regeneration of Papyrus

1. How many papyrus harvests do you make in a month?

2. Please give reason(s) for your response to 1.

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3. How many months does harvested papyrus take to re-grow in a 'typical' year?

4. Are there human factors limiting re-growth of papyrus in the wetland that you harvest from?

(a) Yes (b) No **(Go to E)**

5. If Yes in 4, what are these human activities?

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E: Gender Dimensions

1. Who typically does/did the harvesting in your household?

(Y=Yes, N=No, please circle; give reason if Yes)

Age category in years	10 yrs ago Y N	Now Y N	**Reason if Yes**
Men $\geq$ 45			
Men 18-44			
Men $\leq$ 17			
Women $\geq$ 45			
Women 18-44			
Women $\leq$ 17			

2. Who typically makes/made the products in your household?

Age category in years	10 yrs ago Y N	Now Y N	**Reason if Yes**
Men $\geq$ 45			
Men 18-44			
Men $\leq$ 17			
Women $\geq$ 45			
Women 18-44			
Women $\leq$ 17			

3. Who typically sells/sold the finished products at market?

Age category in years	10 yrs ago Y N	Now Y N	**Reason if Yes**
Men ≥ 45			
Men 18-44			
Men ≤ 17			
Women ≥ 45			
Women 18-44			
Women ≤ 17 yrs			

4. Who are/were the main beneficiaries of wetland products in your opinion?

Please rank benefits as (a) Low, (b) Moderate or (c) High

Age category in years	10 yrs ago	Now
Men ≥ 45		
Men 18-44		
Men ≤ 17		
Women ≥ 45		
Women 18-44		
Women ≤ 17 yrs		

F: Production and Marketing

1. How did you learn the skills needed to make a living from papyrus? (*Please circle one or more*)

(a) Taught by another person, *please specify*

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(b) Trained by a local organization, *please specify*

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(c) Trained by an external organization, *please specify*

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(d) Other, *please specify*

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2. Please fill in the table on the next page to the best of your ability. If you are unable to answer any question, just leave it blank.

Goods	*How many papyrus plants to make one?*	*How long does it take to make?*	*What price (KSh) can you get for it?*
Seat for 1 person			
Seat for 2 people			
Seat for 3 people			
Small mat			
Medium mat			
Large mat			
Small basket			
Medium basket			
Large basket			
Other (Please write below)			

3. How do you sell your products? (*Please circle one or more*)

(a) Through an NGO, *please specify*

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(b) Directly at local markets, *which ones?*

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(c) Directly at neighbouring markets, *which ones?*

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(d) Through middle-men/women

(e) Through a Commodity Interest Group (CIG)

(f) Through a Community Based Organization (CBO)

(g) Another way, *please specify*

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4. If answer to 3 is NGO, CIG or CBO please give details of the sales arrangement you have with them.

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5. Would you be willing to learn how to make higher quality products, such as paper, from papyrus? (a) Yes (b) No

6. Please give reason(s) for your answer to 5.

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G: Resource Ownership

1. Are the wetlands that you normally use owned by anybody?

(a) Yes (b) No **(Go to 3)**

2. If Yes in 1, who owns the papyrus that you use (*Please circle one or more*)?

(a) Individuals (private ownership)

(b) Community (communal ownership)

(c) County council (trust land)

(d) Others, *please specify*

3. Is there any control over access to the wetlands where you harvest papyrus?

(a) Yes (b) No **(Go to 5)**

4. If Yes in 3, who controls access to the wetlands? (*Please circle one or more*)

(a) Individual owners

(b) Community groups, *please specify*

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(c) Central government, *please specify*

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(d) Local government, *please specify*

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(e) Others, *please specify*

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5. Are there any rules governing the *harvesting* of papyrus from the wetlands?

(a) Yes (b) No **(Go to 7)**

6. If Yes in 5, please specify the rules and the person(s) who has/have set these rules?

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7. Do you know of members of other tribes who use papyrus in the same way as you do?

(a) Yes (b) No **(Go to H)**

8. If Yes in 7, please specify the other tribes and their specific location where possible.

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H: Significance to household livelihood

1. What is your household size?

Total: Adult male: Adult female: Children:

2. Do you support any dependents? (a) Yes (b) No **(Go to 5)**

3. If Yes in 3, how many dependents do you support from within your household?

4. And how many dependents do you support from outside your household?

5. What proportion of your total income do you subsidize with proceeds from the sale of papyrus products? (*Please circle one*)

(a) ≤25% (b) 26 – 50% (c) 51 – 75% (d) 75 – 100%

6. Do you have any other sources of your income, apart from using papyrus?

(a) Yes (b) No **(Go to 8)**

7. If Yes in 6, please state them and give a brief description where necessary.

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8. What challenges/constraints do you face by making a living from papyrus?

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9. How best do you think these constraints can be overcome?

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Thank you very much for taking part.

Appendix 2: Wetland Values Survey (Lake Naivasha version)

These questions are designed to provide researchers with a better understanding of the ways in which people value papyrus wetlands around Lake Naivasha. Your answers will remain anonymous.

You may withdraw from participating in this survey at any time and without giving a reason. Your assistance is greatly appreciated as it may help Kenyans to manage these wetlands in more sustainable ways.

Enumerator: **Location**: **Date:**

Part A: General information

1. Gender (*Please circle one*) (a) Male (b) Female

2. Age group (*Please circle one*) (a) ≤18 (b) 19-35 (c) 36-54 (d) ≥55

3. Education level (*Please circle one*)

(a) None (b) Informal (c) Primary (d) Secondary (e) Middle College (f) University

4. What are your sources of income/livelihood?

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5. What is the distance of your residence from this papyrus wetland?

(a) ≤100m (b) 101-500m (c) 0.5-1.0km (d) 1.1-3.0km (e) 3.1-5.0km (f) ≥5.1km

6. If you live around Lake Naivasha, for how long have you been settled here?

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7. If you have moved here from elsewhere, for which reason(s) did you come to live around Lake Naivasha?

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8. Which community are you from?

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9. How frequently do you visit this wetland?

(a) Several times a day (b) Every day (c) 2-3 times a week (d) Once a week (e) 2-3 times a month (f) Once a month (g) 2-3 times a year (h) Once a year (i) Once every 2-3 years (j) Once every 10 years or more (k) This is my first visit, but I plan to return (l) This is my first visit, and probably my last (m) Any other response:

………………………………………………………………………………………………

Part B: Wetland Values

- Please tell me all that you know or appreciate about this wetland according to your own understanding.
- Is this papyrus wetland important/valuable to you in any way? How does it provide benefits to you?
- Is it important for the environment in any way? Does it provide any benefits to the natural surroundings; which ones?

(*Be sure to tick all 'services' that are mentioned and make detailed notes as appropriate in the table over leaf*)

Provisioning	*Example*	*Held?*	*Notes/examples/details of the service where appropriate*
Freshwater	Water for domestic, industrial and agricultural use		
Food	Harvesting fish, wild animals, wild plants		
	Farming around wetland, aquaculture in ponds		
Fibre	Plant fibre for building, house thatching, commodity production		
	Fodder/grazing for livestock		
Fuel	Plant fibre for fuel		
Biochemical	Source of medicines and other materials from wetland		
Genetic materials	Source of genes for resistance to plant pathogens		
Regulating			
Climate regulation	Influences on local temperature/precipitation, purifying local air supply,		
	Influences on regional temperature/precipitation, source of and/or sink for regional Greenhouse Gases		
Water purification and waste treatment	Retention, removal and recovery of excess nutrients and other pollutants		
Natural hazard	Flooding control, storm		

regulation	protection		
Erosion regulation	Retention of soils and sediments from upstream		
Water regulation	Groundwater recharge/discharge		
Pollination	Habitat for pollinating species such as bees		
Cultural			
Aesthetic	Recognition of wetland's beauty or aesthetic values		
Recreational, social relations	Opportunities for watching animals and birds, boating, swimming, maintaining/expanding human relationships		
Educational, cultural diversity	Opportunities for formal and informal education/training, promotion of culture		
Heritage values, knowledge systems	Values relating to one's heritage, ancestry, maintaining/expanding flows of knowledge		
Sense of place	Values relating to sense of feeling satisfied with one's place in the world		
Spiritual and inspirational	Spiritual and/or religious values, source of inspiration		
Supporting			
Biodiversity	Habitat supporting the survival of wild plants and animals		

Soil formation	Accumulation of organic matter, formation of soils		
Nutrient cycling	Cycling and maintenance of essential nutrients		
Primary production	Production of energy and nutrients by wetland biota		
Photosynthesis	Production of oxygen by wetland biota		
Water cycling	Movement and transformation of water		

1. Please provide any other comments/opinions regarding papyrus wetlands, e.g. concerns/conflicts/issues/changes, positive/negative developments, advantages/disadvantages relating to your own understanding of papyrus wetlands.

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Asante sana

Appendix 3: Site Quality Score checklist

Location: **Date:**

Indicator	*Yes/No*	*Notes*
Burning?		
Over-harvesting?		
Uprooting?		
Patchiness?		
Stunted growth?		
Missing umbels?		
Trampling?		
Livestock?		
Climbing weeds?		

Score:

Appendix 4: Households' Evaluation of Papyrus Briquettes

1. How many people are there in your household?

2. How many bags of charcoal do you use each month; what size (kg) are these?

3. How much do you spend on charcoal each month?

4. How much smoke does this fuel produce compared to regular charcoal?

Much less Slightly less About the same Slightly more Much more

5. How much heat does it produce compared to regular charcoal?

Much more Slightly more About the same Slightly less Much less

6. How does it perform as a fuel compared to regular charcoal?

Much better Slightly better About the same Slightly worse Much worse

7. How many pieces of this fuel would you need to use each day?

8. How much would you be willing to pay for the fuel you received?

9. Do you have any further comments? If so, please write these on the other side.

Asante sana.

Appendix 5: Species identified by Gaudet (1977)

Species	Species (continued)
Abutilon mauritianum (Jacq.) Medic.	*Pistia stratiotes* L.
Acacia xanthophloea Benth.	*Pluchea ovalis* (Pers.) D.C.
Achyranthes aspera L.	*Polycarpon prostratum* (Forsk.) Aschers. & Schweinf.
Amaranthus graecizans L.	*Polygonum pulchrum* Blume
Aster muricatus Less.	*Polygonum salicifolium* Willd.
Azolla africana Desv.	*Polygonum senegalense* Meisn. f. *albotomentosum* R.Grah.
Bidens pilosa L.	*Polygonum senegalense* Meisn. f. *senegalense*
Cassia didymobotrya Fresen. +	*Potamogeton octandrus* Poir.
Ceratophyllum demersum L.	*Potamogeton pectinatus* L.
Chara braunii Gmel.	*Potamogeton schuieinfurthii* A.Bennett
Chenopodium album L.	*Potamogeton thunbergii* Cham. & Schlecht.
Chenopodium ambrosoides L. +	*Psiadia* (*arabica* Jaub. Spach) *punctulata* (D.C.) Vatke
Chenopodium opulifolium Koch & Ziz	*Pteris dentata* Forsk.
Conyza bonariensis (L.) Cronq.	*Pycnostachys deflexifolia* Bak.
Conyza floribunda H.B.K.	*Pycreus mundtii* Nees
Conyza hypoleuca A.Rich.	*Ranunculus multifidus* Forsk.
Conyza steudelii A.Rich.	*Rhamphicarpa montana* N.E.Br.
Crassocephalum picridifolium (D.C.) S.Moore	*Rhus vulgaris* Meikle
Cuscuta campestris Yuncker	*Rhynchelytrum repens* (Willd.) C.E.Hubb.
Cynodon aethiopicus W.D.Clayton & Harlan	*Ricciocarpus natans* (L.) Corda
Cyperus alopecuroides Rottb.	*Rumex usambarensis* (Dammer) Dammer
Cyperus digitatus Roxb. subsp. *auricomus* (Sieber ex Spreng.) Kük	*Salvinia molesta* D.Mitch
Cyperus immensus C.B.Cl. +	*Satureja biflora* (D. Don) Benth.

Cyperus laevigatus L.	*Scirpus inclinatus* (Del.) Aschers. & Schwneinf.
Cyperus nudicaulis Poir.	*Senecio moorei* R.E.Fr.
Cyperus papyrus L.	*Sesbania sesban* (L.) Merr. var. *nubica* Chiov.
Cyperus rigidifolius Sted.	*Solanum nigrum* L.
Drepanocladus sparsus C.Mull.	*Sphaeranthus suaveolens* (Forsk.) D.C.
Epilobium hirsutum L.	*Spirodela polyrhiza* (L.) Schleid.
Erucastrum arabicum Fisch. & Mey.	*Sporobolus spicatus* (Vahl) Kunth.
Eulophia paivaeana (Reichb. f.) Summerh. ssp. *borealis* Summerh.	*Tagetes minuta* L.
Glinus lotoides L. x *G. oppositifolius* (L.) Aug.DC. ex Hell.	*Tarchonanthus camphoratus* L.
Gnaphalium luteoalbum L.	*Thelypteris confluens* (Thunb.) Morton
Gomphocarpus physocarpus E.Mey.	*Typha domingensis* Pers.
Hibiscus diuersifolius Jacq.	*Typha latifolia* L.
Hydrocotyle ranunculoides L.f.	*Utricularia gibba* L.
Hypoestes verticillaris (L.f.) Roem. & Schult.	*Utricularia inflexa* Forsk.
Ipomoea cairica (L.) Sweet	*Utricularia reflexa* Olivo
Lantana camara L.	*Vernonia glabra* Vatke
Lemna perpusilla Torrey	*Vigna luteola* (Jacq.) Benth.
Lemna trisulca L.	*Wolffia arrhiza* (L.) Horkel ex Wimm.
Leonotis nepetifolia (L.) Ait.f.	*Wolffiopsis welwitschii* (Hegelm.) den Hartog & v.d.Plas
Lotus corniculatus L. var. *eremanthus* Chiov.	*Zehneria scabra* (L.f.) Sond.
Ludwigia stolonifera (Guill. & Perr.) Raven	**Conyza stricta* Willd.
Mansonia senegalensis Guill. & Perr.	**Cyperus stuhlmannii* C.B.Cl.
Marsilea gibba A.Br.	**Gnaphalium undulatum* L.
Melanthera scandens (Schumach. & Thonn.) Roberty ssp. *madagascariensis* (Bak.) Willd.	**Polygonum sirigosurn* R.Br.
Monechma debile (Forsk.) Ness	**Senecio discifolius* Olivo
Naias pectinata (Parl.) Magnus	**Senecio nandensis* S.Moore
Nitella knightiae Gr. et St.	**Senecio petitianus* A.Rich.

Nitella oligospira Br.	**Sonchus oleraceus* L.
Nymphaea caerulea Savigny	**Sphaeranthus confertifolius* Robyns
Pennisetum clandestinum Hochst. ex Chiov.	**Sphaeranthus napierae* Ross-Craig
Physalis peruuiana L.	**Verbena officinalis* L.

Key to Appendix 5: This is the complete list of the 108 species identified by Gaudet (1977); those highlighted in grey represent taxa also identified during the present study (34 in total); * indicates species that were not identified by Gaudet (1977) *in situ* but were rather known from earlier collections housed at the East African Herbarium in Nairobi; + indicates plants common between both studies that have undergone taxonomic revisions.

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