1. INTRODUCTION

1.1 General introduction

Namibia is the driest country south of the Sahara. Its climate is arid to semi-arid and is characterized by highly unpredictable rainfall in space, time and amount. Within the borders of Namibia, terrestrial water sources are scarce. All interior rivers are ephemeral, while the perennial rivers are located along the southern and northern border of Namibia.

According to Jacobson (1997) and the WRC (2005), ephemeral rivers are predominant on a global scale, but are nevertheless the least understood. Ephemeral rivers occur mainly in the drylands of the world, where poverty and underdevelopment are often major challenging factors (Seely et al., 2003). In ephemeral rivers, water flow only occurs for hours up to a few days in the usually dry river bed before the channel dries up again. Sometimes no surface floods occur for several years (Jacobson et al., 1995; Seely et al., 2003).

Only 10 % of the inhabitants of Namibia use perennial rivers where water is available throughout the year, for their livelihoods. The other 90 % depend on ephemeral systems, including the 12 westward flowing ephemeral rivers of the Namib Desert (20 %) (Jacobson et al., 1995; NWRMR, 2000). Population growth, sedentarization as well as drought events are putting increasing pressure on the ephemeral rivers of Namibia (Jacobson et al., 1995; Seely et al., 1995; Seely et al., 2003). Although evidence is limited to date, it is foreseen that changes in the hydrologic regime, the driving force behind biological patterns and processes, will result in changes in the structure and functioning of the ephemeral river ecosystems (Jacobson, 1997). These changes, in addition to climate change, are expected to have huge impacts such as land degradation and desertification (Seely et al., 2003).

Namibia is signatory to the UN Convention on Biological Diversity (UNCBD), the Convention to Combat Desertification (UNCCD) and the Framework Convention of Climate Change (UNFCCC). With reference to the dry and sub-humid lands program of the UNCBD, 'Namibia's ten-year strategic plan of action for sustainable development through biodiversity conservation' addresses the need to understand the dynamics behind the ecological, physical and social processes of the dry and sub-humid environments and to assess the consequences of their loss and change (UNCBD, 2000; Barnard et al., 2002). Objective 5 of this plan makes specific reference to Namibia’s wetlands. It calls to adopt "measures improving the protection of wetland ecosystems, biological diversity and essential ecological processes, as well as improving the sustainability of wetland resource use and preventing wetland loss and degradation” (Barnard et al., 2002). The necessity for the sustainable development of Namibia's water bodies has also been realized by the Namibian Water Resource Management Review (NWRMR, 2000). In the frame of the new Water Resource Management Act (GRN, 2004), two ephemeral rivers have been selected to establish pilot basin management committees. The main objective is to bring all stakeholders together and develop a common vision and integrated approach for the water basin resource management. One of these committees was already successfully established in the Kuiseb River basin, the main research area in this study.

With regard to the high population growth and limited natural resources of Namibia, awareness raising of decision makers and resource users with regard to ephemeral river ecosystems is very important (Jacobson and Jacobson, 1995). So far, ephemeral rivers have been mostly ignored by governments and water authorities due to their limited surface flow despite their importance for people, livestock and wildlife and the nation as a whole (Seely et al., 2003). Nevertheless, efforts are made by many countries of the South African Development Community (SADC) to revise this. This is of especial importance as the situation in southern Africa could drastically change through increased aridity due to climate change. At present, policy guidelines and information to guide management and decision makers are missing or incomplete (Seely et al., 2003). The authors underline that the "major challenge… is to balance rights, expectations, responsibilities and opportunities of local people,…., with requirements of the ecosystem to maintain these desired services and with expectations and aspirations of the global community" (Seely et al., 2003). Over the past years, interest in understanding ephemeral river systems has increased, and a variety of activities as well as research has been carried out in ephemeral rivers in southern Africa.

Twelve of Namibia's ephemeral rivers cross the hyper-arid desert in an east-west direction and are often referred to as 'lifelines' (Jacobson and Jacobson, 1995; Jacobson et al., 1995; Kok and Nel, 1996; Jacobson, 1997). They present a vital habitat for humans, livestock and wildlife in the otherwise harsh desert environment (Hamilton et al., 1977; Seely et al., 1980; Hamilton III, 1985; Jacobson et al., 1995; Jacobson, 1997). The rural communities living in the river catchments depend on the vegetation of catchment and river for their agricultural, both commercial and communal, and tourism activities. Large-scale mines, the coastal towns Walvis Bay and Swakopmund as well as the capital Windhoek depend on the ephemeral rivers for their water supply (Jacobson et al., 1995). As a consequence, the hydrological system of several ephemeral rivers has been altered through dam construction and water abstraction (Jacobson et al., 1995). At present, information concerning ephemeral rivers is still limited, making the development of management strategies and determination of sustainable abstraction rates difficult.

On a smaller scale, overuse and elimination of the vegetation of the ephemeral rivers is expected to have significant effects on the ephemeral river ecosystem and the livelihoods of the people living in these areas. A lack of recruitment of trees and shrubs in the ephemeral rivers has already been observed. A loss of the tree species *Faidherbia albida* and *Acacia erioloba*, two key resources of the ephemeral river ecosystem, would limit the capacity to support wild and domestic animals and the human population (Jacobson et al., 1995). Similar to acacia trees in the Middle East (Rohner and Ward, 1999), a biodiversity decline would also be expected. *Faidherbia albida* and *A. erioloba* have been acknowledged as valuable fodder species in many parts of Africa (Le Houérou, 1980; Walker, 1980; Baumer, 1983; CTFT, 1989; Dicko and Sikena, 1992; Barnes et al., 1997). However, the understanding of the basic life history and ecology of most organisms in the ephemeral river catchments is still too limited to ensure their sustainable use (Jacobson et al., 1995). The ecological, social and economic characteristics of ephemeral rivers need to be studied and understood for both conservation and development reasons (Seely et al., 2003). Knowledge of population dynamics, e.g., recruitment and survival of vegetation, is still missing (Jacobson et al., 1995). In addition to biophysical research, participatory research methods are strongly recommended to integrate local resource users.

This study investigates the key processes leading to successful regeneration and recruitment of *F. albida* and *A. erioloba* in ephemeral rivers, with specific focus on the Kuiseb River. Emphasis is given to the role of large herbivores, especially livestock, and to flood related processes. Furthermore, the socio-economic contribution of the two tree species is assessed.

1.2 Research objectives and key questions

The ephemeral rivers of arid to semi-arid western Namibia are experiencing increasing pressure through unsustainable utilization of their natural resources. *Faidherbia albida* and *A. erioloba* are key resources for farmers, livestock and wildlife along these ephemeral rivers. Increasing livestock densities can have a negative influence on the vulnerable recruitment processes of these tree species and on peoples' livelihoods.

This research aims to contribute to the understanding and sustainable management of ephemeral river ecosystems of Namibia. Its purpose is to assess the influence of land use on the regeneration of *F. albida* and *A. erioloba* in the Kuiseb ephemeral river, with further reference to other ephemeral rivers. This is achieved by examining biophysical factors (vegetation, floods, soil) and relating them to the socio-economic situation of the communal farmers in selected areas. Figure 1.1 presents the linkages between the various factors.

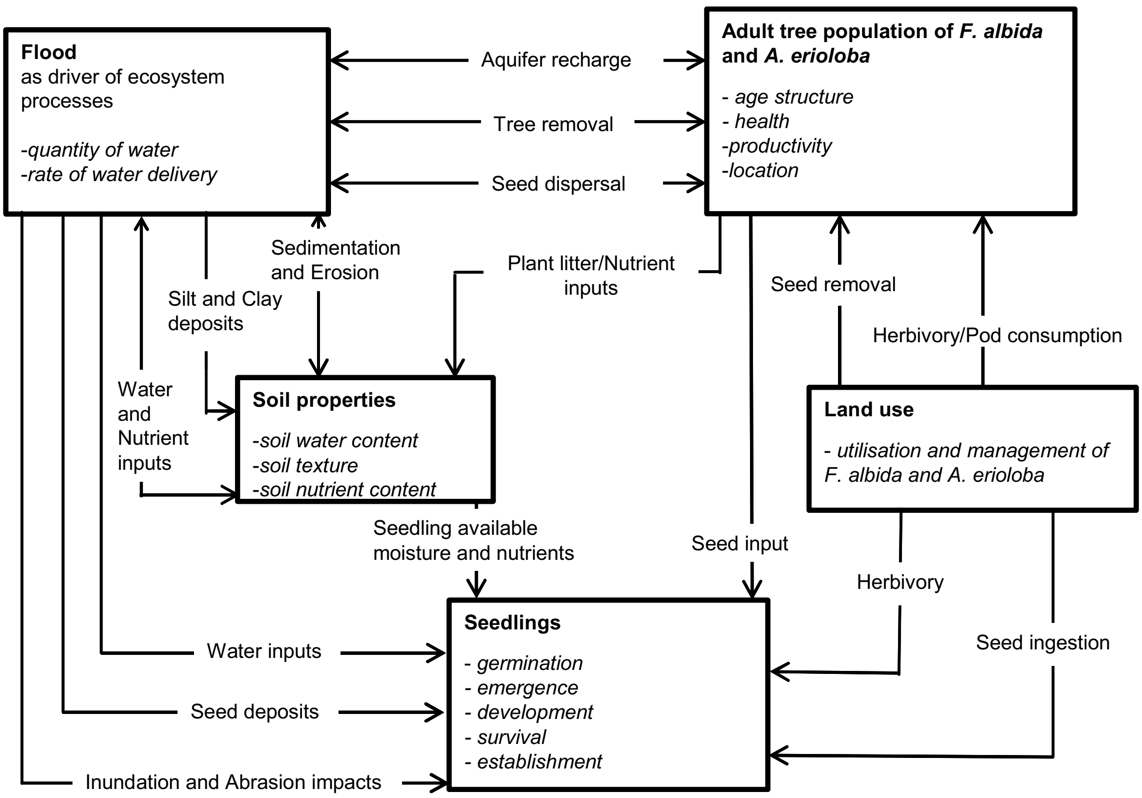

Figure 1.1: Linkages that determine tree regeneration in ephemeral rivers - a conceptual framework.

The following objectives are addressed in this study.

Objective 1
To determine abiotic and biotic factors relevant for *F. albida* and *A. erioloba* regeneration.
Key questions

1. Does seed ingestion have an influence on germination rate and success?
2. How deep can seeds be buried and still manage to germinate and emerge?
3. Is water a determining factor for seed germination and seedling growth?
4. Do soil characteristics (soil texture) influence seedling root and shoot growth?
5. Do seedlings utilize nitrogen from the air?

Objective 2
To determine influence of land use on regeneration of *F. albida* and *A. erioloba.*
Key questions

1. Is regeneration failing to take place?
    a. Does size class distribution reflect disturbance of the population?
    b. Do juvenile and adult densities differ?
2. How does livestock influence the survival of seedlings and juvenile growth?
3. Is the plant fitness of juvenile *F. albida* and *A. erioloba* influenced by land use?

Objective 3
To determine safe sites for *F. albida* and *A. erioloba* regeneration.
Key questions

1. What is the survival rate of seedlings after reflooding?
2. What discharge is needed to allow regeneration at elevated floodplains (safe sites) along the Kuiseb River?
3. Where is successful regeneration taking place across a river cross-section profile?

Objective 4
To describe the value of *F. albida* and *A. erioloba* for the communal farmers.
Key questions

1. How are the study species used by the communal farming population of three selected ephemeral rivers?
2. Do the local users apply any management strategies to sustainably use the resource?
3. What is the monetary value of the two study species?

1.3 Literature Review

1.3.1 Ephemeral rivers

Floods of ephemeral rivers are "characterized by their magnitude, duration, total flow volume and number and magnitude of discharge peaks during the flood" (Jacobson, 1997). Ephemeral rivers have an unpredictable and erratic flow regime triggered by highly variable rainfall in the river catchment. Surface flow lasts from days to weeks and occurs during the rainy season, but years can be floodless if rains are not sufficient (Jacobson, 1997; Seely et al., 2003). In ephemeral rivers, water level and discharge increase until rainfall ceases after which evaporation and infiltration lead to a decrease in the flood volume until the surface water disappears (WRC, 2005). Characteristic of the ephemeral river floods are a fast expansion downriver and a downstream decrease in water availability and stream power (hydrologic decay). This differs from perennial systems, where water is available throughout the year and lateral inundation typical after a slow rise in stage (Jacobson, 1997) (Figure 1.2). In perennial rivers, lateral inundation of the riparian habitat occurs seasonally after heavy rainfall or snow-melts in the mountains (Mertes, 2005). Along ephemeral rivers, inundations are less predictable and might only occur once within several years (Jacobson, 1997). The discharge in perennial rivers is also less variable, while in ephemeral systems it decreases downstream due to infiltration and evaporation (Jacobson et al., 1995).

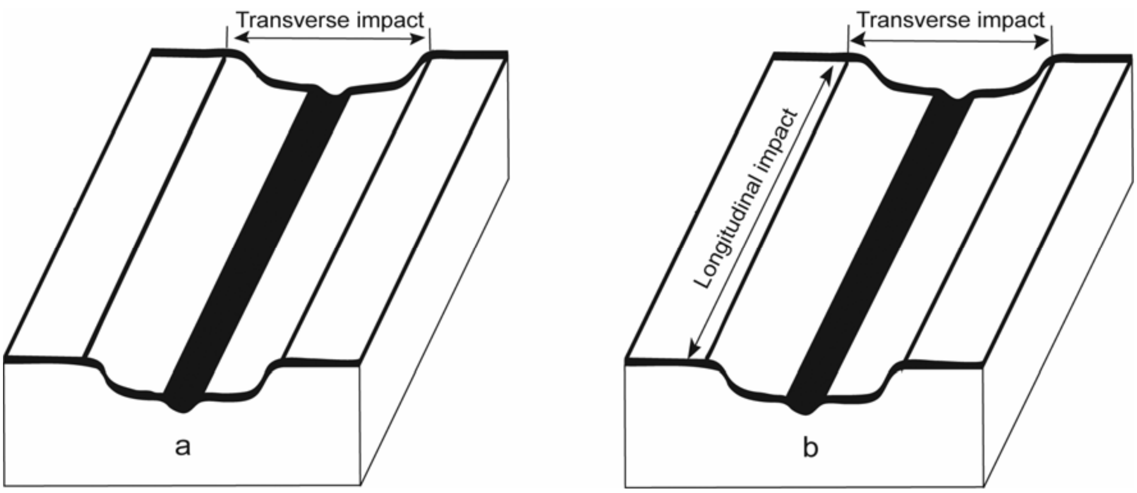

Figure 1.2: Direction of the major influence of surface floods in (a) perennial (transverse) and (b) ephemeral rivers (longitudinal and transverse) (adapted from Bendix, 1994b).

Surface and subsurface water provided by ephemeral rivers is important for the natural biodiversity in drylands, e.g., for vegetation and other biota (Seely et al., 2003). The rare surface flows contribute to many biotic and abiotic patterns and processes: Sediments are eroded or deposited, organic material is transported and retained, habitats are created or destroyed, food sources for fauna are created, enhanced or even diminished (Jacobson, 1997; Jacobson et al., 1999; Friedman and Lee, 2002). The surface floods are crucial for the groundwater recharge of the underlying ephemeral river aquifer, which can store large volumes of water (Jacobson et al., 1995; Seely et al., 2003). It is very difficult to measure this recharge due to site-specific features such as rainfall intensity, soil condition and moisture, surface topography, vegetation cover, land use as well as water table and aquifer characteristics (Christelis and Struckmeier, 2001). This makes it difficult to compute sustainable groundwater use (Seely et al., 2003). The groundwater aquifers provide comparatively secure access to water through boreholes and pumps, which allows permanent settlements, sedentary livestock farming, irrigation and industrial activities (Jacobson et al., 1995; Seely et al., 2003). Nevertheless, these activities are in constant competition for water with the environment, flora and fauna (Seely et al., 1980; Ward and Breen, 1983; Seely et al., 2003). Seely et al. (2003) emphasize that "water consumption should be carefully weighed against the value of the riparian vegetation". Altering the flow patterns through water impoundments in the upper reaches can have long-term impacts on the complex ephemeral system. The effects are various, e.g., reduced inflow of nutrient material and generally reduced productivity of the system (Agnew and Anderson, 1992; Seely et al., 2003). Impacts on aquifer recharge, channel morphology and vegetation structure and distribution can also be expected (Friedman and Lee, 2002; Seely et al., 2003). Limited data concerning historic flood events coupled with high variability make it difficult to understand and sustainably manage ephemeral rivers (WRC, 2005).

Classification of non-perennial rivers has been attempted by many authors. In the work of Uys and O'Keeffe (1997), rivers are classified along a continuum gradient from intermittent, seasonal to episodic stream. The continuum is related to flow variability, which increases towards the episodic state, while flow predictability decreases. In ephemeral rivers, floods are related to unpredictable rainfall events, dry periods last longer than floods, and within five years floods occur in most years. This differs from episodic rivers, which might not flow within a five-year period, and floods occur only after extreme precipitation high in the catchment. Jacobson (1997) defined ephemeral rivers as watercourses with a measurable discharge of less than 10 % per year. Boulton et al. (2000) distinguished between ephemeral, intermittent or temporary and semi-permanent streams. In South Africa non-perennial rivers were classified as semi-permanent (no surface flow for 1-25 % of time), ephemeral (no surface flow for 26-75 % of time) and episodic (no surface flow for at least 76 % of time) although there is still dispute under the experts and only limited scientific proof. Under the South African classification many rivers in Namibia would be considered episodic instead of ephemeral, e.g. Kuiseb River (WRC, 2005). Until a unified classification system is established, the term ephemeral will be applied in this work, but the South African classification will be kept in mind.

1.3.2 Riparian habitats

According to Naiman et al. (1993), "natural riparian corridors are the most diverse, dynamic and complex biophysical habitats on the terrestrial portion of the earth". Riparian habitats are highly acknowledged for their contribution to biodiversity (Risser, 1990; Naiman et al., 1993) and structural diversity of habitats (Smith et al. 1993). They are further important for humans, wildlife and other biota (Jacobson et al., 1995; Seely et al., 2003).

The vegetation growing along perennial and ephemeral river systems is supported by the available surface and groundwater. According to Baker (2005) ephemeral streams do not have the hydrologic conditions to support true riparian vegetation compared to perennial ones. The author underlines that along ephemeral rivers the vegetation does not require the high soil moisture and water availability as in perennial systems and can therefore not be considered as truly riparian. This study follows the definition of CDOW (2004) who consider plant communities affected by and growing adjacent to perennial or ephemeral water bodies, such as rivers, as riparian. Furthermore, riparian vegetation is characterized as distinctly different to the neighboring upland vegetation. Although the habitats along perennial rivers differ from ephemeral ones and support different riparian vegetation as well as an aquatic ecosystem (Figure 1.3), the riparian habitats have both similar characteristics and functions.

Riparian landscapes are formed through combined hydrological, geomorphologic and ecological processes (Malanson, 1993; Naiman et al., 1993) and display steep environmental gradients (Naiman et al., 1993). The dynamics and ecological characteristics of the riparian zones are closely interlinked with and regulated by streamflow, sedimentation and woody debris (Naiman et al., 1993). The authors describe riparian corridors as zones that stretch over the entire stream channel uplands as far as elevated water tables or floods might reach and where soils are able to hold water. Riparian corridors provide very diverse habitats, landforms and communities as well as ecosystem services (Naiman and Décamps, 1990; Naiman et al., 1993). They present important pathways for plants and animals, especially in ephemeral rivers (Hamilton et al., 1977; Seely et al., 1980; Hamilton III, 1985).

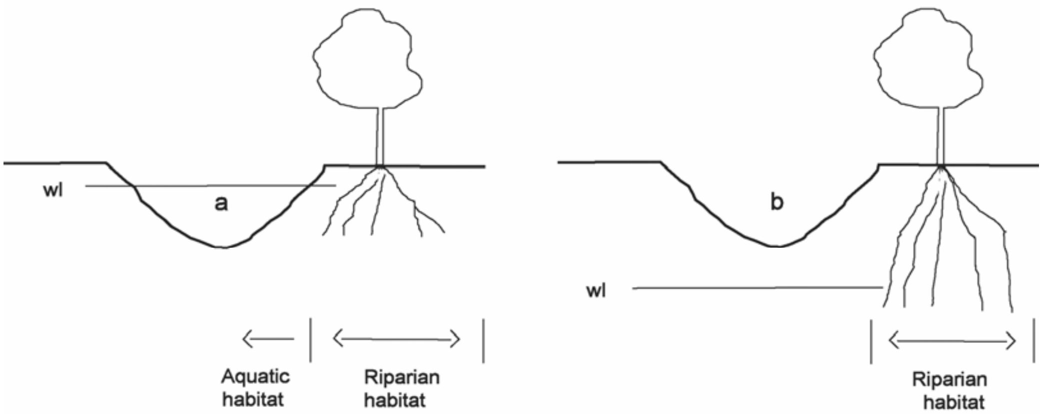

Figure 1.3: Schematic diagram of a perennial (a) and ephemeral (b) riparian habitat, wl illustrates the surface and subsurface water level (adapted from Baker, 2005).

According to Asplund and Gooch (1988), the concept of biological succession is difficult to apply to riparian zones (with special reference to riparian zones in Southwest America). The authors argue that habitat disturbance and instability is not a criterion for biological succession, which they define as habitat/species change through biological activity of a sequence of species. No real biological succession with species replacement takes place in riparian zones. The riparian tree community is in a perpetual succession due to persistent and predictable disturbance events. The situation in riparian