# RIPARIAN ECOSYSTEM MANAGEMENT – A CASE STUDY OF THE ELLIDAÁ AND YTRI-RANGÁ RIVERS IN ICELAND

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## ABSTRACT

Riparian zones act as a link between aquatic and terrestrial ecosystems and play a vital role in their ecological functions. The aim of this research was to assess the prevailing biophysical situations regarding management of riparian zones of the Rivers Ellidaá and Ytri-Rangá in Iceland, identify management strategies in place, identify gaps and challenges faced in management of the R. Ellidaá and establish possible strategies for restoration and management of the R. Ellidaá riparian zone. Methods included observation and acquisition of data from various sectors involved in management of the R. Ellidaá and Ytri-Rangá by use of an interview questionnaire, and GIS mapping. Ellidaá was the main focus of this study in order to illustrate human impact on riparian ecosystems but Ytri-Rangá was chosen as a reference area to contrast with it. The study established that the R. Ellidaá was much more affected by human activities than the Ytri-Rangá. Management measures in place were similar for both rivers. However, the Ellidaá was faced with a number of management gaps. These included limited public awareness, weak enforcement of existing legislation on riparian zones, limited funding and lack of prioritisation for the Ellidaá riparian zone management, lack of collaborative management, urbanisation challenges and existence of the hydropower dam. Management strategies suggested for effective management of the Ellidaá riparian zone include: measures to increase public awareness and education, measure to increase stakeholder participation, enforcement of existing legislation on riparian zones, collaborative management, land use planning and management, compliance inspection and monitoring, prioritisation and funding of restoration projects, political support and political will.

It's important to note that limited attention has been given to research on ecology of riparian zones in Iceland. Thus it is suggested in this paper that further research needs to be undertaken on the hydrological relationship between riparian area and upland ecosystem; biophysical and chemical interactions between the three zones of aquatic, riparian and upland ecosystems in Iceland.

## 1. INTRODUCTION

A riparian zone is the interface between land and water bodies, including streams, rivers, lakes and estuarine marine shores. Riparian zones can therefore be considered as a transitional belt between terrestrial and aquatic ecosystems and are distinguished by gradients in biophysical conditions, ecological processes and biota (National Research Council, U.S, 2002). Naiman, Decamps, and McClain (2005) defined riparian zones as transitional semi-terrestrial areas regularly influenced by fresh water, normally extending from the edges of water bodies to edges of upland communities.

It is important to note that the riparian vegetation acts as a buffer zone along rivers and lake shores in various ways. It may minimise the effects from river spates, e.g. the water flowing from upstream reaches downstream through absorption, hence causing stability in the water flow. Furthermore, the vegetation usually traps sediment and therefore influences sedimentation downstream.

A riparian zone is often a habitat for rare species and it is also a breeding ground for aquatic fauna such as fish and invertebrates (Naiman *et al.*, 2005). Loss of riparian vegetation can decrease the amount of suitable habitat for riparian and aquatic fauna such as fish and invertebrates, thereby reducing stream productivity and fish carrying capacity (Karen, M. & Karen, S., 1998). Riparian vegetation has many critical functions; it provides resistance to flowing water as well as to runoff during floods. The vegetation provides protective cover which helps to absorb the forces exerted by flowing water (Watson & Basher, 2006). Riparian plant canopies intercept, store and evaporate a portion of precipitation and have an important role in influencing stream temperature and the health of aquatic species (National Research Council, U.S., 2002).

Soils found in riparian zones have pronounced spatial variability in structure, particle size distribution and other properties, not only across the riparian area but also vertically within the given soil profile. This is dependent on soil geological formation and the landscape of the area. Soil properties and the microtopography of the valley floor affect the biotic composition of the riparian community (Naiman, Bilby & Bisson, 2000) and hence their biodiversity.

The structure and function of the riparian zone are highly influenced by climate through temperature, precipitation, evaporation and runoff. Floods play a significant role in determining regeneration from seed as well as long term seedling survival. Soil moisture and depth to the water table also influence the composition of the riparian plant communities (Naiman *et al.*, 2005).

Riparian areas supply water for domestic and agricultural uses, forage, and browse for native herbivores, livestock and recreational opportunities. The riparian areas are so important that they have been extensively and intensively used for decades by humans for a variety of purposes that range from providing well-vegetated sites for grazing to places of beauty and solace that renew the spirit of visitors (Chambers & Miller, 2004).

Degradation of riparian zones is a result of complex interrelated responses from geomorphic, hydrologic and biotic processes to climate change and natural and anthropogenic disturbances (Chambers & Miller, 2004). The disturbances can alter the hydrological or sediment regime of the river/stream system and produce changes in the physical properties of riparian ecosystems such as stream channel characteristics, and surface and ground water interactions. Human activities such as agriculture, harvesting of riparian flora and hunting of riparian fauna, grazing and industrial discharges have a great impact on riparian ecosystems. Direct discharge of untreated waste from industries, domestic and urban sources into lakes contribute to various forms of pollution, eutrophication, suspended solids, sedimentation and pesticide residues leached from soils and agricultural plantations (Odadal *et al.*, 2003). Human impact such as dams, deforestation and water use practices pose serious threats to water availability to downstream populations (United States Agency for International Development, 2008). Degradation of riparian zones not only affects the riparian area but also the surface and ground water resources and the aquatic fauna and flora; and the terrestrial ecosystem. Thus, the riparian zone is increasingly seen as ecologically important in landscapes, and identification of the boundaries of such areas is important and has clear management significance (Nally, Molyneux, Thomson, Lake & Read, 2008).

## 1.1 Research Problem

Riparian zones worldwide have been subject to a lot of disturbances such as soil compaction as a result of road and pathway construction; erecting of buildings, especially in urban areas; and reduction in habitat and habitat heterogeneity for the invertebrates and mammals that live in riparian zones (Downs, Skinner & Kondolf, 2008).

Limited priority has been given to riparian zone management; therefore this research can benefit the water resources management institutions in Iceland such as the Directorate of Freshwater Fisheries, Environmental Agency, National Planning Authority, Reykjavik Energy and the Reykjavik municipality in terms of planning and management of water resources, riparian zones and catchment areas. There has been limited of information on riparian zone ecology and management in Iceland since researchers have given limited attention to this area. It is important to note that my attempt is just an initial step in research on riparian zone ecosystems in Iceland.

### 1.2 Research Questions

The following questions were used as guiding tools in this research;

- What are the prevailing biophysical situations of the two case study Rivers Ellidaá and Ytri-Rangá regarding riparian zone management?
- What management strategies are in place for the Ellidaá and Ytri-Rangá?
- What knowledge gaps and challenges are the water resources management authorities in Iceland facing in the management of the Ellidaá and Ytri-Rangá?
- What possible strategies can be established to restore and/or effectively manage the riparian zones of the River Ellidaá?

### 1.3 Research Objectives

- To assess the prevailing biophysical situations regarding management of the riparian zones of the Rivers Ellidaá and Ytri-Rangá in Iceland.
- To identify management strategies in place for the riparian zones of the Rivers Ellidaá and Ytri-Rangá, gaps and challenges faced in the management of the Ellidaá riparian zone.
- To suggest possible strategies for restoration and effective management of the riparian zone of the Ellidaá.

### 1.4 Significance of the Research

Traditionally, ecologists have focused studies purely on either terrestrial or aquatic attributes or processes. It is important to understand the river basin and riparian networks in order to integrate the functional processes linking the terrestrial and aquatic components for effective water resources management and development. While there are studies on water resources and watersheds in Iceland, the riparian zones have received limited attention. The main aim of this study was to provide information to stakeholders (water resources and catchment users, managers, developers and physical planners) on the biophysical conditions of the Ellidaá and Rangá riparian zones and their management.

## 2. MATERIALS AND METHODS

The data for this research were collected by observation of the riparian zones of the Rivers Ellidaá and Ytri-Rangá, interviews of stakeholders using a research questionnaire and GIS mapping.

## 2.1 Site Description

A case study of the Rivers Ellidaá and Ytri-Rangá in Iceland was used to study the management of riparian zones in Iceland. Both the Ellidaá and Ytri-Rangá are spring fed and drain into the Atlantic Ocean. They have similar riparian vegetation types and/or classification. The study area of the Ellidaá was 6 km long from the outlet of Lake Ellidavatn to the estuary, with a catchment area of 280 $km^2$ (Rist, 1990). It flows through the capital city of Iceland, Reykjavik, and illustrates human impact on riparian zone ecosystems with regard to biophysical condition and management. The River Ytri-Rangá on the other hand is 68 km long with a catchment area of 890 $km^2$ (Rist, 1990). But the study covered the Ytri-Rangá from the source of the river (upstream) to mid-stream below the town of Hella through which it flows. There are fewer human interventions along the Rangá and it was therefore chosen as a reference area to contrast with the Ellidaá.

## 2.2 Biophysical Conditions of the River and Riparian zone

Observation of the riparian zones of the Rivers. Ellidaá and Ytri-Rangá was made by taking photographs and GPS co-ordinates of the riparian zones to map the vegetation cover and human activities along the riparian zones. GIS maps from Nytjaland were used to illustrate the location, land use and vegetation cover and classification for the Ellidaá and Ytri-Rangá. Maps of the same scale 1:35,750 were established and a riparian buffer zone of 100 meters from the rivers for both the Ellidaá and Ytri-Rangá were developed to calculate the vegetation cover defined by the Nytjaland classification 2006 (Table 1) at a resolution for a rasta image of 15x15 m for each pixel. Nytjaland is an Icelandic database at the Environment Department at the Agricultural University of Iceland. They have established a geographical database of the vegetation on all farms in Iceland. The database is based on remote sensing, using both Landsat 7 and spot 5 images and existing maps of erosion and vegetation cover (Hallsdottir, Hardardottir, Gudmundsson & Snorrason, 2009). Data on the salmon fish catch for the Ellidaá and Ytri-Rangá for the last two decades (years 1988–2008) and watershed situation data for the Ellidaá were obtained from a database from the Freshwater Fisheries Institute.

Respondents from various sectors involved in water resources management in Iceland were interviewed by the use of a research questionnaire. The questionnaire covered areas of biophysical conditions of the Ellidaá and Ytri-Rangá, and the current management strategies in place, management gaps and challenges and possible strategies to restore and effectively manage the riparian zone of the Ellidaá (see Appendix). The questionnaire was administered directly by the researcher. Eleven respondents were interviewed representing; Reykjavik Energy, Environment Agency, Physical Planning Authority, and Freshwater Fisheries Sector, Policy makers at the municipal level such as Rangárthing and water resources users such as the fishermen and fishing management companies like Laxá Ltd, which is a co-operative institution that oversees fishing activities and also generates revenue from the fishermen (Table 2).

***Table 1**. Land cover classes for the Nytjaland database, Environment Department, Agricultural University of Iceland 2006, and their description. (Source: Hallsdottir* et al., *2009).*

| Nytjaland Class | Brief Description |
|---|---|
| Cultivated land | All cultivated land including hayfields and cropland. |
| Grassland | Land with perennial grasses as dominating vegetation including drained peatland where upland vegetation has become dominating. |
| Richly vegetated | Healthy land with rich vegetation, good grazing plants common, dwarf shrubs often dominating and mosses common. |
| Poorly vegetated land | Healthy land with lower grazing values than richly vegetated land, often dominated by less valued grazing plants and dwarf shrubs, mosses, and lichens apparent. |
| Moss land | Land where moss is more than 2/3 of the total plant cover. Other vegetation includes grasses and dwarf shrubs. |
| Shrubs and forest | Land covered to more than 50% of vertical projection with trees or shrubs higher than 50 cm. |
| Semi-wetland/ upland ecotone | Land where vegetation is mixture of upland and wetland species. *Carex* and *Equisetum* species are common and dwarf shrubs. Soil is generally wet but without standing or stagnant water. This category includes drained land where vegetation is not yet dominated by upland species. |
| Wetlands | Mires and fens. Variability of vegetation is high but mires are dominated by *Carex* and *Equisetum* species and often shrubs. |
| Partly vegetated | Land where vegetation covers from 20–50%, generally are infertile areas and often gravel soil. Areas where the vegetation is both retreating and in progress can be included in his class. |
| Sparsely vegetated | Many types of surfaces are included with the common criterion of less than 20% of vegetation cover in vertical projection. |
| Lakes and rivers | Lakes and rivers |
| Glaciers | Glaciers |

## 2.3 Data Analysis

Responses from the respondents were systematically put into the database to develop tables and graphs. Qualitative analysis was done by cording of responses. For instance, the factors affecting biophysical conditions of the rivers and management measures were coded in clusters. *Institutional* included planning, inspections, monitoring, collaboration and restoration interventions such as wastewater treatment ponds; *legal* included legislative aspects such as enforcement; *socio-economic* included public awareness and education, participation and human intervention or interference and financial issues; and *natural* covered natural factors or occurrences. The suggested management strategies for the Ellidaá were ranked according to the number of respondents for each response or strategy.

***Table 2.*** *Analysis of respondents by category (sector or department, association), roles and responsibility in riparian zone management for the Rivers Ellidaá and Ytri-Rangá in Iceland.*

| **Category of Respondents** | **Number of Respondents** | **Sector/Department** | **Roles and Responsibilities** |
|---|---|---|---|
| Fisheries Biologists | 3 | Fisheries | • Research<br>• Monitoring fresh water resources<br>• Ecological registration of salmon rivers and lakes<br>• Implementation of legislation governing freshwater resources. |
| Director, Fresh-Water Fisheries Department | 1 | Fisheries | • Supervisory role and policy implementation<br>• Develop policy statements<br>• Provision of permits to developers for activities that do not have adverse impact, within the river or along the riparian zone. |
| Municipality Mayor | 1 | Municipality Local Authority | • Policy making<br>• Protection of the fresh water resources within their jurisdiction. |
| Urban Planner | 1 | Planning | • Municipality planning<br>• Design and implementation of planning legislation<br>• Mapping important areas for drinking water<br>• Environmental Impact Review |
| Environmental Health Inspector | 1 | Environment | • Environmental compliance inspection and monitoring<br>• Environmental Impact Review |
| Reykjavik Energy | 1 | Energy utility | • Monitoring and regulating water quantity |
| Private Fisheries Company | 1 | Private | • Enhancing implementation of legislation governing freshwater resources and riparian zone management. |
| Fishing area Landowners Association | 2 | Private | • Organised committee for management of water resources and riparian zones |
| GIS Specialists | 1 | Environment | • Land use mapping<br>• Vegetation cover and classification<br>• Establishment of buffer zones. |

# 3. RESULTS

## 3.1 Prevailing Biophysical Situations Regarding Management of Riparian Zones of the Rivers Ellidaá and Ytri-Rangá

This section covers the prevailing biophysical situations regarding management of the riparian zones of the rivers Ellidaá and Ytri-Rangá. It illustrates the vegetation cover, some ecological interactions between riparian zones and aquatic life such as the fish and watershed and land use along the riparian zones of the Ellidaá and Ytri-Rangá.

### *3.1.1 River Ellidaá*

The vegetation cover is presented in hectares on the map at a scale of 1:35,750 (Fig. 1) within the 100 meter riparian buffer zone from the edge of the River Ellidaá. The map indicates that richly vegetated area covered 9.8% of the zone, poorly vegetated area 24.6% and cultivated land 28.3% (Table 3).

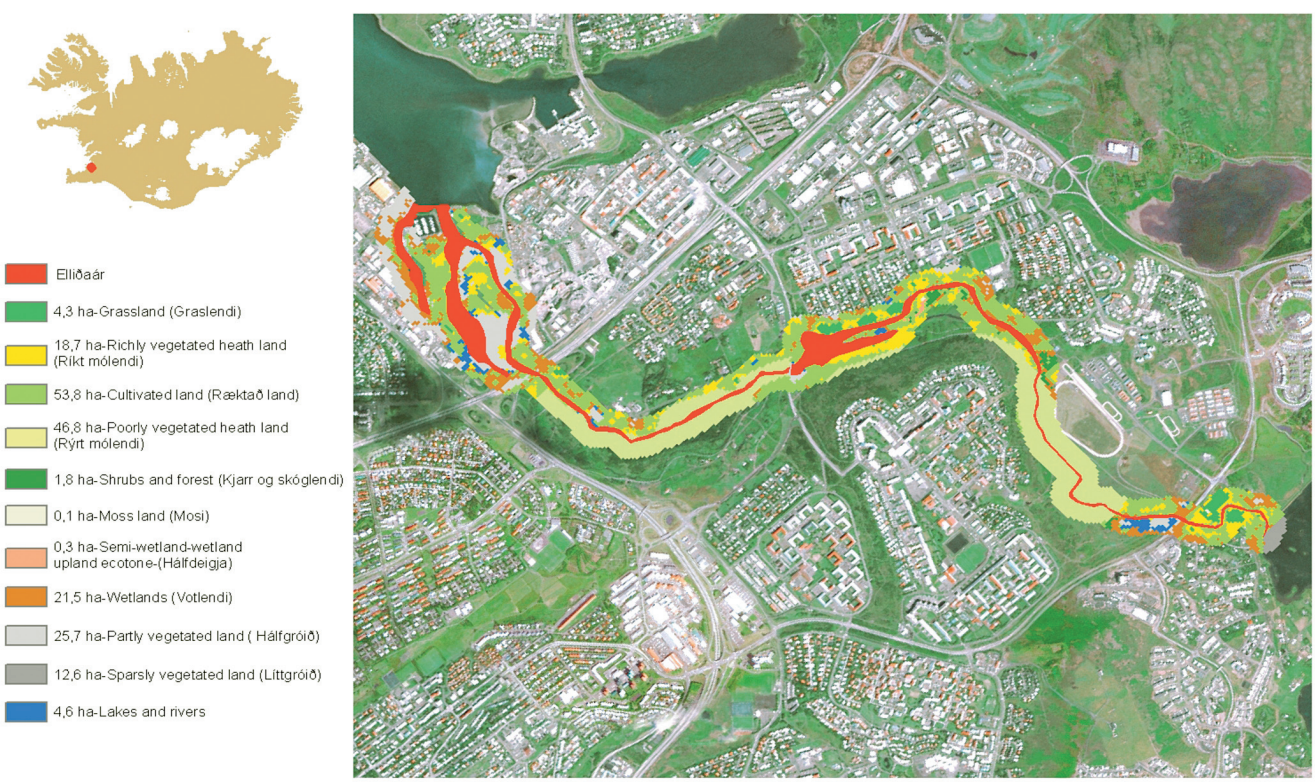


***Fig. 1.*** *River Ellidaá - Land use and cover classes of Nytjaland database within the 100 meter riparian buffer zone. The red colour represents the River Ellidaá, and the other colours are vegetation classifications and coverage in hectare as presented in the legend.*

***Table 3.*** *Vegetation cover by Nytjaland database classification of 100 meter wide riparian zone along the Rivers Ellidaá and Ytri Rangá.*

| | Ellidaá | | Ytri Rangá | |
|---|---|---|---|---|
| **Class** | **Ha** | **%** | **Ha** | % |
| Grassland | 4.3 | 2.3 | 33.6 | 13.3 |
| Richly vegetated | 18.7 | 9.8 | 55.2 | 21.8 |
| Cultivated land | 53.8 | 28.3 | 29.4 | 11.6 |
| Poorly vegetated | 46.8 | 24.6 | 66.6 | 26.3 |
| Shrubs and forests | 1.8 | 0.9 | 2.6 | 1.0 |
| Moss land | 0.1 | 0.0 | 3.7 | 1.4 |
| Semi-wetland/ upland ecotone | 0.3 | 0.2 | 25.4 | 10.0 |
| Wetlands | 21.5 | 11.3 | 7.9 | 3.1 |
| Partly vegetated | 25.7 | 13.5 | 20.1 | 8.0 |
| Sparsely vegetated | 12.6 | 6.6 | 8.6 | 3.4 |
| Lakes and rivers | 4.6 | 2.4 | 0.0 | 0.0 |
| Glaciers | 0.02 | 0.0 | 0.1 | 0.0 |
| | **190.2** | | **253.2** | |

The River Ellidaá runs through the capital city of Iceland, Reykjavik. The riparian zone of this river is mainly impacted by human activities such as: construction of riding paths, construction of buildings, grazing by urban riding horses; surrounded by industrial activities like motor repairs, factories, and a hydroelectric power dam which has been in existence since 1926; a recreation area for activities such as dog walking lies near the estuary, which is like dog toilet area; and human settlement (Figs. 1 and 2).

The River Ellidaá is contaminated with runoff sediments and surface wastewater that flow down into the river. The river bed is covered with algae, which might be an indication of a high level of nutrients in the river, and hence, eutrophication (Fig. 3).

The Ellidaá experiences seasonal changes in the watershed; 42.6% of the watershed dries up seasonally, causing reduction in water quantity. On the other hand, 31.4% of the watershed seasonally experiences an increase in water volume (Table 4).

***Table 4.*** *River Ellidaá watershed situation seasonally and area in $m^2$ and percentage (%) coverage. (Data source: Freshwater Fisheries Institute, Iceland).*

| **Category** | **Area ($m^2$)** | **%** |
|---|---|---|
| Original or normal size | 166100 | |
| Dry up seasonally | 70835 | 42.6 |
| Experience seasonal water level increase | 52214 | 31.4 |

***Fig. 2.*** *Human activities along the River Ellidaá riparian zone.*

***Fig. 3.*** *Algae at the bottom of the River Ellidaá.*

Results also illustrate a decline in the salmon catch in the river over time (Fig. 4). However, it is important to note that both rivers undergo release of fingerlings (young fish) of salmon to boost the production by the Freshwater Fisheries Institute since there is a high demand for these fish.

### *3.1.2 River Ytri-Rangá*

The vegetation cover of the River Ytri-Rangá riparian zone is presented in hectares on a map of scale 1:35,750 within the 100 meter riparian buffer zone from the edge of the river (Fig. 5). Richly vegetated area covered 21.8%, poorly vegetated area 26.3% and cultivated land 11.6% (Table 3).

Direct observation of the riparian zone of the Ytri-Rangá revealed that it had good vegetation cover and diversity. The species included grasses, angelica, mosses and shrub trees like birch and willows (Figs. 5 and 6).

Results illustrated an increase in the salmon catch in the Ytri-Rangá over time (Fig. 4). It should also be noted that salmon fingerlings are annually released into the river to boost its productivity since bed of the Ytri-Rangá is in most cases sandy with very limited gravel or rock. This limits its productivity, especially for invertebrates and salmon, which is the most

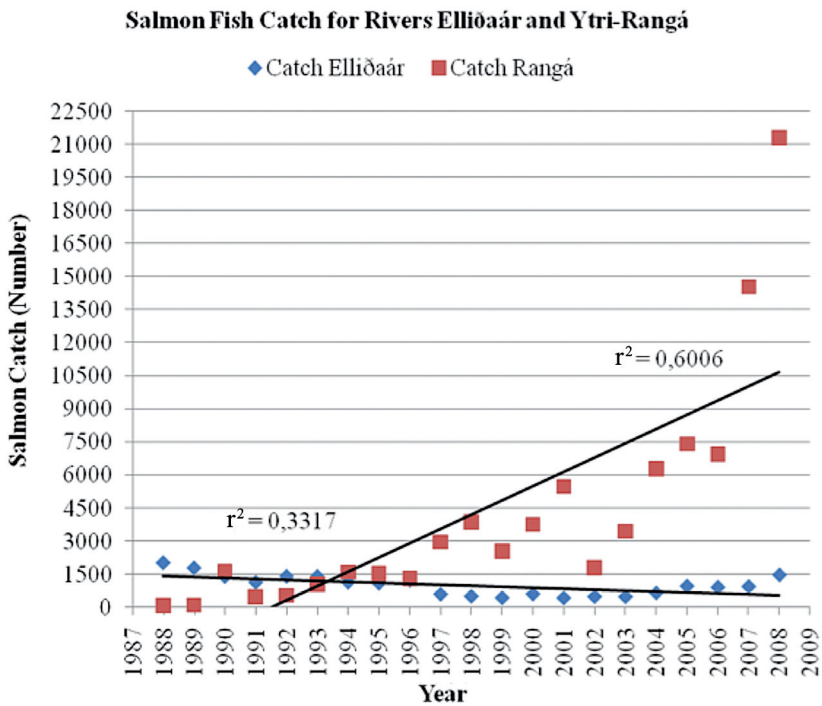


***Fig. 4.*** *Atlantic salmon fish catch in the Rivers Ellidaá and Ytri-Rangá for the last two decades (1988–2008). The regression line (fit line) illustrates a decline in the salmon fish catch in the River Ellidaá with co-efficient of determination ($r^2 = 0.3$) of salmon fish catch over time and increase in Ytri-Rangá River with coefficient of determination ($r^2 = 0.6$) of salmon fish catch over time. However, it is noted that salmon fingerlings (young salmon) have been released in both rivers for the last 10 years by the Freshwater Fisheries Institute; therefore the amount of release could also determine the size of the catch and the huge increase in the Rangá in 2007 and 2008. (Data source: Freshwater Fisheries Institute, Iceland).*

treasured fish species in Iceland. There is no evidence of silt in the Ytri-Rangá; clear right from the source of the river to the downstream reaches.

According to the analysis of responses to my questionnaires, five of the eleven respondents stated that biophysical conditions of the riparian zone of the Ellidaá are poor and the vegetation is encroached on. One respondent maintained that it was good enough, whereas five were not aware of the situation. On the other hand, nine of eleven respondents considered the Ytri-Rangá as a river with very good biopysical conditions regarding the riparian zone and two were not aware of the situation (Table 5). The Ellidaá, was mainly considered to be affected by socio-economic and institutional factors, whereas the Ytri-Rangá was mainly affected by natural factors (Table 6). The natural factors that affected the Ytri-Rangá included the sand that drifted into the river as a result of the Hekla volcanic eruption in 1947, thus reducing its productivity for invertebrates. The management measures suggested were mainly institutional, socio-economic and legal (Table 7).

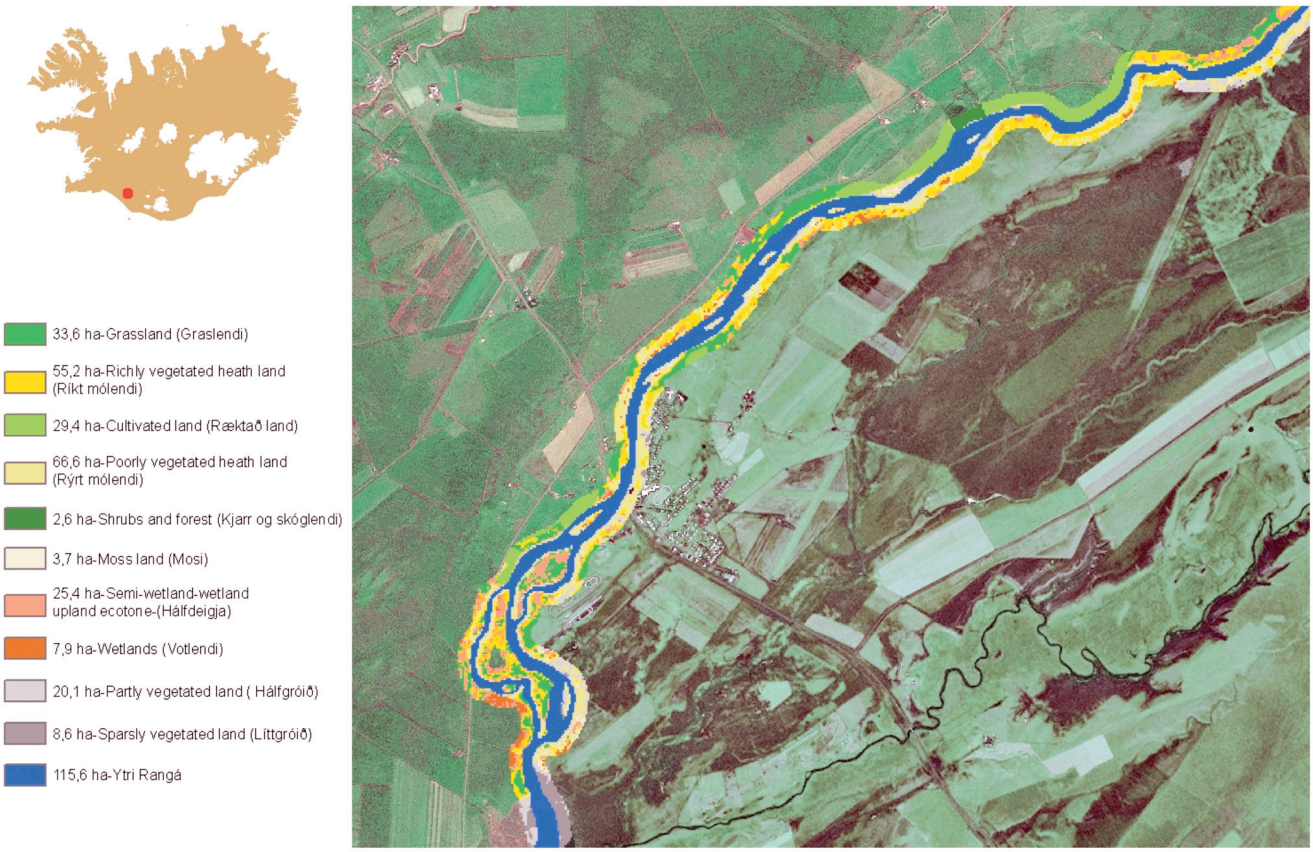


***Fig. 5.*** *River Ytri-Rangá-Land use and cover classes of Nytjaland database within the 100 meter riparian buffer zone. The blue colour represents the River Ytri-Rangá, and the other colours are vegetation classifications and coverage as presented in the legend.*

***Fig. 6.*** *Riparian zone of the River Ytri-Rangá (reference area) with vegetation cover and diversity.*

***Table 5.*** *Number of respondents (N*) and their percentage (%) to responses on the biophysical conditions of the Rivers Ellidaá and Ytri-Rangá.*

| | Ellidaá | | Ytri-Rangá | |
|---|---|---|---|---|
| Description | N * | % | N * | % |
| Good | 1 | 9 | 9 | 82 |
| Bad | 5 | 46 | 0 | - |
| Not aware | 5 | 46 | 2 | 18 |

***Table 6.*** *Number of respondents (N*) and their percentage (%) to responses on factors affecting biophysical conditions of the Rivers Ellidaá and Ytri-Rangá.*

| | Ellidaá | | Ytri-Rangá | |
|---|---|---|---|---|
| Description | N * | % | N * | % |
| Institutional | 3 | 27 | 0 | - |
| Legal | 0 | - | 0 | - |
| Socio-economic | 3 | 27 | 0 | - |
| Natural | 0 | - | 4 | 36 |

***Table 7.*** *Number of respondents (N*) and their percentage (%) to responses on: suggest management measures to effectively manage of Rivers Ellidaá and Ytri-Rangá.*

| | Ellidaá | | Ytri-Rangá | |
|---|---|---|---|---|
| Description | N * | % | N * | % |
| Institutional | 3 | 27 | 4 | 36 |
| Legal | 1 | 9 | 0 | - |
| Socio-economic | 2 | 18 | 2 | 18 |
| Not aware | 5 | 46 | 5 | 46 |

## 3.2 Management Strategies in Place

The management strategies for both the Rivers Ellidaá and Ytri-Rangá are similar and mainly based on institutional and legal frameworks. The existing institutions and legislation with various interests and mandates are all geared towards management of riparian zones and water resources in Iceland. Therefore the Rivers Ellidaá and Ytri-Rangá are not exceptional; the management strategies identified through interviews of various stakeholders are presented as follows.

### *3.2.1 Management Strategies in Place Common to both the Rivers Ellidaá and Ytri-Rangá*

The Management Strategy in place for both the Rivers Ellidaá and Ytri-Rangá are derived from the general national strategies for river bank and water resources management. They include:

The existence of national legislation on river bank management which regulates activities such as construction of buildings and roads, farming and establishing of industries and/or

factories that could have an adverse impact on the riparian zones. According to Freshwater Regulation 2006, chapter 5 article 33, the riparian zones of the river are protected within 100 meters from the water mark from development activities. It also provides the Directorate of Freshwater Fisheries the mandate to regulate activities along riparian zones through licensing (Isaksson, 2009).

Compliance inspection and monitoring are carried out by environmental and public health inspectors to regulate activities along the riparian zone and in the river.

In Iceland there exists an institutional framework from the national to regional levels that is responsible for management of the rivers in Iceland. The institutions fall within different sectors such as the environment, planning, fisheries and energy sectors.

Under the fisheries sector, there are institutional structures in place that regulate the fish catch and also try to ensure that the riparian zone is maintained since there is a strong interest in the fishing business and income is generated by this sector. Private companies are contracted by the fisheries sector. They generate revenue for the farmers who are landowners while also implementing the fish catch regulations on fishing gear that may be used and access to fishing.

#### *3.2.1.1 Management strategies specific to the River Ellidaá*

The Reykjavik city authority together with Reykjavik Energy have established sediment treatment ponds along the drainage areas since the year 2000 to provide settlement basins for sediment from storm and wastewater drains and urban settlements before the water is drained into the Ellidaá (Fig. 7). This minimises the amount of pollutants that drain into the river since the sediments settle at the bottom of the pond and then the top clear water is released into the river. The sludge is then collected, transported and dumped in landfill.

***Fig. 7.*** *Wastewater sediment treatment pond along the River Ellidaá; the pipes channel water from wastewater drains/channels to the pond for settling and then drainage into the river.*

#### *3.2.1.2 Management strategies specific to the River Ytri-Rangá*

The farmers who are landowners along the Ytri-Rangá also have an association for landowners. They are well informed on the regulations concerning fishing and they ensure that the area is well maintained.

### 3.3 Gaps and Challenges Faced in the Management of the Ellidaá Riparian Zone According to the Respondents

The management gaps and challenges that face the management of the Ellidaár are mainly institutional and policy issues as follows:

- Weak enforcement of existing laws and regulations on riparian areas by the environmental agency and freshwater fisheries directorate, for instance the 100 meter no-encroachment zone is not strictly implemented.
- There is limited public awareness and education on the existing legislation on riparian zones and their importance.
- There is lack of collaboration among the various sectors that are involved in management of the River Ellidaá.
- Conflict of interest between natural resources managers and urban planners, especially in terms of the regulation and planning of the riparian area. This has caused degradation of riparian vegetation and pollution of the Ellidaá since the riparian vegetation cannot effectively purify or filter the wastewater that drains into it.
- Urbanisation or expansion of Reykjavik City, creating a lot of pressure on the riparian area of the Ellidaá; this process involves space utilisation for recreation, access, industrial investments and settlements, thus degrading such a fragile ecosystem.
- Limited funds to finance riparian zone management projects, especially for rivers like the Ellidaá, which has been highly interfered with by human activities. It is quite costly to implement appropriate restoration projects in such a riparian zone.

### 3.4 Possible Strategies for Restoration and Sustainable Management of the Riparian Zone of the River Ellidaá

The possible management strategies to restore and effectively manage the riparian zone of the Ellidaá are mainly institutional and socio-economic. The suggested management strategies according to responses from the respondents were prioritised. Measures to increase public awareness and education on riparian zone management and regulations were ranked first and demolition of buildings within the riparian zone was ranked last (Table 8).

Suggested measures to increase public awareness and education included radio and television programmes and sensitisation meetings with riparian zone and water resources users on

***Table 8.*** *Ranking for suggested restoration and management strategies for the River Ellidaá by the 11 respondents.*

| Strategies | Scores | Ranks |
|---|---|---|
| Measures to increase public awareness and education | 10 | 1 |
| Construction of wastewater treatment ponds | 8 | 2 |
| Compliance inspection and monitoring | 8 | 2 |
| Enforcement of existing legislation | 7 | 3 |
| Collaboration between the various sectors | 7 | 3 |
| Research on riparian and water ecosystems | 5 | 4 |
| Measures to increase stakeholder participation in planning | 4 | 5 |
| Adequate funding and prioritising Ellidaá river management projects | 4 | 5 |
| Demolition of buildings within riparian zones | 2 | 6 |

existing laws and regulations on riparian zone and water resources management; also dissemination of information on fish stock and performance of the river in terms of its functionality to all stakeholders was emphasised.

Construction of more waste water treatment ponds to reduce the level of sediments and/or pollutants that drain into the Ellidaá, thus improving the water quality since the riparian zone functions were interfered with by human activities.

The industries both small and large scale surrounding the Ellidaá should treat their wastewater before releasing it into the river. This needs the attention of the Environment Agency in collaboration with the Planning Authority to monitor and inspect the amount and content of effluent that is released into the river.

There is need to enforce existing laws and regulations on riparian zones and water resources management to effectively manage the riparian zones and conserve the water resources as a whole. The Environmental Agency together with the Freshwater Fisheries Directorate should collaborate to enforce the terms of existing legislation and regulations.

Collaboration between the different sectors such as Fisheries, Water, Environment, Planning and Energy was suggested to effectively manage and share information on riparian zones in Iceland. This would avoid duplication, improve working relationships and provide knowledge on all stakeholders' roles and responsibilities, thus improving management and making possible quick solutions to the problems involved in riparian and general water resources management.

More research on riparian zones and water resources needs to be carried out to appreciate the importance and benefits of both riparian and water ecosystems.

Stakeholder sensitisation and planning meetings could increase stakeholder participation, especially in planning and implementation of restoration projects. It is important to involve all stakeholders in planning, management and restoration of the Ellidaá riparian area for effectiveness or success.

Adequate funding and priority should be given by Iceland's national and relevant local government to restoration and management projects to improve both the riparian zone and the aquatic ecosystem of the River Ellidaá.

Buildings within the 100 meter width of the riparian zone and pathways within a 50 meter width should be demolished. Pathways should be reconstructed at least 50 meters from the river to create adequate space for riparian vegetation to regenerate.

## 4. DISCUSSION

### 4.1 Comparison of the Riparian Zones of the Rivers Ellidaá and Ytri-Rangá

The amount and type of land cover within the riparian corridor has a strong influence on bank erosion and in-stream sediment-related variables. A riparian ecosystem may be more sensitive to land-use disturbances than natural ecosystem processes such as erosion due to stream flow (Sponseller, Benfield & Valett, 2001). The effect of pollutants in a water body may be long-lived due to their tendency to be absorbed in the sediments that are thereby released into the food chain (Yahui, Zhang & Jiaguang, 2008). Human activities such as industries pollute the water through effluents and oil spills; waste drains from wastewater channels and runoff resulting from urban pavements as pollutes the stream water since it may contain chemicals. Yujun *et al.,* (2008) emphasises that runoff water often contains many chemicals and ions, including heavy metals, e.g. lead, zinc, iron, and fossil fuels such as petrol and diesel and lubricating oils. The Ellidaá experiences the impact of human activities such as riparian vegetation degradation and pollution due to the amount of sediment and pollutants that drain into the river.

The effects from hydrological alteration for sufficient power supply are always evident on fish, birds, and benthic invertebrates as well as on the river margin vegetation (Nilsson & Brittain, 1996). Reykjavik Energy monitors the water levels of the reservoir Lake Ellidavatn which feeds the River Ellidaá with a large quantity of water to ensure that the power dam continues to function. The company regulate the water level by controlling the outlet which empties into the lower part of the Ellidaá. This is done in order to have adequate water for the dam to function, thus changing the level of the river water. During winter the water level is highly regulated since a large volume is needed to run the hydroelectric power dam to generate adequate power during the winter season when the dark hours outnumber the hours of natural light. However, regulating the amount of water based on ensuring the efficiency of the

hydroelectric power dam poses a challenge to the riparian and aquatic life in the river. Thus, it may affect both riparian and aquatic fauna such as the birds, fish and invertebrates that breed and exist near and in the water.

Excess nutrient loading from urban areas in the river catchments has increased nutrient concentrations considerably. Eutrophication causes a proliferation of certain primary producers that can benefit from the increased nutrient concentration at the expense of species adapted to more oligotrophic conditions (Friberg, 2007). That the Ellidaá contains a lot of algae might be an indication of high nutrient loading. This may be the result of interference with the riparian vegetation and making the riparian zone unable to perform its function of purification before releasing the water into the river, which is therefore also vulnerable to pollution. The Ellidaá also experiences seasonal changes in the water level. Part of the Ellidaá watershed dries up seasonally, causing a reduction in water quantity, and a part of it experiences a seasonal increase in water volume (Antonsson & Gudjonsson, 1998). This shows that the riparian zone cannot consistently recharge and discharge ground and surface water in order to perform its regulating function.

Many ecosystem processes and species have been negatively impacted by the conversion of riparian zones from their natural state, including the Atlantic salmon which relies on riparian areas to provide essential habitat components for all life stages (Laser, Jordan & Nislow, 2009). The rapid loss and deterioration of habitat means that many species could now be under imminent threat (Neil *et al.,* 2009). The interference in the riparian zone of the Ellidaá has also impacted the fish catch. The productivity of salmon, one of the most valuable species, in the Ellidaá has been declining (Fig. 4).

In contrast, the riparian zone of the Ytri-Rangá was chosen as a reference area in comparison to the Ellidaá riparian zone in terms of the landscape, that is, vegetation cover and land use (Fig. 8). The Ytri-Rangá vegetation cover within the 100 meter riparian buffer zone shows that this riparian zone is more richly vegetated and less cultivated and has experienced less encroachment than the Ellidaá zone. In contrast, the Ellidaá riparian zone is more sparsely vegetated, coupled with poor vegetation and has been highly cultivated and thus has experienced a high level of encroachment.

Riparian systems provide diverse land forms, habitats and resources for animals and plants (Corenblit, Steiger, Gurnell & Naiman, 2009). For instance, a vegetated riparian zone plays a crucial role in the life cycle of many aquatic insects. Most aquatic insects have a life period including when they hatch, mature, mate, and then the female returns to the river to lay eggs. During their short terrestrial phase, a vegetated riparian zone provides them with places to rest and hide from predators (O´Grady, 2006). Riparian vegetation functions as the main corridor for adult insect dispersal along a stream and is also important for reproduction for aquatic invertebrates (O'Driscoll, Harrison & Griller, 2006). Therefore, severe loss or degradation

***Fig. 8.*** *Illustration of riparian zones of the Rivers Ellidaá and Ytri-Rangá (reference area), respectively.*

of riparian habitats has led to their impoverishment and impaired function which may have severe consequences on both the riparian habitats themselves and their associated biota (Matos, Santos, Palomares & Santos-Reis, 2009). The Ytri-Rangá exhibits a natural riparian zone with adequate vegetation and limited human interference with the physical and biological functions of the riparian zone, whereas the Ellidaá experiences the impact of human disturbances on both the physical and biological functions of its riparian zone.

The Ytri-Rangá is not naturally productive of salmon due to the sandy nature of the river bed and the too low water temperature for the salmon to survive during the early stage of growth. To increase productivity, there has been release of salmon fingerlings since 1998 (Gudbergsson, 2007). The salmon fingerlings that are being released into the river by the Freshwater Fisheries Institute after nurturing them during an early stage in an artificial fish pond has yielded an increase in the annual salmon catch. This could be because the riparian zone is ecologically supportive of its feeding at that stage (Fig.4).

### 4.2 Gaps and Challenges Faced in Management of Ellidaá Riparian Zone

Weak enforcement of existing legislation on riparian zone is evident in the landscape of the Ellidaá riparian zone used for construction of buildings and tarred pathways. In many places the riparian area is reduced to only about 5 meters from the highest water mark instead of the 100 meters defined by the regulation on riparian zones in Iceland. Environmental policies and regulations are more effective when central officials consistently give priority to environmental protection (Goa, Yin, Ai & Huang, 2009).

There is limited public awareness and education and limited information on the ecological functions of riparian zones in Iceland. Researchers have carried out research on watershed and water resources ecosystems but limited attention has been given to the riparian zones which play very vital roles in the lives of both terrestrial and aquatic ecosystems. The undisturbed riparian zone establishes a suitable habitat for mammals and breeding environment for fish and invertebrates.

Small fish use slower water along margins of large streams and depend on terrestrial organisms from streamside vegetation for food because most aquatic drift organisms escape from them (Karen & Karen, 1998). Therefore, there is need for more attention to riparian ecosystems to improve their management.

Lack of collaboration among stakeholders in water resources management is a contributory factor to poor management of the riparian zone of the Ellidaá. This study found out that each sector works alone and not as a team. For instance the freshwater fisheries directorate are responsible for regulating activities along the river bank, whereas the planners are responsible for spatial planning of the city. Each of them implements their activities without consulting the other and this creates information gaps and management conflicts. There is a need for the various sectors, including the landowners and fish farmers, to collaborate in order to achieve effective management of the riparian zone of the Ellidaá.

Riparian zones in urban areas are characterised by artificial structures and embankments, and this systematically changes the riparian vegetation (Friberg, 2007). The shift in land use towards agricultural and urban development in the last century has contributed to deterioration of many waterways. In urban settings, impervious surfaces and infrastructural constraints on rivers have led to introduction of chemical pollutants, altered flows and system instability (Gretchen & Allan, 2006). Urban development has an array of impacts on stream ecosystem, hence exerting stress on the biological communities (Friberg, 2007). The increased urbanisation and expansion of Reykjavik is a great threat to the Ellidaá. A lot of human interventions are taking place along the Ellidaá; for instance, it is surrounded by industries, settlement, farmland, ongoing construction of buildings, and the city authority has also started using stones for embankment along some parts of the river. All of these pose a challenge to management of the Ellidaá riparian zone.

Inadequate funds and limited priority for river bank management and information on the ecological functions of riparian zones are equally a huge challenge to riparian and water resources managers. It is important for the riparian and water resources managers to prioritise riparian zone management since it is the link between the water resources and water catchment areas. The riparian and water resources managers in Iceland should take into account the ecological functions that the riparian zone performs for the well-being of the Ellidaá water resources and the catchment area.

### 4.3 Possible Strategies for Restoration and Sustainable Management of the Riparian Zone of the River Ellidaá

Globally stakeholders are seeking information and an improved understanding of riparian area dynamics, functions and uses and restoration of degraded riparian areas (Ffolliott, Carlton & Wendy, 2004). Jörg and Markus (2009), argue that water pollution has been significantly

reduced in most European countries fostered by growing public awareness and relevant legislation. Nevertheless, the standards required by ecological communities are still not met. Thus, awareness raising among users is crucial to guarantee successful implementation of riparian ecosystem management and restoration projects (Puig-Ventosa, 2008). It is important to increase public awareness and education on riparian zone management and regulations in order to effectively manage the Ellidaá riparian zone, since it is located in the city of Reykjavik, which is still expanding in terms of population and infrastructural development. This can be done through public awareness measures such as radio and television programmes, inspection of industries and other activities along the riverbank and giving feedback to the management of the industries and developers, sensitisation meetings with fish farmers and dissemination of information among all sectors that are involved in river bank management.

A management conflict can arise between promoting natural river processes and protecting human interest. However, this can be avoided by using an environmental planning approach that includes both analytical ecological models and alternatives that promote the humanities (Larsen, Grivetz & Fremier, 2007). Integrated water resources management redefines a conventional water management approach through closer cross-linkage between environment and society. The role of public participation and socio-economic considerations become more important within the planning and decision making processes (Jörg & Markus, 2009). There is need for stakeholders' full participation in planning, management and restoration of the Ellidaá to avoid conflicts, promote understanding and ease implementation of restoration projects.

Tseira and Amit-Cohen (2009) emphasised that controlling and/or regulating development along rivers is a potentially effective tool in protection of riparian landscape. There is need for a river restoration authority or environment authority in Iceland to limit and control development along the Ellidaá with the help of the existing laws and regulations governing riparian zone utilisation and management.

Water resources management is currently changing the technocratic towards integrated concepts (Jörg & Markus, 2009). A collaborative system enables organisations to communicate, interact and co-operate with each other to achieve their business goals (Yahui *et al.*, 2009). Involvement of multiple interests is often considered a key element to successful ecosystem management and planning (Dyke, Sean, Brody & Thornton, 2005). Collaborative management of the River Ellidaá riparian zone will accelerate success in improvement of the riparian vegetation, its ecological functions and the water resources ecosystem. Thus the various stakeholders need to collaborate and/or the technical institutions should work in collaboration for effective management.

Land use planning has applied one of the best management practices at the riparian and watershed scales to mitigate the impact of urban development. On a riparian scale, riparian vegetation ordinances have been adopted in most countries including the establishment of critical

areas, riparian buffers and no-touch zones to prevent reduction in streamside or river bank vegetation (Vivek & Marina, 2009). The most common approach to protect stream and riparian areas is to use riparian buffers (Richardson & Daneh, 2007). The riparian managers need to use management strategies and monitoring methods that are compatible with their objectives and the response potential of each river or stream (Newman & Sherman, 2008). Effective land use planning, inspection and monitoring of activities along riparian zones should be carried out for effective restoration and management of the Ellidaá riparian zone.

The Polluter Pays Principle (PPP) stimulates the industries to reduce their pollution level since the cost is determined by the level of pollution per industry. The polluter pays principle means that the polluter should be the one to bear the cost of measures to prevent and control pollution (Fischhendler, 2007). The conventional implementation of the polluter pays principle in many countries is based on an environmental tax, which is determined proportionally to the amount of emissions of the polluting substances. Producers must make their own efforts to reduce pollution in order to avoid the penalty for emissions exceeding the level permitted by environmental standards (Glazyrina, Glayzrin & Vinnichenko, 2006). The environmental authority of Iceland should consider the application of the polluter pays principle to the industries surrounding the Ellidaá to reduce pollution since the riparian vegetation cover has been reduced to a level that cannot purify or filter the sediments or the effluents on its own before waste water and pollutants drain into the river.

River and riparian managers must effectively allocate the limited financial and personnel resources to monitor and manage riparian ecosystems (Newman & Sherman, 2008). Thus, there is need for both financial and political support from central and regional government and efforts to disseminate information (Puig-Ventosa, 2008). Priority in terms of resources should be given to effectively manage and restore the riparian zone of the Ellidaá by the national, regional and local government in Iceland.

The primary management emphasis today is maintaining the integrity of riparian areas for their multiple values such as the ecological functions, aesthetics, historic and cultural heritage (Ffolliott *et al.,* 2004). The objective of river restoration can be seen as community- based and technologically based, as well as focusing on ecological improvement. Community objectives are driven by quality of life concerns and may involve improving the aesthetics of degraded river environment and preserving cultural heritage or historic values (Downs *et al.*, 2008). The River Ellidaár riparian zone has had its aesthetic values over past decades, but it has been affected by the urban development and this cannot be easily restored. It is also important to consider the cost-benefit factor. However, with appropriate management measures as discussed above, the human impact can be controlled and reduced to allow the riparian zone to maintain its ecological functions.

The restoration strategies I would recommend include;

- Demolishing the pathways and establishing pathways at least 50 meters from the river and replanting grass, moss, and other riparian species that can create an appropriate environment for the 'spongy like' riparian zone functions of ground and surface water recharge and discharge, sediment retention, filtration, and moderation of micro-climate.
- Establishing a clear Ellidaá riparian buffer zone by demarcation with trees to avoid and reduce encroachment by human development activities.
- Planting of more trees along the watershed and riparian zone to provide good canopy that can regulate erosion, trap some pollutants, moderate micro-climate and provide good habitat for riparian fauna.

## 5. CONCLUSION

Riparian ecosystems are very important by nature of their functions to both aquatic and terrestrial ecosystems. My results illustrate that the River Ellidaá riparian zone is highly encroached and impacted on by human activities compared to the River Rangá. However, to improve the situation, several management strategies can be suggested. They include measures to increase public awareness and education and stakeholder participation, enforcement of existing laws and regulations on riparian zones and water resources management, collaborative management, land use planning and management, compliance inspection and monitoring, prioritisation and funding of restoration projects. Political support and will should be taken into account by both the technical personnel responsible for management of the River Ellidaá and political leaders in Iceland.

To achieve specific, measurable, achievable, realistic and time-bound (SMART) riparian objectives, managers learn from responses to management documented through monitoring and interpreted through riparian and/or river classification (Newman & Sherman, 2008). Thus riparian and/or river classification in land use planning is very important in riparian zone management. Watson and Basher (2005) also emphasised the importance of landscape ecology in riparian management. There is need for urban, regional and national planning authorities to account for both vegetation amount and distribution within riparian zones and watershed planning practices in urban areas (Vivek & Marina, 2009).

Further research needs to be undertaken on the hydrological relationship between riparian areas and upland ecosystems and the biophysical and chemical interactions between the three zones of aquatic, riparian and upland ecosystems in Iceland.

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# APPENDIX

## RESEARCH QUESTIONNAIRE

This questionnaire is to answer questions on the management of riparian (River Bank) ecosystems of the Rivers Ytri-Rangá and Ellidaár, which are vital spring-fed rivers in Iceland. It is important to note that riparian zones are transitional semi-terrestrial areas regularly influenced by fresh water, normally from the edges of water bodies to the edges of upland communities.

The riparian vegetation acts as a buffer zone along rivers and lake shores in various ways. It may minimise the effects from river spates, e.g. by slowing down the water flowing from upstream down into the rivers through absorption, hence creating stability in the water flow. The vegetation usually traps sediment and therefore influences down river sedimentation. The riparian zone is often a habitat for rare species and these species may move along the unique networks of the riparian vegetation; it is also a breeding ground for aquatic fauna such as fish, and aquatic invertebrates.

This research is therefore carried out in partial fulfillment of the requirements of the Training Course in Land Degradation Assessment and Restoration at the Agricultural University of Iceland.

The research aims to assess the management situation of the riparian zones of Rivers Ytri-Rangá and Ellidaár in Iceland, to identify riparian zone management gaps and challenges, and to establish possible strategies for restoration and sustainable management of riparian zones.

In recognition of your role within the institution or sector of water resources management, you have been selected to participate in this study and your contribution is very important to this research.

**How to complete this questionnaire**

*Please answer all sections that concern your institution or sector (it will take approximately 30 minutes).*

*Give the answer that first occurs to you. Your answer reflects your opinion/insight into the situation and available data that you have in the institutional data bank in regard to the Rivers Ytri-Rangá and Ellidaá.*

**Thank you for your co-operation in advance!**

**Section A: General Information**

1. In which Organization/ Ministry/ Department do you work/ serve?

……

2. What is your position in that Organization/ Ministry/ Department?

……

3. Is water resources management mainstreamed in your Organization's/ Ministry/ Departmental activities?

a) Yes (if yes go to Qn.4) b) No

4. What is the role of your Organization/ Ministry/ Department in management of the River Ytri-Rangá and/or the Ellidaár?

……

5. What role do you, as an individual play in management of the River Ytri-Rangá and/or the Ellidaár in regard to the biophysical and chemical composition of the water and riparian zone ecosystem?

   a) Policy Maker

   b) Managerial /Supervisory

   c) Compliance Inspection and Enforcement

   d) Technical Monitoring and Data Collection

   e) Others (Specify)

**Section B: To Study the Prevailing Biophysical Situation of the Rivers Ellidaá and Ytri-Rangá**

**Section B-I: River Ellidaá**

**Biophysical Functions and Management**

1. What is the biophysical conditions of the River Ellidaá in relation to:

a) water quality and quantity for ecological functionality

1) Good 2) Bad

More information ----------

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b) fish species and reproduction (trend of fish catch for the last five years)

1) Good 2) Bad

More information ----------

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c) other invertebrates (their interactions and reproduction)

1) Good 2) Bad

More information ----------

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d) the aquatic and riparian vegetation diversity and cover

1) Good 2) Bad

More information ----------

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e) landscape

1) Good 2) Bad

More information ----------

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***Please attach information or data for fish catch trend for the last five years and any other relevant data/information on a separate sheet or soft copy that can be important for this research.***

2. a) According to your assessment, experiments and experience, do you think the biophysical condition or performance of the River Ellidaá is good as per the requirements of a good functional river (aquatic resources and riparian) ecosystem?

1) Yes 2) No

b) If no, give reasons and/or factors that are affecting its biophysical functions or conditions?

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3. Suggest possible management measures or strategies to restore the biophysical functions of the River Ellidaá

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**Section B-II: River Ytri-Rangá**

**Biophysical Functions and Management**

1. What is the biophysical conditions of the River Ytri-Rangá in relation to:

   a) water quality and quantity for ecological functionality

      1) Good 2) Bad

      More information ----------

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   b) fish species and reproduction (trend of fish catch for the last five years)

      1) Good 2) Bad

      More information ----------

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   c) other invertebrates (their interactions and reproduction)

      1) Good 2) Bad

      More information ----------

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   d) the aquatic and riparian vegetation diversity and cover

      1) Good 2) Bad

      More information ----------

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   e) landscape

      1) Good 2) Bad

      More information ----------

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***Please attach information or data for fish catch trends for the last five years and any other relevant data/information on a separate sheet or soft copy that can be important for this research.***

2. a) According to your assessment, experiments and experience, do you think the biophysical condition or performance of the River Ytri-Rangá is good as per the requirements of a good functional river (aquatic resources and riparian) ecosystem?

1) Yes 2) No

b) If no, give reasons and/or factors that are affecting its biophysical functions or conditions?

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3. Suggest possible management measures or strategies to restore the biophysical functions of the River Ytri-Rangá

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**Section C: General Management of Riparian Ecosystem for the Rivers Ellidaá and Ytri -Rangá**

1. What are the current strategies your institution has put in place to effectively manage the riparian ecosystem?

**Ellidaá** ----------

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**Ytri-Rangá** ----------

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2. What main gaps can you identify in the management of the riparian zones?

**Ellidaá** ----------

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**Ytri-Rangá** ----------

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3. What are the challenges you are faced with in management of riparian zones?

**Ellidaá** ----------

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**Ytri-Rangá** ----------

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4. Suggest possible strategies to restore and/or effectively manage the riparian zones?

**Ellidaá** ----------

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**Ytri-Rangá** ----------

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***Please attach relevant information or data on separate sheet or soft copy that can be available to the researcher.***