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Low water on the Rhine River. (http://w3.trib.com/~rlund/pictures/travpics/Low.Rhrein.gif, 1999).

The Rhine Action Program: Restoring Value to the Rhine River

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Historically, the Rhine River was a viable ecosystem system until human activities caused drastic ecological degradation. The degradation of the Rhine River is a result of channel alterations for flood control and a shipping route and discharges of agricultural, industrial, and municipal wastewater. By 1986, the degradation was so acute that the nations bordering the Rhine River developed and implemented an action plan for ecological rehabilitation called the Rhine Action Program (Plan). The major obstacles for ecological rehabilitation indicated in the Rhine Action Program were the effects of regulating the channel and discharging of toxic materials into the Rhine River. The main goal of this program is to improve water quality to enable the return of migratory fish species through rehabilitation efforts. This paper presents an overview of the Rhine River and the Rhine Action Program with a focus on restoring migratory fish and their habitat.

The Rhine River flows through several nations, from the headwaters in the Swiss Alps to the North Sea. The Rhine River spans a total length of approximately 1320-km and drains a catchment area of about 185,000-km2 including parts of Switzerland, France, Germany, Austria, Liechtenstein, Luxembourg, and the Netherlands (Van Dijk et al. 1995). The Rhine catchment area is the most densely populated and industrialized river basin of Western Europe with more than 54 million people and 10% of the worlds chemical industry (Van de Kraats, 1994). The Rhine River was a free flowing system until 100 years ago when the mainstream was altered into the most important ship canal in Europe for the transport of goods. Regulation measures on the mainstream and its tributaries include channeling of the mainstream, construction of dams, weirs, sluices, dikes, and closure of the estuarine river mouths which increase water stagnation (De Ruyter Van Steveninck et al. 1990). The Rhine River is a combined glacier- and rain-fed river with a well-balanced stream flow; the average discharge is 2200 cubic meters per second (Fredrich and Muller, 1984). This river is the most ecologically stressed river in Europe and has been for decades.

The combined effect of human activity, pollution, and river alterations caused a drastic decline in aquatic species. (See Table 2 & 3 in the appendix for aquatic species.) Most of the changes to the aquatic organisms occurred from 1890 to 1950, when 27 species were diminished or lost. Historically, 47 indigenous species inhabited the Rhine River, seven of these can not be found anymore, such as the last sturgeon observed in 1942 (De Ruyter Van Steveninck et al. 1990). The Rhine River was formerly a Salmon *salar* river until pollution and channel regulation alterations occurred. In the late 1880's, 250,000 Salmon *salar* were caught annually in Germany and the Netherlands alone. In the early 1900's, Salmon *salar* catches began to decrease rapidly and by the 1950's, Salmon *salar* were extinct in the Rhine River (Lelek et al. 1990).

In 1963 the states bordering the Rhine River developed the Convention of the International Commission for the Protection of the Rhine (ICPR) in response to deteriorating water quality. The participants in this commission are Switzerland, France, the Netherlands, Germany, Luxembourg, and the European Union since 1976 (Van Dijk et al. 1995). Agreements on emission reductions, oxygen concentration improvement, organic compound and heavy metal loads of the Rhine River were effectively made and reached. However, the river was declared ecologically dead in the early 1970s when an acute mercury pollution wave led to massive mortality among aquatic species. Cladocerans and fish died instantly when exposed to the water of the Lower Rhine (Schulte et al. 1992). Eventually, this pollution wave led to a chronic pollution problem due to bioaccumulation in the foodchain (Carbiener et al. 1990).

During the early 1980s decreases in pollution discharges, water purification plants, and sanitation measures on the Rhine River and in its catchment area reduced pollution levels (Lelek et al. 1990), resulting in a slight recovery of the biological communities. Nevertheless, on November 1, 1986, another heavy pollution wave now called the Sandoz Accident occurred in the course of putting out a warehouse fire in Basle, Switzerland. The warehouse contained 30,000 kg of toxic chemicals including insecticides, herbicides, and fungicides (Van Dijk et al. 1990). This discharge of organophosphorous and organochlorine compounds had a high selective mortality effect on the eel *Anguilla anguilla* population (a fish formerly considered less sensitive to pollution). This incident was also extremely detrimental to other fish populations, macro-invertebrates, and plankton communities (Lelek et al. 1990). In response to the Sandoz accident, the ICPR developed the Rhine Action Program.

This program is an example of landscape-level planning and site-scale implementations to rehabilitate and protect the Rhine River ecosystem. All river management policy decisions affecting ecological and other functions such as navigation, flood control, and hydroelectric power production are considered collectively by all the Rhine states (Van Dijk et al. 1995). Many diverse groups are involved in site-specific rehabilitation projects all along the Rhine River that are guided by the landscape level goals and objectives set forth in the Rhine Action Program. Local management and rehabilitation projects are set up at regular intervals along the Rhine River. The government ministries of Switzerland, France, Germany, Austria, Liechtenstein, Luxembourg and the Netherlands develop these projects. Each project is managed by various natural resource agencies. The projects are dependent on broad commitment and efforts from interest groups at international, national, and regional levels (Van Dijk et al. 1995). There are many other groups involved in the rehabilitation efforts such as local high schools, businesses, non-government organizations (NGOs), zoological institutes, the Nature Conservancy, and private citizens.

The overall goal of the program is to improve water quality by meeting the following objectives, by the year 2000 (Van den Brink et al. 1994; Van Dijk et al. 1995): 1) To create conditions that can support the return of higher trophic level species such as Salmon *salar*; 2) To protect the Rhine River as a source for drinking water; 3) To decrease the contamination of sediments, suspended matter, and the biota due to toxic compounds; 4) To meet water quality standards mandated in the North Sea Action Plan; 5) To follow the 'Ecological Master Plan for the Rhine River'. This plan dictates two major ecosystem based goals: a) To restore the mainstream and its main tributaries, as habitats for migratory fish; and b) To improve and protect ecologically important areas of the Rhine River and the Rhine valley with an emphasis on increasing the biodiversity of indigenous flora and fauna.

Decades of pollution and human activities in the regulated Rhine River have permanently altered the ecology of the entire drainage area. The most damaging human activities are agricultural uses, and industrial uses such as sand, gravel, and clay extraction for the production of bricks (De Ruyter van Steveninck, 1992). River regulation has reduced the ability of migratory fish to reproduce, altered low and high flow rates, and decreased the total area of floodplains. A decrease in species diversity and abundance continued at a steady rate until rehabilitation efforts improved water quality and the river habitats or biotopes. A biotope is a region uniform in environmental conditions and in its populations of animals and plants for which it is the habitat (Merriam-Webster, 1996).

The initial years of the Rhine Action Program focused exclusively on water quality improvement. The Rhine states agreed on a target reduction of 50% of the pollution caused by priority compounds by the year 1995. In addition water quality targets were set for about 50 priority compounds based on the requirements for drinking water supply, the protection of aquatic life forms, and on human tolerance levels for fish consumption (Schulte, 1992). Rehabilitation efforts involved sewage and water treatment plants, decrease in point source discharges, reinforcing shorelines with large stones and planting of riparian vegetation, and use of seasonal chemical and biological concentration techniques to monitor water quality.

Recent monitoring studies indicate that the water quality targets for two-thirds of the priority compounds are within compliance levels. The total phosphorus and nitrogen, cadmium, and micropollutants have been reduced by nearly 50%. However, these compounds periodically exceed compliance levels. These reductions are a result of reduced sewage and water treatment effluent, reduced toxic discharges, removal of contaminated sediments, and the increased use of phosphate-free detergents. The overall reduced toxicity of the Rhine River has allowed for rapid oxidation of ammonium, which is near compliance levels (De Ruyter van Steveninck et al. 1992). River regulation and shoreline stabilization have fixed processes of sedimentation and erosion in the floodplains and in the channel during low flow (Jongman, 1992). The targets for mercury, copper, zinc, lead, chloroform, hexachlorobenzene, and polychlorinated biphenyls (PCBs) have not been reached (Van Dijk et al. 1995). Studies have indicated that contaminants such as zinc may inhibit sediment microbial breakdown of natural and artificial substrates (Van den Brink et al. 1994). This implies that otherwise biodegradable pollutants will continue to persist in the Rhine River sediments.

However, rehabilitation efforts have been successful in improving water quality enough to allow the biological communities to recover slightly. Concentration techniques have shown an increased relative growth rate of the natural phytoplankton community, insect community, submerged macrophytes, and macroinvertebrates. The numbers of anadromous and catadromous species, leeches, flatworms, molluscs and some other crustaceans, and many exotic species such as *Corophium curvispinum* (Van Dijk et al. 1995), have also increased. The current success of exotic species is linked to abundant food availability (phytoplankton, suspended organic matter), resulting from increased eutrophication (Van den Brink et al. 1994).

Improvement in water quality allowed local rehabilitation projects to focus on restoring migratory fish. Several biotopes were identified that are essential for various fish species life history including shorelines, islands edges, natural riverbed sections, harbors, mouths of tributaries, and stretches of side-waterbodies (Lelek et al. 1990). Migratory fish require the entire river as habitat for their life cycle. Rehabilitation efforts involved removal of concrete or metal walls in small areas in the channeel; removal of small dams to provide some stretches of swiftly moving water for fish migration; installation of fish passes or ramps; restocking of fish; and reopening the Rhine River to its floodplains.

In the Rhine and its tributaries, 32 ha of spawning grounds and 250 ha of nursery grounds exist (Schulte et al. 1995). These areas were identified as sufficient sites for re-stocking efforts. In 1987 a Salmon *salar* -smolt release program for the Rhine River and its tributaries was started. In 1989, six Salmon *salar* were caught in the entire Rhine drainage basin. In 1992, 18 Salmon *salar* were caught in the entire drainage basin (Schulte et al. 1995). Natural reproduction has been recorded since 1992 and in 1994 newly hatched yolk-sac alevins were found in natural spawning grounds in the Sieg River (a tributary of the Rhine River) and its tributary the Brol River (Marmulla, 1996). The number of Salmon *salar* caught continues to increase slowly. Success of stocking and reintroduction of fish indicates enough improvement of water quality to increase and sustain 40 indigenous and 15 introduced fish species (Van Dijk et al. 1995).

Terrestrial habitat improvements started later than water quality measures. Historically, the diverse flora of marshes, rivers, and dry, sunny grasslands characterized the Rhine River ecosystem. (See Table 1 in the appendix for plant species.) Almost 85% of the vegetation types consisted of grasslands (Jongman, 1992). The influence of the hydrologic regime was evident by the distribution of grassland types that showed distinct gradients from dry and sunny locations to wet and shady ones in short distances. By 1970, the tidal influence on the floodplains of all the states bordering the Rhine had disappeared because the estuaries were closed off from the main channel (Lelek et al. 1990). The lack of tidal influence has reduced the number of dry, sunny vegetation types as well as wet, shady types. The focus of terrestrial habitat improvements has been the reconnection of floodplains with the mainstream by removing dams and other structures. Additional rehabilitation efforts include seed plantings of native grass and forb communities representative of the dry-to-wet gradients, weeding exotics and pests, and removal of contaminated soils and sediments. However, plantings of native grasses and forbs have failed on artificial soils in former clay pits filled with sand after excavation (Van Dijk et al. 1995).

Aquatic and terrestrial habitat rehabilitation has favored recolonization of a few species. The rate of species recovery depends on maintaining water quality that can sustain aquatic populations. Species recovery also depends on the existence of donor communities within the Rhine River drainage basin. Other large rivers, floodplains, and dry-to-wet grasslands similar to the Rhine River drainage basin are hundreds of km away. The degree of isolation of large rivers in Europe is significant enough to impede species recolonization (Fuchs et al. 1990). The aim of the Rhine Action Program is to create an ecological network along the Rhine River and its tributaries, consisting of several large ecologically important reaches (1000-6000 ha each) with smaller connecting areas. At present, 7500 ha of floodplain have been identified as ecologically important areas, 40% of this area has been reconnected with the main channel. The remaining 60% is expected to be successfully rehabilitated within the next 25 years along with an additional 5000 ha (Van Dijk et al. 1995).

The Rhine River Drainage Basin is influenced by pollution and regulation measures that have negatively affected the river system. The level of degradation is severe enough to hinder rehabilitation processes for decades. The lack of a reference system creates difficulty in determining appropriate biological criteria and measures of success. More detailed information is needed on the dynamics of fish communities such as predator-prey ratios, possible competition mechanisms between ubiquitous, exotic, and indigenous species, and fish movements between the mainstream and adjacent side-waters (Lelek et al. 1990). Current publications do not provide adequate information on the organization, management, and administration of the Rhine Action Program or on the progress in reaching the stated goals and objectives. Publications on rehabilitation techniques and successes are very limited. An additional complication in researching the Rhine Action Program is the lack of material written (or translated) in English. The lack of current detailed information creates difficulties in assessing whether or not the Rhine Action Program is successfully rehabilitating the Rhine River and its tributaries. Improved water quality and ecological recovery of some species and their habitats in the Rhine River has been documented. However, pollution inputs, eutrophication, and human activities remain serious problems. In addition, the loss of species and isolation from donor communities impedes recolonization. Recovery of the Rhine River ecosystem will take decades to recover rather than a 12-year rehabilitation program deadline.

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Appendix 1: Partial list of animal species of the Rhine River basin identified in the literature. (Prior/post restoration).

Families & Species		Fish and Eel Families	
Acheta	Heteroptera	Acipenseridae	Gadidae
Bivalvia	Hirudinea	Anguillidae	Gasterosteidae
Chironomidae	Insecta	Centrarchidae	Ictaluridae
Chlorophyceae	Megaloptera	Cichlidae	Osmeridae
Chysophyceae	Mollusca	Clupeidae	Percidae
Coleoptera	Nematoda	Cobitidae	Petromyzontidae
Crustacea	Odonata	Coregonidae	Pleuronectidae
Cryptophyceae	Oligochaeta	Cottidae	Salmonidae
Cyanophyceae	Planaria	Cyprinidae	Siluridae
Dinophyceae	Plecoptera	Esocidae	Thymallidae
Ephemeroptera	Simuliidae		
Euglenophyceae	Trichoptera		
Gastropoda	Tricladida		

(Creuze Des Chatelliers, 1992, De Ruyter Van Steveninck, 1990).

Appendix 2: The occurrence of fish and lamprey species in the Rhine River: (A) indigenous species, (B) allochthonous species, (C) indigenous species found after the Sandoz Accident in 1986.

Family & *Species*	A	B	C		Family & *Species*	A	B	C
Petromyzontidae					Cyprinidae			

Lampetra fluviatilis	*		*		*Leuciscus cephalus*	*		*
Lampetra planeri	*				*Leuciscus idus*	*		*
Petromyzon marinus	*		*		*Leuciscus leuciscus*	*		*
Acipenseridae					*Leuciscus souffia agassizi*	*		*
Acipenser sturio	*				*Phoxinus phoxinus*	*		*
Clupeidae					*Pseudorasbora parva*		*	
Alosa alosa	*		*		*Rhodeus sericeus amarus*	*		
Alosa fallax	*				*Rutilus rutilus*	*		*
Salmonidae					*Scardinius erythrophthalmus*	*		*
Hucho hucho		*			*Tinca tinca*	*		*
Oncorhynchus tschawytscha		*			*Vimba vimba*		*	
Salmo gairdneri		*			Cobitidae			
Salmo salar	*				*Cobitis taenia*	*		*
Salmo trutta	*		*		*Misgurnus fossilis*	*		*
Salmo trutta m. fario	*		*		*Noemacheilus barbatulus*	*		*
Salvelinus alpinus	*		*		Siluridae			
Salvelinus fontinalis		*			*Silurus glanis*	*		*
Coregonidae					Ictaluridae			
Coregonus oxyrhynchus	*				*Ictalurus melas*		*	
Coregonus lavaretus	*		*		Anguillidae			
Thymallidae					*Anguilla anguilla*	*		*
Thymallus thymallus	*		*		Gadidae			
Osmeridae					*Lota lota*	*		*
Osmerus eperlanus	*		*		Gasterosteidae			
Esocidae					*Gasterosteus aculeatus*	*		*
Esox lucius	*		*		*Pungitius pungitius*	*		*
Cyprinidae					Centrarchidae			
Abramis brama	*		*		*Lepomis gibbosus*		*	
Alburnoides bipunctatus	*		*		*Micropterus dolomieu*		*	
Alburnus alburnus	*		*		*Micropterus salmoides*		*	
Aspius aspius	*		*		Percidae			

Barbus barbus	*		*		*Gymnocephalus cernuus*	*		*
Blicca bjoerkna	*		*		*Perca fluviatilis*	*		*
Carassius auratus		*			*Stizostedion lucioperca*		*	
Carassius carassius	*		*		Cichlidae			
Chondrostoma nasus	*		*		*Astronotus ocellatus*		*	
Ctenopharyngodon idella		*			Cottidae			
Cyprinus carpio	*		*		*Cottus gobio*	*		*
Gobio gobio	*		*		Pleuronectidae			
Hypophthalmichthys molitrix		*			*Platichthys flesus*	*		*
Leucaspius delineatus	*							

(Lelek, 1990).