ENVIRONMENTAL AND SOCIAL IMPACTS OF RESERVOIRS: ISSUES AND MITIGATION

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Summary

Dams and reservoirs have played a key role in economic development, serving a variety of purposes, including electricity generation, flood control, and irrigation. However, large dams have been a subject of growing international debate and controversy. Disagreements and confusion over what happened in the past has splintered the debate, with polarization between people grouped in stark terms as proponents and opponents of dams.

There is a growing concern that dam projects cause irreversible environment change, which are often complex, multiple, and essentially negative. Large dams have enormous consequences for people's lives and livelihoods, including controversial issues such as displacement and resettlement. The opponents of dam construction argue that the social and economic consequences (and environmental) of large dams are more far-reaching than those associated with other infrastructure projects because of the huge impact across time and space in both the ecosystem and in social, economic, and cultural structures. Provided that such communities are relocated with adequate compensation, new economic opportunities and social benefits, they can exploit the new circumstances as a chance to strengthen their income-earning capacity and thus their living standards. The new settlement may provide upgraded infrastructure facilities and reduced exposure to natural hazards.

The concerns and adverse impacts of dams can be minimized or eliminated by careful planning and design that incorporate public involvement and input early in the process. The challenge for the future will be the utilization of dams and reservoirs for the wise management of the world's water resources as part of each nation's social and economic development goals.

1. Introduction

Rivers, watersheds, and aquatic ecosystems are the biological engines of the planet. They are the basis for life and the livelihoods of local communities. Understanding, protecting, and restoring ecosystems at river basin level is essential to foster equitable human development and the welfare of all species. Dams transform landscapes and create risks of irreversible impacts. Clashes between dam proponents and critics have brought the large dams issue into focus as one of the most intensely debated issues in sustainable development.

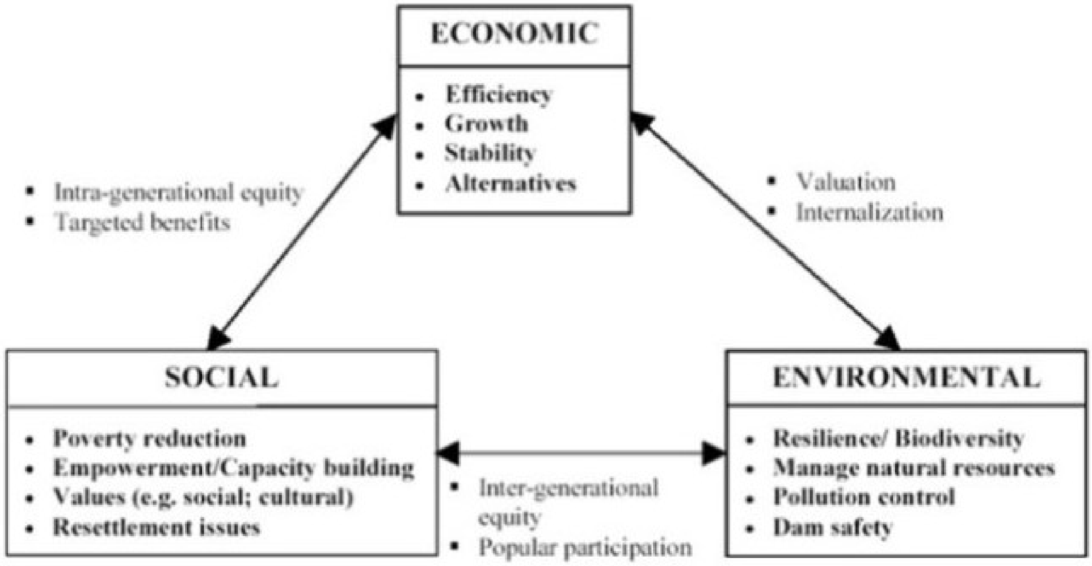

Figure 1. Approach to sustainable development (modified from Munasinghe M. (1993). *Environmental economics and sustainable development*, World Bank Environment Paper No. 3, 120 pp. Washington, DC: World Bank)

The earliest concept of sustainable development emphasized the need for economic development to be in harmony with constraints set by the natural environment, one that satisfies the needs of the present generations without putting in jeopardy the satisfaction of needs of the future. More recently, it has also been stressed that economic development should be compatible with political and social institutions. Therefore, a holistic concept of sustainable development has emerged in which economic, ecological, social, and political factors need to be simultaneously considered. Participation by individuals, particularly at the community level, is seen as an important means for achieving sustainable development and formulating development goals. As applied to dam projects, the core idea of sustainability and development is that all resource management decisions must give adequate weight to accommodating both consumption and conservation as well as to the legitimate role of equity. Dam promoters face the challenge of devising sustainable strategies that both accommodate societal demands and maintain the essential geomorphic and ecological functions of hydrologic systems while simultaneously pursuing the attainment of economic prosperity, environmental quality and social equity (Figure 1).

Large dams have been the subject of growing international debate and controversy. They have played a key role in economic development, serving a variety of purposes, including electricity generation, flood control, and irrigation. Dams provide about 20% of the world’s electric power. They also provide flood control services and water supplies for agriculture. There are about forty-five thousand large dams in the world. About half of the world’s dams are in China and India. Yet concern about their adverse environmental, social, and even economic impacts is growing.

Disagreements and confusion over what happened in the past have splintered the debate and have grown increasingly, with high polarization between people grouped in stark terms as proponents and opponents of dams. Mistrust among the various interest groups with different agendas made it difficult to achieve a collaborative consensus-building process. Dam projects have been a classic target of the strong environment lobby and the critiques of top-down technocratic development due to the immense nature of the impacts created by these vast undertakings. Controversies surrounding dam projects, including environmental and social destruction and high price tags, have grown, especially in the last twenty years in developing countries. Dams like the Sardar Sarovar Dam on the Narmada River, India (see Box 1), the Three Gorges Dam on the Yangtze River, China, the Lesotho Highlands Water Project in southern Africa, proposals for many mega dams on the Mekong River, and the Auburn Dam on California's American River have all been fraught with opposition, resulting in some projects being canceled or delayed in favor of alternative proposals for water and power.

Amongst the 30 large dams planned for the Narmada, India, the Sardar Sarovar Dam is the largest with a proposed height of 136.5 m. The proponents claim that the multipurpose Sardar Sarovar Project (SSP) would irrigate more than 1.8 million hectares of mainly drought-stricken areas, and provide electricity and flood control. The opponents counter that these benefits are grossly exaggerated and would never accrue to the extent suggested and full costs are concealed. The project would displace more than 320 000 people and owing to related displacements by the canal system and other allied projects, at least one million people are expected to be affected if the project is completed. No environmental impact assessment has ever been produced for SSP.

Under intense pressure, the World Bank was forced to constitute an independent review committee, the Morse Commission. The first independent review of any of the Bank funded projects, its report indicted that: "In 1985, when the credit and loan agreements were signed, no basis for designing, implementing, and assessing resettlement and rehabilitation was in place." The opponents alleged that the Bank approved the loan violating its own guidelines on resettlement and the environment and this support brought considerable legitimacy to the project and contributed to a humanitarian disaster. The resultant international furore forced the Bank finally to withdraw from the project.

Following a writ petition by an NGO calling for a comprehensive review of the project to take into consideration all the concerns raised, the Supreme Court of India halted construction of the dam in 1995 at a height of 80.3 m. However, in an interim order in February 1999, the Supreme Court gave the go-ahead for the dam's height to be raised to a height of 88 m. In October 2000, in a 2 to 1 majority judgment, the Supreme Court allowed immediate construction on the dam up to a height of 90 m. Further, the judgment authorized construction up to the originally planned height of 138 m in 5-meter increments subject to receiving approval from the Relief and Rehabilitation Subgroup of the Narmada Control Authority. Opponents are skeptical and argue that this essentially unfettered clearance from the Supreme Court has come despite major unresolved issues on resettlement, the environment, and the project's costs and benefits. They also allege the Supreme Court made the judgment based on false information submitted by the state governments.

Critics of the projects say that even to this day, years after the construction began, no survey has been completed for villages affected by the reservoir's backwaters. People who will lose land or livelihood due to the project's irrigation canal, compensatory afforestation, wildlife sanctuary, construction colony, and other dam-related infrastructure are not currently entitled to rehabilitation. Also, it is said that the already resettled people have suffered extreme economic hardships and psychological trauma. Many had been displaced under conditions of intimidation and physical violence by the authorities. Land of totally inadequate quality and quantity has been made available to the oustees. The NGOs are challenging the concerned authorities to produce master plans for rehabilitation with details of agricultural land, which could be jointly inspected to establish cultivability and adequacy for village-wise resettlement. However, the government of Madhya Pradesh (which is facing the largest submergence due to the project) has stated that there is no land available even to resettle oustees up to 90 m, and NGOs allege that the authorities are attempting to give cash compensation, avoiding allotment of agricultural land.

The Morse Commission, commenting on the public opposition wrote: "the opposition, especially in the submergence area, has ripened into hostility. So long as this hostility endures, progress will be impossible except as a result of unacceptable means." The opponents of the dam agree and say that the construction has only been able to continue because of the unacceptable and illegal flooding of villages and the repression of peaceful protests. If the dam is raised any further the protests will continue and repression intensified.

Sources: The Friends of Narmada; Narmada Bachao Andolan Press Releases.

Box 1. The controversy—the Sardar Sarovar Dam

The aim of this paper is to discuss environmental and social impacts of dam construction and how mistakes from the past can be rectified for better implementation of such projects. While acknowledging the vast benefits that can be derived from reservoirs, the discussion details the negative impacts, too, in order that these adversities are lessened and dam construction can be utilized as a positive development objective without hampering the well-being of the society, environment, and their interrelations. The discussion is far from exhaustive; however, references and other sources of information are provided where necessary.

2. Impacts of Reservoirs

The International Commission of Large Dams (ICOLD) defines large dams as dams with a height of 15 m or more from foundation to crest. Dams between 10 and 15 m also fall into this category if: crest length is over 500 m or spillway discharge over 2000 $m^3 s^{-1}$ or reservoir capacity is more than one million cubic meters.

At present, more than 45 000 large dams and an estimated 800 000 small dams regulate the world's rivers: some have been built to supply water including irrigation, control floods, provide for navigation, fishing and recreation, and importantly to generate electricity. The reservoirs have played an instrumental role in economic development; however, there has been growing controversy about the failure of these projects to address environmental and social concerns. Opponents of large dam projects claim that the benefits are outweighed by their environmental and social costs and the related direct and indirect economic concerns.

2.1 Benefits of Reservoirs

Hydropower is one of the least expensive sources of energy and most importantly a clean power source with relatively negligible production of noxious gases or solid and liquid wastes. The efficiency of a modern hydropower plant exceeds 90%, which is more than twice the efficiency of a thermal plant. Reservoirs are also a more reliable source of water supply for irrigation, domestic and industrial use. The reservoirs directly support many activities including fisheries, navigation, and recreation. Several examples of these benefits are given in Box 2.

Hydropower generation in the US—a clean and cheap source of energy

It is estimated that about 10% of US electricity is generated from hydropower, with approximately 77 000 MW of conventional capacity and 18 000 MW of pumped storage, producing over 300 billion kWh annually with further undeveloped capacity of about 30 000 MW. The equivalent of this to fossil-fueled generated power fired by oil, coal, or natural gas would be 520 million barrels of oil, 129 million tons of coal, or 3.16 trillion cubic feet of gas. Thus, if hydropower generation were completely replaced with coal-fired generation, there would be an increase of pollutants emitted to the atmosphere, including 7.7 million tons of particulates and 296 million tons of CO_2. That is, if the energy produced by hydropower were generated instead by coal, pollutants from coal would increase by 16%. In the US, only 0.6 cents per kWh is needed to finance the operation and maintenance of a hydropower plant and conversely 2.2 and 2.1 cents per kWh is required for nuclear and coal power plants, respectively. (Sources: USCOLD Newsletter, July 1996; EIA Annual Energy Review 1999, Energy Information Administration, US Dept. of Energy.)

Flood control in China

Flooding is one of the most serious problems that China faces, with about 70% of the land area vulnerable, and it also accounts for 40% of the total economic loss from all disasters. The Chinese government has made great achievements in controlling flooding (ranging from 20-year return periods to 100-year floods) with the construction of over 86 000 reservoirs reaching a total capacity of 450 billion m^3, 71% of which belongs to the large reservoirs. The total length of dikes amounts to 251 000 km, and the area of land protected by dikes reaches 34 million hectares.

(Source: Nanfang Zhoumou, August 8, 1998.)

Fisheries development in Citarum River, Indonesia

Floating-net aquaculture was introduced in Saguling and Cirata Dams (flooded area: 5340 and 6600 ha, respectively), West Java, as a new income-generating venture for displaced people. The ventures have been very successful in terms of fish production and generating new employment. The reservoirs were inundated during the second half of the 1980s, and by the end of 1997, the annual fish production from aquaculture cages from the two reservoirs exceeded 25 000 tons.

Irrigation in Sri Lanka

A major option for assisting project-affected people to become beneficiaries of dam construction is to incorporate them within irrigation schemes, such as during earlier phases of the Mahaweli Project, Sri Lanka, where resettlers and downstream hosts were given priority over all other categories. The economic welfare of the landless poor and small farmers in the Dry Zone in Sri Lanka was highly dependent on rainfall patterns. The timing and intensity of seasonal rainfall determine the degree and success of paddy cultivation, the mainstay of domestic agriculture. In parts of the Dry Zone where there were no major irrigation systems, paddy cultivation was limited to the main rainy season but even within this season, crops may not succeed unless water can be stored for later use during the crop period. Mahaweli Project, which was completed in the early 1980s, has contributed significantly to increased production and higher living standards for these farmers, with a reliable and streamlined irrigation network. By 1999, 142 329 hectares of lands were irrigated under Mahaweli Project and a further 195 328 hectares of land were fed by diverted Mahaweli irrigation systems. It is expected that a further 29 600 hectares will come under irrigation within the next few years with the implementation of the proposed Moragahakanda project. (Source: *Daily News*, January 9, 1999.)

Box 2. Some major benefits derived from reservoirs

2.2 Environmental and Ecosystem Impacts

There is a growing concern that dam projects cause irreversible environment change, which are often complex, multiple, and essentially negative. Artificial lakes profoundly alter the natural functioning of the entire ecosystem associated with them, ranging from altering flow regimes, changing water temperature and chemistry, modifying algal and macroinvertebrate communities, disrupting resident and migratory fish communities, altering channel geomorphology and sediment transport, and impacting the abundance and diversity of physical habitats. Rivers are longitudinally linked systems with processes occurring in the upper reaches impacting downstream reaches. In addition, processes occurring in the downstream reaches can impact upstream reaches as denoted by biophysical legacies (e.g., reduced gene flow, changes in community structure, and alteration of nutrient cycling). The disruption of these linkages by dams represents a significant disturbance to the entire ecosystem processes.

2.2.1 Effects of the Barrier Caused by the Dam

- The reservoir causes the suspended particles to settle, thereby limiting its storage capacity (e.g., Kulekhani hydro project, Nepal) and at the same time limits the flow of sediments downstream, which hampers agricultural activities on floodplains owing to limited nutrient-rich sediments. Decreased load of sediments carried by the river will cause scouring of the riverbed downstream.
- Disruption to species migration along the river (e.g., around 5–14% of the adult salmon are killed at each of the eight dams they pass while swimming up the Columbia River, Canada).
- Increased amphibian and bird populations and changes in patterns of faunal migration; disruption of habitats. (The Rosana Dam in Brazil destroyed one of the few remaining habitats of the black lion tamarin.)
- Entrapment of nutrients in the reservoir can lead to high eutrophication and subsequent excessive growth of aquatic weeds (e.g., Kotmale Dam, Sri Lanka) and low dissolved oxygen, which will be detrimental to fisheries (e.g., Saguling Dam, Indonesia).
- Deterioration of the water quality due to decomposition of flora and fauna, pollution from increased human activity including agriculture, recreation, and industries (e.g., Saguling Dam, Indonesia).

2.2.2 Alteration of the Natural Flow Patterns of Rivers

Impoundment by the reservoir will increase the water velocity immediately below the dam, reduce peak river flows, increase low flows, and totally eliminate the annual cycle of the discharge previously governed primarily by climatic factors. This has many implications for the environment.

- Impacts on quantity of water needed to maintain the downstream biological activity (e.g., dams built across the rivers that feed the Aral Sea have reduced its volume to about 25% of its 1960 volume); changes in floral and faunal community downstream (e.g., the population of the Kafue lechwe declined significantly following the construction of the Kafue Gorge Dam, Zambia); loss of wetlands (Delta Intérieure of the river Niger in Mali).
- Increased scouring of riverbeds downstream and bed degradation; increased coastal erosion (e.g., alteration of sediment flow along the river Volta after the construction of Akosombo Dam, Ghana).
- Changes in water quality downstream including physical parameters (e.g., impacts of 24 dams may have led to 2300 km of the Orange-Vaal River, South Africa, having a modified temperature regime).
- Narrowing of river channels and becoming overrun with vegetation.
- Less natural submergence for flood recession agriculture (e.g., Kariba and Cahora Bassa Dams on the Zambezi River); reduction in groundwater recharge and less removal of parasites by natural flooding (e.g., Bakolori Dam on the Sokoto River, Nigeria).
- Saltwater intrusion in estuary and further upstream (e.g., Lower Volta after the construction of Akosombo Dam, Ghana) and alteration of the salinity balance in

coastal regions, which alters the species distribution and productivity (e.g., effects of Aswan High Dam on the coastal waters of the Mediterranean).
- Reduced soil fertility and salinization of floodplains (e.g., Aswan High Dam).
- Disruption of spawning beds in shallow areas (e.g., Senegal River; Kainji Dam on the Niger, West Africa).

2.2.3 Indirect Effects of Reservoirs

- Negative environment effects due to construction activities.
- Habitat loss due to inundation (e.g., India has lost an estimated 479 000 hectares of forest land to various river valley projects between 1950 and 1975).
- Environment degradation due to increased human activities such as intensive agriculture, industries, and increased pressure on lands.
- Alteration of tectonic activity (e.g., Vougland Dam, France); changes in water tables—higher around the reservoir and lower downstream; frequent landslides (e.g., Clyde Dam, New Zealand); dam breaking (e.g., the Great Johnstown Flood in Pennsylvania).

2.3 Socioeconomic Impacts

Large dams have enormous consequences for people's lives and livelihoods, which include controversial issues such as displacement and resettlement. The opponents of dam construction argue that the social and economic consequences (and also environmental) of large dams are more far-reaching than those associated with other infrastructure projects because of the huge impact across time and space in both the ecosystem and in social, economic, and cultural structures. The impacts, both positive and negative, can be better illustrated in connection with the dam project cycle.

2.3.1 Pre-construction

The planning stage of a dam, whether construction proceeds or not, can take several years and may distract investors away from the area proposed to be flooded, thus depriving the community of any developmental activities. In addition, the psychological stress prevalent among the communities because of the imminent loss of their assets, the uncertainty and insecurity of the future, can be a real traumatic experience for the would-be resettlers. Although these issues cannot be quantified; social as well as the economic implications are significant.

2.3.2 Involuntary Resettlement

According to the World Bank, forced population displacement caused by dam construction is the single most serious counter developmental social consequence of water resources development. The displacement toll of the 300 large dams that, on average, enter into construction every year is estimated to be above four million people, with at least 40 million so relocated over the past two decades. The social cost of involuntary resettlement varies greatly between projects; however, a disproportionate number of oustees are tribal or landless people who in many instances were resettled with force and violence. The trauma of resettlement can be devastating as a result of weakened or dismantled social networks and life support mechanisms, thereby leading to loss of their capacity to self-manage. With extensive comparative analysis of resettlement issues related to dam construction, Cernea (1990) has identified eight risks that lead to social impoverishment: landlessness, joblessness, homelessness, marginalization, increased morbidity, food insecurity, the loss of access to common property, and social disarticulation. Scudder (1997) has added a ninth risk, which is the loss of resiliency.

However, resettlement can have positive impacts if well planned, but this takes time. Usually the second generation of the displaced community can realize the benefits of a successful resettlement with better utilization of the resources available to them. Provided that such communities are relocated with adequate compensation, new economic opportunities, and social benefits, they can exploit the new circumstances as a chance to strengthen their income-earning capacity and thus their living standards. The new settlement may provide upgraded infrastructure facilities and reduced exposure to natural hazards.

2.3.3 Construction

Reservoir construction projects demand large amounts of skilled and unskilled labor, which can benefit the surrounding communities. Although many of the dam construction projects promise to provide employment opportunities for local people, they often tend to be a minority of the labor force. For example, in Saguling Dam in Indonesia, not more than twenty-five resettlers were employed, and in James Bay Project in Quebec, less than 5% of the labor force were Cree Indians. Most of the local people seldom have the skills required by the contractors. Crash training programs seldom bring skills up to the required standards (e.g., Lesotho Highland Water Project). Moreover, contractors bring their own labor with previous construction experience; for example, on completion of Gezouba Dam in China, many of the 40 000 workers are expected to join the Three Gorges Dam Project. Opportunities also arise in material supplies, and small-scale businesses that cater for the new community; however, there is a possibility that such construction towns become “ghost-cities” after the construction is complete. A high incidence of sexually transmitted diseases and increasing spousal abuse and suicide have also recorded in a few cases (e.g., James Bay Project, Quebec).

2.3.4 Post-construction

The newly created reservoir can support numerous economic activities that generate employment for both local people and immigrants. However, the changes in the downstream flow patterns can severely disrupt economic activities and social organization downstream. Farming patterns on floodplains are severely affected and require irrigation water. Fish populations fall and the effects are felt even in the estuarine areas where the productivity can drop to extremely unacceptable levels. Economic activities and social organization in the downstream regions can therefore be disrupted with increased rates of out-migration, reduced agricultural productivity and hence land prices, and many other negative impacts. Loss of historic or cultural sites is another cause for concern that arises as a direct impact of reservoir inundation.

2.3.5 Health and Welfare

The large artificial lake created by the dam's reservoir provides a habitat in which water-borne diseases and parasites thrive. It is increasingly acknowledged that the spread and incidence of diseases such as schistosomiasis, Japanese encephalitis, and malaria is the direct result of large-scale water projects. For example, the construction of Akosombo Dam, Ghana, has created habitats in which insects, snails, and other animals, which serve as vectors for waterborne diseases, thrive.

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Biographical Sketches

Dr. Jagath Manatunge is a research associate at the Department of Environmental Science and Human Engineering, Saitama University, Japan. Early training in civil and environmental engineering at the University of Moratuwa, Sri Lanka, led to graduate work in water pollution control at the University of London and culminated at Saitama University following research on the broad field of limnology. His current research interests include socioeconomic aspects of man-made lakes with particular emphasis on technology transfer and diffusion, sustainable development of water resources, river and lake water pollution control. Currently he is conducting research on socioeconomic aspects of aquaculture development in three reservoirs in the Citarum River in West Java, and water pollution aspects. He has authored several papers on aspects related to lake and reservoir management. In 1999, he received a research fellowship from the Japan Society for the Promotion of Science.

Dr. Mikiyasu Nakayama is the Associate Dean and a Professor of the United Graduate School of Agricultural Science, Tokyo University of Agriculture and Technology. He received his BA (1980), MSc (1982) and PhD (1986) from the University of Tokyo. He served as a programme officer in the United Nations Environment Programme (UNEP) between 1986 and 1989. In UNEP, he participated in projects such as Zambezi River, Lake Chad, and the Mekong River. From 1989 to 1999, he was engaged in teaching water resources management and its international and environmental aspects at Utsunomiya University. He has been serving as an advisor/expert for several United Nations Organizations (UNEP, UNCHS, UNCRD, and UNU), and for Non-Governmental Organizations (IUCN and ILEC). He participated in UNEP's environmental management project for the Aral Sea between 1990 and 1992. From 1994 to 1996, he was seconded to the North African Department of the World Bank to focus on water resources management projects in Morocco, Tunisia and Iran. His research interests include environmental monitoring and management of river and lake basins with particular emphasis on application of satellite remote sensing data and use of GIS, environmental impact assessment methodologies applicable for involuntary resettlement due to dam construction and involvement of international organizations in management of international water bodies.

Dr. Tilak Priyadarshana is a researcher at the Department of Environmental Sciences and Human Engineering, Saitama University, Japan. He graduated from the University of Ruhuna in Sri Lanka and afterwards he continued his research for a Ph.D. at the Department of Civil and Environmental Engineering at Saitama University, Japan. His major interests include community ecology with major emphasis on aquatic ecosystems and how major ecological processes, such as competition (i.e., bottom-up forces), predation (i.e., top-down forces), and keystone species (i.e., intermediate, strong regulators, often in the middle of the food web) structure freshwater communities and in turn how these findings can be utilized to manage aquatic ecosystems. He is the author of several research publications on ecological restoration of lakes and reservoirs.