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ENVIRONMENTAL EFFECTS OF HYDROPOWER RESERVOIRS ON WILD MAMMALS AND FRESHWATER TURTLES IN AMAZONIA: A REVIEW

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ABSTRACT

Brazilian legislation only grants the necessary licenses to build hydroelectric plants (previous license, installation and operation licenses) if environmental impact assessment studies are carried out, and if mitigation and compensatory measures are taken. The formation of a reservoir causes natural habitat loss and significant alteration for wild terrestrial and aquatic mammals, and hydroelectric plants in Amazonia have affected ecological feeding and reproductive habitats of aquatic mammals and chelonians. Monitoring programs carried out in those reservoirs have shown mammals and chelonians fitting their feeding and reproductive behavior repertoire to the new habitat created by reservoirs. During the initial phase of implantation of the hydroelectric reservoir, terrestrial mammal species are taken out of their usual home ranges to already occupied areas, a phenomenon known as the dam's extended effect. The reservoir formed in an area previously without that body of water now has an influence on the phenological rhythms of the surrounding vegetation as well as altering the seasonal phases of the hydrological cycle (flood phase, drying phase, drought, and flooding phase) which aquatic mammals and freshwater turtles' movements fit in with, in function of food availability and appropriate reproductive habitats. Programs to monitor those animal populations can establish guidelines to mitigate environmental impacts by means of proper management procedures for conservation and sustainable use.
Keywords: Hydropower; mammals; monitoring; reservoir; turtles.

RESUMO

EFEITOS AMBIENTAIS DE RESERVATÓRIOS DE HIDRELÉTRICAS SOBRE MAMÍFEROS SILVESTRES E TARTARUGAS-DE-ÁGUA-DOCE NA AMAZÔNIA: UMA REVISÃO. A legislação brasileira condiciona as licenças prévia, de instalação e de operação de empreendimentos hidrelétricos impactantes, no roteiro dos estudos de impacto ambiental (EIA/RIMA), incluindo a identificação e a avaliação dos impactos ambientais e os programas de monitoramento inerentes ao plano básico ambiental (PBA) com o estabelecimento de medidas mitigatórias e de compensação por perda ambiental, conforme a legislação a cargo do Ibama (Instituto Brasileiro de Meio Ambiente e Recursos Naturais) e outros órgãos federais e estaduais. A formação de reservatórios causa perda e alteração de hábitats naturais para mamíferos terrestres e aquáticos, e as hidrelétricas na Amazônia têm acarretado efeitos nos hábitats alimentares e reprodutivos de quelônios aquáticos. Os programas de monitoramento nesses reservatórios têm mostrado ajustes de comportamento alimentar e reprodutivo de mamíferos aquáticos e de quelônios aos novos ambientes criados. Na fase de implantação do empreendimento, com a formação do reservatório, mamíferos terrestres são deslocados de suas áreas de vida para áreas vizinhas já ocupadas, pelo fenômeno que se convencionou chamar de efeito estendido de barragem. O reservatório, formado em área antes sem essa massa d'água, influencia o ritmo fenológico da vegetação de seu entorno, como também altera a sazonalidade típica das quatro fases do ciclo hidrológico (cheia, vazante, seca, enchente) com as quais mamíferos aquáticos e tartarugas normalmente sincronizam seus movimentos em função da oferta de hábitats alimentares e reprodutivos. O monitoramento dessas populações

animais pode estabelecer diretrizes para mitigar esses impactos por meio de medidas de manejo adequado com fins conservacionistas e também de uso sustentável.
Palavras-chave: Hidrelétrica; mamíferos; monitoramento; reservatório; tartarugas.

INTRODUCTION

Hydroelectric power generation is the most important source of electric energy in Brazil, responsible for about 80% of the energy produced (Balanço Energético Nacional 2010). Many hydroelectric plants are in operation in the country and many others are planned for different river basins, mainly in Amazonia. In addition to the great potential for hydropower resources to supply "clean" electricity for Brazilian socio-economic development, hydroelectric power production is largely free of the environmental contaminants that are produced by fossil-fueled power plants. However, the environmental costs of large reservoirs have been considerable, with loss of habitat and biodiversity. Flooding of habitats covered by vegetation causes the release of methane and carbon dioxide, but the effect of that is a function of the amount of vegetation flooded in addition to age and size of the reservoir (Ferrèr 2007). There has been a real conflict between human needs for socio-economic development and conservation of nature with protection of biodiversity. Reservoirs adversely impact wild mammal populations, both in their terrestrial and aquatic habitats, and in Amazonia they also have affected aquatic chelonians such as *Podocnemis expansa* and *P. unifilis*, both traditionally important socio-economic sources for local people (Alho 1985).

The greatest effects caused by building reservoirs are habitat loss and alterations with consequent impacts on biodiversity. Large reservoirs flood the land and alter river-associated habitats such as riparian vegetation. Water in reservoirs is usually stagnant (lentic) when compared to the running water of rivers (lotic), altering water quality with consequent effects on aquatic organisms, including aquatic mammal and other freshwater species. Additionally, the effect of a dam, which closes one end of the reservoir to store water for hydroelectric generation, alters the river' normal seasonal hydrological cycle (1- dry season or lower water; 2- rising water season; 3- wet season or high water; 4- falling phase or river discharge) impacting aquatic and freshwater turtle species, whose movements are synchronized with the normal flow of the river (Alho & Pádua 1982b). Thus, the reservoir can limit normal seasonal movement of aquatic species in search of ecological resources, due to the conversion of the seasonal pulse typical of river hydrology (alteration of river flow pattern) into a reservoir which retains water.

Because of emerging consciousness in our society, the environmental impact assessment of great hydropower projects has been vehemently discussed among governments, scientists, managers, the business community, politicians, NGOs and has gone through multistakeholder processes to reach an innovative partnership to license hydroelectric plants. For example, fiery debate has increasingly been seen in the news on the Madeira (Jirau and Santo Antonio) and Xingu (Belo Monte) river dams (Lestinge & Almeida Jr. 2009). In addition to habitat loss and the impact on riverine inhabitants, the discussion raised questions about how much river flow is necessary to ensure ecological sustainability, including natural flow quantity, seasonal timing, and water quality among many other ecological requirements.

The first impact on animals occurs as soon as the reservoir is filled up (Alho *et al*. 2000). In some cases the area of the future reservoir is cleared by removing some vegetation, with animal rescue. However, in a pre-filling phase, wild animals are pushed out of their home ranges and territories, moving into adjacent regions, due to the noise and alteration caused by people and machinery at work. The magnitude of this impact depends on the conservation status of the area where a future reservoir will be formed, as well as the size of the reservoir.

The construction of dams and the impact of the reservoir on biodiversity and other effects have been the focus of studies such as the one carried out by the World Commission on Dams (WCD 2000), supported by the World Bank and the IUCN (World Conservation Union), emphasizing the need to solve conflicts between the benefits of hydropower energy and the devastating effects on the environment and local human societies. To attenuate this conflict, a fair balance between the benefits and the adverse impacts has to be obtained through technical and scientific knowledge, information gathering and dissemination, high-quality reviews, and public hearings. In Brazil, one of the weak points is the lack of full implementation of plans, programs and projects to mitigate and compensate environmental loss, identified in the environmental impact assessment studies. On the one hand, the energy derived from hydropower is needed for socio-economic development, while on the other, the economic benefits must repay the financial costs of plans, programs and projects to deal with the negative effects of the dams through realistic means to protect biodiversity for the entire lifetime of the hydroelectric facility.

The aim of this study is to review the adverse impacts of hydroelectric reservoirs on biodiversity, taking terrestrial and aquatic mammals and freshwater Amazonian turtles as a paradigm for discussion. The study raises expectations for measurable ecological returns, in terms of real implementation of conservation units as a compensation for environmental loss, and wildlife management for conservation as a result of applied monitoring programs to mitigate adverse effects on mammals and turtle populations.

EFFECTS OF RESERVOIRS ON TERRESTRIAL MAMMALS

The area that a wild animal inhabits to fulfill its daily needs and activity has considerable ecological interest. Social contact, familiarity with the area, and social organization are factors that may influence the individual's daily activity, in addition to food gathering. The animal's home range is defined as the area in which an individual travels in its normal activity of food gathering, mating, and caring for young. The home range is usually a fixed residence of the animal or its social group. Within the home range there may be some actively defended territory (Alho *et al*. 2000).

In general, the size of home range is influenced by the kind of habitat the animal selects. Wild mammal densities are generally influenced by components of the habitats that affect the abundance and possibly the spatial and social structure of the populations. It is generally assumed that each mammal species occupies a range within the environmental gradient which may influence population size and behavioral interactions. Mammals actively select their habitat on the bases of environmental cues that offer suitable feeding and reproductive niches, among other needs. In addition, seasonal fluctuation of habitat resources depends upon the natural hydrological phases of the river where the reservoir dam is built. Thus, rescue and translocation of animals are not part of a regular routine to be carried out in hydroelectric plants, as discussed in the next sections. Animals are not moved into an empty space, but must fit into an existing biological context. This context implies occupied territories, already used home ranges, intra and inter competition for food, space and mate, behavioral interactions, carrying capacity based on offer of ecological resources, and so on (Alho *et al*. 2000).

When the river dam is under construction, the noise produced by machinery, light, presence of workers and other activities disturb wild animals, which will then try to escape to adjacent habitats. In addition, the formation of the reservoir displaces resident animals to nearby areas. A phenomenon known as the reservoir's extended effect affects mammalian species, which move from their original home range areas to adjacent areas already occupied by the same species. This phenomenon was studied by Sá during the filling up of the Samuel reservoir in Rondônia, Brazil, in 1995. During the initial phase of higher densities of animals in areas adjacent to the reservoir the competition for food, nesting sites and other ecological resources is tighter. Additionally, the phenomenon known in behavioral ecology as the principle of xenophobia makes free ranging individuals, without fixed home ranges, more vulnerable to be submissive in disputes with resident species for ecological resources, like available food, space and other vital requisites. The result is that soon the animals displaced by the effects of the reservoir will die or move to another area, the previous ecological densities will return, and the final result is the unsuccessful attempt of the displaced animals to establish themselves in another area.

The presence of the reservoir contributes to the negative impact of forest reduction with habitat fragmentation, which has been considered in the scientific literature as one of the most severe human-caused factors in habitat alteration and biodiversity loss (MMA 2003; Laurance & Bierregaard Jr. 1997, Laurance & Vasconcelos 2009). Environmental fragmentation alters the continuous vegetation cover into isolated fragments, with the following biological consequences:

- Forest reduction, impacting terrestrial species distribution with a consequent diversity loss.
- Shrinking of the habitat area for terrestrial mammals, since it decreases survival and reproductive indexes within a smaller area, resulting in tighter competition for ecological resources.
- Isolation in fragments of rare and endangered habitat-specialist species, generally requiring specific terrestrial and aquatic habitats of a high quality.
- Isolation in fragments of ecological communities, characteristics acquired as a result of the long evolutionary history of the region, whose species interact in such a way that they form a unit. The heterogeneous interacting ecological processes that govern that ecological community are disrupted by the process of fragmentation and habitat simplification.
- Loss of biodiversity due to the restrictions imposed by the previous processes described, with negative impact on flora and fauna, including genetic isolation of populations.
- Edge effect, with the sharp cuts in previously continuous forest, resulting in direct influence of wind and sunlight and other negative effects on wildlife, pushing animal species to the interior of the fragment, increasing ecological competition.

RESCUE AND TRANSLOCATION OF ANIMALS

Wild fauna rescue and translocation have been carried out over the past decades in Brazil while hydroelectric reservoirs are filled. Translocation consists of humans moving wild animals from one part of their distribution area to another site within this distribution range (IUCN 1987).

However this topic has been highly controversial. While there has been an effort to deal with the problem of saving the animals, there have also been claims that this procedure is unsuitable because rescued wild animals transplanted to adjacent areas already occupied by resident animals have no chance of thriving and will soon die. However, saving animal lives from flooding is desirable from the ethical point of view, particularly under pressure from the media, particularly TV news, and this operation is better than doing nothing. The latter would result in highly negative publicity for the hydropower enterprise. However, rescue programs should be carried out under rigorous scientific criteria. Thus, the animals that are rescued are high-profile species like the howler monkey of Tucuruí because they are mostly in the public eye, adopted by the media, passing on a protectionist message. The real ecological facts about conservation are complex, and they tend not to be addressed to the non-scientific public.

A scientific approach to rescued animals is one positive objective of operations (Fischer & Lindenmayer 2000). However, due to the number of animals involved in rescue operations, as shown at the Tucuruí reservoir (Alho 1988) death is the fate of most of the individuals rescued and transported to adjacent similar habitats, which animals are not familiar with. Ecological or environmental returns of animal rescue and translocations have been much questioned by the scientific community. Massive animal rescue and uncontrolled translocation is not a remedy for injured biodiversity; it is not a panacea for all troubles caused by negative environmental impacts; it is rather a kind of an aspirin solution. This is nothing more than propaganda and sensationalism and is perceived by the general public as achieving protection by saving and releasing wild animals. Scientific use for several purposes, including zoological collections for museums or other studies such as on parasitology, *ex-situ* conservation as live animals to be confined in zoological parks, should be applied to take advantage of the sudden offer of wildlife.

According to the report "Operação Curupira", the formation of the Tucuruí reservoir (2,230 km²) in 1985 involved filling up the hydroelectric plant's reservoir, with a dam in the Tocantins River in the state of Pará. As a result, thousands of wild animals were displaced from their home ranges and territories due to the inundation of forest habitats (Eletronorte 1985). In fact, the number of rescued animals in Tucuruí is impressive: about 300,000 animals were rescued from filling up the reservoir. Most of these animals are arboreal and tend to jump into the water during the sudden flooding of their forest habitats. Or they are terrestrial animals with low mobility and hence find it difficult to escape from flooding.

Among arboreal mammals, 28,925 common three-toed-sloths *Bradypus tridactylus* and 19,652 howler monkeys *Alouatta belzebul,* 11,935 two-toed-sloths *Choloepus didactylus,* and 9,935 porcupines *Coendou sp* were captured in the reservoir, escaping from the water (Alho 1988). Among slow-moving animals, there were 49,426 tortoises *Chelonoidis* formerly *Geochelone* (two species *Chelonoides carbonaria* and *Chelonoides denticulata*) and 9,731 armadillos *Dasypus novemcinctus.* In total, 102,370 mammals and 99,519 reptiles were captured in the reservoir being filled up (Alho 1988).

Several other studies confirm the large number of animals living in areas where a hydroelectric reservoir will be formed. An aerial survey carried out in the region of the Paraná River, in Brazil, where the reservoir of Porto Primavera hydroelectric was later formed, revealed high densities of marsh deer *Blastocerus dichotomus* (Pinder 1996). Later, rescue operations confirmed the large number of marsh deer living in that region.

In Mato Grosso state, in an area dominated by savanna vegetation (Cerrado), the animal rescue operation named "Operação Tapiti", of a dam reservoir in the Manso River, rescued 94 porcupine species (*Coendou prehensilis)* from a gallery forest that was flooded (Alho *et al.* 2000).

Some published work on mammal species threatened by filling a hydroelectric dam reservoir report the role of translocated animals being monitored. A health evaluation of translocated free-ranging primates from a dam reservoir in French Guiana revealed the animals' health status: infestation by ectoparasites (ticks, larvae of dipterous insects, fleas and lice) and endoparasites like *Entamoeba, Strongyloides and Trypanoxyurus* were common in fecal samples of howlers (Benoît *et al.* 2001). This study also revealed infestation by *Trypanosoma rangeli, Plasmodium brasilianum* and similar protozoa of *Trypanosoma cruzi.* This study shows the need for futher investigations on this topic.

Moreover, a review of 180 studies and a number of theoretical papers published over 20 years (Fischer & Lindenmayer 2000), on animal re-introductions, concluded that translocations where the objectives were to solve human-animal conflicts generally failed. According to this study, re-introductions have a chance of being more successful when the source population is wild, involves a large number of animals, and the cause of original decline is removed. This trend appears to apply to re-introduction programs to restore endangered species, like the one carried out in Poço da Antas Reserve, in Rio de Janeiro, Brazil, with the golden-lion-tamarin *Leontopithecus rosalia*, although in this case the source was captive-bred animals (zoo-born at the National Zoo, in Washington DC, USA). These animals went through a highly intensive training program before being released into their original habitats. Even in this case mortality is high (around 70%), since animals become disoriented in the wild, do not know how to get food, and are helpless in the presence of predators (Kleiman & Rylands 2008).

Monitoring after animal release in similar habitats is a requirement, especially long-term monitoring to figure out the real purpose of the translocation procedure. More data collection on this procedure is needed to discuss or qualify operational success in animal translocations from reservoir impacted wildlife. Therefore, rescue, reintroduction and translocation procedures are not projects for massive numbers of animals, as a solution for the enormous number of wildlife affected by the impact of filling the reservoir of large hydropower plants. Translocations have to be limited to research controlled monitoring projects. These focal projects are extremely technical and highly specific in order to furnish positive and negative scientific responses for animal translocations. Based on current knowledge and the negative results of previous massive translocations, an experimental phase is urgently required.

Monitoring translocated animals is important to verify the mortality rates among individuals and to test how much time marked animals need to establish a new home range. Monitoring translocated animals in hydroelectric projects by radiotelemetry has been carried out in some experimental field work (Neri *et al.* 1997, Ostro *et al.* 2000, Richard-Hansen *et al.* 2000, Rodrigues *et al.* 2001). Five black-tailed marmoset *Callithrix (Mico) melanura* (Primates – Callitrichidae) individuals were monitored by radiotelemetry as part of a project on translocated wildlife affected by flooding the Manso River reservoir in the state of Mato Grosso, western Brazil (Alho *et al.* 2000). Only one death was recorded among the translocated animals. Two pairs established their home ranges in the new area, after some exploratory behavior (Schneider 2001).

Concluding, Fischer & Lindenmayer (2000) recommend that the value of animal relocations as a conservation tool could be enhanced through: (1) more rigorous testing for the appropriateness of the procedure in each specific case, judging success or failure of potential relocations; (2) better monitoring after relocation.

EFFECTS OF RESERVOIRS ON SEMI-AQUATIC AND AQUATIC MAMMALS

The most common semi-aquatic mammals occurring in Amazonia are the large Rodentia, the capybara *Hydrochoerus hydrochaeris*, two Mustelidae, the freshwater otter *Lontra longicaudis* and the giant otter *Pteronura brasiliensis.* Common aquatic mammals are two Cetacea, the Amazon River dolphin *Inia geoffrensis,* and the tucuxi dolphin *Sotalia fluviatilis,* and one Sirenia, the Amazonia manatee *Trichechus inunguis*. Other mammal species with life history connected with water and so vulnerable to effects of dam reservoirs are marsupials such as *Chironectes minimus, Micoureus demerarae, Marmosops noctivagus* and *Marmosa murina.* Wild rodents strongly linked to habitats close to water are the semiaquatic *Nectomy squamipes* and the *toró* arboreal spiny rat belonging to *Echimys* genus, usually seen vocalizing on branches over the water of rivers and seasonal lakes. Large mammals also exhibit dependence on habitats near water, like the tapir *Tapirus terrestris.*

Semi-aquatic and aquatic mammals exhibit anatomical, physiological and behavioral adaptations to feed and reproduce in aquatic habitats. Therefore, environmental alterations caused by negative impacts on habitats potentially affect their feeding and reproductive habitats. For example, the freshwater otter *Lontra longicaudis* and the giant otter *Pteronura brasiliensis* rely mainly on fish as prey. As dam reservoirs usually affect ecological fish communities, any new way of life for mustelids requires radical changes in diet. These two species show a synchrony of dispersal movement with the hydrological regimen of the river, dispersing through the inundated forest and temporary lakes during the high waters, following schools of fish. Since dam reservoirs impact the normal hydrological flux of rivers, this consequently affects dispersal movements of otters to capture prey. The beginning of the wet season represents the stimulus that triggers the dispersal movement of the two mustelids to establish new feeding and reproductive habitats (Kruuk 2006). As semi-aquatic species the otters colonize terraces on the banks of rivers and lakes, territory which is strongly defended. Communal latrines are marked territories.

Other aquatic mammals include the two Amazon freshwater dophins, the tucuxi *Sotalia fluviatilis,* and pink dolphin *Inia geoffrensis* also exhibit dispersal movement synchronized with the hydrological regimen, following fish dispersal. In addition, these two cetaceans require good water quality to survive. The manatee *Trichechus inunguis* inhabits areas with a high density of aquatic floating vegetation, on the banks of rivers and lakes with quiet waters. Expansion and retraction of these habitats depend on the flooding and drying seasons, while in contrast reservoirs generally stabilize the seasons, impacting the manatees.

EFFECTS OF RESERVOIRS ON AQUATIC CHELONIANS IN AMAZONIAN RIVERS

The main negative impact of hydroelectric reservoirs on aquatic life is that they break seasonal hydrological flow with annual flooding of habitats. Water flow dynamics are altered by the river dam and its reservoir. Animal movement, dispersion and migration between flooded forest and river canal are limited by the presence of the reservoir, which represents a barrier to micro and macro animal movement and dispersion. Sedentary species are benefited at the cost of migrants. Riparian habitats slightly upstream of the dam will be submitted to a greater flood charge, while habitats downstream will experience less charge. These impacts affect physiognomies, phenological rhythms, feeding and habitats for animals.

Reservoir borders do not duplicate habitats similar to those that previously existed along the river due to differences such as those in lentic and lotic conditions, seasonal flooding and water quality. The lack of seasonal hydrological variation, the intensities of water supply and the use of water to generate electric power are some of the limitations. The reservoir usually causes negative impacts by reducing diversity and altering ecological communities of invertebrates, algae and aquatic macrophytes, fishes, aquatic birds and mammals, amphibians, aquatic chelonians and other organisms, which are important in the food chain. During the different processes of the implantation of the reservoir, a great amount of material, such as soil and sediments, is moved, with excavation, construction of roads, ports, canals, and the dam itself.

As a consequence of the movement of heavy machinery for the implantation of infrastructure to support the reservoir dam, an increasing degree of water turbidity is observed due to erosion and sedimentation, with reduction of photosynthesis of submersed plants and plankton algae. The reduced number of plants also reduces primary productivity, which affects secondary production, including fish and freshwater chelonians, due to the decrease in feeding habitats. In addition, the increase in sedimentation affects the degree of dissolved oxygen and the reduction of sunlight penetration in the water, decreasing the presence of bacteria that are important in the process of decomposition of organic material, such as leaves and dead plants.

Most importantly, the reservoir will transform a lotic environment into a lentic or semi-lentic one, promoting the alteration of community structure of phyto and zooplanktons, which will affect other aquatic organisms, including fish and chelonians. Among zooplankton species are Rotifera, Cladocera, Copepoda, Protozoa and other groups. The density of these organisms varies as a function of the hydrological regime of the river, which is altered by the presence of the reservoir dam (Rodrigues *et al*. 2009, Lansac-Tôha *et al*. 2009). Additionally, the bentonic macroinvertebrates (Porifera, Hydrozoa, Turbelaria, Olygocheta, Hiridinea, Insecta (including larvae and adults), Aracnida, Crustacea, Gastropoda and Bivalva) inhabit the deep substrate of environments such as tree trunks, pieces of wood, leaves, macrophytes, algae and others. The distribution of macroinvertebrates, which are important organisms in the food chain, is directly influenced by the water flux, substrate and the format and size of the reservoir. Macroinvertebrate species are usually taken as good indicators of water quality, particularly in lotic systems.

The hydropower processes of construction, particularly the reservoir dam, result in the degradation of key habitats of aquatic species, affecting feeding and reproductive habitats. The effects are expressed by negative impacts on adjacent seasonally flooded forest, which provides feeding habitats for many species during the high waters, and on seasonal beaches, during the dry season, as reproductive habitats for species, including the giant Amazon freshwater turtle *Podocnemis expansa.*

Three freshwater turtle species are ecologically and socio-economically important in the Brazilian Amazon due to traditional human consumption: the giant turtle *Podocnemis expansa,* the yellow spotted turtle or "tracajá" *Podocnemis unifilis,* and the six-tubercled turtle or "pitiú" *Podocnemis sextuberculata.* Other species occurring in Amazonian rivers and flooded areas include small species such as the "cabeça-torta" *Mesoclemmys gibba,* the mud turtle or "muçuã" *Kinosternon scorpioides,* the medium sized spotted-legged turtle or "aperema" *Rhinoclemmys punctularia,* the big-headed turtle or "cabeçudo" *Peltocephalus dumerilianus,* the "matamatá" *Chelus fimbriatus,* and the twist-necked turtle or "jaboti-machado" *Platemys platycephala.*

Turtles are ancient animals that evolved into shelled form over 200 million years ago. They have the following life history characteristics:

- Are slow growing animals that reach sexual maturity at an advanced stage of their life history and are long-lived animals.
- Show low recruitment indices due to high rates of predation on eggs and young.

Adult populations are extremely vulnerable to unsustainable hunting pressure due to human consumption. The capture pressure on nesting adults and their eggs occurs on nesting beaches during the dry season, but adults are also captured in their feeding habitats during the high water season. In Amazonia, the giant turtle *Podocnemis expansa* is hunted not only to obtain meat, but as part of the local way of life and traditional culture (Alho 1985).

Seven phases of turtle nesting behavior (Alho & Pádua 1982a) have been identified:

1. Aggregation of the reproductive turtle population in shallow water, prior to landing on the nesting beach.
2. Landing and reaching the nesting grounds.

3. Deambulation or beach exploration.
4. Excavation of the nests.
5. Laying;
6. Filling the nests.
7. Returning to the water.

There is a synchrony between the ebbing regime of the river and the movement of reproductive turtles from their feeding habitats and the nesting beach, where they aggregate to exhibit nesting reproductive behavior (Alho & Pádua 1982a). Turtles have their feeding habitat in flooded areas adjacent to riverbanks, including temporary seasonal lakes. They perceive the ebbing regime and move to the beach area. When the turtles reach the nesting beach, they remain offshore for 15 or more days with their heads out of the water and oriented toward the beach. This is the aggregation phase. After the water stabilizes at a lower level the nesting behavior starts. From evening through early morning, they move towards the beach, quietly and slowly emerging from the water in waves of approximately 20 females.

In addition to the giant turtle *Podocnemis expansa,* the yellow spotted turtle or "tracajá" *Podocnemis unifilis,* and the six-tubercled turtle or "pitiú" *Podocnemis sextuberculata* nest on the nesting beaches, locally known as "tabuleiros".

Habitat degradation is the greatest negative impact resulting from a dammed hydropower reservoir. The huge infrastructure necessary for construction of a dammed reservoir disturbs the nesting behavior of the turtles. The movement of boats on the river to transport building materials disrupts the dispersion movement of reproductive females. In addition, more people are attracted to the hydropower plant area, motivated by the offer of jobs, and consequent hunting pressure occurs. Nesting turtles are extremely vulnerable to noise and human movement near nesting sites.

The reservoir drastically alters two important habitats of the chelonians: the feeding habitats of the flooded forest and the nesting beach. While the giant turtle *Podocnemis expansa* is a river specialist, since it depends on the presence on a nesting beach to reproduce, the tracajá *Podocnemis unifilis* can adapt better to changes caused by the presence of the reservoir, since this species does not exhibit a communal reproductive behavior as does the Amazon giant turtle, and is also less demanding about reproductive niches, nesting in small spots along the banks of the lake (Alho & Pádua 1982a, b, Fachín-Terán & Vogt 2004).

The feeding habitat is degraded by alterations in the riparian seasonal flooded forest and riverine ecosystem that would normally offer ecological resources. This alteration is mainly expressed as changes in phenological rhythms of the alluvial forest. In addition, increased nutrient levels from nearby pasture run-off and treated effluent discharges, as well as the invasion of introduced species, all contribute to feeding habitat degradation.

Large Amazon turtles belonging to the *Podocnemis* genus feed upon plant leaves and fruits in flooded alluvial forest. Occasionally they can take advantage of dead fish and other animal remains left by predators at the bottom of the water. Part of the diet of *P. unifilis* involves the plants known as "maria-mole" *Commelina longicaulis*, "pimenteira-brava" *Polyganum acuminatum* and "corticeira" *Aeschymene sensitiva* (Portal 2002).

Huge dammed reservoirs being built along the rivers of Amazonia flood the selected habitats of all the above turtle species, causing irreversible changes in their natural processes or behavioral interactions that are essential for the species to perform dispersal movement, use of preferred feeding and reproductive niches to fulfill the ecological life requirements. Long-term monitoring activities within reservoirs are necessary to investigate how turtle populations are structured in the new environment, how they can find food and suitable sites to successfully reproduce. Sustainable use in reservoirs can be achieved, but management intervention to ensure target species survival in the newly formed environment is essential to understand their habits, ecosystem and population structure and dynamics.

High populations of freshwater chelonians, particularly the tracajá *Podocnemis unifilis,* may flourish in a hydropower reservoir if an accurate and careful management plan is applied to conserve the target species. This procedure involves a heavy reliance on manipulation of species and their habitats. It also includes changes in habitats to benefit the target species, sometimes bringing benefits to other aquatic chelonians. Building nesting sites in sand-banks is one of the procedures. Controlling eggs and young lost is another management measure to increase population size. Allocated efforts are necessary for nest protection, predator control, habitat restoration and to avoid overhunting.

Conservation action also includes a complex monitoring activity to maintain ecosystem processes in the new reservoir, in order to protect sustainable populations of the targeted freshwater turtle, as well as the whole biodiversity of the new environment. These actions are effective management procedures to achieve successful results in hydropower reservoirs. Furthermore, another effective action is to encourage local people to engage in the conservation project in order to empower neighboring human communities to take ownership and some responsibility for sustainable use and species protection.

Part of the income arising from a hydropower enterprise has to be set aside to guarantee the necessary funding for a long-term monitoring program to improve the management plan. In this way sustainable use and conservation of target species such as the tracajá *Podocnemis unifilis* and *P. expansa*, may be achieved and negative impacts reduced.

LESSONS LEARNED: EFFECTIVE MONITORING PROGRAMS AND SUGGESTIONS FOR SUCCESSFUL WILDLIFE MANAGEMENT FOR CONSERVATION

Lessons learned from the effect of previous hydropower plants on wildlife conservation are vital for the management of wildlife in the areas surrounding future plants. In this section I examine some of the lessons we learned in reviewing the research, monitoring, and evaluation efforts of projects and their effects on advancing knowledge dealing with adaptive management in the hydroelectric plants. However, the actual effectiveness of these approaches is still debatable. The objective here is to provide a balanced input between a reliable and efficient hydroelectric energy-producing system and protecting, mitigating, and enhancing wildlife conservation.

Rescued animals threatened by dam reservoirs may be used for scientific purpose. Many animal populations of different species will have their habitats destroyed when flooding of the dam reservoir begins. For example, knowledge derived from rescued animals is important to build reference collections in museums and universities to achieve biodiversity inventories, to carry out parasitological studies, to collect genetic material, to supply animals to zoological parks and private parks, and many other purposes that make the most of our rich wildlife. This objective was achieved in an approach carried out by scientific institutions with rescued animals as part of the project on wildlife affected by flooding the Manso River reservoir in the state of Mato Grosso, western Brazil (Alho *et al*. 2000). More than 150 invitations were sent to Brazilian universities, research institutions, zoological parks and biologists to take advantage of a well installed field work station to collect material for research. Live animals were also available, with all activities following pre-approved research proposals.

The energy industry, driven by the development of construction and operation of the hydropower plant, has been the most effective means of increasing local employment. However, the problem of immigrants attracted by the improved economic situation should be considered in the management plans.

It is agreed that there is a correlation between increasing human demography and degree of deforestation in the Amazonia. Since the hydropower plants attract more immigrants, more deforestation and habitat loss is expected within the area of influence of the plant. This tendency has been observed in hydropower plants and their reservoirs in Tucuruí, Samuel, Santo Antonio, Jirau, Dardanelos and others.

Scientific research, wildlife monitoring, and evaluation of the effects of the hydropower plant (the impacts identified and evaluated during the environmental impact assessment studies) are central to adaptive management and are the means by which the science and policy interface is informed to achieve biodiversity conservation. Monitoring of a given mammal species or freshwater Amazonian turtle allows researchers to know if expected outcomes are being realized, and this information can be used to adjust management actions, under the environmental impact being monitored, to adjust conservation needs for the focal species and its habitat. If desired outcomes are not being reached, project revision and corrections can be made to increase the likelihood of achieving desired results to conserve biodiversity under the impact of the reservoir.

There are intrinsic complexities inherent in research and monitoring, considering the magnitude of the adverse environmental impacts to which the habitats and their associated biodiversity are submitted, especially given limitations in project scope, finances, and skilled personnel, carried out under a relatively short period of time. In addition, it is not easy to condense advice into a simple set of management recommendations that apply to previous natural status, before the establishment of the identified environmental impacts, due to the dam and reservoir, in large and complex ecosystems, with interdependent relationships among non-living and biotic requirements.

The hydroelectric enterprises (including Eletrobrás), should provide funds to support wildlife monitoring and restoration projects through revenue from power purchase and earmarked revenue including that from the region's electricity consumers. These funds would support wildlife mitigation actions to compensate the environmental costs of hydropower plants, as defined in the Brazilian legislation, to fit into the assessment of effects of multiple management actions in large areas impacted by the hydroelectric plant. Financial provisions for wildlife monitoring and evaluation have been difficult to maintain through the funding process, in a medium/long-term activity.

Based on the last 20-year history of hydropower activities concerning wildlife conservation in Brazil, it is time to establish a review process, forming a committee to give recommendations, resulting in a sustained dialogue between government officials (Eletrobrás, Ibama, ICMBio), scientists, and wildlife managers about what constitutes appropriate research, monitoring, and evaluation project and programmatic levels, leading to improved monitoring program designs for the conservation of key species and ecological communities. Knowledge gained is essential for a proper policy to develop an optimum mix of management actions to achieve adaptive management.

Therefore, effective monitoring projects, dealing with the identified environmental impacts, to achieve management procedures for wildlife conservation, considering the lessons learned about hydropower reservoirs in Brazil, may be summarized as follows:

- **Effectiveness monitoring of mammal and Amazonian freshwater turtle species to achieve management actions for conservation.** This project activity provides data for monitoring of habitat and species requirements for feeding and reproductive niches and interactions in community structure and ecosystem requisites. The local data collected through monitoring activity can be used to draw conclusions about known regions concerning species distribution, habitat requirements, behavior, feeding and reproductive ecology, and other species characteristics. The methods of obtaining field data are well described in the literature, but lately Ibama has demonstrated preferences for RAPELD (*Rápida Avaliação de Pesquisas Ecológicas de Longa Duração*), a method for biodiversity surveys in long-term ecological research sites (PPBio 2010). The PPBio (Brazilian Biodiversity Research Program) is a survey project of the Brazilian Ministry of Science and Technology which employs the RAPELD method. Therefore, it is important, at first, to reach overall consensus on a proper sampling design for data collection, as well as data analysis and treatment for final interpretation and conclusion. The monitoring program has to answer the question about the adverse effects of the environmental impacts of the reservoir on the focal species and provide effective means to improve species conservation through management. This implies a broader approach, including community structure and habitat restoration. Thus, monitoring projects are considered effective if they are able to detect real overall effects of environmental impacts on wildlife target species. The scientific findings on the negative effects of the environmental impacts have to support management actions in order to protect the target species and restore its habitat.
- **Management action for conservation of target species.** Restoration efforts in the hydroelectric plants constitute a massive long-term attempt at ecosystem restoration. Monitoring mammal and freshwater target species, among other monitoring studies, are usually required by the Government authority (Ibama) before hydroelectric projects are authorized, and analysis of these studies may provide convincing specific results for the effects of the environmental impacts, mainly the negative role of the reservoir on wildlife. The analysis of multiple monitoring projects can suggest causal relations on effects of the impacts on wildlife. Therefore, scientific and technical interpretations of available data, provided by monitoring activities, will provide the guidelines for effective management action for

species, community and habitat restoration. The meaning of wildlife management here is perceived to be a technical-scientific procedure to be practiced in order to achieve biodiversity conservation. Thus, this focus has to be emphasized to make it clear that it does not involve financial gain from wildlife management, as is the case with game-management or socio-economic projects.

However, it is expected that under the persistent and permanent effect of some environmental impact, during the operation phase of the hydropower enterprise, these management actions will inevitably face limitations, and some species will be excluded from a previously pristine ecological community structure. Therefore, under persistent impact, simplification of community structure is expected in some areas under the influence of the reservoir. On the other hand, the creation of a conservation unit to compensate the irreversible environmental impact of the hydropower, which is stipulated in Brazilian legislation, can protect pristine biotic communities, if the protected area is under a well planned and implemented management plan.

In conclusion, these guidelines can accomplish successful medium/long-term monitoring programs to deal with effects of dammed reservoirs for hydropower plants, to achieve effective biodiversity conservation. Appropriate and intensive monitoring projects can be implemented to offset the effects of the reservoir on wildlife species. Thus, more efficient and pragmatic means may be found to put biodiversity protection into practice, in the context of large-scale construction and operation of a hydroelectric plant.

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