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CHAPTER 6

A Socioeconomic Analysis of the Effects from the *Loricariidae* Family in Mexico: The Case of the "Adolfo López Mateos" or "Infiernillo" Reservoir

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INTRODUCTION

When an exotic species becomes invasive, the consequences are generally negative; however, some positive effects are also possible. In this paper we explore the consequences of the introduction of fish from the *Loricariidae* family (loricariids) in Mexico. We analyze these effects in three areas: fishing activities, natural capital and the aquarium trade. The results of our analysis indicate that loricariids have negative effects on natural capital and on fishing activities, but positive effects on the aquarium trade—specifically the generation of profits. In summary, the impact from the introduction of loricariids translates into losses of nearly US $16.5 million annually.

Background

The aquarium trade is a productive activity that in Mexico has grown more than 100 percent during the last decade. It currently generates income above a billion pesos annually, figured in retail prices (Ramírez Martínez and Mendoza 2005)

Without a doubt, the most important period of expansion in Mexico's aquarium trade has been the last twelve years. The causes of this significant growth are basically related to two aspects: population growth, especially in urban areas, and the behavior of the economy (Ramírez 2007).

The economic crisis that upset the country in 1994 provoked a drastic decline in the importing of freshwater ornamental fish, and this affected the process of expansion that the aquarium trade was beginning to experience. Nevertheless, this situation allowed national producers of ornamental fish to expand significantly, given the increase in the demand and prices for these fish. This not only led producers to increase their production, but also to incorporate new fish varieties, including species from the loricariid family, commonly known as *plecos* or *peces diablo*. These fish, originally from the Amazon, Orinoco and Paraná Basins in South America, are in great demand among aquarists. They are believed to keep aquariums "clean," since they eat the algae that forms on the glass sides and on the objects found inside the aquarium.

The growth in production of freshwater ornamental fish also meant an increase in the ecological risks resulting from this type of production, especially from the release—accidental or intentional—of exotic species that can potentially turn into an invasive plague, causing serious environmental, economic and social damages. This is what happened with the loricariids in the Balsas River basin, specifically in the area of the "Infiernillo" reservoir (Ramírez Martínez 2007).

The profitable nature of the aquarium trade led to an uncontrolled increase in "backyard fish farms" that lacked appropriate safety measures and that dumped some species into the rivers when prices declined. This is how exotic species were introduced into freshwater bodies, with the risk of turning into a plague. They were dumped into environments similar to those of their origin, but without the natural enemies that would typically guarantee equilibrium in an ecosystem.

As mentioned, these fish originally from the Amazon were introduced into Mexico through imports, and aquarists began to raise them, especially in the state of Morelos, which is where the vast majority of the country's aquatic producers are located. Whether due to neglectful practices or whether these fish were intentionally dumped in freshwater bodies when the prices offered were very low or when the fish could not be sold, what we know for certain is that loricariids reached the Balsas River, and without their natural enemies, they became a highly dense population that soon displaced a number of species native to the river. Since the Balsas River flows into the "Adolfo López Mateos" reservoir, also known as the "Infiernillo" Reservoir (Chapter 5), the loricariids entered the reservoir and turned into a plague, intensifying an already-existing crisis affecting tilapia fishing. Problems due to the overexploitation of tilapia fish had been experienced for several years. In addition, due to a particular behavior of loricariids, in which they dig into the shoreline to build their nests (Mendoza *et al*. 2007), certain problems in the environmental characteristics of the reservoir had begun to appear, such as murkiness in the water and also erosion.

The purpose of this paper is to determine the economic and ecological effects—both positive[21] and negative—from loricariids on fishing activity, natural capital and the aquarium trade.

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[21] The reference to "positive" effects does not signify that loricariids are intrinsically beneficial, but rather that there is an area of commerce that generates profits that can be quantified.

The primary effects on fishing activity include losses in man-hours, as well as deterioration of fishing gear. The effects on natural capital include deterioration of water quality and shoreline formation. In the case of the aquarium trade, effects are determined on the basis of an analysis of the volume of loricariid sales, considering both national production and importation.

Effects on Fishing Activities

The "Adolfo López Mateos" ("Infiernillo") reservoir, completed in 1963, was artificially constructed for the purpose of generating electricity, with an installed capacity of 624,000 kilowatts (Orbe-Mendoza 2007). Reservoirs not only fulfill the primary objective for which they were built, but also serve as sources of food for family consumption and of commercial activities (Orbe-Mendoza *et al.* 1999). Fishing activities in the "Infiernillo" reservoir began only a few years after its construction, specifically at the beginning of the 1970s. With the aim of generating an opportunity for the economic development of nearby communities, government authorities decided to introduce commercial fish species in the reservoir, including some types of *mojarras* and carps. The idea was that these new species, together with the native species of the Balsas River such as the Balsas catfish (*Ictalurus balsanus*) and Balsas *mojarra* (*Cichlasoma istlanum*), would lead to a significant scale of fishing activity in the area.

Fishing activity in the reservoir began in the 1970s, and gradually increased. By 1987 it was the water reservoir with the greatest fishing production in Latin America. That year 18,953 metric tons of tilapia and 4,888 metric tons of carp and catfish were caught. However, such production intensity was already near the maximum sustainable level (Jiménez-Badillo *et al.* 2000).

After that year, fishing production began to decline, primarily due to the overexploitation of tilapia. The catching of immature fish and the uncontrolled increase in fishing activity (measured in the total number of fishing nets used) had such an impact that by the year 2000, the total annual production had decreased to only 7,356 metric tons of fish, including 1,699 metric tons not officially registered. In other words, production for that year represented only 30 percent of the 1987 production level.

When fishermen catch immature fish (during their first stage of maturation), this has a negative effect on the average size of the fish population, which in turn has a negative effect on the price at which these fish can be sold. Here it is important to mention the case of the Chinese tilapia, which is the most competitive in markets and supermarkets due to its low price and large size, and because it has passed quality controls and has an appealing visual appearance.

Figure 6.1 illustrates the evolution of fishing activity from 1981 to 2003 (Orbe-Mendoza, 2007). As we can see, most of the fish caught were tilapias, which replaced both carp and catfish. In fact catfish are not even considered in this analysis, since the amount caught by fishermen was so minimal.

We can also see in this graph that beginning in 1988—the year that fishing activity passed the maximum sustainable level—the amount of fish caught began to decline. In the case of tilapia, the most important commercial species in the reservoir, the amount of fish caught in 1997 was less than half of the amount for 1987.

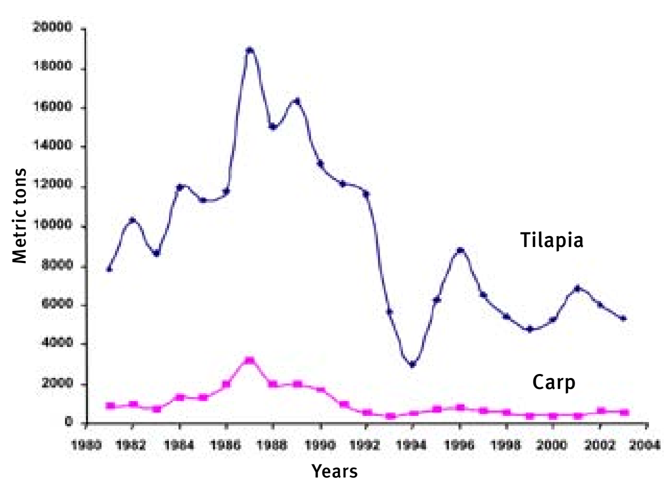
Loricariids began to appear in the reservoir in 1998, and beginning in 2001 there was an increase in their proportion of the total fish caught.[22]

Another factor that permitted the proliferation of loricariids is eutrophication, since the phosphorous content of the system, plus the poor quality of the water in the reservoir and the water temperature (between 20 and 30 degrees centigrade) create an environment that is difficult for other types of fish to live in (Mendoza *et al.* 2007 and Escalera Gallardo and Arroyo Damián 2005).

Loricariids have brought negative effects on fishing activity in the reservoir. Their bone structure of hard spines damages fishing nets, and some fishermen damage their hands when they try to free these unwanted fish from their nets. This can lead to wounds and even tetanus, however the fishermen insist they are protected against this risk through vaccination campaigns organized by the National Defense Secretariat (*Secretaría de la Defensa Nacional*—Sedena). The negative impact is also felt in the number of additional hours required to catch the same number of fish caught before the loricariids appeared, and there is also additional expense for extra fuel.

To obtain information, interviews were conducted with a group of fishermen from the La Huacana, Churumuco and Arteaga municipalities located around the reservoir (in the state of Michoacán).[23] One of the main results indicates that each of the fishermen inter-

Figure 6.1: Evolution of Fishing Activity in "Adolfo López Mateos" Reservoir



Source: Orbe-Mendoza 2007.

[22] Data provided by Carlos Escalera.

[23] Interviews conducted by Carlos Escalera and Miriam Arroyo, September 2007.

Table 6.1: Basic information on fishing

Type of information	Minimum value	Average value	Maximum value
Nets per fisherman	20	40	50
Price per net (between 30 and 40 meters long)	P$220	P$240	P$250
Government assistance (Number of nets per year)	3	4	5 5
Fishing days per week	5	5	5
Fishing days per year	260	260	260
Price per kg of small tilapia	P$4.00	P$4.00	P$4.00
Price per kg of large tilapia	P$7.00	P$8.00	P$10.00
Liters of fuel consumed per fishing trip	5	6	8
Number (approx.) of fishermen	3,000	3,000	3,000

viewed possesses between 20 and 50 fishing nets—violating official standards[24] that stipulate a limit of only five nets per fisherman. The average length of the nets used by the fishermen interviewed is 60 meters, although in La Huacana it is only 30 meters. Orbe Mendoza (2007) states, however, that in Nuevo Centro each fisherman has between 20 and 90 nets and in Churumuco between 8 and 30 nets. Thus, the average number of nets used is likely higher than that concluded from the interviews conducted for this chapter. Other basic information on fishing is presented in Table 6.1.

This table provides the results of field interviews conducted by Carlos Escalera in the La Huacana, Churumuco and Arteaga municipalities in the state of Michoacán. The prices for tilapia are those offered for fish right off the boat. Fishermen are out on their boats five days a week, and they receive government assistance through three to five fishing nets provided free-of-charge to each fisherman every year. The average value is presented for each type of information, as well as minimum and maximum values.

Table 6.2 presents the effects from loricariids since their proliferation in the reservoir.

It also presents average values and indicates the intervals between minimum and maximum values. From this table we can infer that the greatest damage to fishing activity caused by loricariids is in fishing nets, since before the appearance of these fish, nets could last between one and three years, and currently they only last between three and six months (20–30 percent of the previous average life). This means that nets must be replaced a number of times a year. Another impact is manifested in the number of hours dedicated to fishing, since before, fishermen were out in their boats between five and seven hours a day, and since the appearance of loricariids, the amount of time has increased to between seven and nine hours a day. This translates into lost hours that could be used for other productive activities or for leisure time.

With regard to the daily catch of tilapia, we find that between 200 and 500 kilos were previously registered daily, however currently this amount has decreased to only 70 kilos. This translates into losses in fishermen's permanent income. Also, they report that the proportion of small tilapia is 70–80 percent of the total net catch, with the remaining corresponding to medium-size tilapia.

An interesting finding is that fishermen do not report additional fuel costs since the appearance of the loricariids. In interviews they explained that since the reservoir is not very wide where they fish, they do not have to go very far to reach the shoreline, where they

Table 6.2: Effects on Reservoir Fishing Since the Appearance of Loricariids

	Before proliferation of loricariids			After proliferation of loricariids		
	Minimum value	Average value	Maximum value	Minimum value	Average value	Maximum value
How long nets last, in years (months)	1 (12)	2 (24)	3 (36)	0.25 (3)	0.33 (4)	0.5 (6)
Hours of fishing per day	5	6	7	7	8	9
Daily catch of small and large tilapia (kg)	200	300	500	30	50	70
Daily catch of small tilapia (kg)	140	225	400	21	38	56
Daily catch of medium-size tilapia (kg)	60	75	100	9	12	14

[24] See Mexican Official Standard NOM-027-PESC-1999, which regulates fishing in the reservoir, in Semarnap 2000.

Table 6.3: Total losses in fishing equipment

Number of fishermen	Minimum value	Average value	Maximum value
3,000	-P$48,096,000	-P$72,000,000	-P$86,400,000

throw out the loricariids, and in fact, many fishermen simply throw these fish back into the water.

The exact number of fishermen is unknown. The number of members in fishing cooperatives is reported at slightly over 2,000 fishermen, plus a considerable number of fishermen are independent—nearly 40 percent of the total number registered in cooperatives (Orbe-Mendoza 2007). So for our purposes here, we have used an estimate of 3,000 fishermen.

Losses in fishing nets

Losses in fishing nets are calculated as the difference between the previous and current total values of nets purchased annually. Because of the way the formula is structured, the values will be positive. For our operations here, we have calculated minimum, maximum and average values. Findings indicate that on the average a fisherman must spend an additional P$24,000 (nearly US $2,200) per year on nets, or between P$16,032 and P$28,800 (between US$1,400 and 2,600). This represents a very significant loss if we look at the total amount for all fishermen. Table 6.3 presents the total losses in fishing nets for overall fishing activity.

This table indicates that the average total losses in fishing nets vary between P$48 and P$86 million. These are significant amounts if we take into account that fewer fish caught signifies a financial blow to an economic activity that is already in a downturn.

It is important to emphasize that the number of nets needed could be reduced by approximately 9 to 12 per year if fishermen would work only from 6:00 a.m. to 3:00 p.m., and if they would not leave their nets out during the night, since the nighttime habits of loricariids make the nets vulnerable to damages.[25] This compliance with standards would signify a reduction in losses of between P$4,500,000 and P$6,500,000 annually. Nevertheless, due to the volume of loricariids caught, the losses in fishing nets will continue to exceed P$40 million.[26] Calculated based on the NOM-017.PEC-1999 (Araceli Orbe, personal communication).

Because of the eutrophication process in the reservoir and the overexploitation of its resources, a practical solution would be to enforce the recommendation to respect the standard that stipulates a maximum of five nets per year per fisherman. This would also contribute to diminishing the serious losses in fishing equipment. The government assists fishermen by providing each of them with between three and five nets per year, however due to the overuse of nets and the reduction in their useful life, this assistance is insufficient.

Table 6.4: Losses in hours worked per year

Number of fishermen	Annual Losses
3,000	-P$13,622,700

Losses in hours worked

In Tables 6.1 and 6.2 we can see that before the appearance of the loricariids, the number of hours worked daily per fisherman ranged from five to seven hours. It is common in this zone to work five days a week, or a total of 260 days a year. Since the appearance of the invasive species in the reservoir, the new workday ranges from seven to nine hours a day, signifying two extra hours worked per day. Even with this increase, the number of fish caught is not as high as the number typically caught before the appearance of the loricariids. If we consider the current minimum daily wage in this zone, which is P$69.86,[27] and an eight-hour workday, then we can calculate the hourly wage for each fisherman at P$8.73. The results indicate an annual loss of P$4,540.90 per fisherman. And if we multiply this figure by the total number of fishermen, we arrive at the amount of total losses per year as indicated in Table 6.4.

Table 6.4 reflects the loss in productivity per worker resulting from the proliferation of loricariids. Unlike the case of losses in fishing nets, we cannot see a direct solution in this category for diminishing the negative impact from the invasive species.

Losses in the fish catch

After loricariids were introduced in the reservoir, the amount of fish caught decreased by more than half (see Figure 6.1). This phenomenon has occurred, first of all, because when fishermen use more nets than those permitted and leave them out at night, the number of loricariids caught in the nets increases (with the resulting damage), thereby reducing the probability of catching fish that can be commercialized. Other factors include the competition from loricariids for resources and nesting sites, as well as the accidental swallowing of tilapia eggs by loricariids. Since most of the commercial fish caught are tilapia (approximately 90 percent of the commercial catch, according to the historic series), the decision was made to calculate the losses in the fish catch based on the decrease in tilapia fishing. Our results should therefore be considered a partial (minimal) amount of the total value of the losses in the commercial species caught.

On the basis of the interviews conducted, we learned that the proportion of small tilapia caught represents 70–80 percent of the total tilapia catch, with medium-size tilapia at 20–30 percent of the total.

Our results indicate that since the introduction of loricariids in the reservoir, every fisherman loses between P$200,000 and P$580,000 per year in the decreased amount of fish caught. The overall losses corresponding to the total number of fishermen are presented in Table 6.5.

[25] A comment made by Carlos Escalera, based on sampling conducted in the reservoir.

[26] Calculations based on NOM-017.PEC-1999 (Araceli Orbe, pers. communication).

[27] Data obtained from the National Minimum Wage Commission (*Comisión Nacional de Salarios Mínimos*) http://www.conasami.gob.mx, corresponding to zone "C." For the purposes of this study, calculations are made using this amount, since a minimum wage has not been established for fishermen, and the objective is to obtain at least a minimum value of loss. The wages established by Conasami are daily wages, and therefore hourly wages are calculated by dividing daily wages by eight hours (the number of numbers in a normal work day). As indicated earlier, fishermen report working two hours more than they used to, since the proliferation of loricariids.

Table 6.5: Losses in the tilapia catch

Number of fishermen	Minimum value	Average value	Maximum value
3,000	-P$649,740,000	-P$978,120,000	-P$1,744,080,000

We can see in this table that the losses in the commercial fish catch range from P$650 million to P$1.7449 billion per year. These amounts illustrate that fishing was previously a very profitable activity in this reservoir. Nevertheless, *the entire loss is not attributable to loricariids*. Tilapia fish have been overexploited in this reservoir since the late 1980s, and also, this is a man-made reservoir, and thus it has a shorter life than a natural reservoir.[28] In addition we need to consider the eutrophic conditions characterizing this reservoir.

In order to arrive at the proportion of the total loss that can be attributed to loricariids, it would be necessary to use an econometric model that establishes a direct relationship between the following two variables: the *number of tilapia caught* and the *presence of loricariids in the reservoir*. Unfortunately, in this case it is not possible to estimate such a model, since not all the needed information is available.

Losses in fuel

Based on interviews conducted with fishermen, it was determined that the presence of loricariids has not generated additional fuel expenses. Those interviewed explained that when they catch loricariids, they dump them on the shoreline or just throw them right back into the water. We might expect that they would spend more time and fuel in traveling to the shoreline to dump the loricariids; however, the fishermen say they are generally only a kilometer from the shoreline, and they consider any additional expense in time and fuel to be minimal.

Losses in health status

Because of the particular bone structure characterizing loricariids, there is a high probability that fishermen will suffer injuries to their hands when they work to free the fish from the nets, and this can cause illnesses such as tetanus, which if not treated, can lead to death. The risk of acquiring tetanus can be prevented by receiving the corresponding vaccination once a year, at a cost of between P$50 and P$150. However, the fishermen typically protect themselves by taking advantage of the vaccination campaigns sponsored every year by the federal government through Sedena, allowing them to be vaccinated at no cost. The fishermen say they have been receiving tetanus vaccinations since before the loricariids appeared in the reservoir, since accidents with the spines on catfish, carp and tilapia fish are common. The total cost of prevention can be obtained by multiplying the cost of a single vaccination by the number of fishermen (see Table 6.6).

Table 6.6: Cost of preventing tetanus in fishermen

Number of fishermen	Minimum value	Average value	Maximum value
3,000	P$150,000	P$225,000	P$300,000

Since the purpose of using this vaccine is to prevent tetanus—which can be caused by the spines on loricariids, carps, catfish or tilapias—and we are unaware of the relative probabilities of tetanus being caused in relation to each of these species, we can divide this cost equally among the four species. In this case a fourth of the total cost for the vaccine would correspond to loricariids, specifically between P$37,500 and P$75,000 annually. Here we should keep in mind that this cost is assumed by the federal government, which thus avoids the costs involved in treating the illness, as long as prevention efforts keep fishermen from becoming ill and from losing days of work from this illness.

Changes in household structure

The minimal profit from fishing has obliged fishermen to seek other alternatives in productive activities such as agriculture and commerce. Given the inhospitable conditions in this region, however, changing economic activity is not a simple matter, and more than 40 percent of fishermen have been unable to do so (Escalera Barajas 2005). As a result, national and international migration is increasingly frequent. Since it is often the male head of the household who emigrates to seek work elsewhere, women are entering the labor market, opening a micro-business of their own, or it is even common to see women doing the fishing.

The structure of households is altered when men are absent, and when women enter the labor market and are no longer dedicated to caring for their children. In some cases, however, the amount of remittances sent by the men who are working elsewhere is enough to maintain the household economic structure unchanged. For some families, migration is also an alternative way to "accumulate capital," with remittances used to start up a business or finance the purchase of capital goods, such as motorboats or pickup trucks for transporting merchandise.

Beyond economic aspects, migration brings other changes such as the empowerment of women. In the absence of their husbands, women take charge of their households and make decisions regarding their children's education and the way family income is spent. It is believed that women are more efficient than men in distributing income among the various needs of households. On the basis of this principle, for example, the *Oportunidades* government program provides economic assistance to households according to the number of school-age children, and the assistance is given directly to mothers,[29] in order to prevent fathers from spending the money on items other than their children's education.

Economic alternatives for using loricariids

As already mentioned, loricariids have negative effects on fishing activities. However, partial compensation for these damages is possible through an alternative for using loricariids. In the search for a profitable use of this species, the National Council for Science and Technology (*Consejo Nacional de Ciencia y Tecnología*—Conacyt) is currently financing a project for using loricariids in the production of surimi, and in the extraction of collagen and digestive enzymes. The final study on this project includes an assessment of the profitability of this alternative use of loricariids.

[28] Dr. Roberto Mendoza, personal communication.

[29] For more information, please consult **http://www.oportunidades.gob.mx**.

In addition, Carlos Escalera and Miriam Arroyo of CIIDIR-IPN-Michoacán are conducting a study on using fishmeal from loricariids to feed tilapias.[30] One of the preliminary results from the study indicates that tilapias fed fishmeal made from loricariids grew to a larger size than tilapias fed commercial fishmeal.

Orbe-Mendoza (2007) reports that loricariids are used for human consumption in Brazil, and explains the way in which they are cooked. However, a warning about this kind of use had been provided by Chávez *et al.* (2005), who found an accumulation of heavy metals in the loricariids in *Laguna de Bay*. Nevertheless, these results cannot be generalized since each ecosystem has its own particular characteristics. For example, in the study on using fishmeal from loricariids, researchers did not find an accumulation of large amounts of dangerous metals in the fish from the reservoir. However, they did not analyze mercury content, and consequently, the most advisable option is to use loricariids initially only for animal consumption, while an analysis is conducted to assure there is no bioaccumulation.

Actually, communities located around the reservoir are already consuming loricariids in ceviche and soups. The problem here is that loricariids have a bony layer that makes them more difficult to handle than other fish such as tilapias. However, communities are beginning to experiment with baking loricariids in solar ovens, and after a few minutes in the ovens, the bony layer can be more easily removed.

Effects on Natural Capital

Initially, the field of economics only considered capital (machines), work (labor force) and land as the factors involved in production. Also, some of the negative effects from productive activities were not taken into account in economic analyses. For example, the possibility that exploiting forests to commercialize wood could affect air quality was not considered, nor was the fact that wastes dumped by factories into water bodies could kill not only fish but also the human beings who consumed products contaminated by those wastes. In reality, the deterioration and pillaging of natural resources was not of great concern in economics, since this field of study was based on the principle that only that which has a market has value, or in other words, only what can be bought and sold has value.

This posture changed in the mid–20th-century when a group of scholars became aware of the importance of ecosystems—not only because of the value of their use, but due to their function as regulators of climatic factors.

Georgescu-Roegen (1971) introduces the concept of entropy to demonstrate the negative effects from the overexploitation of natural capital. This concept establishes that energy is conserved in quantity, but deteriorates in quality, and in this way leads to a phenomenon of progressive disorder. This author and others (Pearce *et al.* 1990, Dasgupta *et al.* 1979) are giving shape to a new vision of ecological economics that includes natural capital as a fundamental part of economic processes.

In ecological economics, as much importance is placed on the problem of environmental contamination as on poverty or epidemics—and in fact the links between these phenomena are acknowledged. One of the ways to analyze environmental problems from an economic viewpoint is to study natural capital.

This analysis is based on knowledge of the economic activity that generates the goods and services that society is interested in. It is pointed out that technology and capital (physical, human and natural) are used in the production process. Natural resources and the environment are included in the concept of *natural capital*. And the sum of the three types of capital represents the total capital.[31]

Each generation's capacity to fulfill its own goals, such as reducing poverty, will depend on what it can produce with the wealth of capital it possesses (the combination of the different types of capital). This capital is composed of the capital inherited from the previous generation plus what it is able to generate. If we want to assure that the next generation will have the same standard of living as that enjoyed by the current generation, *we need to pass on the same total capital per capita* (Pearce 1993).[32]

This would seem to be a simple rule. However, the problem is that economic activity is frequently associated with a decrease in natural capital. For example, the use of detergents in washing gill nets is a contributing factor in the contamination of the reservoir's water. In reality what happens is that one type of capital is increased at the expense of another: natural capital. How can we know what the net effect is? Stated another way: At what point is the principle of sustainability violated?

We can identify two basic ways in which this principle is violated:

1. By consuming all the natural capital. When all that is gained in natural capital is consumed, or in other words, when no amount of natural capital is saved or invested, this clearly indicates an unsustainable path. It is like having an investment account in a bank, and every year withdrawing a part of the principal, plus all the interest generated. Clearly, if nothing is reinvested, the account will soon be reduced to zero. In the same way, if a fishing community catches more fish than what is permitted in terms of sustainability, and furthermore, if it catches immature fish, it will deplete the foundation of fishing resources in the long term, and it will also deplete the fishermen's source of income.

2. By reinvesting natural capital in human or physical capital, without achieving an equivalent value. When what is gained in natural capital is reinvested in manufacturing or human capital, a more complex situation emerges. In this case the key lies in evaluating the degree to which one type of capital can be substituted with another. For example, it would be important to analyze what would happen if the community mentioned above would use its income from fishing to build roads, or to buy the machinery needed to install a plant for making fishmeal, or to acquire some type of technical training that would enable community members to generate income from a different type of activity to compensate for the loss in its wealth of fishing potential.

The substitution rate varies according to whether there is more of one type of capital than of another. For example, when there is a lack of manufacturing capital, it is a good idea to invest part of one's profits in this type of capital. Eventually, after having ac-

[30] The final product of this study will be the Master's thesis developed by Miriam Arroyo on sustainable agricultural production.

[31] Three other types of capital frequently mentioned in the literature are financial capital, social capital and political capital.

[32] This rule of constant capital is known as the axiom of weak sustainability in sustainable development literature.

cumulated a greater amount of manufacturing capital, it becomes more important to invest in natural capital. For a community with a wealth of fishing potential but with limited financial resources—and the Churumuco municipality is an example of this—it is a good idea to begin to invest part of the returns from fishing activity in more modern fishing techniques. Nevertheless, there will come a time when improved fishing equipment will be useless if the entire fish supply has been depleted. Consequently, it is necessary to reduce the amount of fish caught, in order to increase the biomass for the future.

It may be that in some cases there are no possibilities for substitution. It is argued that all types of natural capital have critical levels, and when they are surpassed, irreversible losses and even catastrophic events can be provoked (Rees 1994; Daly 1989; Meadows 1993). Nevertheless, it is not necessary to wait until a natural resource reaches a critical level before deciding to conserve that resource and assure that investments are made. It is enough to have a basic conviction of the importance of investing in such a resource.

A basic rule of sustainability can be drawn from these ideas: *to maintain total capital at a constant level, while taking care to never allow natural capital to be reduced beyond its critical levels.*

The more physical and human capital there is, the greater the relative value of natural capital, since when the market functions adequately, the value of this relative scarcity of natural resources will be eventually manifested in increased prices for these resources. These increases will serve as signs that will lead to the conservation of natural capital and investment in maintaining this capital. Nevertheless, the problem with natural resources and the environmental services derived from them is that frequently *the market does not function adequately.* This means that the signs indicating the need for their conservation and maintenance are not generated, and thus are not perceived by those who make decisions regarding their use. There are basically two sources of these distortions: market failures and failures in government policies.

Natural capital and its valuation

It should not be necessary to stress the importance of the environment for the positive functioning of not only the economy but the overall society as well. In economics, we can analyze the wealth of an ecosystem in terms of the environmental goods and services it generates. For example, mangrove swamp ecosystems fulfill very important functions as natural barriers against hurricanes and as vital areas for shrimp production. The way that environmental services are classified varies, however the primary services that are typically considered are the following:

- Carbon sequestration
- Soil fixation
- Water filtration
- Regulation of gases
- Regulation of nutrients
- Habitat for plants and animals
- Landscape resources

The main problem in measuring environmental goods and services is the absence of markets for their negotiation, and consequently, the lack of explicit prices assigned to these goods and services. In effect, there are no markets for the majority of the uses and functions of ecosystems, or such markets are only in the early stage of development. No one purchases water filtration services, and the carbon sequestration market is in its very early development. These are not goods that are bought and sold like cars, nor are these services that can be sold like the advice given by a lawyer or like a haircut.

A product without a market has no price, and consequently the development of environmental economics has been focused on establishing the value of the benefits provided by the environment, on the basis of not only the values of its direct use (activities within the ecosystem) but also the values of its indirect use (effects outside the ecosystem). For the case concerning us here, the values of indirect use would be services provided by the reservoir, such as carbon sequestration, shoreline formation, and water quality. It is also important to consider the value corresponding to the existence of the ecosystem's species, or in other words, the value of these species based on the simple fact that they exist. This set of values forms part of the total economic value of a particular environmental good or service.

Generally speaking, environmental valuation methods have their limitations. Even so, the calculation made offers the best approximation of the "price" of an environmental good or service, and assigning a minimum possible value can assist in decision-making.

There are various methods that can be used in environmental impact valuation:

- Direct valuation methods
- Substitute markets/goods methods
- Contingent valuation methods
- Travel cost method
- Avoided cost method
- Benefit transfer methods

For the case we are addressing here, the decision was made to calculate the valuation of the environmental services provided by the reservoir, such as carbon sequestration, water quality and the value of the species inhabiting the reservoir, and then to calculate the effects of loricariids on these environmental services.

It is important to mention that calculations are based on the inter-bank exchange rate effective October 1, 2007, at 10.90 pesos to the dollar.

Carbon sequestration

Carbon sequestration consists of conserving the inventories of this element in soil, forests and water bodies. Carbon is sequestrated during respiration and photosynthesis processes in plants, and these processes are important because they contribute to the regulation of atmospheric gases. Given the current context of global warming, the storage of CO_2 in soil, vegetation and water bodies is especially important.

Chmura *et al.* (2003) conducted a comparative study in various parts of the world (Mexico, United States, Australia, and other countries) and found that specifically in Mexico, freshwater bodies sequester an average of 146–194g C/m^2 per year, and in some mangrove swamp areas such as *Laguna de Términos*, even more than 300g C/m^2 per year is sequestrated.

To estimate the economic value of carbon sequestration, it is necessary to use the price at which a metric ton of carbon is valued. Adger *et al.* (1995) has calculated the total economic value for Mexico, using the global opportunity cost and a price of US$20 metric ton/C. Pearce (2001) considers the price to be US$10 metric ton/C. For the purposes of this study, it was decided to use the range from US$14.43 to US$47 metric ton/C, as calculated by Tol (2005). In his study, Tol reviews more than 20 studies conducted in different countries on carbon sequestration, and he arrives at this particular range as a result of a number of robust statistical exercises.

According to Orbe-Mendoza (2007), the water surface area of the "Infiernillo" reservoir varies between 14,000 and 30,000 hectares. In order to avoid the risk of overestimating carbon sequestration, the calculations in this study are based on a value of 14,000 hectares, as if no fluctuations were registered. Based on these figures, and considering a range of sequestration between 146 and 194g C/m^2 per year, the value of annual average carbon sequestration fluctuates between P$3,214,946 and P$4,271,915.

Since carbon sequestration services are associated with the problem of global warming and the markets for environmental services that receive greenhouse gases, it is necessary to observe what takes place with the cycles of other gases. According to Gunkel (2000), it is common in lakes that tend to be eutrophic (such as the "Infiernillo" reservoir, according to Orbe-Mendoza 2007) to find the production of gases such as methane and butane. It is also known that the presence of certain species impacts biogeochemical cycles, and loricariids are one example of this (Flecker *et al.* 2002). In addition it is necessary to consider the already mentioned behavior of loricariids in relation to the bottom soil in water bodies (Mendoza *et al.* 2007, Hoover *et al.* 2004). Specifically, when they stir up the soil in their search for food, they disrupt the vegetation—which is the source of carbon sequestration in the water. In addition, the action of removing sediments from the reservoir's bottom makes the water increasingly murky, and this affects the process of plant photosynthesis. However, since we lack even an estimate of the approximate total loricariid population, we are unable to calculate the exact proportion of the loss in carbon sequestration in the reservoir. In order to calculate this effect, it was decided to use damage rates of 1, 5 and 10 percent.[33]

Table 6.7 provides the values of the losses of carbon sequestration that can be attributed to the presence of loricariids in the reservoir.

Table 6.7: Losses in carbon sequestration attributed to loricariids

Percentage of loss	Annual amount (Low)	Annual amount (High)
1%	P$32,149	P$42,719
5%	P$160,747	P$213,596
10%	P$321,495	P$427,191

As we can see, the low value appears to be conservative, while the high value seems exaggerated. However, as long as we do not have an estimate of the size of the loricariid population in the reservoir, it will be difficult to establish the precise value. In addition, the reservoir is very large, and we do not know which areas of the reservoir may be experiencing the greatest damage from the invasive species, although it is believed these may be the shallowest areas. At any rate, the values specified should be considered as minimum estimates.

Water quality

This concept is related to the amount of available water, and the quality of this water, in ecological and environmental terms, for use by humans as well as animals and plants. It is important to mention that wetland systems can be used instead of traditional treatment plants, since they are less expensive and promote the removal and assimilation of chemical substances that are beneficial for the environment (Breaux *et al.* 1995, Kazmierczak 2001, Day *et al.* 2004).

The chemical composition of water bodies is a factor that limits or favors the systems' biological productivity—which in turn determines the trophic interactions that occur there (Fretwell 1977).

In order to calculate a valuation of water quality, it is necessary to determine a price per hectare for the body of water. In the United States, this exercise was carried out by Kazmierczak (2001), who reviews various studies and arrives at the value of US$567/acre/year. Breaux *et al.* (1995) calculate a minimum value of US$785/acre/year, while Lant and Roberts (1990) obtain a value of between US$39 and US$44 acre/year. Due to the considerable difference between the average incomes in the United States and Mexico, we have used the latter figures in the current study.

Based on these figures, we calculated a value of between P$14,705,708 and P$16,591,055 for the reservoir's water quality.

As indicated previously, the way that biogeochemical cycles function is associated with physicochemical and biological factors. In other words, the composition of soil, water and the atmosphere is influenced by the presence of different species.

According to Hoover *et al.* (2004) and Flecker *et al.* (2002), when loricariid populations dig their nesting holes, they increase the water's murkiness, producing significant changes in the water's levels of dissolved nitrogen. This means that loricariids are agents that negatively impact the quality of environmental services provided by the reservoir's water; however, it is necessary to clarify something here. Loricariids are not the only source of contamination for this resource. As mentioned previously, all artificial reservoirs have a limited life, and it appears that this reservoir has already been eutrophic for a considerable amount of time.

The Churumuco municipality, with more than 10,000 inhabitants, dumps its wastewater into the reservoir, negatively affecting the water quality. In addition fishermen wash their fishing nets with detergent one or more times a week, and this is another source of contamination due to the chemical substances contained in the products used. The fishermen argue that tilapias can distinguish dirty nets and avoid them.

[33] We consulted with Dr. Roberto Mendoza regarding the use of these values.

Table 6.8: Losses in water quality attributable to loricariids

Percentage of loss	Annual amount (Low)	Annual amount (High)
1%	P$64,944	P$108,240
5%	P$324,720	P$541,200
10%	P$649,440	P$1,082,400

The three effects described (wastewater generated by the general population, detergent residue from net washing, and the murkiness caused by loricariids), together with the discharge of agricultural products that wash into the Balsas River and flow into the reservoir, generate an unfavorable environment for the proliferation of commercial fish species and facilitate the multiplication of loricariids.

The damage to or loss of water quality is calculated using the *replacement cost technique*, which determines the amount necessary for water quality to remain at the levels specified in Mexican Official Standard NOM-012-SSA1-1993. Thus, if we consider the most widespread technology in Mexico for denitrification (specifically, oxidation lagoons and ventilation in tanks with anoxic and aerobic phases), we find that the costs for treatment in a system with a capacity of between 3,785 and 25,740 m^3/d range between P$0.66 and P$1.10 per liter/day, with the removal of as much as 94 percent of ammonia and 70 percent of nitrates. Given that the reservoir has a total capacity of 9,840 cubic meters of water (Conagua 2006), a clean-up process with the technological described here would cost between P$6,494,400 and P$10,824,000. And the value of the loss in water quality provoked by the three unfavorable conditions addressed here could be estimated within this same range.

The problem is that we do not know the proportion of this damage attributable to loricariids. So, as in our calculations for carbon sequestration, we will assign a damage level of 1, 5 or 10 percent. Table 6.8 indicates the values of the loss in water quality due to loricariids. As before, these figures should be considered to be minimum estimates.

Shoreline formation

Shoreline formation services are related to the prevention of wind erosion, run-off, swells, the absence of vegetation and other processes in which subsoil is removed (Costanza *et al.* 1997).

The erosion of shorelines has environmental consequences, such as habitat destruction, increased murkiness of water and the release of nutrients such as nitrogen. Loricariids dig their nesting holes along the edges of lakes, and in the process, they dig up material that turns into sediment, and when there are many nesting holes, the shoreline erodes. Flecker *et al.* (2002) found that loricariids erode a strip of shoreline between two and four feet wide each year. They also demonstrate that in addition to moving sediment, loricariids accidentally swallow eggs of native species. Walker (1968) also stated that mud and silt feeding could result in resuspension of sediments and/or changes in substrate size. Novales-Flamanrique *et al.* (1993) point out that the *Plecostamus* provide additional nutrients by excretion and by sediment stirring besides the huge amount of sediment removed by armored catfishes during their nesting activities (hundreds of tons in the Wahiawa reservoir) (Devick *et al.* 1988). Nevertheless, loricariids are not the only agents responsible for the erosion of shorelines, since wind, inadequate slopes and the absence of surface aquatic plants also play a role in this process. Gestring (2006) questions the erosion values obtained by Hoover *et al*. (2004), and proposes that only between 25 and 40 percent of erosion is caused by loricariids. He also indicates that the repair cost is US$40 per foot of repaired shoreline.

The "Infiernillo" reservoir's shoreline is approximately 120 kilometers long (Escalera Barajas 2005). Its depth is highly variable, and ranges between 30 and 70 meters (Orbe-Mendoza 2007). For the purposes of obtaining a minimum estimate, we used a depth of two meters, which corresponds to a value of at least P$343,307,098 from soil formation.

To calculate the loss of soil caused by loricariids in the "Infiernillo" reservoir, both the minimum values from Gestring (2006) were used—with an erosion rate of 0.15 m—as well as those from Hoover *et al.* (2004)—with an erosion rate of 0.6 m. In the first case the loss caused by loricariids came to P$51,496,065, and in the second, P$205,984,259. In their calculations of minimum values, Gestring considers an erosion rate of 0.15m, and Hoover, 0.6m. Results indicate that according to Hoover's values, the loss of soil caused by loricariids comes to P$205,984,259, and using Gestring's values, it comes to P$51,496,065.

Despite the large difference between the two estimates, both are over P$50 million. Thus, we can conclude that the damage to shoreline formation caused by loricariids is considerable.

Losses in fauna

We have been able to corroborate the damages caused by loricariids to the environmental services provided by the "Infiernillo" reservoir, although the data is insufficient to establish a correlation between the presence of this invasive species and detrimental effects on fishing activity. There is consensus, however, in the literature specializing in this area regarding the changes to biogeochemical cycles caused by exotic species, as well as the behavior of these species as competitors and predators of native species. And it is agreed that the damage caused is beyond what might correspond to competition for food and space (Hastings *et al.* 2006).

The loricariids are causing negative effects for the Balsas catfish (*Ictalurus balsanus*) and Balsas *mojarra* (*Cichlasoma istlanum*), but the extent of these effects has not been established. Local communities place a very high value on these two species, due to their taste, market price and traditional use.

It is important to remember, however, that the Balsas catfish has also been displaced by the tilapia. The problem is that we cannot precisely identify the extent of the negative impact on the Balsas catfish caused by loricariids and that caused by tilapias.[34] Independently of the precise extent of the damage, we can say that loricariids are the most damaging invasive species in the reservoir, and they compete with the Balsas catfish for resources and nesting areas, affecting them directly.

[34] For further substantiation of the potential of locariids to negatively affect resident fish populations, see the earlier section on "Environmental Impact Potential."

Table 6.9: Summary of effects attributed to loricariids

Effects on fishing activity	[P$]
Losses in nets	-$48,000,000
Losses in hours worked	-$13,623,000
Losses from diminished fish catch (we will use 10 percent here)	-$65,000,000
Losses in health status	-$150,000
Subtotal 1	**-$126,773,000**
Effects on natural capital	
Carbon sequestration	-$32,150
Water quality	-$64,945
Shoreline formation	-$51,495,000
Loss in fauna	-$79,185
Subtotal 2	**-$51,671,280**
Effects on aquarium trade	(unknown value)
Gross Loss	**-$178,444,280**

One option for establishing the values corresponding to the existence of native species is to use a contingent valuation method, which provides us with a minimum estimate for the value of these species. It is important, however, to use this method carefully since this valuation frequently depends on the degree to which there is familiarity with the species in question. In other words, there is a certain degree of subjectivity involved in this method. However, since we do not have access to a better method, it can at least provide a ballpark figure, or an initial step toward obtaining a reference value.

Since there are no studies in Mexico on the existence value of catfish or carp, the decision was made to use the value of US$21 per acre, obtained by Roberts and Leite (1997) through contingent valuation of fishing resources and habitat in lakes and wetlands in the state of Minnesota. The size of the "Infiernillo" reservoir is 14,000 hectares, and therefore the calculated existence value comes to P$7,918,458. This is the value of the fishing resources corresponding to native species, and it may be diminishing, however we cannot be certain of the degree to which loricariids are responsible. If we consider values of 1, 5 and 10 percent losses of habitat caused by loricariids (similar to our exercise with carbon sequestration), then the values of the loss would be between P$79,184 and P$791,846 (between US$7,200 and US$72,000).

Effects on Aquarium Trade

The aquarium trade emerged as an industry in Mexico in the 1950s, when the first commercial farms for raising ornamental fish were established and when the first public aquariums were created. It was also during this period that Mexico's first association of aquarium business owners was formed (Ramírez Martínez and Mendoza 2005).

By the early 1970s, only five people were registered as dedicated to commercially raising ornamental fish in aquariums and tanks. During this period, freshwater ornamental fish were sold in pet stores and neighborhood markets. It is estimated that annual sales amounted to US$500,000, with an increasing tendency due to growing demand. The value of ornamental fish imported in 1973 was approximately US$21,000 (INP 1974, cited in Ramírez Martínez and Mendoza 2005).

Over the last 12 years, the aquarium trade in Mexico has demonstrated an average annual growth rate of just over 10 percent, signifying an accumulated growth of more than 100 percent. Currently, approximately 35 million fish are sold throughout the country, with an annual value of US$140 million (retail prices) (Ramírez Martínez and Mendoza 2005). The number of fish imported has risen to approximately 12 million fish each year, and 10 percent of them are loricariids.[35]

Nevertheless, the rapid growth of the industry of freshwater ornamental fish production also brought an increase in the ecological risks represented by this industry, including the intentional or accidental release of a large number of organisms into natural aquatic environments, with the possibility of becoming invasive aquatic species. Thus, the development of the aquarium industry in Mexico has provoked negative effects in aquatic environments throughout the entire country, and this situation has been intensified by the lack of adequate normativity. Currently, the country lacks regulatory measures for requiring producers and those who buy and sell these fish to develop infrastructure that is adequately designed and operated, and for implementing biosafety measures to avoid the ongoing escape of non-native species into the natural environment (Ramírez Martínez and Mendoza 2005).

Loricariids are among the ten families of freshwater ornamental fish with the highest import and sales volumes in Mexico, specifically: *Cichlidae*, with 107 species; *Characiidae*, with 64; *Anabantidae*, 12; *Pimelodidae*, 11; *Aplocheilidae*, 13; *Conaitidae*, 15; *Callichthyidae*, 24; *Loricariidae*, 20, and *Cyprinidae*, 27 (Álvarez and Fuentes 2004, cited in Ramírez Martínez 2007).

[35] Comments made by Carlos Ramírez

Commerce with loricariids can be quantified at minimally 1,200,000 fish per year (as mentioned earlier, loricariids represent 10 percent of total fish imported). Nevertheless, it is important to note that data is lacking on the volume of commerce with loricariids of national origin.[36] This information is difficult to obtain, due to the illegal commerce of loricariids caught in the wild in various water bodies in Mexico. The illegal sale of loricariids caught in the wild negatively affects the sale of fish raised in aquariums and sold by legally established businesses. In order to arrive at an estimate of the value of commerce with loricariids, it would be necessary to conduct a market study that includes both interviews with the primary wholesale traders and an analysis of illegal trade.[37]

Summary of Effects

After reviewing the various possible effects from loricariids on the "Adolfo López Mateos" reservoir, it is important to determine their total combined value.

Table 6.9 summarizes all the effects from a conservative perspective (using minimum values in each category), and presents a gross value[38] that takes into account all the losses in natural capital and fishing activities.

Table 6.9 indicates that the gross losses derived from the presence of loricariids in the "Infiernillo" reservoir amount to P$178 million, or approximately US$16.4 million.

It is important to take note that these figures need to be reviewed, since some of them, such as those on shoreline formation, may be overestimated due to the considerable differences, in this case, between Churumuco, Arteaga and La Huacana (the municipalities where the reservoir is located) and Florida (the US state corresponding to the erosion rates used for calculations). Nevertheless, the results from this study offer an initial assessment of the problems arising from the introduction of loricariids in the Balsas River basin (specifically the "Infiernillo" reservoir) and can serve as a basis for other studies on invasive species.

[36] Comments made by Carlos Ramírez

[37] Ibid.

[38] Since it has not been possible to obtain the total income obtained through the use of loricariids (necessary for calculating a net value of the losses derived from the introduction of this species), the results of the current study correspond to gross values.