Commission for Environmental Cooperation Commission for Environmental Cooperation Trinational Risk...

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Trinational Risk Assessment Guidelines **for Aquatic Alien Invasive Species**

Test Cases for the Snakeheads (*Channidae*) and Armored Catfishes (*Loricariidae*) in North American Inland Waters

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In Memoriam

The authors and the CEC Secretariat dedicate this report to the memory of Dr. Salvador Contreras Balderas†, 1936 - 2009

Disclaimer

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Preface

There are few environmental issues that are as well documented as the impacts of alien invasive species. The movement of people, commodities and their conveyances through international commerce has increased the risk of movement of these unwanted organisms. Although many non-native species provide great benefits to society as a whole, a small subset of them, once established, causes significant and often irreparable damage to the native ecosystems and economies of their new host countries. When the Joint Public Advisory Committee (JPAC) expressly advised the CEC Council to focus cooperative work on issues related to Alien Invasive Species, the Trinational Alien Invasive Species Project was set in motion.

Canada, Mexico, and the United States all have extensive experience in addressing alien invasive species. Most of the earlier work had been directed toward those alien invasive species that impacted human health and agricultural resources. Less emphasis had been placed on those whose impacts were restricted to the continent's pristine ecosystems. On what aspect of alien invasive species behavior and interactions with indigenous species would the CEC focus? Clearly, there was need to ensure that the work undertaken was not being done elsewhere (to avoid redundancy) and that what would eventually be produced through the CEC was relevant and consistent with the needs of North America's environmental resources as a whole. Whatever the CEC did, it also had to be accomplished within a reasonable time and within the available budget.

Consensus was quickly reached that two issues had to be addressed before relevant work on alien invasive species could be started under the CEC. The first was to determine the gaps in current international protection coverage and the second was to agree upon an evaluation process that the CEC could use to address specific alien invasive species. To address the first issue, the Trinational Aquatic Alien Invasive Species Working Group[1] needed to determine what the CEC was willing to take on. A review of the major gaps in North American regulatory coverage of invasive species showed that animal species falling outside the jurisdiction of the animal health organizations were not currently being addressed elsewhere and represented a significant gap in alien invasive species regulatory coverage. The movement of live plant material, both aquatic and terrestrial, was also identified as a serious gap. Because of the latter gap, an agreement was reached with the North American Plant Protection Organization (NAPPO) that they would take charge of closing the plant and plant pest gaps and the CEC would focus on those pertaining to animals. This arrangement helped to ensure that there was no duplication of international effort and that an existing gap in AIS coverage was being addressed by the CEC.

To address the second issue, the Working Group agreed to draft CEC Trinational Aquatic Invasive Species Risk Assessment Guidelines. Clearly, future trinational CEC risk assessments would need to incorporate mechanism ensuring that all three countries used the same risk approach, and organized and presented their data in a similar way. The Working Group looked at a number of different risk assessments techniques and processes but chose the "Review Process" developed by the Aquatic Nuisance Species Task Force (ANSTF) in the United States as their starting point (ANSTF 1996). The review process uses available information and puts it into a format that can be understood and used by risk managers or policy makers. Another plus of using the ANSTF Review Process as a basis for the draft CEC Risk Assessment Guidelines was that it had already been tested on a number of organisms under real world conditions. In addition, it was written to be easily understood by all interested parties (especially important in international work). It also had the added plus of meeting the requirements of the various international trade conventions and agreements.

A decision matrix was created to help guide the Working Group in choosing the appropriate test subjects. Each of the three countries identified three taxa that were perceived as threats to its environment and these were discussed in an open forum between the three countries. Canada agreed to focus on the snakehead fishes while Mexico focused on the armored (suckermouth) catfish risk assessment. It was also agreed that the Working Group would conduct two limited economic studies on the impacts of the armored catfish. The Infiernillo Reservoir in Mexico and peninsular Florida were chosen as evaluation sites for addressing the socioeconomic impacts of these catfish populations. The United States compiled the first draft of both the Canadian and Mexican risk assessments for the CEC Secretariat.

Although the purpose of these assessments and economic evaluations was to test the CEC Risk Assessment Guidelines, some individuals may be tempted to use the assessments for other purposes. The Working Group believes that although the assessments contain sound, usable information, they were not intended to be as detailed, as comprehensive, or involve the level of resources and time that would be required for a national regulatory decision to be based on them. It is the consensus of the Working Group that these assessments did indeed show that the Risk Assessment Guidelines should be adopted by the CEC. However, the field of risk analysis is evolving quickly and the CEC Risk Assessment Guidelines need to be flexible enough to accommodate new methodologies and processes as they become available. These assessments are thus a good starting point but are not intended as the final word for national regulatory action.

It is rare to be involved in a multi-national project in which all members are so motivated and in which the identified goals so unanimously held. It was my pleasure to be part of the CEC Trinational Alien Invasive Species Working Group, and to all who helped make this a memorable project, I wish to convey my deepest thanks.

Richard Orr
National Invasive Species Council (retired)
20 December 2007

[1] The Trinational Alien Invasive Species Working Group includes experts from DFO in Canada; Conabio, Semarnat, and UANL in Mexico; and the National Invasive Species Council in the United States.


1

CHAPTER 1
Trinational Risk Assessment Guidelines for Aquatic Alien Invasive Species

Richard Orr (1) and Jeffrey P. Fisher (2)*

INTRODUCTION

In 1993, Canada, Mexico and the United States signed the North American Agreement on Environmental Cooperation (NAAEC) as a side agreement to the North American Free Trade Agreement (NAFTA). The NAAEC established the Commission for Environmental Cooperation (CEC) to help the Parties ensure that improved economic efficiency occurred simultaneously with trinational environmental cooperation. The NAAEC highlighted biodiversity as a key area for trinational cooperation. In 2001, the CEC adopted a resolution (Council Resolution 01-03), which created the Biodiversity Conservation Working Group (BCWG), a working group of high-level policy makers from Canada, Mexico and the United States. In 2003, the BCWG produced the "Strategic Plan for North American Cooperation in the Conservation of Biodiversity." This strategy identified responding to threats, such as invasive species, as a priority action area. In 2004, the BCWG, recognizing the importance of prevention in addressing invasive species, agreed to work together to develop the draft CEC Risk Assessment Guidelines for Aquatic Alien Invasive Species (hereafter referred to as the Guidelines). These Guidelines will serve as a tool to North American resource managers who are evaluating whether or not to introduce a non-native species into a new ecosystem. Through this collaborative process, the BCWG has begun to implement its strategy as well as address an important trade and environment issue. With increased trade comes an increase in the potential for economic growth as well as biological invasion, by working to minimize the potential adverse impacts from trade, the CEC Parties are working to maximize the gains from trade while minimizing the environmental costs.

Objectives of the Guidelines

The objective of the Guidelines is to provide a standardized process for evaluating the risk to biodiversity of introducing aquatic non-indigenous organisms into a new environment.

The Guidelines provide a framework where scientific, technical, and other relevant information can be organized into a format that is understandable and useful to managers and decision makers. The Guidelines were developed to function as an open process with early and continuous input from the appropriate scientific and technical experts.

The Guidelines were designed to be flexible and dynamic enough to accommodate a variety of approaches in evaluating the invasive potential of introduced aquatic species depending on the available resources, accessibility of the biological information, and the risk assessment methods available at the time of the assessment. The Guidelines may be used as a purely subjective evaluation, or be quantified to the extent possible or necessary, depending on the needs of the analysis. Therefore, the process will accommodate a full range of methodologies from a simple and quick professional judgmental process to an analysis requiring extensive research and sophisticated technologies.

The importance of conducting a high-quality risk assessment is that it can provide a solid foundation for justifying corrective action. The specific function of the Guidelines is to present a process that can be used to: (1) evaluate recently established non-indigenous organisms, and (2) evaluate the risk associated with individual pathways (e.g., ballast, aquaculture, aquarium trade, fish stocking, hull fouling, live bait).

The History and Development of the Guidelines

These Guidelines were modified from the US Aquatic Nuisance Species Task Force's Generic Non-indigenous Aquatic Organisms Risk Analysis Review Process in 1996. The development of these Guidelines have been synchronous with, and functionally tied to, the development of various ecological risk assessments and with the international trade agreements and their associated risk standards. The applicability of these guidelines was recently reviewed (Leung and Dudgeon 2008).

In addition to the above projects and numerous other pertinent works, the following quality criteria (modified from Fischoff *et al.* 1981) were used in designing the Guidelines:

- **Comprehensive** – The assessment should review the subject in detail and identify sources of uncertainty in data extrapolation and measurement errors. The assessment should evaluate the quality of its own conclusions. The assessment should be flexible to accommodate new information.
- **Logically Sound** – The risk assessment should be up-to-date and rational, reliable, justifiable, unbiased, and sensitive to different aspects of the problem.
- **Practical** – A risk assessment should be commensurate with the available resources.
- **Conducive to Learning** – The risk assessment should have a scope sufficiently broad to carry over value for similar assessments. The risk assessment should serve as a model or template for future assessments.
- **Open to Evaluation** – The risk assessment should be recorded in sufficient detail and be transparent enough in its approach that it can be reviewed and challenged by qualified independent reviewers.

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Risk Analysis Philosophy

The risk assessment process allows for analyzing, identifying and estimating the dimension, characteristics and type of risk. By applying analytical methodologies, the process allows the assessors to utilize qualitative and quantitative data in a systematic and consistent fashion.

The ultimate goal of the process is to produce quality risk assessments on specific aquatic invasive organisms, or to evaluate those non-indigenous organisms identified as being associated with specific pathways. The assessments should strive for theoretical accuracy while remaining comprehensible and manageable, and the scientific and other data should be collected, organized and recorded in a formal and systematic manner.

The assessment should be able to provide a reasonable estimation of the overall risk. All assessments should communicate effectively the relative amount of uncertainty involved and, if appropriate, provide recommendations for mitigation measures to reduce the risk.

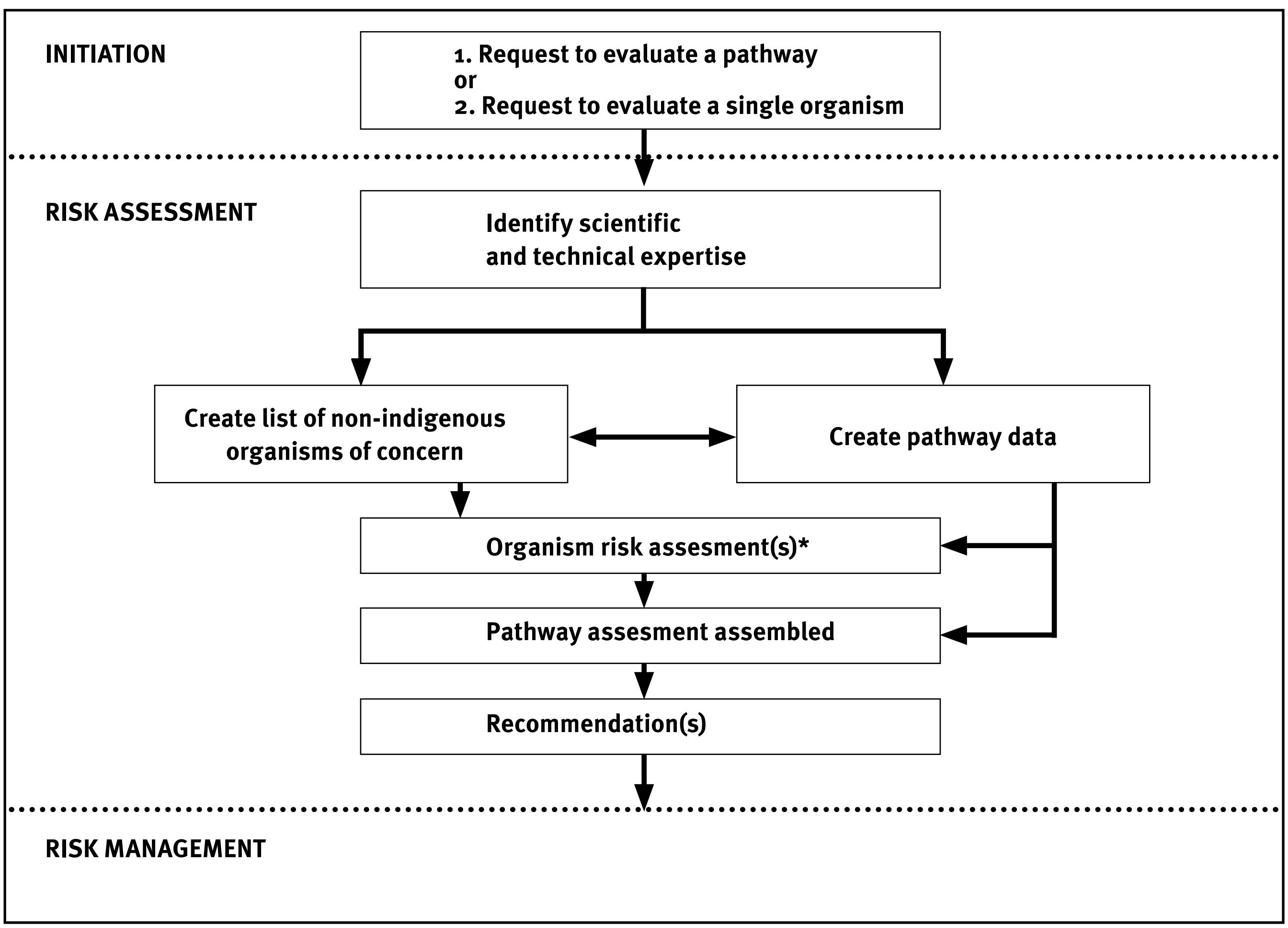
Caution is required to ensure that the process clearly explains the uncertainties inherent in the process and to avoid design and implementation of a process that reflects a predetermined result. Quantitative risk assessments can provide valuable insight and understanding; however, such assessments can never capture all the variables. Quantitative and qualitative risk assessments should always be buffered with careful professional judgment. Goals that cannot be obtained from a risk assessment are:

1. A risk assessment cannot determine the acceptable risk level. What risk, or how much risk, is acceptable depends on how a person, agency, or country perceives that risk. Risk levels are value judgments that are characterized by variables beyond the systematic evaluation of information. Under existing international law each country has the right to set its own acceptable risk level as long as they maintain a degree of consistency in their risk decisions.

2. It is not possible to determine precisely whether, when, or how a particular introduced organism will become established. It is equally impossible to determine what specific impact an introduced organism will have. The best that can be achieved is to estimate the likelihood that an organism may be introduced and estimate its potential to do damage under favorable host/environmental conditions.

The ability of an introduced organism to become established involves a mixture of the characteristics of the organism and the environment in which it is being introduced. The interaction between the organism and receiving environment largely determines whether it fails or succeeds at invading, establishing and/or spreading. These factors cannot necessarily be predicted in advance by general statements based only on the biology of the organism. In addition, even if extensive information exists on a non-indigenous organism, many scientists believe that ecological dynamics are so turbulent and chaotic that future ecological events cannot be accurately predicted.

Figure 1.1. Risk Analysis Framework



** For details on the Organism Risk Assessment see Figure 2 "Risk Assessment Model." Pathways that show a high potential for introducing non-indigenous organisms should triger detailed risk analyses.*

If all were certain, there would not be a need for risk assessment. Uncertainty, as it relates to the individual risk assessment, can be divided into three distinct types:

- **a)** uncertainty of the process – (methodology)
- **b)** uncertainty of the assessor(s) – (human error)
- **c)** uncertainty about the organism – (biological and environmental unknowns)

Each one of these presents its own set of problems. All three types of uncertainty will continue to exist regardless of future developments. The goal is to succeed in reducing the uncertainty in each of these groups as much as possible.

The "uncertainty of the process" requires that the risk methodologies involved with the Guidelines never become static or routine but continue to be modified when procedural errors are detected and/or new risk methodologies are developed.

"Uncertainty of the assessor(s)" is best handled by having the most qualified and conscientious persons available conduct the assessments. The quality of the risk assessments will, to some extent, always reflect the quality of the individual assessor(s).

It is the most difficult to respond to the "uncertainty about the organism." Indeed, it is the biological uncertainty more than anything else that initiated the need for a risk process. Common sense dictates that the caliber of a risk assessment is related to the quality of data available for the organism and ecosystem that will be invaded. Those organisms for which copious amounts of high-quality research have been conducted are the most easily assessed. Conversely, an organism for which very little is known cannot be easily assessed.

A high degree of biological uncertainty, in itself, does not demonstrate a significant degree of risk. However, those organisms that demonstrate a high degree of biological uncertainty do represent a real risk. The risk of importing a damaging non-indigenous organism (for which little information is known) is probably small for any single organism but the risk becomes much higher when one considers the vast number of these organisms that must be considered. It is not possible to identify which of the "unknowns" will create problems—only to assume that some will.

The paucity of data does not mean that the organism will have no negative impact, but it also does not mean that it will. Demonstrating that a pathway has a "heavy" concentration of non-indigenous organisms for which little information is present may, in some cases (based on the "type" of pathway and the "type" of organisms), warrant concern. However, great care should be taken by the assessor(s) to explain why a particular non-indigenous organism load poses a significant risk.

This need to balance risks with uncertainty can lead assessors to concentrate more on the uncertainty than on known facts that may affect impact potential. Risks identified for AIS in other regions often provide the justification in applying management measures to reduce risks in other regions where the species have not yet been introduced. Thus, risk assessments should concentrate on evaluating potential risk.

Some of the information used in performing a risk assessment is scientifically defensible, some of it may be anecdotal or based on experience, and all of it is subject to the filter of perception. However, we must provide an estimation of risk based on the best information available and use that estimation in deciding whether to allow the proposed activity involving the non-indigenous organism and, if so, under what conditions.

Assessments should evaluate risk in order to determine the management actions that are commensurate with the identified risks. Estimations of risk are used to restrict, modify or prohibit, high risk pathways, with the goal of preventing the introduction of invasive species.

The following quote is taken from the NRC (1983) Red Book, entitled *Risk Assessment in the Federal Government: Managing the Process*:

> We recommend that regulatory agencies take steps to establish and maintain a clear conceptual distinction between assessment of risks and consideration of risk management alternatives; that is, the scientific findings and policy judgments embodied in risk assessments should be explicitly distinguished from the political, economic, and technical considerations that influence the design and choice of regulatory strategies.

This can be translated to mean that risk assessments should not be policy-driven. However, the Red Book then proceeded with a caveat:

> The importance of distinguishing between risk assessment and risk management does not imply that they should be isolated from each other; in practice, they interact, and communication in both directions is desirable and should not be disrupted.

This can be translated to mean that the risk assessment, even though it must not be policy-driven, must be policy-relevant. These truths continue to be valid (NRC 1993).

The Guidelines for Conducting Pathway Assessment and Organism Risk Assessments

The need for a risk assessment starts either with the request for opening a new pathway that might harbor aquatic invasive organisms, or the identification of an existing pathway that may be of significant risk. All pathways showing a potential for non-indigenous organism introduction should receive some degree of risk evaluation. Those pathways that show a high potential for introducing non-indigenous organisms should trigger an in-depth risk assessment.

Continuous open communication between the risk managers and the risk assessors is important throughout the writing of the risk assessment. This is necessary to ensure that the assessment will be policy relevant when completed. Risk managers should be able to provide detailed written questions that they need answered to the risk assessors before the risk assessment is started. This will allow the assessors to focus the scientific information relevant to the questions (issues) that the risk managers will need to address.

The following details of the Guidelines focus on evaluating the risk of non-indigenous organisms associated with an identified pathway. Figure 1.1 outlines the flow of a pathway analysis, dividing the process into initiation, risk assessment, and risk management. Specific organisms needing evaluation which are not tied to a pathway assessment would proceed directly to the "Organism Risk Assessments" box in Figure 1.1 and the "Organism Risk Assessments" section.

Collecting Pathway Data

Specific information about the pathway must be collected. This information, coupled with additional data would fulfill the "Collect Pathway Data" element in Figure 1.1.

Specific information needed about the pathway will vary with the "type" of pathway (e.g., ballast water, aquaculture, aquarium

Table 1.1. Screening Tool

Category	Organism Characteristics	Concern
1a	species non-indigenous, not present in country	yes
1b	species non-indigenous, in country and capable of further expansion	yes
1c	species non-indigenous, in country and reached probable limits of range, but genetically different enough to warrant concern and/or able to harbor another non-indigenous pest and/or introduce risk of hybridization	yes
1d	species non-indigenous, in country and reached probable limits of range and not exhibiting any of the other characteristics of 1c	no
2a	species indigenous, but genetically different enough to warrant concern and/or able to harbor another non-indigenous pest, and/or capable of further expansion and/or introduce risk of hybridization	yes
2b	species indigenous and not exhibiting any of the characteristics of 2a	no

trade, fish stocking). The following generalized list of information has been useful in other non-indigenous risk assessments:

1) Determine exact origin(s) of organisms associated with the pathway.
2) Determine the numbers of organisms traveling within the pathway.
3) Determine intended use, or disposition, of pathway.
4) Determine mechanism and history of pathway.
5) Review history of past experiences and previous risk assessments (including foreign countries) on pathway or related pathways.
6) Review past and present mitigating actions related to the pathway.

Creating a List of Aquatic Invasive Organisms of Concern

One element identified in Figure 1 is the need to "Create List of Non-indigenous Organisms of Concern." To create such a list, the following generalized process is recommended:

1) Determine what organisms are associated with the pathway.
2) Determine which of these organisms qualify for further evaluation using the table below.
3) Produce a list of the organisms of concern from (step 2) categories 1a, 1b, 1c, and 2a. Taxonomic confusion or uncertainty should also be noted on the list.
4) Conduct organism risk assessments from the list of organisms developed in step 3.

Based on the number of organisms identified and the available resources, it may be necessary to focus on fewer organisms than those identified using the above table. When this is necessary, it is desirable that the organisms chosen for complete risk assessments be representative of all of the organisms identified. A standard method is not available because the risk assessment process is often site or species specific. Therefore, professional judgment by scientists familiar with the aquatic organisms of concern is often the best tool to determine which organisms are necessary for effective screening. This screening has been done using alternative approaches. Different approaches can be found in each of the three log commodity risk assessments (USDA Forest Service 1991, 1992, 1993).

Organism Risk Assessment

The Organism Risk Assessment element in Figure 1.1 is the most important component of the Guidelines used in evaluating and determining the risk associated with a pathway. The Organism Risk Assessment can be independent of a pathway assessment if a particular non-indigenous organism needs to be evaluated. Figure 1.2 represents the Risk Model that drives the Organism Risk Assessment.

The Risk Assessment Model is divided into two major components: "Probability of Establishment" and the "Consequence of Establishment." This division reflects how one can evaluate a non-indigenous organism (e.g. more restrictive measures are used to lower the probability of a particular non-indigenous organism establishing itself when the consequences of that establishment are greater).

The Risk Assessment Model is a working model that represents a simplified version of the real world. In reality, the specific elements of the Risk Model are not static or constant, but are dynamic showing distinct temporal and spatial relationships. Additionally, the elements are not equal in weighing the risk, nor are they necessarily independent. The weight of the various elements will never be static because they are strongly dependent upon the non-indigenous organism and its environment at the time of introduction.

The two major components of the Risk Assessment Model are divided into seven basic elements that serve to focus scientific, technical, and other relevant information into the assessment. Each of these seven basic elements is represented on the Organism Risk Assessment Form (Appendix A) as probability or impact estimates. The individual elements may be determined using quantitative or subjective methods. See Appendix B for a minimal subjective approach.

The strength of the assessment is that the information gathered by the assessor(s) can be organized under the seven elements. The cumulative information under each element provides the data to assess the risk for that element. Whether the method used in determining the risk for that element is quantitative, qualitative or a combination of both, the information associated with the element (along with its references) will function as the information source. Placing the information in order of descending risk under each element will further communicate to reviewers the thought process of the assessor(s).

Adequate documentation of the information sources makes the Guidelines transparent to reviewers and helps to identify information gaps. This transparency facilitates discussion if scientific or technical disagreement on an element-rating occurs. For example, if a reviewer disagrees with the rating that the assessor assigns an element, the reviewer can point to the information used in determining that specific element-rating and show what information is missing, misleading, or in need of further explanation. Focusing on information to resolve disagreements will often reduce the danger of emotion or a preconceived outcome from diluting the quality of the element-rating by either the assessors or the reviewers.

The specific questions and rationale for each of the Risk Assessment Model elements addressed are listed below. Note: when evaluating an organism that is not associated with a pathway, or an organism recently introduced, the answer to the first two Group 1 questions below would automatically be rated as "high" because entry into the new environment is either assumed or has already occurred.

A. Elements - Group 1: Assess Probability of Organism Establishment

1. Aquatic Non-indigenous Organisms Associated with Pathway (At Origin) – Estimate probability of the organism being on, with, or in the pathway.

The major question inherent to this calculation is: does the organism show a convincing temporal and/or spatial association with the pathway? For example, hull fouling of recreational boats has been shown to provide a viable pathway for the introduction of the zebra mussel into uncolonized waters of North America from the lower Great Lakes, although a different pathway (ballast water) is recognized as responsible for their initial introduction into the Great Lakes.

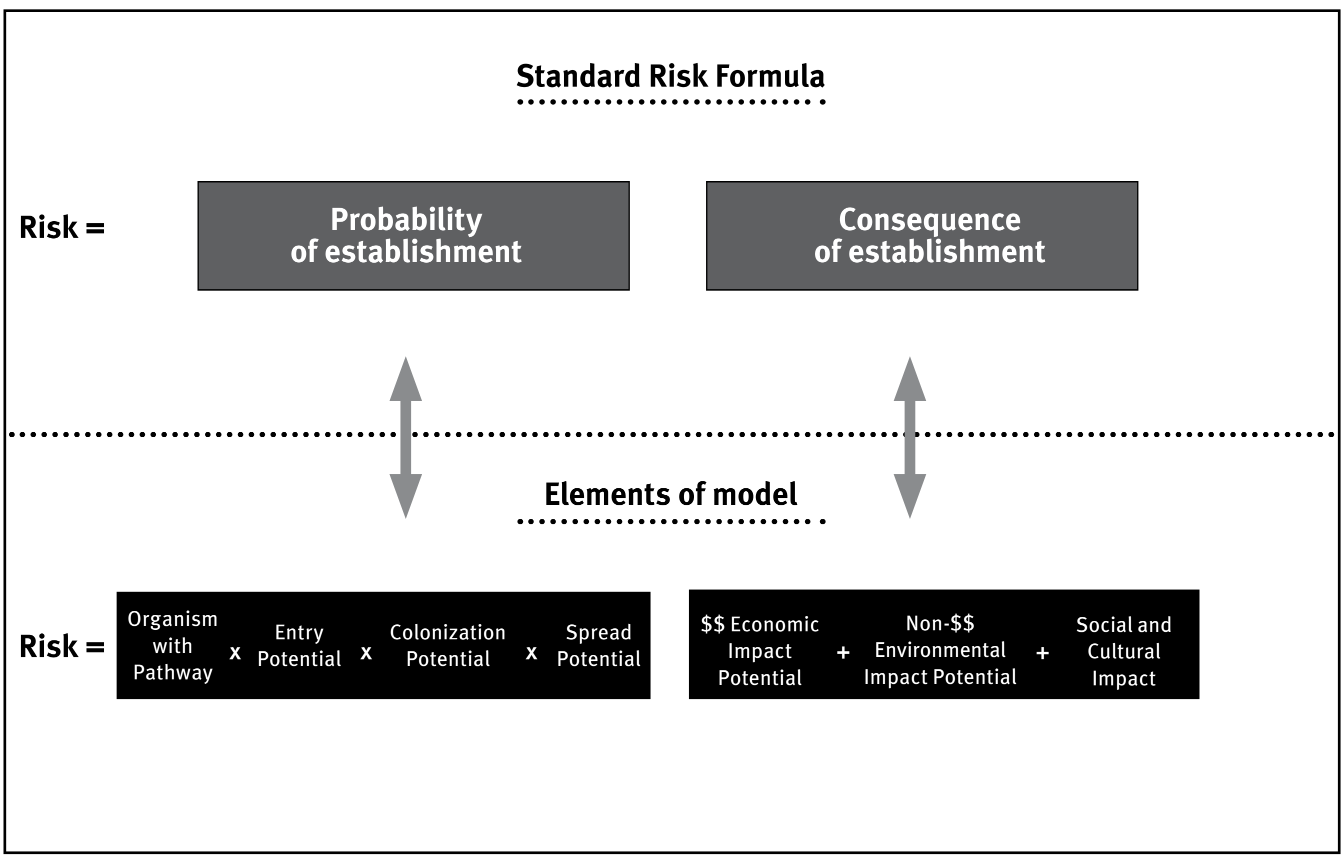
2. Entry Potential – Estimate probability of the organism surviving in transit.

The entry potential considers the probability of that the organism in the pathway could enter (i.e., be released) into the environment of concern. Some of the characteristics of this element include: the organism's hitchhiking ability in commerce; its ability to survive during transit; the stage of life cycle of the organism during transit; the number of individuals expected to be associated with the pathway; and/or whether it is deliberately introduced (e.g., as a biocontrol agent or for fish stocking). For many species that would be evaluated under these guidelines, the probability of entry would be considered "1" (i.e., 100%). Typical examples would include species released for biological control or sport fishing opportunities such as mosquito fish (*Gambusia* spp.) for mosquito control, and smallmouth bass for recreational fisheries into waters west of the continental divide. In other cases, a species may be intentionally brought into a region where it is not indigenous through commerce, but its probability of entry into the environment is less than 100%. The importation of snakehead fishes in the live food trade represents a typical example of this case.

3. Colonization Potential – Estimate probability of the organism colonizing and establishing a reproductively viable population.

Some of the characteristics that should be considered in this

Figure 1.2. Risk Assessment Model



For model simplification, the various elements are depicted as being independent of one another. That is, the order of the elements in the model does not necessarily reflect the order of calculation.

analysis include: the potential for the organism to obtain adequate food resources; abiotic and biotic environmental resistance factors (e.g., geographical and temporal associations); propagule pressure—the number of individuals likely to be introduced via the pathway; and, the ability to reproduce or hybridize in the new environment. This qualitative estimation must consider whether the environmental factors, such as water quality, climate, and physical habitat components like temperature, structure, and flow, are within the environmental tolerance limits of the organism to permit a self-reproducing population to be established.

4. Spread Potential – Estimate probability of the organism spreading beyond the colonized area.

Some of the characteristics of this element include: ability for natural dispersal, ability to use human activity for dispersal, ability to readily develop races or strains, and the estimated range of probable spread based on the availability of suitable habitat conditions. For example, Genetic Algorithm for Rule-Set Projection (GARP) modeling considers a variety of climatic variables in the native range of an organism and applies that information to evaluate the potential spread of an organism, or class of organisms, in new environments that may share those climatic conditions.[1]

B. Elements – Group 2: Assess Consequence of Establishment

1. Economic Impact Potential – Estimate economic impact if established.

Some of the characteristics of this element of the guidelines include: economic importance of hosts, damage to crop or natural resources, effects to subsidiary industries, exports, lost ecological services, and direct control and management costs. Economic impacts may be calculated from direct monetary expenditures that result from the damage caused by the species, such as the costs required to clean water intake lines of zebra mussels. A monetary assessment of the loss of ecosystem goods and services may also be calculated but the uncertainty with these estimates will likely be higher.

2. Environmental Impact Potential – Estimate environmental impact if established.

Some of the characteristics of this element include: ecosystem destabilization or modification or degradation, reduction in native biodiversity from the loss or reduction in quality of preferred habitats, reduction or elimination of keystone species, reduction or elimination of endangered/threatened species, loss or reduction in quality of preferred habitat conditions for native species, and impacts of future control actions. If appropriate, impacts on the human environment (e.g., human parasites or pathogens) would also be captured under this element.

3. Social and Cultural Influences – Estimate impact to social and cultural practices.

Some of the characteristics of this element include: impacts to aboriginal cultures and other cultures of national and regional importance, and social impacts that are not easily captured under the economics elements.

The elements considered in the "Consequences of establishment" box in Figure 1.2 can also be used to record positive impacts that a non-indigenous organism might have, e.g., its importance as a biocontrol agent, pet, sport fish, scientific research organism, or its use in aquaculture. The elements in the case of deliberate introductions would record information that will be useful in determining the element-rating that provide a balance between the cost, the benefit, and the risk of introducing the non-indigenous organism.

The Organism Risk Assessment Form (Appendix A) should be flexible. Each non-indigenous organism is unique and the assessor needs to have the freedom to modify the form to best represent the risk associated with that particular organism. However, the seven elements need to be retained to estimate the risk. If the assessor feels additional information, ideas, or recommendations would be useful, they should be included in the assessment. The assessor can combine "like" organisms into a single assessment if their biology is similar (e.g., tropical aquarium fish destined for temperate North America).

The number of risk assessments to be completed from the list of non-indigenous organisms in a particular pathway (Figure 1.1) depends on several factors. These include the amount of information on the organism, the available resources, and the assessor's professional judgment concerning whether the completed assessments effectively represent the pathways' non-indigenous organism risk.

The source of the information under each element and the degree of uncertainty the assessor associated with each element needs to be recorded in the Risk Assessment. The use of the Reference Codes at the end of each statement, coupled with the use of the Uncertainty Codes for each element, fulfill these requirements. (Reference Codes and Uncertainty Codes are described in Appendix A.)

Summarizing Organism and Pathway Risk

An estimate of risk is made at three levels in the Guidelines. The first level places a risk estimate on each of the seven elements within the Risk Assessment (element-rating). The second level combines the seven risk element estimates into an Organism Risk Potential (ORP), which represents the overall risk of the organism being assessed. The third level links the various ORPs into a Pathway Risk Potential (PRP), which will represent the combined risk associated with the pathway.

[1] See Peterson and Vieglais 2001, Kolar 2004, and Herborg *et al.* 2007.

The most difficult steps in a risk assessment are assigning quantitative or qualitative estimates to an individual element, determining how the specific elements in the model are related, and deciding how the estimates should be combined. There is no "correct" formula for completing these steps. Various methods such as geographical information systems, climate and ecological models, decision-making software, expert systems, and graphical displays of uncertainty, may potentially increase the precision of one or more elements in the Risk Assessment Model. Indeed, risk assessments should never become so static and routine that new methods cannot be tested and incorporated.

When evaluating new approaches, it is important to keep in mind that the elements of the Risk Assessment Model are dynamic, and not equal in value. New approaches appropriate for assessing one organism may be immaterial or even misleading in evaluating another organism.

The high, medium, and low answers to the approach presented in Appendix B for calculating and combining the various elements are based on professional judgment. The process in Appendix B is a generic minimum for determining and combining the element estimates and not necessarily "the best way it can be done."

The strength of the Guidelines is that the biological statements under each of the elements provide the raw material for testing various approaches. Therefore, the risk assessment will not need to be re-done to test new methods for calculating or summarizing the ORP and PRP.

On risk issues of high visibility, examination of the draft assessment should be completed by pertinent reviewers not associated with the outcome of the assessment. This is particularly appropriate when the risk assessments are produced by the same agency, professional society, or organization responsible for the management of that risk.

Components of the Final Assessment

- Introduction
- Pathway information
- A complete list of the organisms of concern
- The individual Organism Risk Assessments
- Response to specific questions requested by risk managers
- Summation of the methodology used in determining the ORPs and PRPs
- Summation and responses to outside reviewers

2

CHAPTER 2
Snakehead (*Channidae*) Trinational Risk Assessment

Becky Cudmore* and Nicholas Mandrak

INTRODUCTION

This chapter assesses the risk of several snakehead species to the three North American countries. A brief background summary of the *Channidae* family is provided, along with an analysis of the environmental and economic risk some species in the family may represent, based on an application of the CEC Risk Assessment Guidelines outlined in Chapter 1. Pursuant to the objectives of the overall project outlined in Chapter 1, this case study focuses on the potential risks associated with those snakehead species in the live food and aquarium trades of North America only (Table 2.1; Figures 2.1 to 2.5).

Summary of the *Channidae* Family

Although the taxonomy of snakehead fishes is not complete, authorities currently recognize two genera in the *Channidae* family, *Channa* (26 species) and *Parachanna* (3 species) (Courtenay and Williams 2004). It is possible, in some cases likely, that species complexes and forms exist within the family and a taxonomic revision of the family is currently underway (W. Courtenay, retired USGS, pers. comm.). The current view is there may be 36 snakehead species, as several subspecies within the species complexes of *C. gachua*, *C. marulius* and *C. striata* may be elevated to the species level (W. Courtenay, pers. comm.). For the purposes of this report, we considered the 29 species listed in Courtenay and Williams (2004).

Table 2.1. Snakehead Species and Associated Pathways Assessed

Common name	Scientific name	Associated pathway
Northern snakehead (Figure 2.1)	Channa argus	Live Food
Chinese snakehead (Figure 2.2)	C. asiatica	Live Food
Blotched snakehead (Figure 2.3)	C. maculata	Live Food
Bullseye snakehead (Figure 2.4)	C. marulius	Aquarium
Giant snakehead (Figure 2.5)	C. micropeltes	Aquarium

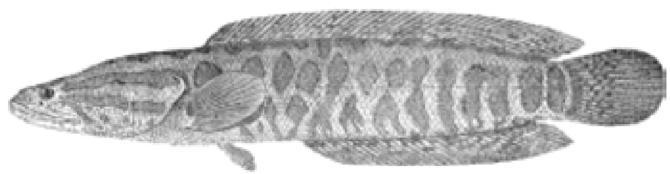
The native distribution of these freshwater fishes range within Asia, Malaysia, Indonesia, and, for the *Parachanna* spp. only, Africa (Courtenay and Williams 2004). Fifteen species are characterized as tropical-subtropical, 12 as subtropical-warm temperate, and one species as warm-cold temperate.

The following general biological information on the snakehead family is derived from the biological synopsis compiled by Courtenay and Williams (2004).

The body of snakeheads is torpedo-shaped, which tapers toward the tail. They have a single, long dorsal fin, a long anal fin, and a small head with a large mouth.

Very little is known about the life span of snakeheads, but it is suspected that some of the smaller species may live for only a few years, while larger species may live longer, reaching sexual maturity within two years. Most species are small as adults at about 170 mm, but some can grow to larger sizes, reaching 1.8 m. Many species are obligate air breathers, others are facultative air breathers. Snakeheads possess suprabranchial chambers for aerial respiration, and the ventral aorta is divided into two parts to permit aquatic and aerial respiration. Therefore, some snakehead species are capable of surviving hypoxic conditions and can remain out of water for considerable

Figure 2.1. Northern Snakehead (*Channa argus*)



(Source: Courtenay and Williams 2004, p. 45).

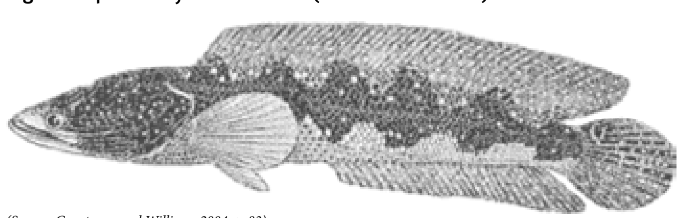
Figure 2.2. Chinese Snakehead (*Channa asiatica*)

(Source: Courtenay and Williams 2004, p. 53).

Figure 2.3. Blotched Snakehead (*Channa maculata*)

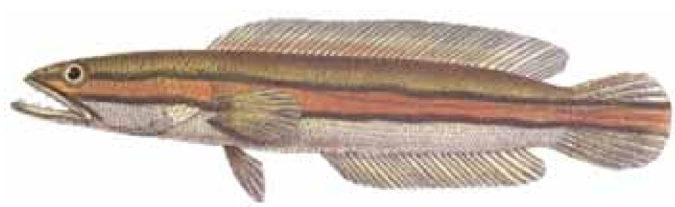
(Source: Courtenay and Williams 2004, p. 77).

Figure 2.4. Bullseye Snakehead (*Channa marulius*)



(Source: Courtenay and Williams 2004, p. 83).

Figure 2.5. Juvenile Giant Snakehead (*Channa micropeltes*)



(Source: Courtenay and Williams 2004, p. 93).

* Department of Fisheries and Oceans Canada, Burlington, Ontario

periods of time, as long as they remain moist. Their metabolism and oxygen demands are reduced in cold temperatures, allowing for survival under ice. Several species also have the ability to move overland as a result of writhing and wriggling motions in search of food resources, escaping from drying habitats, or both.

Spawning in their native ranges occurs during the summer months with spawning pairs reported to be monogamous for at least the spawning season. Some species are nest builders, constructing a vertical column of vegetation.

Fry feed on zooplankton with diet changing to small crustaceans and insects. All snakehead species are carnivorous thrust predators as adults, consuming mainly fishes.

Snakeheads have been exported live into North America and other nations for the live food and aquarium trades. There have also been instances of accidental releases in several nations, resulting in subsequent establishment and ecological impact (Chiba *et al.* 1989; Courtenay and Williams 2004, FIGIS 2005).

ASSESSMENT OF PROBABILITY OF SNAKEHEAD ESTABLISHMENT

Organisms Associated with Pathways—Live Food and Aquarium

Live Food Trade

Many species of snakeheads are favored as a food item in various parts of Asia and in India, providing a food source for local peoples, as well as a highly valued food source for exporting to many countries around the world (Courtenay and Williams 2004). The three snakehead species that have been associated with the live food trade in North America include the northern snakehead, Chinese snakehead and blotched snakehead (Table 2.1; Figures 2.1 to 2.3)

CANADA

According to Goodchild (1999) and Crossman and Cudmore (2000), no records of snakehead imports imported live into Ontario have been reported; however, Canadian Food Inspection Agency (CFIA) data suggests this may not be the case. In 2003, 541 kg of "fresh water snake fish" entered Ontario via the Niagara Falls port of entry (CFIA, unpublished data). Positive identification of this import as snakeheads is not possible, but the presumption is that this shipment was likely snakehead. Currently, records from the Canadian Food Inspection Agency (CFIA) indicate that the only province receiving live snakeheads for the live food trade is the western province of British Columbia (Cudmore and Mandrak, unpublished data) (Figure 2.6).

There was no indication in this dataset of the species of snakeheads that were being imported. A small subset of import records from the Canadian Border Services Agency (CBSA) indicates that at least three species are being imported to British Columbia for the live food trade: Chinese, blotched and giant snakeheads (Figure 2.7) (Cudmore and Mandrak, unpublished data). All were imported from Hong Kong, with the exception of the giant snakehead (5 kg), which was imported from Vietnam (Cudmore and Mandrak, unpublished data). As the giant snakehead is a popular aquarium species, it is possible that the reason for its importation was not for live food, but for the aquarium trade.

The data represented in Figure 2.7 must be considered very preliminary. These data represent only 145 of 243 importers of live fishes from a one-year period from 1 October 2004, to 31 September 2005. Therefore, it is very likely that other snakehead species highly valued as food fish may be imported as well, such as northern snakehead. In fact, northern snakehead has been observed live in a Vancouver market (W. Courtenay, ret-USGS, *pers. comm.*).

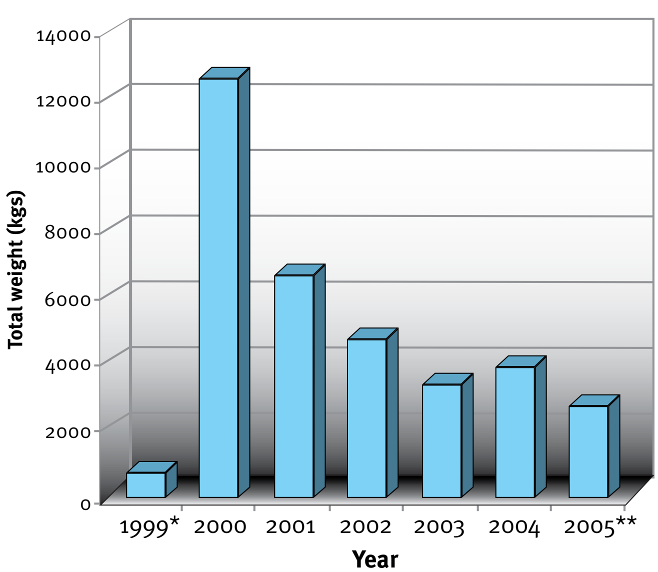
MEXICO

Snakeheads are not known to have been imported into Mexico for the live food trade. A search of Asian markets in Mexico City in February 2006 did not find any live snakeheads (R. Mendoza, University of León, Mexico).

UNITED STATES

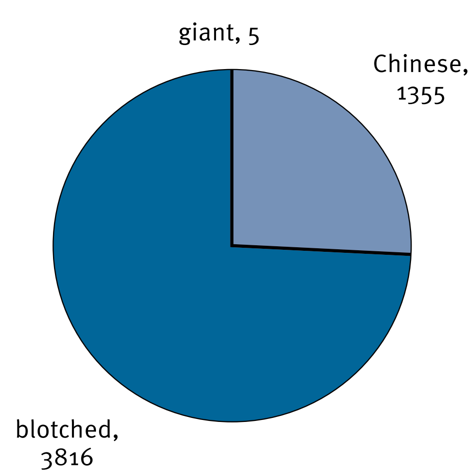
In the United States, a complete picture and understanding of the live food trade is also difficult to obtain. Records indicate an increase in

Figure 2.6. Weight (kg) of Live Snakeheads Imported into British Columbia for Food, December 1999* to mid-August 2005**



(* 1 month, ** 6.5 months)

Figure 2.7. Weight (kg) of Snakehead Species Imported Live into British Columbia for Food through Vancouver International Airport



Source: Courtenay and Williams 2004

live snakehead (specific species unknown) imports from 1997–2002 (Table 2.2a) (Courtenay and Williams 2004). The total declared value during these 5 1/2 years was US$132,687. It is not known from these records whether the reason for importation was for food or for aquarium use. These snakeheads were exported to the United States from nine countries, with China contributing the highest amount by number and weight (Table 2.2b).

Aquarium Trade

Although snakeheads can grow to large sizes and the costs associated with feeding them in aquaria are quite high, there are many enthusiastic snakehead aquarists (Courtenay and Williams 2004). Generally, the smaller species and the brightly colored juveniles of the larger species are found in the trade. However, these species are incompatible with other fishes, require expensive food, and quickly outgrow their aquaria. As a result, many individuals have been released into natural waters outside their native range (Courtenay and Williams 2004). The two snakehead species most associated with the aquarium trade are the bullseye snakehead and the giant snakehead (Table 2.1, Figures 2.4 and 2.5).

CANADA

According to the data compiled from 145 of 243 importers of live fishes into Canada from a one-year period, from 1 October 2004, to 31 September 2005, only giant snakeheads have been imported via the Pierre Elliott Trudeau International Airport at Dorval (Montreal), Quebec. Aquarium importation data, recorded not by weight but by number of individuals, show that 282 individual giant snakeheads were imported from Singapore and 25 from Malaysia (Cudmore and Mandrak, unpub. data) (Figure 2.6).

MEXICO

Snakeheads are not known to have been imported into Mexico for the aquarium trade.

UNITED STATES

As previously indicated, the import data collected for live snakeheads in the United States from 1997–2002 did not provide the reason for their importation.

Entry Potential

Live Food and Aquarium Trade

The potential for snakeheads to survive in transit while being shipped overseas to North America is high. Many species are obligate air breathers, others are facultative air breathers. Therefore, some snakehead species are capable of surviving hypoxic conditions and

Table 2.2a. Importation of Live Snakeheads (All Species) into the United States from 1997 to May 2002

Year	Number of Individuals[1]	Weight (kg)[2]	Total declared US$ value (individuals and weight combined)
1997	372	892	5,085
1998	1,488	1,883	12,032
1999	6,044	8,512	27,718
2000	8,650	9,240	39,990
2001	18,991	1,681	21,185
2002[3]	15,688	-	26,077
Totals	**51,233**	**22,208**	**$132,087**

[1] not included in number of kilograms
[2] not included in number of individuals
[3] Data are for January-May 2002

Source: Courtenay and Williams 2004

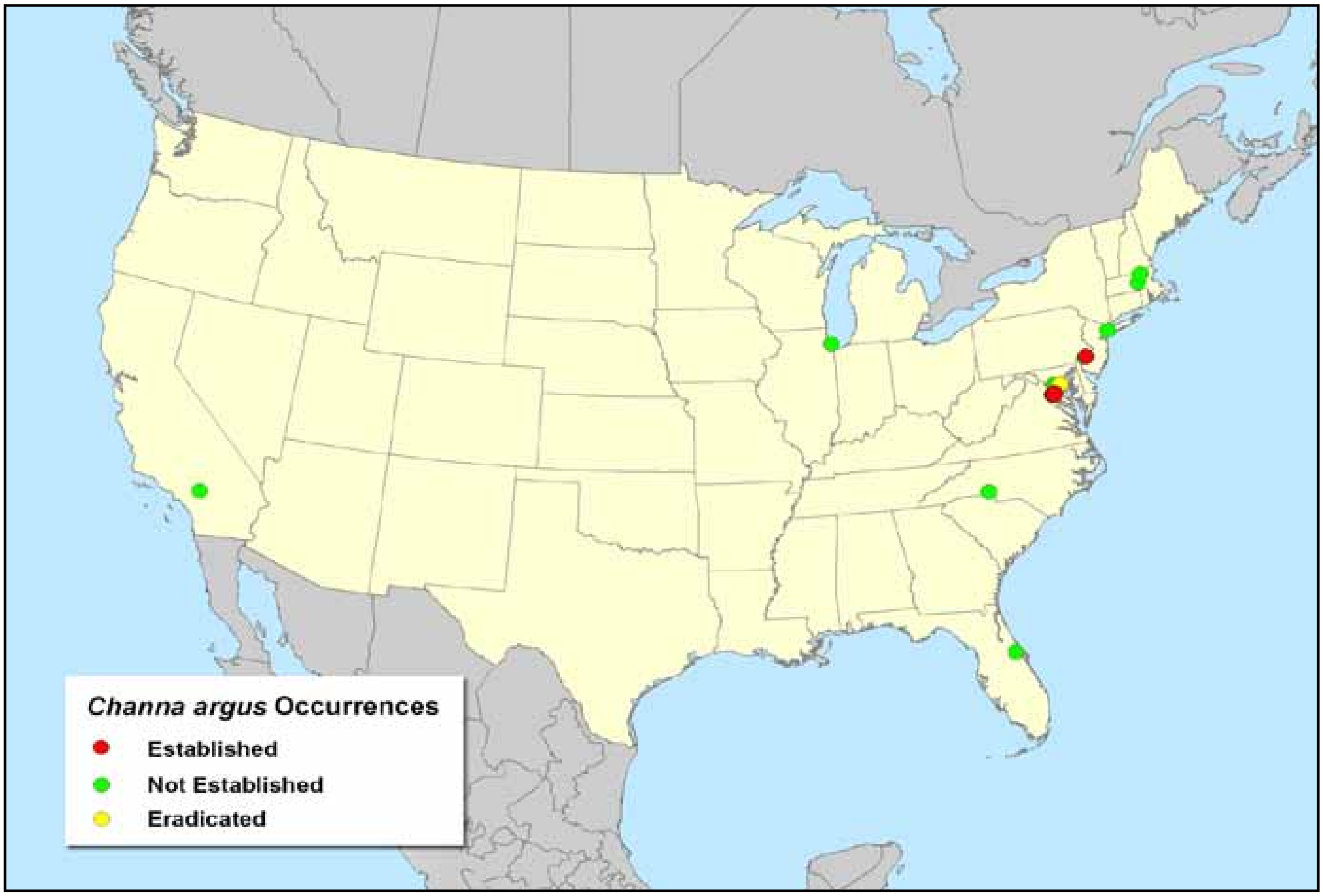
Table 2.2b. Importation of Live Snakeheads (All Species) into the United States from 1997 to May 2002

Year	Number of Individuals[1]	Weight (kg)[2]	Total declared US$ value (individuals and weight combined)
China	48,533	20,323	125,295
Hong Kong	2	-	50
India	572	-	1,498
Indonesia	300	-	96
Nigeria	970	-	659
Switzerland	50	-	100
Thailand	1,084	-	1,420
United States	25	-	38
Vietnam	1,079	1,435	4,265

[1] not included in number of kilograms
[2] not included in number of individuals

Source: Courtenay and Williams 2004

Figure 2.8. Distribution of Northern Snakehead in the United States, May 2007



Source: Amy Benson, US Geological Survey

can even survive out of water for considerable periods of time as long as they remain moist.

The entry potential depends on the vectors and pathways of introduction through which northern snakehead could be introduced from established populations in North America and from deliberate and/or accidental releases from the live food fish and aquarium trades.

There are several established populations of northern snakehead in the United States (Figure 2.8), which may become sources for invasive movement into other areas of the United States and into Canada and/or Mexico.

The live trade of these species for the food and aquarium industries provides a source for accidental or deliberate release for ceremonial or animal rights reasons. It has been suggested to Ontario conservation officials that snakeheads are more preferable than Asian carp for ceremonial release as a prayer species as they are a highly resilient species, giving stronger "karma" for the afterlife of the releaser (B. Ingham, Ontario Ministry of Natural Resources, pers. comm.). The potential for unauthorized release of some snakehead species for recreational fishing reasons also exists.

Accidental release during transport could also occur with the live fish food market trade. In 2001, a driver for a Canadian fish wholesaler bound for Seattle, WA, was stopped in Blaine, WA. He declared his shipment to be three boxes of live lingcod [the proper common name is burbot (*Lota lota*)]. The fish were, in fact, pond-raised northern snakeheads, which were shipped from China without water to Canada (Courtenay and Williams 2004). The probability of accidental release during transportation of live fishes is unknown, but has occurred (B. Brownson, Ontario Ministry of Natural Resources, pers. comm.).

CANADA

Only the province of Ontario has banned possession, transportation and sale of live snakeheads; but snakeheads are not federally prohibited for import into the country for the live food trade. British Columbia and Quebec are the only Canadian provinces that currently import live snakeheads for retail and institutional uses.

MEXICO

There is no legislation preventing the importation of snakeheads into Mexico.

UNITED STATES

The family *Channidae* was listed as "Injurious Species" under the federal Lacey Act in October 2002 and it is therefore illegal to import live snakeheads into the United States or to transport them between states. As a consequence, the species is not widely or commonly available in the United States.

Colonization Potential

To estimate the potential distribution of each species in North America, a Genetic Algorithm for Rule-Set Production (GARP) analysis was used. This type of analysis has been used by others to predict potential distribution of invasive species (e.g., Drake and Lodge 2006). Information on nine environmental variables (maximum, mean and minimum air temperatures, wet day index, annual river discharge, precipitation, compound topographic index, slope, and frost frequency) was collected from the native ranges of the five snakehead species and input into the GARP analyses. The nine variables were chosen because they are the only ones for which global information is available. It is recognized that other parameters, such as water temperatures in the species' native range, could considerably improve the accuracy of the modeling but such information is not yet available at the global scale used by GARP. Thus, the GARP models were developed for the native distribution of each snakehead species and used to predict their potential distribution in North America, based on the existing global environmental data layers. The analyses create random rules (algorithms) and repeatedly analyze their accuracy until a maximum prediction of accuracy is reached. The environmental layers used to identify potential distribution are tested for their relevance for, and contribution to, the prediction of the distribution. The results for each species can be found in Figures 2.9 to 2.11 below.

The results of the GARP modeling suggest that of the five snakehead species analyzed, one species, the northern snakehead, is predicted to be able to survive in all three countries (Figure 2.9). The remaining four species are predicted to be able to survive in the United States and Mexico (Figures 2.10–2.13). Of the nine environmental layers (variables) used in the modeling, air temperature (minimum, mean and maximum) contributed the most to the models, while slope, annual river discharge and wet day index contributed the least (Figure 2.14).

Spread Potential

Most snakehead species are tolerant of a wide range of environmental conditions as evidenced by the rapid spread and establishment in Asian and Japanese populations (USGS 2004). Feeding, spawning and nursery habitat, as well as food resources exist in North America. Northern snakehead have already spread and established populations in the United States (Figure 2.9). Additional populations of apparently reproducing populations of northern snakehead have

Figure 2.9. Potential Distribution of Northern Snakehead in North America using GARP Modeling

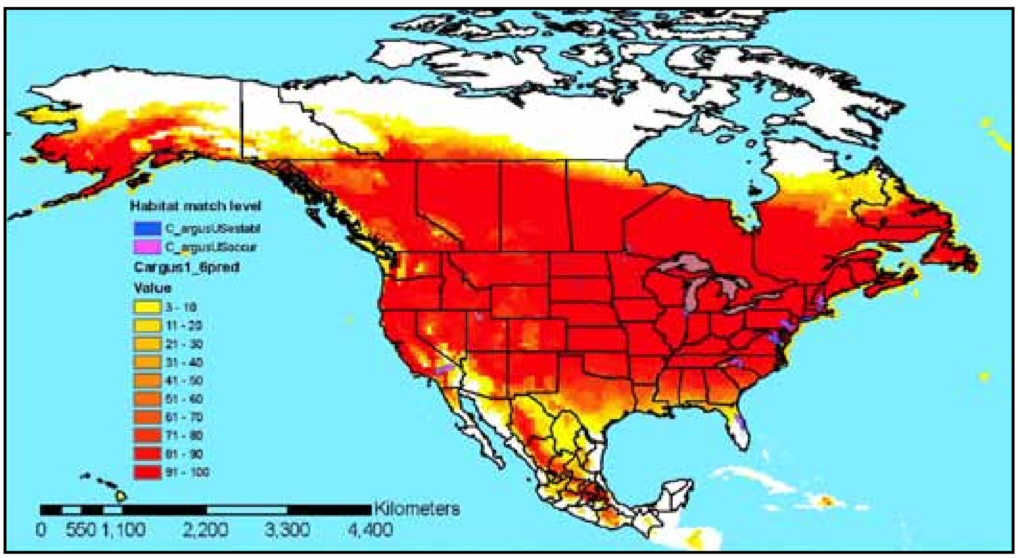


Figure 2.10. Potential Distribution of Chinese Snakehead in North America using GARP Modeling

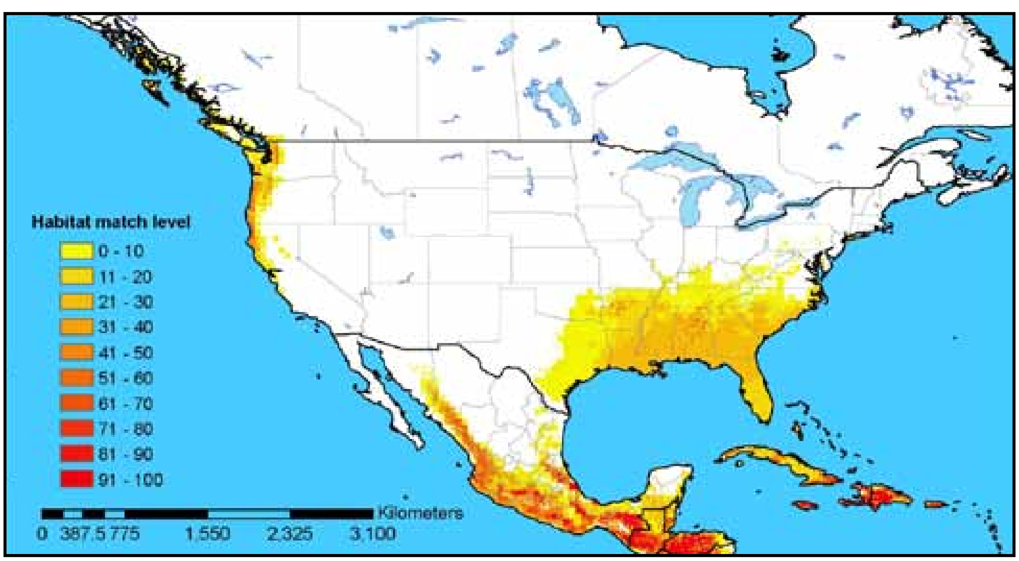


Figure 2.11. Potential Distribution of Blotched Snakehead in North America using GARP Modeling

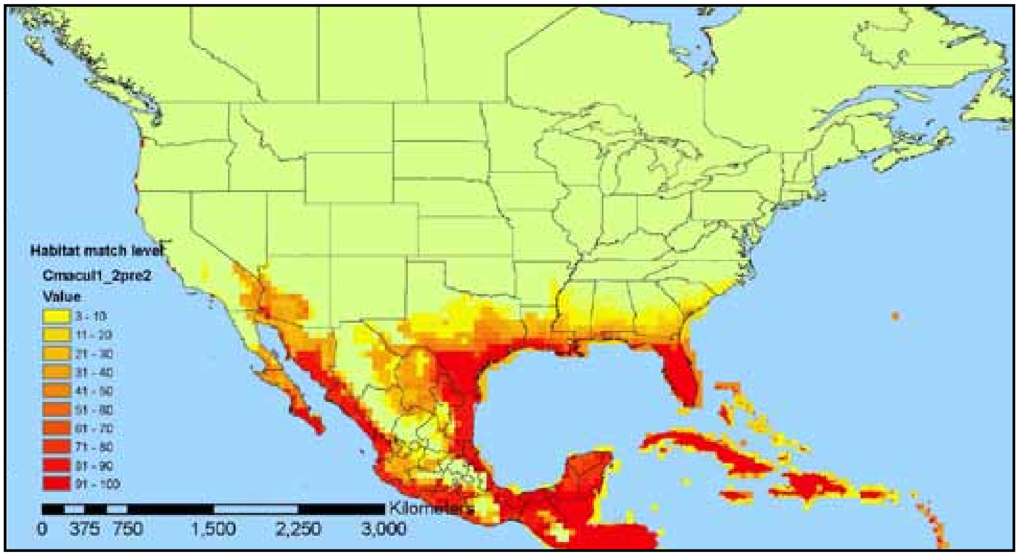


Figure 2.12. Potential Distribution of Bullseye Snakehead in North America using GARP Modeling

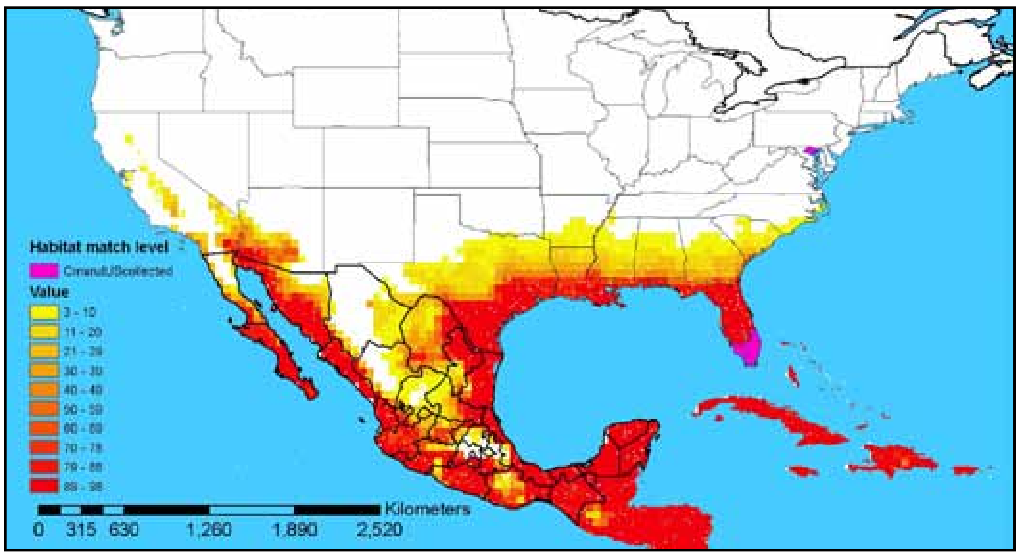
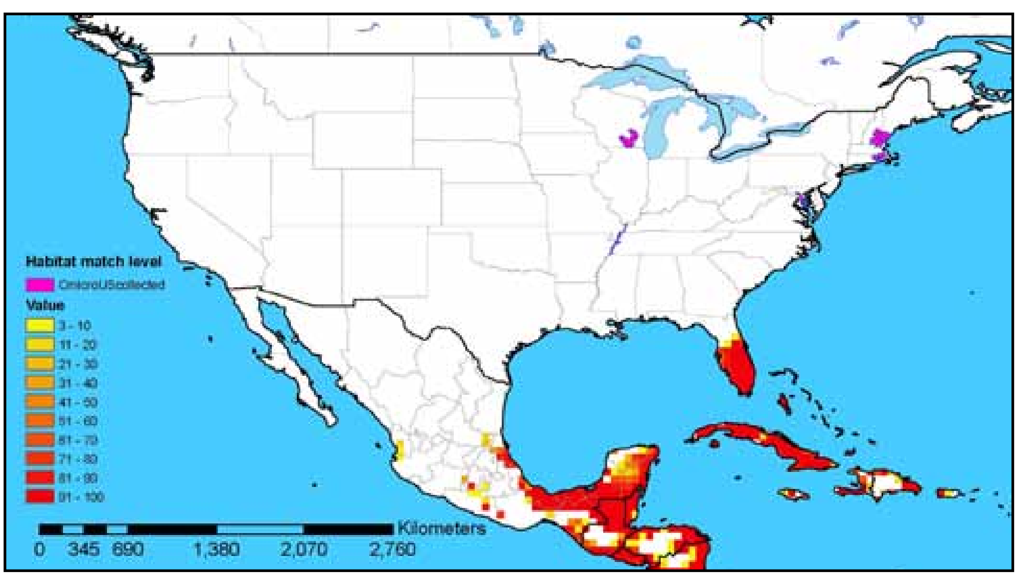


Figure 2.13. Potential Distribution of Giant Snakehead in North America using GARP Modeling



very recently been documented in Arkansas and New York State, providing some preliminary validation for the modeling of spread projected by GARP and shown in Figure 2.9.[2] Unless populations are at the edge of their potential distribution, the GARP models indicate broader environmental conditions would not preclude spread.

The potential for human-mediated spread also exists as some snakehead species can be used for food and for a recreational fishery. Unauthorized transfers may facilitate the spread from any established populations.

CONSEQUENCES OF ESTABLISHMENT

Economic Impact Potential

The economic impact potential of the introduction and establishment of snakehead was not quantified for this report. Significant monetary expenditures have been associated with the investigations of snakehead reports in the Potomac basin (e.g., snakehead roundups, etc.), but an accounting of the total expenditures for these control and management costs was not readily available. Addressing the socioeconomic impact of snakehead introduction remains a data gap for North America and adequate resources were not available to explore this question.

Environmental Impact Potential

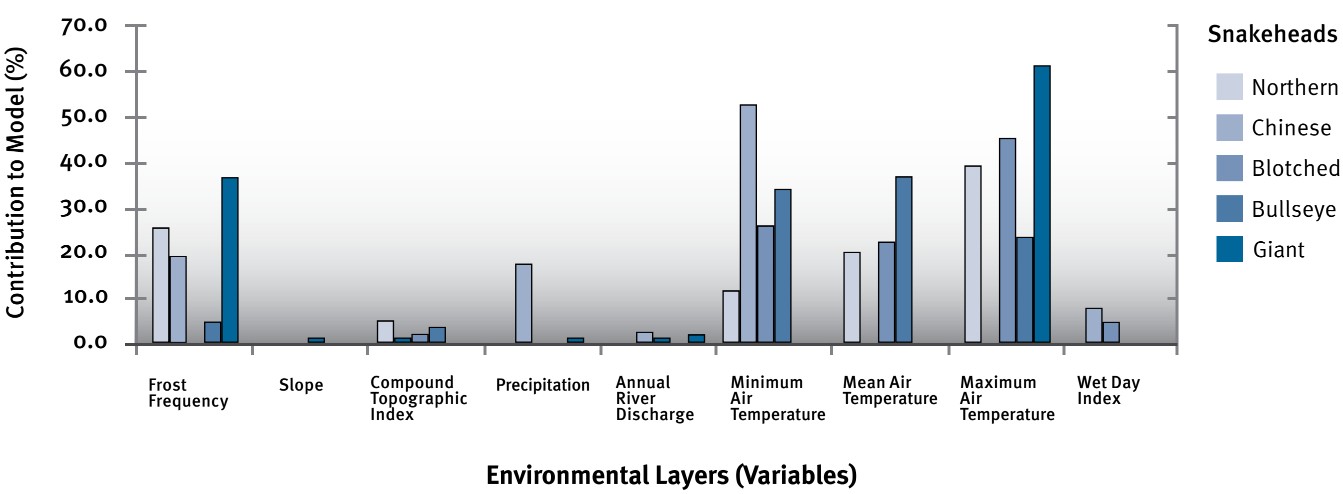
Based on the results of its introduction throughout the world, there would appear little doubt that snakeheads have the potential to significantly impact native fish populations due to their voracious predatory feeding habits and ability to out-compete other fish for food resources. They are also highly fecund and resilient to a wide range of environmental conditions (ISSG 2005). After a deliberate introduction of the northern snakehead to develop a recreational fishery, Japan reported adverse ecological impacts from predation on native species; however, no further information on specific impacts or species was mentioned (Chiba *et al.* 1989, ISSG 2005). In those waters of the United States where established reproducing populations exist, clear evidence of impact on native fishes is still equivocal. As snakeheads are not closely related to any native fish species in North America, they are highly unlikely to have any direct genetic impact on native fishes.

Social and Cultural Influences

In their native range, snakeheads contribute significantly to both commercial and recreational fisheries and are used in aquaculture. They are highly valued as both a food and an aquarium fish. Some cultural groups desire to have familiar species available for consumption; therefore, these species are in high demand and are imported into North America. Their availability in both the live food markets and the aquarium trade in Canada and the United States provides a source for deliberate release of live individuals for ceremonial or animal rights reasons. As noted, snakeheads are a highly resilient species, and thus may be preferred for ceremonial release as a prayer species as they are considered to have stronger 'karma' for the afterlife of the releaser (B. Ingham, Ontario Ministry of Natural Resources, pers. comm.).

Summaries of the risk assessment forms, prepared in accordance with the guidance given in Chapter 1, are provided in Appendix A. These forms summarize risks for each snakehead species considered in the preceding text.

Figure 2.14. Contribution of Environmental Layers (Variables) to Potential North American Distribution of Snakehead Species, as Predicted by GARP Modeling



[2] Walter Courtney, personal communication, 7/23/08.


3

CHAPTER 3
Armored Catfish (*Loricariidae*) Trinational Risk Assessment

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INTRODUCTION

This chapter assesses the known and potential ecological and economic risks associated with the North American aquarium trade in several fish species of the family *Loricariidae*, otherwise known as the "armored" or "suckermouth" catfishes. Because the taxonomy of the *loricariid* catfishes is not fully resolved, this assessment primarily considers the risks from a subset of the species of *Loricariidae* that are currently known in the aquarium trade in North America. Subsequent chapters focus on detailed case studies addressing the socioeconomic impacts of these fishes in Mexico and the United States, respectively.

Background of the Armored Catfish Families

The armored catfishes include two South American families of fishes, the *Callichthyidae* and *Loricariidae*. A brief background of their distinguishing characteristics follows.

Callichthyidae

The callichthyids are characterized by two rows of spineless plates extending along each side of the body, above and below the lateral line. They have an adipose fin that may also contain a spine. Nearly all species in the family possess a pair of short barbels on the upper jaw and two or more on the chin, and the fishes' air bladder is divided into two compartments enclosed in a bony casing. Over a dozen species of the genus *Corydoras* are popular with the aquarium trade (Migdalski and Fichter 1989). They can breathe air and, thus, are tolerant of waters with low oxygen content. All of the species are small, rarely exceeding 10 cm, but *Callichthys callichthys* (cascarudo, or armored catfish) may attain lengths of approximately 18 cm (Migdalski and Fichter 1989). One species of callichthyid, *Hoplosternum littorale*, is known to have become established in the Indian River lagoon system in Florida (Nico *et al*. 1996), and one recent report suggests that this population has spread throughout many parts of southern and central Florida (Nico and Muench 2004).

Loricariidae

The *Loricariidae* is the largest family of catfishes, including approximately 825 nominal species, 709 of which are considered valid, and 83 genera that are considered valid as of January 2006.[3] Taxonomic studies are ongoing to address uncertainties in the systematic relationships of the species as new species are discovered almost annually (Nelson 2006). A distinguishing characteristic of this South American fish family is their bony plate armoring that extends along three rows across their entire dorsal surface. The body is ventrally flattened, with the ventral surface of the fish wider than the height of the fish, such that in cross-section they appear somewhat triangular. All species possess a subterminal sucking mouth that is developed for sucking organic matter and algae from the substrate; hence the term, "suckermouth" is commonly used to name these fishes. The suckermouth is also useful to the fish in maintaining station in the strong currents of their native habitats. Table 3.1 lists some loricariid species common to the aquarium trade and Figures 3.1 to 3.11 illustrate some of the morphologic similarities and differences among them.

Assessment of Probability of Loricariid Establishment

Assessment of Loricariids in Pathway

Live Food Trade

Although several species of loricariids are consumed for food within their native ranges and efforts have been made to utilize problem populations as a food source for humans and animals elsewhere (see Chapter 5), no such substantial trade in loricariids is thought to occur. Specimens were recently observed, however, in the Vancouver, BC, fish market in 2007 but the dispensation anticipated for these specimens could not be determined (B. Cudmore, personal communication). Notwithstanding, this recent observation suggests the live food trade pathway cannot be completely discounted as an additional mechanism for the spread of loricariid catfish into North American waters.

Aquarium Trade

Loricariids are considered a 'bread and butter' fish of the aquarium trade in all three countries of North America (Table 3.1). Thus, there is strong potential for introduction of fishes in this family to come from the aquarium trade pathway. Most species of loricariid catfish brought into North America for the aquarium trade originate in Colombia, Peru or Brazil, with the proportions differing among the importing countries. However, both the United States and Mexico also produce loricariids domestically for distribution through aquarium stores and other outlets. In both cases, the industry is supported by non-native populations that have been established in the wild. Significant amounts of the imports into Canada also originate from the United States.

* 1-UANL; 2-ENVIRON International; 3-USGS Florida Integrated Science Center, Gainesville, Fl; 4-IINSO-UANL; 5-consultant; 6-CIIDIR-IPN; 7-Semarnat; 8-Conabio

[3] See J. Armbruster's taxonomic key at http://www.auburn.edu/academic/science_math/res_area/loricariid/fish_key/key.html.

Table 3.1. Simplified Taxonomy of Selected Genera and Species of *Loricariidæ* Catfishes Known to the Aquarium Trade

Subfamily/Tribe	Scientific Name	Common Name
Pterygoplichthys	*Pterygoplichthys* anisitsi* (formerly *Liposarcus*)	
	Pterygoplichthys disjunctivus (formerly *Liposarcus*)	Vermiculated sailfin catfish
	Pterygoplichthys gibbiceps* (formerly *Glyptoperichthys*)	Leopard plecos
	Pterygoplichthys joselimaianus* (formerly *Glyptoperichthys*)	Gold spot plecos
	Pterygoplichthys lituratus* (formerly *Glyptoperichthys*)	
	Pterygoplichthys multiradiatus (formerly *Liposarcus*)	Orinoco sailfin catfish
	Pterygoplichthys pardalis (formerly *Liposarcus*)	
	Pterygoplichthys parnaibæ* (formerly *Glyptoperichthys*)	
	Pterygoplichthys punctatus* (formerly *Glyptoperichthys*)	Yogi, Trinidad, Guimares silver, or Imperial Ranger plecos
	Pterygoplichthys scrophus* (formerly *Glyptoperichthys*)	Rhino, Alligator or Chocolate plecos
	Pterygoplichthys undecimalis	
	Pterygoplichthys xinguensis (formerly *Glyptoperichthys*)	
Loricariinæ	*Farlowella acus*	Twig catfish
	Farlowella gracilis	
	Rineloricaria filamentosa	
	Rineloricaria parva	Whiptail catfish
Ancistrini	*Ancistrus cirrhosus*	Bristlemouth catfish
	Ancistrus spp.	
	Ancistrus dolichoptera* (formerly *Xenocara*)	Blue chin xenocara
Acanthicus	*Pseudacanthicus* leopardus* (formerly *Stoniella*)	
Hypoptopomatinæ	*Otocinclus affinis*	Dwarf sucker catfish
Hypostomini	*Hypostomus plecostomus*	Plecostomus, Pleco
	Hypostomus spp.	Suckermouth catfishes

*Based on Armbruster 1997, 2004 and Armbruster and Sabaj 2002, with additional annotations by Armbruster (in correspondence, December 2008).

Loricariid catfish are highly sought by aquarists because of their distinctive appearance, hardiness, and propensity for consuming algae from all submerged surfaces. However, several species grow to large sizes, outgrowing their confined space, and are apparently released by aquarists into surrounding waters. Such introductions are thought to be one of the mechanisms responsible for the populations currently established in portions of Mexico (see Chapter 4), Texas (Nico and Martin 2001; López-Fernández and Winemiller 2005) and Florida (Nico *et al.* 1996; Ludlow and Walsh 1991). It is thought that loricariid catfish were first introduced into American waters in the 1950s (Burgess 1958) but did not reach problematic population levels until the 1990s (Hoover *et al.* 2007). The presence of *Pterygoplichthys* in southeastern Florida was first reported in 1971 (Courtenay *et al.* 1984) and establishment was later confirmed (Courtenay *et al.* 1986). Recent reports have also identified the presence of *Pterygoplichthys pardalis* in the Sepulvida Basin and Los Angeles River in Los Angeles (personal communication from Camm Swift to Walt Courtenay, 20 June 2007), and a population of the Orinoco sailfin catfish (*P. multiradiatus*) was recently reported by the NAS alert system from Horse Creek in Desoto and Hardee Counties in Florida. In these latter cases, the release of the catfish by aquarists is presumed the likely source of the introduction.

The following text summarizes elements of the aquarium trade pathway for each country that have relevance to the risk assessment of loricariids.

CANADA

In Canada, 145 of 243 importers bringing live fishes into Canada from 1 October 2004 to 30 September 2005 imported species of loricariid catfish (Cudmore and Mandrak, unpub. data). A total of 140,362 of these imported fish were listed as 'plecos,' and 11 species were represented, including: (*1*) *Pterygoplichthys anisitsi*, (*2*) *P. gibbiceps*, (*3*) *P. multiradiatus*, (*4*) *P. joselimaianus*, (*5*) *Peckoltia brevis*, (*6*) *P. vermiculata*, (*7*) *Panaque nigrolineatus*, (*8*) *Hypostomus plecostomus*, (*9*) *H. punctatus*, (*10*), *Beaufortia levereti*, (*11*) *B. kweichowensis*. The countries of origin for these fishes included Malaysia, Hong Kong, United States (California. Florida, Michigan), Singapore, Sri Lanka, Colombia, Vietnam, Czech Republic, Taiwan, Cuba, Thailand, Trinidad and Tobago, Brazil, Peru, Venezuela and Ecuador.

MEXICO

In Mexico, it is estimated that there are approximately 10 million fish imported by the aquarium trade (INEGI 2005a). Of these, twenty

Figure 3.1. *Pterygoplichthys gibbiceps* (formerly *Glyptoperichthys*)

Source: FishBase/JJPhoto 2006

Figure 3.2. *Pterygoplichthys joselimaianus* (formerly *Glyptoperichthys*)

Source: FishBase/JJPhoto 2006

Figure 3.3. *Pterygoplichthys lituratus* (formerly *Glyptoperichthys*)

Source: Amazon Exotic Imports 2005

Figure 3.4. *Pterygoplichthys punctatus* (formerly *Glyptoperichthys*)

(Source: FishBase/JJPhotos 2004

Figure 3.5. *Pterygoplichthys scrophus* (formerly *Glyptoperichthys*)

Source: FishBase/JJPhotos 2004

Figure 3.6. *Pterygoplichthys multiradiatus*

Source: FishBase/JJPhotos 2006

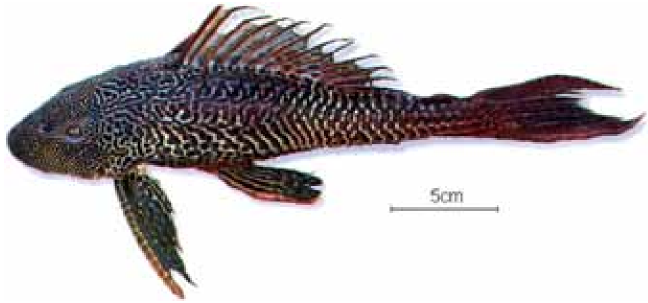
Figure 3.7. *Pterygoplichthys anisitsi*

Source: FishBase/JJPhotos 2006

Figure 3.8. *Pterygoplichthys disjunctivus*

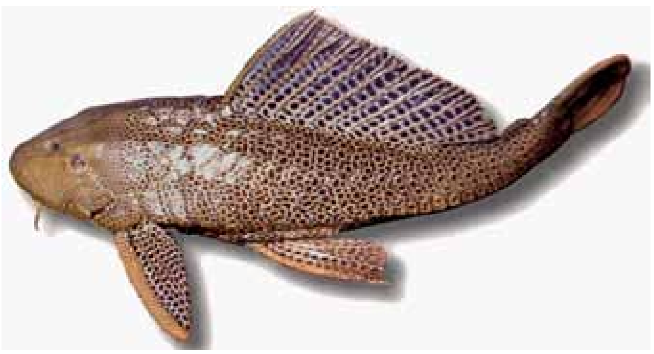
Source: FishBase/JJPhotos 2006

Figure 3.9. *Pterygoplichthys pardalis*



Source: FishBase/JJPhotos 2002

Figure 3.10. *Pterygoplichthys undecimalis*



(Source: FishBase/JJPhotos 2005)

Figure 3.11. *Pterygoplichthys xinguensis*

(Source: FishBase/JJPhotos 2004-)

species belong to the loricariid family and are estimated to represent five percent of total imports, or roughly 500,000 fish annually (Álvarez-Jasso 2004).

UNITED STATES

The United States trade in ornamental fishes is monitored, to some extent, through the USFWS Law Enforcement Management Information System (LEMIS). Records of all legally imported and exported plants and animals from the United States are maintained in this database, and data fields include: taxonomic information, country of importation/exportation, port of arrival, purpose and the number and/or mass of individuals. A recent review of this database identified some 26,469 records of freshwater fishes for the year 2005, with total imports amounting to 171,865,168 individuals and exports of 21,029,694 (J. Olden, University of Washington, personal communication). Figures 3.12 through 3.14 reflect the general breakdown of the most traded species (Figure 3.12) and the pathways for distribution into the United States (Figures 3.13 and 3.14), as recorded in LEMIS. LEMIS does not maintain records of loricariid introductions, so the "propagule pressure" of loricariid catfish imported into the United States is not fully understood at present. Furthermore, the full extent of the domestic industry remains to be determined, and quantitative estimates in the US of the loricariid trade in the US remains a 'work in progress.'

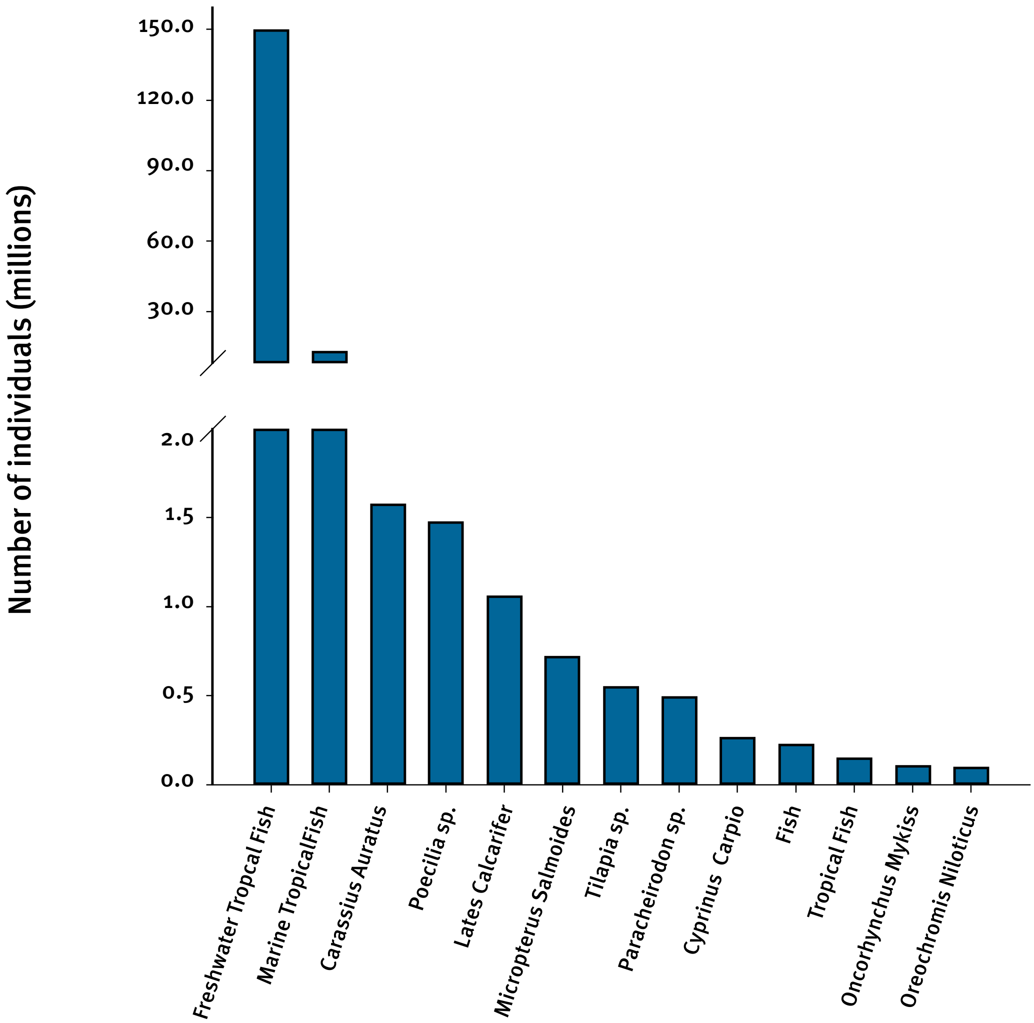
Hill and Martinez (2006), in a recent workshop sponsored by the US Army Corps of Engineers, have provided some perspective on the cottage industry that has developed around these species in Florida. According to these authors, there are currently about 170 farms where loricariids are cultured to supply the domestic demand for common varieties (e.g., *Ancistris spp.*, *Hypostomus spp.*, *Pterygoplichthys disjunctivus*, and *P. multiradiatus*). Roughly 80 percent of this production occurs in Hillsborough County (FL), notably one of the locations where wild populations have become established (Ludlow and Walsh 1991). As a result of the establishment of viable populations in the wild, the Florida industry is shifting away from brood stock maintenance toward the collection of egg masses deposited in the wild, and the subsequent incubation and grow-out of fry from these egg masses (Figures 3.15 and 3.16). The more "fancy" (colorful and unusual) species of suckermouth catfish, however, are still imported from South America.

Entry Potential

The entry potential considers the probability of the species' surviving in transit through the pathways of introduction, as well as the probability of survival if deliberately or inadvertently released into the environment. An analysis of entry potential should consider what drives the demand for the species' in trade such that other sources of entry are not overlooked.

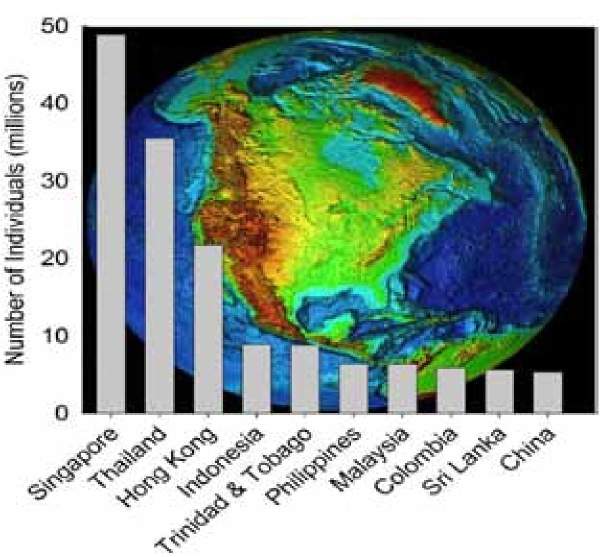
The long history of the successful transport of loricariid species from their countries of origin into CEC-member countries through the aquarium trade is well established. Thus, it can be assumed that the probability for survival through the transit process is essentially 100 percent. The probability of survival if released is less studied, but examples throughout many regions of the world indicate there is sufficient probability for survival in many tropical and subtropical regions. For example, populations have become established in the Philippines (Chávez *et al.* 2006), Taiwan (Liang *et al.* 2005); Puerto Rico, Panama, Trinidad, Guyana, Japan and Peru (FishBase); Singapore, Sumatra, Malaysia and Java (Page and Robins 2006). Given the broad occurrence of these species in

Figure 3.12. Trade of Freshwater Fish Species in the United States (for 2005), as Recorded in LEMIS



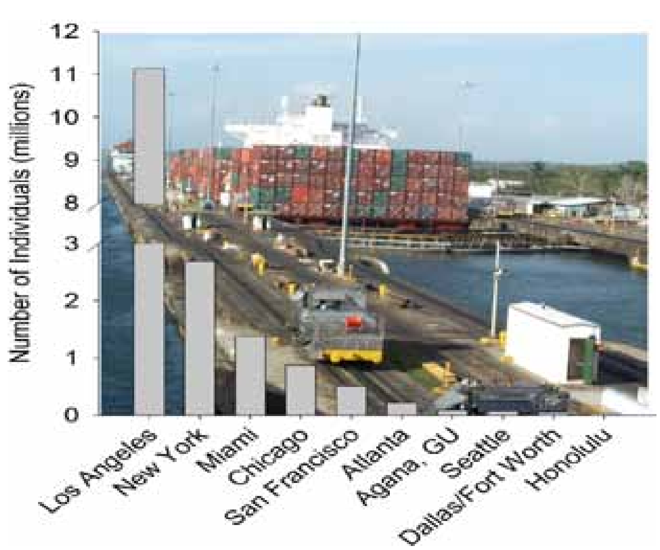
Source: Olden 2006, by permission

Figure 3.13. Principal Sources of Freshwater Fish Imported into the United States (for 2005), as Recorded in LEMIS



Source: Olden 2006, by permission

Figure 3.14. Principal Ports of Entry for Freshwater Fish Entering the United States and US Territories (for 2005), as Recorded in LEMIS



Source: Olden 2006, by permission

Figure 3.15. Loricariid Egg Collection in the Wild

Source: J.E. Hill and C.V. Martinez 2006. Culture of Loricariid Catfishes in Florida. Gainesville, FL 30–31 May 2006.

the aquarium fish trade, populations not yet identified in other countries are conceivable.

Other potential sources of entry that may be ancillary to the aquarium fish trade of these species exist as well. Possibilities include:

- escape from commercial tropical fish importers and fish farmers,
- dispersal of adults from established populations,
- intentional release for biological control of unwanted snails or plants (e.g., as occurred in Puente de Ixtla, Morelos, Mexico)

Natural events, such as hurricanes (as occur regularly in the southeastern United States and Mexico) or typhoons (as happened in the Philippines) may substantially increase the likelihood for entry into uncolonized waters from adjacent colonized waters (see Hubilla and Kis 2006).

CANADA

No records have confirmed that populations of loricariids have become established in Canadian waters. However, several records of loricariids caught in the wild are documented by the Canadian Biodiversity Information Facility and by the Royal British Columbia Museum. The species captured and recorded by these sources include: *Pterygoplichthys spp.* (Lake Erie, western basin), *Liposarcus* (*Pterygoplichthys*) *pardalis* (Duffins Creek, Ontario), *Panaque nigrolineatus* (Sydenham River, Ontario), and *Panaque suttonarum* (Shawingan Creek, Vancouver Island). These occurrences are thought to have resulted from aquarium releases.

MEXICO

Within Mexico, a significant population of loricariid catfishes has established itself in the Infiernillo Reservoir (Chapter 5). The species' distribution elsewhere in the country is increasing, and expanding populations of *Pterygoplichthys anisitsi*, *P. disjunctivus*, *P. multiradiatus*, and *P. pardalis* have also become established in the Grijalva-Usumacinta River; at least one species has spread through this watershed into Guatemala (Valdez-Moreno and Salvador Contreras, *pers. comm.* 2006). Another population has colonized the small basins surrounding Laguna de Terminos (Wakida-Kusunoki 2007).

UNITED STATES

In the United States, populations of loricariid catfishes have established in Hawaii (Sabaj and Englund 1999), Texas (Nico and Martin 2001; López-Fernández and Winemiller 2005), Florida (Ludlow and Walsh 1991, Nico *et al.* 1996;) and Nevada (Courtenay and Deacon 1982). It is unknown if the recent finding of a population in the Los Angeles River is reproducing, but large burrows found in the banks of the Sepulveda basin in Los Angeles suggest reproduction may be occurring there.

Colonization Potential

Colonization potential is the probability that an organism can establish self-sustaining population(s) once it has been released into the environment—by whatever mechanism. Numerous biotic and abiotic factors are involved in determining colonization potential and, with the loricariids, the lack of information on numerous ecologically relevant parameters makes predicting colonization potential challenging for many species that are in the aquarium trade. The following text summarizes the biotic and abiotic factors that may influence colonization potential as currently understood. Biotic information relevant to

Figure 3.16. Loricariid Egg Mass Incubation

Source: Hill and Martinez 2006

Figure 3.17. Male loricariid catfish guarding burrow

Source: Hill and Martinez 2006

understanding the potential for colonization includes information on physical characteristics of each species (size, morphology, etc.), physiological tolerances, life span, age to sexual maturity, spawning and agonistic behaviors, migratory requirements, fecundity, prey preferences, and biotic interactions. Abiotic factors reflect the physical conditions of the habitat that are preferred and tolerated by the species in question. Thus, factors such as minimum temperatures, hydrology, turbidity, substrate, salinity and stream velocity can all be important at predicting colonization potential.

Biotic Factors Potentially Influencing Colonization Potential

Most species within the *Loricariidae* family are generally nocturnal fishes that inhabit streams, lakes, and weedy, mud-bottomed channels. Bottom detritus and benthic algae are commonly their major food sources, but they also feed on worms, insect larvae, and various bottom-dwelling aquatic animals (Gestring *et al.* 2006). Loricariid catfishes often show high digestibility rates for organic matter (Yossa and Araujo-Lima 1998).

Loricariids, particularly the species that can grow to larger sizes, can be aggressive about defending territory and can compete for food. However, the mutability of these behaviors is poorly understood with respect to population size. In the Infiernillo Reservoir, the subject of Chapter 5, extensive schooling behavior of loricariids has been documented, suggesting that at high population densities, when resources are less limited, such agonistic behaviors may be reduced.

Most species of loricariids are burrow spawners (Figure 3.17). These fishes construct horizontal burrows in stream or pond banks that are 120–150 cm deep and shape is variable although the tunnel usually extends downward into the bank. Burrows are used as nesting tunnels and eggs are guarded by the males until free-swimming larvae leave the burrow, but sometimes also permit survival during drought. Fish can survive in the moist microhabitat even when water levels fall below the opening to the chambers.

Growth is rapid during the first two years of life, with total lengths of many sailfin catfishes exceeding 300 mm by age 2 (Hoover *et al*. 2007). Specimens in aquaria may live more than 10 years. The size range for most of the adult species in the Loricariid family is 30–50 cm, but individuals have been observed to reach 70 cm. Fecundity of loricariids is on the order of 500 to 3,000 eggs per female, depending on species and size. High fecundity may facilitate establishment, and female-biased sex-ratios may facilitate expansion of newly introduced populations (Liang *et al.* 2005; Page and Robbins 2006).

Liang *et al.* (2005) determined that females had significantly different external features from males in all but 2 of 13 morphometric characteristics they examined (e.g., body depth, predorsal length, eye diameter). However, the distinctions were very minor and statistical differences identified were only discernible through the large sample sizes they collected; gender distinction using morphometry in the field remains difficult to all but the most experienced taxonomists. The most assured way to differentiate the sexes is by the extrusion of eggs from gravid females during spawning seasons; measurement of plasma vitellogenin can also be used if laboratory facilities are available. In addition, certain similar growth patterns are documented in both sexes (Rapp Py-Daniel and Cox Fernandes 2005). However, Moodie and Power (1982) reported sexual dimorphism based on the mobility of pectoral fins.

The overall sex ratio of loricariid catfishes is often found to be female-biased. This finding may simply represent a sampling bias from males practicing parental care during the reproductive season, and thereby escaping capture more easily during collections. The reproductive season peaks during the summer (based on GSI values) but lasts several months and in some places it takes place during the whole year (see Chapter 5). They start reproducing at approximately 25 cm, and fecundity is moderately high. Hoover (2004) reported fecundity ranging from 472 to 1283 mature eggs/female. Gestring *et al*. (2006) quantified 1,983 eggs/ripe female in *P. multiradiatus* (Gestring *et al*. 2006). Escalera Barajas (2005) reported 975 eggs in females averaging 245 mm and 280 g. Mazzoni and Caramaschi (1997) reported a fecundity of 912 eggs in *Hypostomus spp.* The range in fecundity reported by these researchers may be associated with variations in the degree of parental behavior exhibited by the representative species in the loricariid family. Many loricariids exhibit male parental care for eggs and early fry. While males of some species carry eggs under large flaps of their lower lip, most loricariid fathers guard eggs and hatchlings in protected nests cavities. The degree to which these behaviors alter fecundity, relative to other factors such as size, has not been explored.

Suckermouth catfishes are capable of breathing air by swallowing it and extracting oxygen through the gut lining (Armbruster

1998). This characteristic allows them to withstand drought conditions in stagnant water or humid burrows (as well as long trips, like those from the Amazon Basin to North America). Loricariid catfish possess large-sized blood cells and large amounts of DNA per cell—factors that relate to their low metabolic rate and capacity to tolerate changes in body fluid composition (Fenerich *et al.* 2004). These cellular characteristics may enable their tolerance of challenging physiological stressors that may occur during drought periods (Brauner and Val 1996; McCormack *et al.* 2005). Collectively, these aspects of their physiology have provided them with a physiological advantage over other less tolerant fishes (Stevens *et al.* 2006).

Because they have evolved heavy external bony plates, and potential endemic predators in North American waters have little or no experience with this species, predation pressure on juveniles may be less intense in places where they have invaded than in their native range. Schooling behavior evidenced in several locations where they have become established may also reduce predation pressures.

Abiotic Factors Potentially Influencing Colonization Potential

Loricariid catfishes can be found in a wide variety of habitats, ranging from relatively cool, fast-flowing and oxygen-rich highland streams to slow-flowing, warm lowland rivers and stagnant pools poor in oxygen. Based on an evaluation of all species reported in FishBase, the thermal range preferred by the loricariids is approximately 20–28ºC. What likely plays the most significant role in restricting their range is the lower lethal temperature. Gestring (2006) reported lower lethal temperatures for *P. multiradiatus* as 8.8ºC and 11.1ºC for *Hypostomus spp.*; work is ongoing to establish these limits in a broader array of species.

Some species prefer rocky habitats and rapids, others shallow sandy lagoons or habitats with abundant woody debris (e.g., trees, branches, rootwads). Still others prefer shallow jungle creeks or deeper regions of larger rivers. The diversity of habitats potentially occupied or sought by *Loricariidae* species would suggest that nearly all types of freshwater environments within North America that provide temperature conditions suitable for the species' year-round survival could support some species of loricariids. Thus, when the thermal regime is suitable, other habitat adaptations, such as responses to water velocity or abundance of food supply, may play equally or more-important roles in shaping the distribution and spread of loricariid catfishes in new environments.

Like many fishes, loricariids exhibit differences in habitat use between large and small individuals. Smaller fish are generally collected only from the tributaries, whereas larger fish are generally collected from the mainstem (Power 1984; Liang *et al.* 2005). These findings suggest that early development occurs in smaller channels of streams. Power (1984) suggests that juveniles may select the smaller stream channels to avoid high velocity mainstem channel habitat, to avoid predators, and/or to improve their feeding opportunities.

Loricariids are highly tolerant of polluted waters and can adapt readily to varying water quality conditions (Nico and Martin 2001). They are often found in soft waters, but can adapt very quickly to hard waters. They can thrive in a range of acidic to alkaline waters (pH 5.5 to 8.0). Furthermore, some species are salt-tolerant. Although salinities in which they have been collected are not reported, waters have been described as "quite brackish." Table 3.2 summarizes species of loricariids that have become established in Mexico and the United States, and some of their physiological and habitat preferences. Based on the wide array of conditions tolerated by the loricariid catfishes and their inherent biological characteristics (e.g., high fecundity, territoriality), introduced populations may become locally abundant (colonized) in a short period of time (Hoover *et al.* 2007).

[4] Hoover *et al.* 2004.

Table 3.2. *Loricariidae* **Species Reported in Mexico and the United States and Some Biological and Niche Preference Data**

LORICARIIDAE SPECIES	TEMP (ºC)	dH*	pH	SIZE (cm)
*Pterygoplichthys*** *gibbiceps*	23–27	4–20	6.5–7.8	50
P. joselimanianus	24–29	4–8	6.5–7	30
P. lituratus				37
P. parnaibae				29
P. punctatus	22–26			28.5
P. scrophus				27.5
P. xinguensis				27
P. anisitsi	21–24	25	6.5–8.2	42
P. disjunctivus				70
P. multiradiatus	22–27	4–20	6.5–7.8	70
P. pardalis	23–28	10–20	7–7.5	70
P. undecimalis				50
TOTAL	**21–29**	**4–20**	**6.5–8.2**	

*Degrees of water hardness (as mg/L calcium)
**Synonymized as per Armbruster 2004 and personal communication (December 2008)

Spread Potential

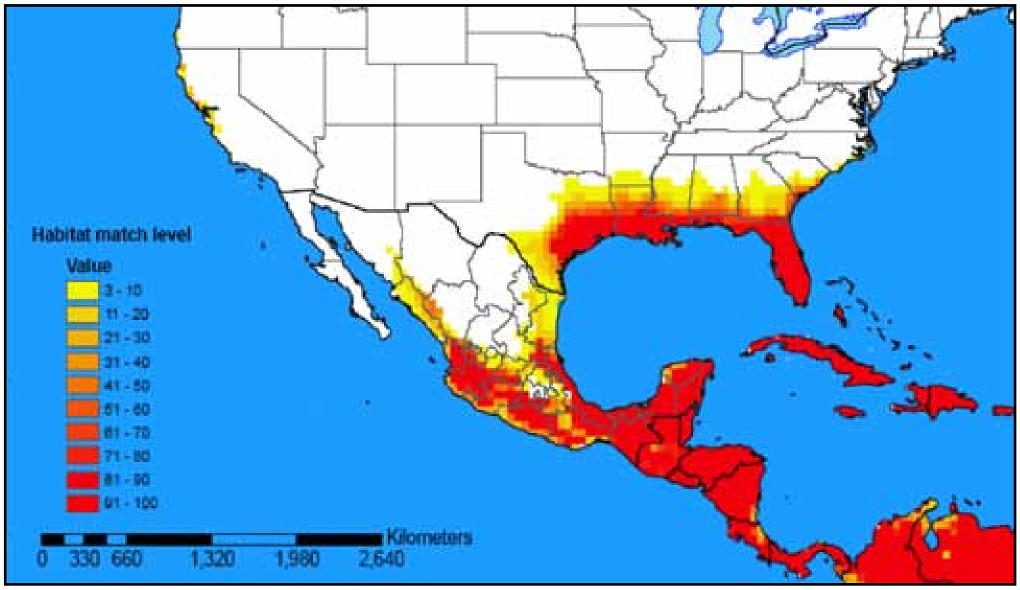
Analyzing the potential for the spread of loricariids assumes that a population has colonized. Considering the probability for spreading requires an assessment of the environmental characteristics in the areas vulnerable to future colonization based on hydrological connectivity and other human-based and natural factors.

Environmental Characteristics of Vulnerable Receiving Waters

Environmental factors in receiving waters that prevent colonization or spread of introduced loricariid populations remain little studied. As discussed, loricariids have exhibited tolerance to a wide variety of water quality conditions and, therefore, have potential to invade both polluted and unpolluted waters. Loricariid catfishes are equipped to tolerate polluted environments through their air breathing ability. They have evolved several modifications of the digestive tract that allow it to function as an accessory respiratory organ. Air breathing increases at night, regardless of dissolved oxygen concentration. They also exhibit substantial cardiac hypoxia tolerance that allows them to survive in hypoxic and polluted waters. However, they may move from polluted waters to cleaner waters upstream.

They are also highly adapted to high water velocities. In laboratory swim tunnels, they can maintain station and move freely in water velocities greater than 1 m/s.[4] Such characteristics could enable the loricariid catfishes to ascend gradients impassable to most other fishes, such as earthen dam spillways or other near-vertical structures such as natural cascades and waterfalls.

Figure 3.18. Potential distribution of *Loricariidae* in North America using GARP modeling



As discussed, the absolute thermal thresholds for cold tolerance are not known for many loricariid catfish species, but movement into thermal refugia (e.g., springs and seeps during winter) seems likely, and the utilization of thermally enriched sewage outflows has been demonstrated in Houston (Nico and Martin 2001). The acclimation of some introduced populations to cooler subtropical and temperate climates over time must be considered a possibility.

The spread potential of the loricariids is therefore related to a variety of the distinctive features exhibited by this fish family: moderately high reproduction rate, spawning behavior in deep burrows (reducing the ability to eradicate populations effectively), parental care, territoriality, resistance to desiccation, protected by a heavy armor, rasping teeth and dorsal spines used for defense, and the ability to utilize atmospheric oxygen somewhat—thus having the possibility to survive out of water much longer than other fishes. Data are not sufficient to ascertain which among these factors may play the greatest role in determining spread potential, but all likely play a role. It is worth noting, however, that the *Loricariidae* have been found to have an 80% rate of establishment for introduction events outside their geographic range worldwide and are thus given the highest risk score in other risk assessments (Bomford and Glover 2004).

GARP Modeling

To further estimate the potential distribution of loricariid species in North America, a Genetic Algorithm for Rule Set Production (GARP) analysis was used, similar to that applied for the snakehead (Chapter 2) and others to predict the potential distribution of invasive species (e.g., Drake and Lodge 2006). Information on nine environmental variables (maximum, mean and minimum air temperatures, wet day index, annual river discharge, precipitation, compound topographic index, slope, and frost frequency) from the native ranges of three loricariid species was used to estimate the potential spread of the *Loricariidae* family collectively. The nine variables were chosen as they are the only variables for which we have global information. The GARP modeling results for the *Loricariidae* family is projected in Figure 3.18 below. While these results should be considered preliminary, they conform generally with empirical findings to date from the United States and Mexico where loricariids have been introduced.

As demonstrated below, large parts of Mexico and the southeastern United States appear vulnerable to the spread of loricariids. Definitive modeling at the watershed scale is needed to consider the potential spread of specific species and GARP modeling does not support resolution at this finer scale.

CONSEQUENCES OF ESTABLISHMENT

Economic Impact Potential

Both positive and negative economic impacts of the loricariids in the aquarium trade must be considered. Full economic analyses at the national level of each country have not been conducted. The following text summarizes the current knowledge.

CANADA

There is no evidence that loricariids are having a negative socioeconomic impact on Canadian waters, as no established populations have been identified.

MEXICO

The first record of these fishes in Mexico was *Liposarcus* (=*Pterygoplichthys*) *multiradiatus* in the Río Balsas in 1997. Three years ago the first invasive status was registered in the basin. At present, the problem has become severe, as some species have already established themselves in the Infiernillo Reservoir, one of the largest bodies of freshwater in the country (120 km in length and 40,000 ha superficies, 2.250 billion m^3). This reservoir was the site of the largest freshwater fishery in the country (several tilapia species constituted 90 percent of the fish population, accounting for 20 percent of the nation's production in continental waters). Before the invasion, fishermen captured 20,000 tons of tilapia per year, more recently they have been catching between 13,000 to 15,000 tons of sailfin catfish. These fishes have been affecting the fishing gear and boats of fishermen, and thus their way of living. Overall, nearly 43,000 jobs have been lost in this one location. The loss of incomes from either directly from fishing or indirectly through fishery support services has affected fishers and their dependants, creating a difficult socioeconomic situation.

The invasion is not restricted to this reservoir but has expanded to the whole Balsas basin, one of the most important in the country: draining a number of important rivers in the south of Mexico. In 2003, other invasions were registered, this time at the Usumacinta River (one of the largest of the country) draining into the Atlantic Ocean, mainly in the state of Tabasco, where fishermen have started requesting the state government to take immediate action on the matter.

Because the loricariid fishes do not have any economic value to the community associated with the Infiernillo Reservoir and are not accepted as food by the general population, ongoing research is being directed to obtaining a byproduct, such as fishmeal. Unfortunately, the quality is not very good due to the bone structure of these fish (the ash content is quite high in the final fish meal, resulting in low digestibility if it is intended as a feed ingredient). However, there is a possibility of using this fishmeal as a natural fertilizer. Studies to understand how loricariids have affected the fish community are being performed. As has been the case with other species introduced from South America, when these fish have been caught in the wild and then released in a region with similar characteristics, they are more prone to become established.

UNITED STATES

The United States can identify both positive and negative economic impacts from loricariid populations that have established in the wild and from the aquarium trade in loricariids (Chapter 4). As previously discussed, the impacts of the species may be watershed-specific and dependent on the local socioeconomic factors. Florida's cottage industry for egg mass collection to support the aquarium trade creates positive economic impacts, as does the aquarium trade in loricariids. Negative impacts have not been fully accounted, but might include costs of shoreline armoring in localized areas, loss of fishing opportunities and damage to commercial gear (e.g., Lake Okeechobee), and the possibility of losses from out-competition and harassment caused by the catfishes (e.g., effects on native darter species in Texas and manatee harassment in Blue Springs, Florida). Table 3.3 summarizes the perceptions of eight researchers in the United States who have had first-hand experience studying the introduced loricariid populations. As reflected in the table, opinions on the economic and environmental impacts of introduced loricariids are not uniform.

Table 3.3. Summary Responses from Professional Inquiry on the Environmental and Economic Impacts of Introduced Loricariid Populations in the United States

Question 1: What species and in what regions do you study introduced suckermouth catfish?	
Respondent	**Response**
(#1)	*Pterygoplichthys multiradiatus*, *P. disjunctivus*, *Hypostomus spp.* in southeastern Florida fish communities
(#2)	*P. disjunctivus*, *P. pardalis*, *P. anisitsi*, *P. multiradiatus*
(#3)	*P. disjunctivus*, *P. pardalis*, *P. anisitsi*, *P. multiradiatus* in Florida
(#4)	*Hypostomus spp.* in San Felipe Creek, Del Rio, Texas
(#5)	*Hypostomus spp.* and *Pterogoplichthys spp.* in the San Marco, Comal and San Antonio rivers
(#6)	Principally populations of loricariids in Florida
(#7)	*P. disjunctivus*, east-central Florida
(#8)	*P. disjunctivus* in Volusia Blue Springs and Gemini Springs, Florida
Question 2: Do you believe that population control or environmental management is possible? If so, at what level?	
(#1)	The most critical environmental limiting factor for loricariids in Florida is coldwater temperature, but as a group they already occupy most of their potential Florida range. Therefore, unless there is a complete freeze-over in Florida waters, or a viable commercial market develops for this species, there will be no major impact to loricariid species abundance. Commercial fishermen do not assert population control, where such freshwater fisheries exist.
(#2)	Prevention should be the first barrier. It may be possible to reduce abundance in some locations, but based on the Hillsborough River studies, eradication is not feasible. Environmental management would only be useful in highly modified habitats located in urban areas.
(#3)	Doubtful that it is possible to control populations over large areas. Shoreline hardening/barriers are effective, but expensive.
(#4)	Hopefully population suppression since eradication does not seem possible.
(#5)	Difficult at best. Currently unknown.
(#6)	Eradication is unlikely, except maybe in localized areas. Population suppression and damage reduction may be possible.
(#7)	Unlikely except in small areas where shoreline armoring could be incorporated.
(#8)	Probably only damage control is possible, as the population densities (in Blue Springs) are too large

Table 3.3. Summary Responses from Professional Inquiry on the Environmental and Economic Impacts of Introduced Loricariid Populations in the United States (continued)

Question 3: What measures of control and management are being practiced in your region?	
(#1)	Relative abundance monitoring and standing crops estimates of Orinoco sailfin, vermiculated sailfin, and suckermouth catfish in SE Florida to assess effects on native fish. Some upscale private companies are installing erosion barriers to reduce effects exacerbated by loricariids.
(#2)	None beyond abundance monitoring.
(#3)	There are no direct control programs, but there are considerable egg collecting programs for ornamental fish trade in Florida. Despite this, there is not likely a negative effect on catfish abundance.
(#4)	Work under the State Wildlife Grant to determine effective measures. The objective is to quantify the dietary preferences and degree of overlap between the Devil's River minnow and the loricariid catfish, and to investigate the efficacy of eradication techniques. Stomach content analysis is done monthly, and an exclusion chamber experiment will be used to assess food preferences.
(#5)	Minimal to none.
(#6)	None in Florida.
(#7)	None to date.
(#8)	None.
Question 4: What measures do you think would be effective?	
(#1)	Measures include permanent barriers along the shoreline; heavy liners with rip-rap overburden; and native plant fringes—which are likely less effective due the burrowing action of the species'. All measures are expensive.
(#2)	The measures depend on population size and ecosystem characteristics. In central Florida, I would restrict access to nesting sites and over fish the loricariid populations. In the Grijalva-Usumacinta basin (Mexico) trapping during the dry season could reduce the populations in pristine basins where other species have to be protected.
(#3)	Perhaps a larger commercial market coupled with intense egg collection could reduce abundance (likely only effective in isolated circumstances.)
(#4)	A variety of passive capture techniques are being investigated for their effectiveness, including hoop nets, trammel nets, catfish trap nets, frame nets and a variety of baits.
(#5)	Educating the public, especially aquarists, to avoid putting their unwanted fishes into open waters. Movies such as "Finding Nemo" have actually hurt the cause dramatically.
(#6)	Systematically visit nesting colonies during the breeding season and capture and remove adults and any eggs and young. This may be mostly effective in areas where breeding habitats are limited. Prevention will likely require added educational programs and law enforcement.
(#7)	Harvesting of adults and egg masses in small ponds and urban lakes. In rivers and canals no method would be effective, as too labor intensive and costly.
(#8)	Unclear if any method would help.
Question 5: Do you believe that suckermouth catfishes pose significant environmental impacts to local biota? If so, are the impacts high, moderate or low?	
(#1)	No. Researcher has examined stomach contents of more than four hundred *P. multiradiatus* over a 12-month period in a Florida canal and 94 percent of the stomach volume was composed of detritus, algae, sand and decomposing plant matter. Microcrustaceans and native fish eggs constituted 1 percent or less of the total stomach volume. Because detritus, algae and decaying plant matter are underutilized as a food by native fishes, this researcher considers risks to native Floridian fishes to be low.
(#2)	Loricariids are having moderate impacts on local biota of the Hillsborough River. There are some hypothetical negative impacts that should be studied in less modified habitats than the canals of southern Florida, including: predation on demersal fish eggs (shad) in St. John River, changes to the trophic chain of alligator, pelican and other birds, and impacts on invertebrate communities.
(#3)	Suckermouth catfish are not having a major negative impact on native fishes in Florida. Indirect effects might be mediated through invertebrates. However, if these effects are important to native fish dynamics then there might be a higher effect on fish populations. There may be impacts on native fish that use cavities for nesting- although the catfish burrows may increase the abundance of nesting sites for these fish. The question has not been thoroughly investigated, but existing evidence of native fish populations does not indicate loricariids are causing major negative effects.

Table 3.3. Summary Responses from Professional Inquiry on the Environmental and Economic Impacts of Introduced Loricariid Populations in the United States (continued)

(#4)	Impacts are high. There is a documented decline in Devil's River minnow and its congener, manatial roundnose minnow. Current hypotheses include: 1) competition over food resources 2) direct predation of minnow eggs by catfish.
(#5)	In addition to competition problems identified among native algivores such as the threatened *Dionda diaboli*, significant habitat competition and interference has been identified between *Hypostomus spp.* and the native San Felipe gambusia, *Gambusia clarkhubbsi*.
(#6)	Largely unknown and not sufficiently studied.
(#7)	Impact is low to moderate, primarily due to their burrowing activities creating low water quality conditions (sedimentation, eutrophication).
(#8)	Yes. Population density and harassment to manatees is a significant impact, as are the burrowing actions and catfish droppings that are adding nutrients to the water systems.

Source: J.J. Hoover, by permission

Environmental Impact Potential

Several authors assert that environmental impacts to endemic species from Loricariid introductions are possible through direct competition for food and space (Nico and Martin 2001; Flecker 1996; Devick 1989; Hubbs *et al.* 1978; Hoover *et al.* 2004). Other authors contend that loricariid catfishes can also have negative indirect impacts on endemic species through incidental ingestion of substrate-attached eggs (Hoover *et al.* 2004), snails or other aquatic benthos (Bunkley-Williams *et al.* 1994). As opportunistic benthic feeders, these mechanisms for impact are plausible, whether or not evidence has shown them to be expressed in all locations where introductions of loricariids have occurred. Their burrowing behavior and habitat selection for breeding may also create significant impacts, but the severity and interpretation of those impacts appears to be determined, at least in part, by the characteristics of the waters where they invaded (Table 3.3). Evidence for these impact pathways is discussed below.

Suckermouth catfishes "plow" the bottoms of streams and lakes while foraging, occasionally burying their heads in the substrate and lashing their tails. These behaviors can uproot or shear aquatic plants and reduce the abundance of beds of submersed aquatic vegetation, creating floating mats that shade the benthos from sunlight. As highly efficient algivores and detritivores (Power et al., 1989; Armbruster 2003), loricariids may compete directly with other fishes such as *Dionda diaboli* (Garrett *et al.* 2002, in López-Fernández and O. Winemiller 2005). By grazing on benthic algae and detritus, loricariids may alter or reduce food availability and the physical cover available for aquatic insects eaten by other native and non-native fishes where they are introduced (Page and Robbins 2006; Liang *et al.* 2005). Cohen (2008) quantified gut contents of suckermouth catfishes from the San Marcos River in central Texas and assessed the degree of dietary overlap between the suckermouth catfish and native herbivorous fishes by comparing gut contents and through stable isotope analysis and concluded that gut content assessments of Guadalupe roundnose minnow *Dionda nigrotaeniata* and two additional *Dionda* species suggest high dietary overlap between the *Dionda* complex and suckermouth catfish. These data indicate introduced suckermouth catfishes in spring-influenced streams are potential direct competitors with native taxa in spring-influenced streams of central and west Texas.

The potential effects on altering insect community assemblages was demonstrated by Flecker (1992), under controlled conditions in simulated neotropical artificial streams with the loricariid *Chaetostoma milesi*. Flecker concluded that the effect of grazers such as *C. milesi* is principally to change the distribution and abundance of resources important to neotropical stream insects, rather than through the direct predation on the insects. Feeding on mud and silt can re-suspend sediments, causing turbidity and reduced depth of the photic zone, and/or could result in changes in substrate size. In addition, nutrients can be prematurely diverted from the "consumer" components of food webs and transformed into feces available only to scatophags and decomposers (i.e., bacterial, fungi).

Because they are benthic feeders and may attain large sizes, loricariids may displace smaller, less aggressive or otherwise less resilient North American benthic fishes (e.g., darters, madtoms, and bullhead catfishes). For example, Stevens *et al.* (2006) reported that typical estuarine fish assemblages in the mouth of the Peace River and upper Charlotte Harbor were replaced with a simpler fish community, including the introduced brown hoplo (*Hoplosternum littorale*) and sailfin catfish (*Pterygoplichthys spp.*) after hurricane Charley. According to the US Fish and Wildlife Service (2005), the Devils River minnow is threatened by the presence of armored catfish. Fish collections by G. Garrett in 1997 from San Felipe Creek revealed for the first time the presence of armored catfish (*Hypostomus spp.*). Collections in 2001 to 2003 confirmed that armored catfish are reproducing and are abundant in San Felipe Creek (López-Fernández and Winemiller 2003). Established breeding populations of *Hypostomus spp.* also exist in the San Antonio River, Texas, and have been cited as potentially competing with *Dionda episcopa* in this system due to its food habitats (Hubbs *et al.* 1978, Hoover *et al.* 2004). Although Dionda species are common in spring runs in Central Texas, they are now absent from these habitats in the San Antonio River, further suggesting possible displacement by the armored catfish (Hubbs *et al.* 1978).

Most species of loricariids are relatively sedentary and may be attractive prey to fish-eating birds. Their defensive erection of dorsal and pectoral spines has been cited as posing a potential danger to birds, such as pelicans, that attempt to swallow whole fish, although other researchers contest this (Bunkley-Williams *et al.* 1994). Loricariids may also compete for space through their habitat selection for breeding. The nesting burrows of loricariids sometimes form a large “spawning colony” in which several dozen occur in very close proximity. These colonies can compromise shoreline stability, increasing erosion and suspended sediment loads. Siltation, bank failure, head-cutting, and elevated turbidity can occur as a result (Hoover *et al*. 2007). In Florida, sailfin catfish tunneling is believed to damage canals and levees and result in increased siltation (Ferriter *et al*. 2006), although as demonstrated in Table 3.3, not all researchers agree with this interpretation of the environmental impact. Goodyear (2000) suggests that *Pterygoplichthys multiradiatus* competes directly with and impedes successful spawning of native fish. In Lake Okeechobee, it feeds and burrows at the bottom and destroys submerged vegetation, essentially displacing native fishes that would otherwise use the aquatic vegetation for spawning and refuge (Fox 2002).

Finally, as with all non-native species introductions, loricariids can host infectious pathogens to which native species are not adapted or resistant. Loricariids are generally resistant to diseases but many harbor parasites, including flukes, roundworms and protozoans. Some loricariids have been associated with the protozoan, *Trypanosoma danilewskyi* (*carassii*), known to afflict cold freshwater cyprinid fishes (e.g., carp, goldfish, tench) with anaemia, likely resulting in death (Kailola 2004). Epizotic commensal chironomid larvae have been found among the oral bristles of different species (not present in species lacking bristles). An unidentified dinoflagellate occurred on the skin, fins and gills of *Pterygoplichthys gibbiceps*. Mortality rates were up to 100 percent in some consignments after 7 to 14 days, and the parasite was not treatable with malachite green, formalin or affected by changes in salinity, due to the formation of cysts (Pearson 2005).

Summary of Risks from the Loricariids

Loricariid risks are summarized in Attachment 2A, the Organism Risk Assessment Form for the *Loricariidae* family. This exercise has highlighted how biotic and abiotic factors in the environment where loricariid species have been introduced govern the severity of their impact. In neotropical Mexico, introductions appear to be at the root of environmental and socioeconomic effects that have not yet been controlled. Temperate conditions throughout Canada will likely prevent loricariids from ever becoming significant pest fishes, although the vulnerability of portions of western Canada requires further study. In the United States, significant effects on native fish fauna have been identified in Texas ecosystems, but are less equivocal in Florida, where several researchers believe the species has extended to its maximum range.

GARP modeling suggests, however, that there is significant possibility for the spread of the family into waters of the states adjacent to Florida and Texas. Based particularly on the Mexican experience, the propagule pressure from aquarist release and/or intentional distribution into these as-yet un-colonized waters is cause for concern. The ecological and socioeconomic effects of a further spread of loricariids in these waters cannot be determined from existing data, but would likely be significant, costly, and damaging in many of the potentially vulnerable aquatic systems in the American southeast.

4

CHAPTER 4

Social and Economic Impacts of the Loricariid Catfish in Florida

Gretchen Greene and Donna Lee*

INTRODUCTION

The sailfin and suckermouth catfishes (commonly referred to as 'plecos', 'placostas', 'lacostas', 'lipos' and other names—here both populations will be referred to generically as "loricariids") have been established in the state of Florida for many years. Most people place the arrival of these species in the state sometime in the 1970s.[5] However, their unusual rapid expansion in certain locations is most pronounced beginning in the late 1990s and since the turn of the millennium. Researchers have noted that the population is hardy and seems to thrive in both flood and drought conditions. In recent years in Florida, hurricanes have caused flooding, and droughts have also occurred. These species have expanded recently in Lake Okeechobee in southern Florida and in the lakes of central Florida. However, the canals of southern Florida, near Boca Raton, which have hosted the populations since the 1970s, are apparently not experiencing increases of similar magnitudes, despite atmospheric and hydrologic events like hurricanes and flooding that have helped the populations spread in lakes and ponds.

The purpose of this paper is to identify the potential economic impacts of these invasive aquatic species within the state of Florida. Some people are currently benefiting from the presence of loricariid catfishes because they are valuable aquarium fish, and the egg masses of the wild fish are gathered and sold to aquaculture facilities that then sell to pet stores. But despite their abundance, no economic value has yet been discovered for the mature wild fish. Positive economic benefits to aquaculturists, egg gatherers, and the pet trade aside, the species is believed by some to be associated with a variety of negative impacts.

These include:

- Losses to tilapia fishermen using haul seine gear in central Florida lakes;
- Losses to homeowner associations from the fish burrowing into retention pond bank structures;
- Losses to cast net fishers, and haul seine fishers in Lake Okeechobee;
- Possible impacts on valuable commercial and recreational species.

Each of the alleged impacts is considered below and the best available information used to evaluate it. Particular attention is paid in each instance to concurrent factors that affect the populations of loricariid catfishes in the relevant area, and concurrent economic factors influencing the gain or loss attributable to the species. Often, the presence of the fish in abundance can be correlated to poor or disturbed ecosystem conditions and declining native fish stocks. A clear cause and effect relationship between these fish and other simultaneous economic losses is difficult to confirm or quantify, however. In a couple of cases, the economic impacts may be clearly defined and are directly related to loricariid catfish population expansion. In other cases, some commercial fishermen believe that there is a relationship between the population growth and the decline of other species, though the clear causal relationship is undefined at this time.

Background

Many populations of loricariid catfish are believed to have started through illegal aquarium releases. Non-indigenous populations in Hawaii, Mexico, Texas, and Florida are believed to have originated in this way. As discussed in the preceding chapter, the fish grow rapidly to large sizes, which can be disruptive in small aquarium tanks. When aquarium owners find that they can no longer cope with the fish, they may feel compelled to release them into the wild, perhaps assuming that natural predation will take care of the problem (Hoover *et al.* 2007). Often, this does not happen, however.

Loricariid catfish have now begun to increase in abundance in many of the lakes, streams, and canals in Florida. Within the state, they are among many introduced species thriving in both natural and manmade environments. Little is known about the causes of invasions, nor why and how some populations seem to have expanded rapidly, while others have remained stable.

* Entrix, Inc.

[5] Hoover 2004 and numerous interviews.

Figure 4.1. Loricariid Catfish Burrowing on bottom of Lake Okeechobee

Source: Donald D. Fox, Biological Administrator, Florida Fish and Wildlife Conservation Commission, Okeechobee Fisheries Office.

Diverse Habitats

Biologists have identified several features that seem to have allowed the species to thrive in the state:

- Flood and drought conditions;
- Clay soils that are conducive to burrowing for laying eggs; (see Figure 4.1)
- Shallow water, as found in manmade structures and natural lakes in Florida;
- Steep banks for burrowing, for instance, those found in housing development retention ponds;
- Warm temperatures;
- Running water, as in irrigation canals, and natural streams;
- Degraded systems with an abundance of algal detritus for food supplies.

The only known feature that has been identified as a population check is temperature. Unseasonable freezes in Florida have been known to produce fish kills.

Sources of Information

For the purpose of this report, fishery biologists, managers, and commercial fishermen were interviewed about the loricariid catfish. Many interviews were conducted during a field trip on 26–27 January 2007. Follow-up interviews were conducted over the telephone in subsequent months.

Economic Approach

This report depends primarily on the interviews with knowledgeable people to describe the overall potential economic impact of this species. Some impacts are well defined and clearly tied to the loricariids. Others are only perhaps to be associated with the spread of the loricariids, having occurred while other significant system alterations were underway. In the report below, every effort is made to identify the confluence of ecologic and economic factors that are associated with a particular trend or impact.

Ideally, the measurement of a particular impact involves extending an economic trend associated with the invasive species into a future scenario and comparing that with a control scenario where the species is absent. However, because the spread of this species has occurred so recently and particularly because of concurrent atmospheric, hydrologic, and economic events, it is not possible to separate the effects associated with these system alterations from effects that could be attributed to the fish. Instead, the goal of this document is to compile the available information to date so that future research might be able to build on it and determine effects associated to the species with greater clarity. Where possible, annual impacts directly attributed to the species are quantified.

Economic Benefits

It is not clear what role the steady demand for loricariids in the ornamental fish industry has played in the expansion of the wild species. Certainly, these fish are grown and sold successfully in Florida and have been for some time. While these producers are not suspected of releasing the fish accidentally into the wild, aquarium owners themselves may release the fish without fully understanding the potential consequences. Described elsewhere as risk pathways, there are economic benefits associated with the species in this industry.

Aquarium Trade

Since the early 1960s there have been fish farmers who produce loricariid catfish fry and brood stock in ponds near Tampa. These producers are conservatively estimated to sell at least 10 million fish per year to shippers who sell a variety of ornamental fish.[6] Typically, shippers do good business selling loricariids because large "big-box" stores, such as Walmart and PetSmart, will also buy the more expensive exotic fish from a shipper who can guarantee large numbers of loricariids. They typically sell for approximately $.20 per two-inch fish, or for about a nickel per half inch. Hence at the farm gate, supplying loricariids is likely to be at least a $2 million industry in Florida, and one that helps support a much larger ornamental fish industry.

Egg Harvesting

The same fish farmers will pay $5 for loricariid egg masses. Since the proliferation of the species began in certain areas, loricariid farmers have come to depend on wild egg collectors rather than on raising their own brood stock. Egg collectors may collect 100 to 150 egg masses per day, yielding an income of about $500 to $750 dollars. It is not known how many people are involved in egg collection. The season begins in April or May and continues through September or October. Collectors might work six or seven days per week, depending on how involved they are in the activity.

[6] Interview with Dr. Jeffrey Hill, University of Florida, 6 November 2006.

Based on preliminary estimates of survival, and an assumption of 600 eggs per egg mass, about 17,000 egg masses would be needed to supply the aquaculture business with 10 million fish. At a price of $5.00 per egg mass, this represents $85,000 in income annually to the egg mass collectors. Because people do this as a part-time source of income, or the fish farmers collect these themselves, it is difficult to know how many people are benefiting from this cottage industry.

Potential Uses

Nearly everyone interviewed for this study commented that if only an economic use for loricariids could be discovered, the frustrations would cease. There is no market for them as food, both for reasons of taste and because the hard spine and outer shell of the fish makes it difficult to handle and clean. Many people suggested that they might be ground into pet food, or that some similar use of the protein and biomass should be developed. Reportedly, one entrepreneur is grinding up and freezing loricariids into blocks for sale as bait to crab trap fishers.

This is an area for potential future research.

ECONOMIC IMPACT OF BURROWING

Loricariid catfish create burrows in river or lake banks in which to live. The burrows are one half to one meter deep and about the width of the fish. The catfish lay their eggs in the burrows, which are then guarded by the male fish. Several dozen of these burrows can occur in close proximity when catfish form a 'spawning colony' compromising the shoreline stability and increasing erosion. This may lead to serious problems in some locales, such as bank failure and head cutting. Loricariid catfish are reported to cause up to 4 meters of erosion annually (Hoover *et al.* 2004). Rivers and lakes with relatively open banks are particularly susceptible to extensive catfish burrowing, causing shoreline collapse (Hoover *et al.* 2007).

The extent to which loricariid catfish burrowing causes bank erosion is debatable, however. Although, as mentioned above, Hoover *et al.* (2004) have suggested that catfish-induced erosion could decrease the shore by four meters annually, Gestring (2006) suggests that only 10 to 25 percent of annual shoreline erosion can be attributed to them. This would create considerably less and more localized annual erosion than Hoover *et al.* (2004) suggest. Gestring (2006) bases his estimate on data from erosion control companies in Florida. Though these companies claim a maximum of 25 percent of shoreline erosion is attributable to loricariid catfish, the fish is primarily said to contribute 'little to none' to their annual income (Gestring 2006).

In Florida, homeowners with houses on freshwater lakes pay to control erosion. The erosion control industry grosses between $15 and $22 million annually in the state (Gestring 2006). When erosion control companies were asked the extent of their annual income attributable to loricariid catfish borrowing, one company reported 30 percent while four more reported little to none. Assuming these five companies make up the erosion control industry in Florida and that they are of equal size, the economic damages associated with loricariid catfish burrowing can be estimated. For the company that reported 30 percent of its annual gross income from loricariid catfish damage, that fraction of its annual income is between $900,000 and $1.32 million. If we assume that the other four companies reported an average of five percent of annual gross income due to loricariid catfish damage, each company will make between $150,000 and $220,000 from the fish. And if we assume that net revenue is half of gross income, then the total annual net revenue attributable to the loricariid catfish in the state's erosion control industry would be between $1.5 and $2.2 million.[7]

FISHING IN CENTRAL FLORIDA – CASE STUDY

In recent years, the rapid increases in loricariid catfish populations have disrupted, or interfered with at least two commercial fisheries within Florida. In Polk and Lake Counties in central Florida, population increases are limiting the number of lakes where commercial fishermen can continue fishing profitably. The economic impacts of loricariid catfish are identified, and where possible analyzed quantitatively. Although the haul seine fishery in fishery in Polk and Lake Counties is small, data have been kept for nearly 20 years and loricariid catfish bycatch has been documented for the past five years. Hence, this fishery is analyzed more closely to provide a better quantitative picture of both economic trends in the fishery and loricariid catfish population trends.

Within Polk and Lake Counties, there are several lakes that support small fisheries. Since the introduction of tilapia in the early 1980s, that fishery has provided income for up to 30 fishermen operating haul seine gear, another 25 people working in fish packing houses, and numerous others participating in a cast-net fishery. Unfortunately, the number of cast-net fishermen is unknown, since it consists of those who wish to buy a $25 commercial fishing license that entitles the holder to sell fish to the packinghouses. It is estimated that as much as 75 percent of the caught fish sold from these lakes is provided by the cast-net fishermen.[8] One estimate is that in the past there may have been 100 to 125 cast-net fishermen, and that number may have dropped to 50 to 75 in recent years.

The haul seine fishermen operate with coordination through the Fish and Wildlife Conservation Commission (FWC), which allocates five haul seine permits. The FWC also records harvest data for that fishery and recently has begun recording the "trash fish" harvest estimates, which include loricariid catfish. Tom Champeau, director of the fishery, provided these data so that some of the impacts could be analyzed within the context of other economic features of the fishery. Interviews with fishermen were also used to conduct the analysis.

Although most or all five of the permits used to be in operation, at present just one operator is known to still go fishing regularly. Captain Taren Thomas Wadley operates under this permit. She shared her frustrations about the loricariid catfish that began occurring in the early 1990s in some lakes. The table below provides an estimate of how the catch of loricariid catfish and tilapia (called "nile perch" in this area) changed over the course of an invasion into

[7] All estimates are based on Gestring 2006.
[8] From an interview with Tom Champeau, 11 April 2007

several lakes (see Table 4.1). These estimates are based on Captain Wadley's data for marketable fish and on her recollections of relative pounds of catch of the game, catfish, loricariid catfish and other species that are returned to the lakes. Among the "other" fish reported in the table are shad, gar, and brown hoplo. The brown hoplo is another exotic species that has recently appeared in some of these lakes. Data from Table 4.1 are depicted graphically in Figure 4.2.

Table 4.1 demonstrates two important features of the loricariid catfish invasion. The first is that the invasion arrived at different times in different lakes and grew at differing rates. Hence, now when the loricariid catfish appear in a new lake, fishermen become concerned that eventually they will proliferate as they did in other lakes. The second important feature is that in many of the lakes the haul seine fishery catches more loricariids than any other fish species. For example, in 2007, 80 percent of the fish Captain Wadley netted in the Stockade Pit were loricariid catfish, while only 10 percent were marketable tilapia (see Figure 4.3). Captain Wadley no longer fishes in Six-Mile Creek, the Stockade Pit, the Reservoir, or Lake Hunter. She still fishes the other lakes, although she has concerns about the invasion whenever loricariids are present. Lake Hancock is the primary lake that has been fished since the 1900s, and despite the fact that last season produced loricariids in numbers that made commercial fishing barely a break-even effort, Captain Wadley will continue to fish there. Due to the size of this lake it is more possible to relocate to a new spot in the lake, if one spot produces too many loricariid catfish.

The way the loricariid catfish obstruct the haul seine fishery is by making it less and less worthwhile to fish for tilapia, because the catfish are too difficult and time-consuming to remove from the net. For example, in 1999, Captain Wadley stopped fishing Lake Hunter because 65 percent of the haul now consisted of loricariids. In a typical haul of 10,000 lbs., this would mean 6,500 lbs. of catfish, complete with sharp spines, and abrasive coatings, and just 2000 lbs. of tilapia. The abrasive outer coating of the loricariids can damage the tilapia and other fish and the spines can tear the haul seine nets. Most difficult is the time needed to remove all of the catfish from the nets.

Economic History of the Fishery

For the period between 1996 and 2002, the tilapia represented 55 percent of overall harvested fish, while native catfish represented 25 percent of harvested fish, shad represented 15 percent, and non-marketable 'trash' fish represented five percent of the total. The breakdown by species is presented in Figure 4.4.

The total annual harvest has fluctuated significantly since 1985. In the last two decades, the greatest harvest of marketable fish occurred between 1987 and 1989 with an annual fish harvest of 870,989 pounds, 668,399 pounds, and 787,599 pounds, respectively. The general trend of fish harvest varies from year to year, and has declined steadily for the last four seasons. In 2006, 269,557 lbs were harvested. Figure 4.5 depicts the pounds of harvested fish for market from 1985 to 2006.

Table 4.1. Changes in Share of Total Catch by Fish for Lakes in Lake and Polk Counties, mid-1990s to Present (Percentages based on estimates and personal recollections)

Lake	Year	Tilapia	Catfish	Gamefish	Other[2]	Loricariid Catfish	TOTAL
Stockade Pit	1983 – 93[1]	Good					100
	2007	10	8	2		80	100
Six-Mile Creek[3]	1993					Too many for fishing to continue	
The Reservoir	1993	70	5	20			95
	2006	30	5	5		60	100
Lake Hunter[3]	1995	45	25	30			100
	1999	20	12	3		65	100
Lake Bonnet	1996	75	20	5	4S	5	109
	1999	60	15	12	4S	9	100
	2006	50	12	2	4H	30	98
Banana Lake[3]	1995	45	25	30			100
	2007	30	20	8	2H	40	100
Lake Garfield	2001	50	20	20	10G		100
	2006	17	8	8	56H	11	100
Lake Hancock[3]	2002	80	10	5		5	100
	2005	50	8	2		40	100
	2006	30	8	2		60	100

Source: Interviews with Taren Thomas Wadley

Notes: 1) Captain Wadley stopped fishing in the Stockade Pit in 1993, but tried again in 2007.
2) "Other" fish include Shad (S), Gar (G), or Brown Hoplo (H)
3) Shaded rows indicate lakes no longer profitable to fish

Figure 4.2. Changes in Share of Total Catch by Fish for Lakes in Lake and Polk Counties, mid-1990s to Present [estimated proportions of the catch]

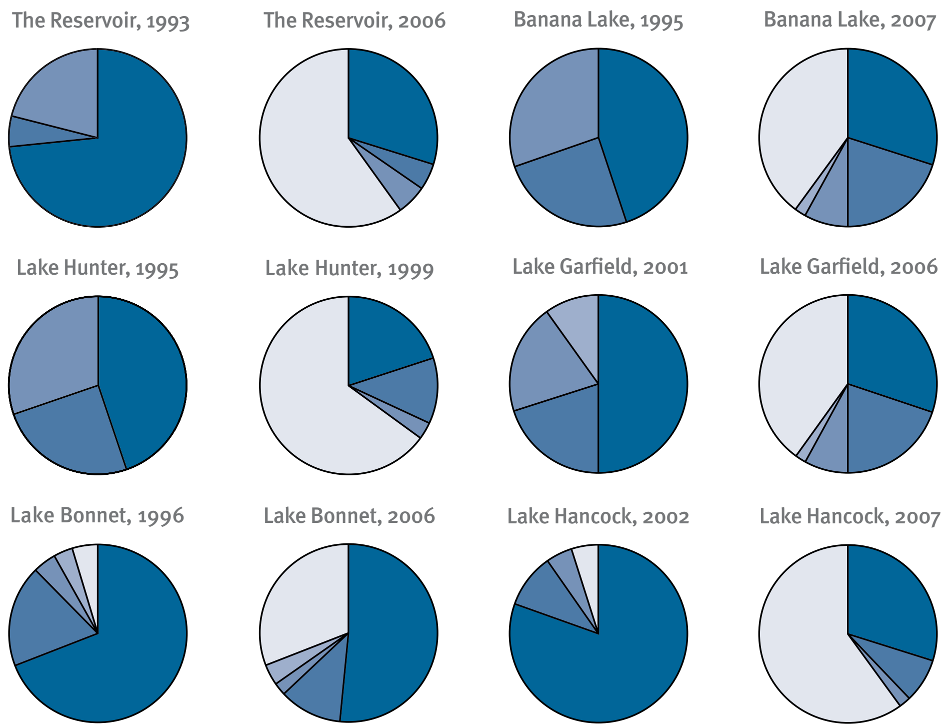
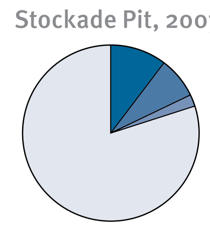


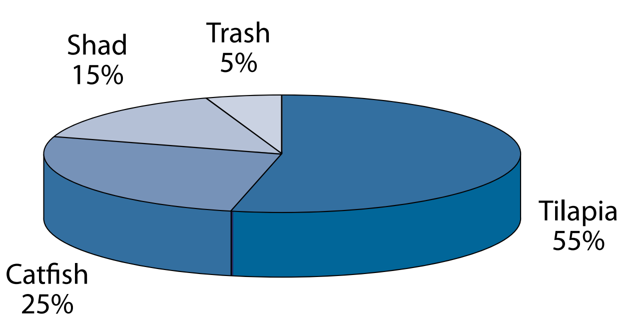
Figure 4.3. Stockade Pit Total Catch
[estimated proportions of the catch]



The market value of the harvested fish has similarly fluctuated from year to year, generally following the harvest pattern and including a steady decline over the past four seasons. Figure 4.6 presents the market value of harvested fish between 1985 and 2006.

The harvest of tilapia is consistent with economic theory as is presented in Figure 4.7. The figure presents the market value per pound of harvested fish and the quantity of fish harvested between 1985 and 2006. The lines appear to be reflections of one another, suggesting that as the quantity of fish harvested increases, the price per pound decreases. The pattern seemed more or less intact until the last five years, when changes in the two began to fluctuate in the same direction, with 2002 showing slight increase in both price and harvest but between 2003 and 2006 both decreasing. This suggests that other factors are beginning to play a more important role in the market. Competition from low-priced imported tilapia is reported to be the main source of the lower price pressure. Coupled with this pressure, fishermen have also had to contend with the loricariid catfish invasion.

Figure 4.4. Percentage of Fish Harvested by Species, 1996–2002



Specific records on the number of loricariid catfish in each haul have been kept since 2003, the point at which they became a significant problem.[9] Figure 4.8 presents the annual combined harvest of marketable fish and the number of loricariid catfish over the past four years. The harvest of marketable fish has declined since 2003, while the number of catfish has increased. The figures presented for 2005 are an average of the percentage of 2004 and 2006 fish catch since no species-specific data were available for that year.

To compare the market price of tilapia received, the price per pound is changed to real 2006 dollars. Real dollars are simply the nominal value of the harvested fish converted to the value in 2006 dollars. For example, the price per pound of fish received in market in 1985 was $.35, which translates to $.70 per pound in 2006 dollars—the highest value of any year. By 1987, the price of marketable fish was down to its lowest value in the twenty-year period at $.26 per pound, which is almost matched in 2006 at $.27 per pound. There is great fluctuation in the price per pound of marketable fish between these years. The real dollar value of marketable fish is plotted against the total harvested pounds in Figure 4.9. Note that the price received per pound (until 2003) was high when the total harvest is low and vice versus. This is consistent with economic theory.

When tilapia harvesters fish for a day and harvest their catch, it is called a pull. The average weight of harvested fish per pull between 2003 and 2006 was 6,141 pounds. Information on the number of pounds per pull is not available before this time. Using this average number of pounds per pull, the number of annual pulls can be derived based on the annual number of pounds of marketable fish harvested. Figure 4.10 presents the annual number of pulls versus the price per pound of marketable fish in real 2006 dollars.

[9] Personal Communication with Taren Wadley

Table 4.2. Profitability Scenarios of Tilapia Fishing in the Presence of Loricariid Catfish

Scenario	Tilapia (lbs)	Loricariid catfish (lbs)	Hours to Fish	Share	Hourly Wage	Hourly Loss	Loss/boat per day
A	3,000	-	7	$98.13	$14.02	$0.00	$0.00
B	3,000	3,000	9	$94.38	$10.49	-$3.53	-$222.50
C	3,000	7,000	11	$90.63	$8.24	-$5.78	-$445.00
D	3,000	9,000	15	$83.13	$5.54	-$8.48	-$890.00

Source: Personal Communication from Taren Wadley

Figure 4.5. Harvested Pounds of Fish for Market, 1985–2006

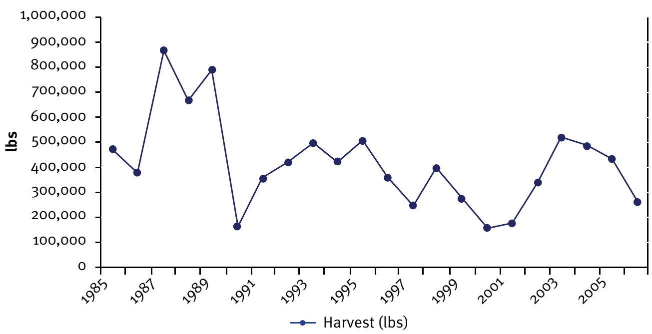


Figure 4.6. Market Value of Harvested Fish, 1985–2006

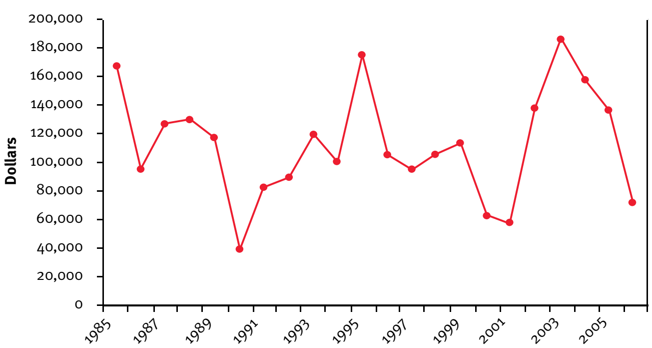
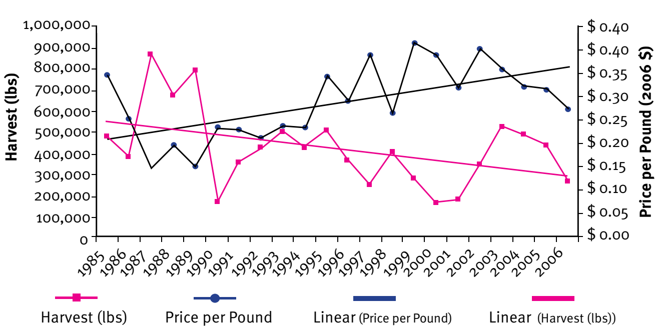


Figure 4.7. Pounds Harvested and Price Per Pound, 1985–2006



Tipping Point Analysis

Commercial fishing for tilapia and shad is conducted up in the following manner. First, the haul seine net is laid out, slowly forming a "C" shape. Over several hours the "C" shape is slowly closed and the fish are corralled toward the pocket at the end of the net. Next, the 'pocket' must be picked up or drawn to the boat. Then, 'dipping' is the process of transferring the 'keeper fish' (i.e., tilapia and shad) from the net to the boat. The entire process requires about six to nine hours under favorable conditions for fishing. This has increasingly included hauls that might have up to 5,000 lbs loricariid catfish per haul. The time involves five to six hours to set the net, thirty to forty-five minutes to pick up the pocket, and half an hour to two and a half hours for dipping. If the haul includes 7,000 lbs of loricariid catfish and 2,500 lbs of tilapia, the time to set the net and pick up the pocket will remain the same, but the time it takes for dipping will increase substantially, requiring a 11 or 12 hours per day overall. When the amount of loricariid catfish increases in a haul, additional labor is required to release them.[10]

The decision to take a boat out and fish is based on the expected profitability of fishing day. Table 4.2 presents the level of loricariid catfish that makes fishing for tilapia no longer profitable. When the hourly wage rate is below minimum wage, the opportunity cost of fishing exceeds the profit earned from fishing, so it is no longer financially viable. The minimum wage rate for 2006 in Florida was $6.40 per hour.[11] This analysis assumes eight shares per boat and revenue for marketable fish of $.38 per pound, which was the average revenue per pound between 1985 and 2006 in real dollars. The eight shares include one for each of seven people involved, and one extra for the boat, which goes to the captain. The costs associated with a day of fishing include equipment and maintenance costs of the boat, motor, nets, gloves, etc and are broken into fixed costs and marginal costs. Fixed costs are $250 per day for each day of fishing regardless of the length time spent fishing. The marginal costs are about $15 per hour, so the longer the fishing day the greater the marginal costs incurred by the boat.[12] Four scenarios are presented in Table 4.2. Under scenarios A and B, fishing would be undertaken for the day. The decision to fish or not to fish could go either way in Scenario C. The final scenario represents a case where, if the fishermen had known their results ahead of time, they would not have fished at all.

[10] Personal Communication with Taren Wadley

[11] State of Florida, 2006 "Florida Minimum Wage" available at **http://www.floridajobs.org/resources/fl_min_wage.html**, accessed April 2007.

[12] Personal Communication with Taren Wadley

Under all of the scenarios, the tilapia catch is assumed to be 3,000 pounds. Under Scenario A, it is assumed that no loricariid catfish are caught, or this might be considered the pre-invasion scenario. Under Scenario A, a share is expected to be $98.13 for the day, implying an hourly wage of $14.02. There is slightly less profit and a lower associated share value with each of the subsequent scenarios, due to the marginal hourly costs of operating the boat. More importantly, because more time is involved in the latter three scenarios, as compared with the first, the hourly wage declines progressively until in the last scenario, the hourly wage is below minimum wage, and the opportunity cost of fishing becomes high.

Implications of the Analysis

Losses directly attributable to the loricariid catfish can be calculated from these estimates. For example, assume that the fishing season consists of 5 months, or 20 weeks of opportunities. It is not unreasonable to further assume that since the invasion; at least one haul per week has been similar to the one described in scenario B, and one in scenario C is assumed to occur once every two weeks. Over the season, suppose Scenario D occurs on three occasions. This suggests over four hours of unpaid labor per week, times seven people, times 20 weeks, or an additional 480 hours per season of labor.

To be sure, many much worse scenarios have also been reported, where 12,000 pounds of loricariid catfish have been caught in the haul seine. But also many much more profitable scenarios have occurred, where up to 8,000 pounds of tilapia are caught, and in these cases hourly wages are much better. For the purpose of this analysis, however, a conservative approach is taken, assuming that 10,000 pounds of tilapia are caught in an average week during three to four hauls. The analysis also assumes that once per month, or five times per year, Scenario D was encountered.

The economic loss per boat attributable to loricariid catfish under this estimate may be calculated by the wage loss shown in Table 4.2, times the total number of hours worked on the days with the heavy loricariid catfish compositions. In this way, account is taken not only for the loss in wages during the hours that would have been worked even in Scenario A, with little or no loricariid catfish, but also for the fact that additional labor is required. Multiplying this number by seven gives the total loss per boat per day. Assuming that there are 20 losses per year for Scenario B, 10 losses for Scenario C, and four losses for Scenario D, the total loss per year per boat due to loricariid catfish is $12,460. Over the course of the past 14 years, this suggests the current value of past losses at $174,440 per haul seine permit.

Prospects for the Fishery

The tilapia fishery in this region has been suffering from competition from imports during the same period that the loricariid catfish invasion has occurred. This competition from imports has held prices low, so that the declining harvest has not resulted in higher prices, as had occurred in previous years. Also, hurricanes and the low water conditions brought about by demand for residential and irrigation water have hurt the tilapia fishery. Perhaps more important to the analysis, however, is to consider that fishing in several of the lakes is no longer profitable because the loricariid catfish population has increased to the point that fishing there is no longer eco-

Figure 4.8. Fish Caught by Species, 2003–2006

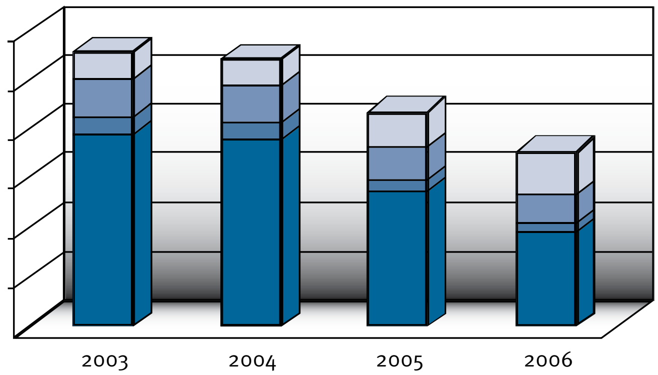


Figure 4.9. Market Price per Pound of Fish (2006 dollars), 1985–2006

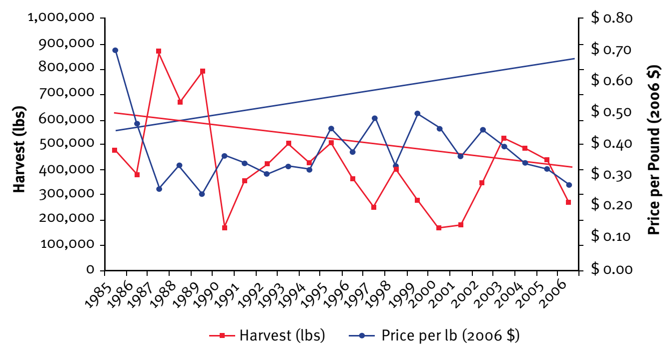


Figure 4.10. Annual Number of Pulls and Market Price of Fish, 1985–2006

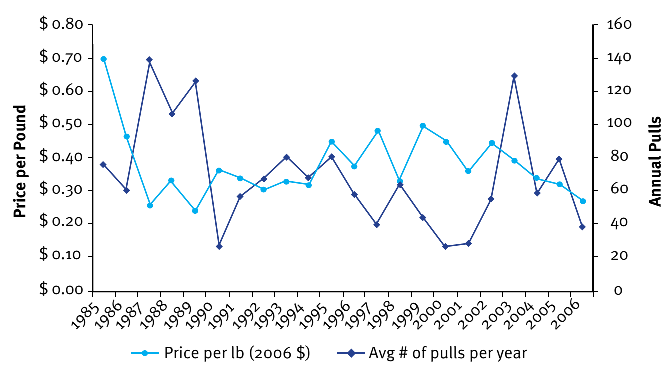


Figure 4.11. Loricariid Catfish Skeletons after a Freeze

Source: Donald D. Fox, Biological Administrator, Florida Fish and Wildlife Conservation Commission, Okeechobee Fisheries Office.

Figure 4.12. Shiner Cast Net Fisherman with Loricariid Catfish

Source: Donald D. Fox, Biological Administrator, Florida Fish and Wildlife Conservation Commission, Okeechobee Fisheries Office.

nomically remunerative. Economic losses are not restricted just to the haul seine fishermen: the unknown number of cast net fishermen in the area have experienced losses in the form of damages to their nets and the additional time required to remove the noncommercial fish from their nets. As the tilapia fishery declines, so does the fish processing business (fish houses) that brings these fish to market. The picture may not be completely bleak, however. During the same period that loricariid catfish have become a problem, the brown hoplo has also begun to thrive along with the catfish, and markets for hoplo are gaining in strength.

FISHING IN LAKE OKEECHOBEE – CASE STUDY

In Lake Okeechobee in southern Florida, the quantity of loricariid catfish caught incidentally has increased, as fishermen using "haul seine" gear target bluegills and redear sunfish. The incidental catch of loricariid catfish also adversely affects the cast net fishery in Lake Okeechobee since, like the haul seiners, they must pay to dispose of the non-target species they catch (to discard them, they must pay $29/ton). The commercial fishery in Lake Okeechobee includes 10 haul seine-fishing permits, eight of which are currently in operation. Additionally, there is unlimited "trot" line fishing and an unlimited number of cast net fishermen. The fishery is open 12 months per year on weekdays and has operated in essentially the same way since its reorganization in 1982.[13] Lake Okeechobee is also home to one of the most famous recreational bass fishery in the world, and so part of the design of the commercial fishery includes a requirement to dispose of the incidental catch of "rough fish" or those that do not contribute to the recreational bass fishery. These include the native gar and shad, as well as the non-native tilapia and loricariid catfish.

Loricariid Catfish Population

The first documented identification of the loricariid catfish in Lake Okeechobee occurred in 1994.[14] Between 1994 and 2001, it is possible that periodic freezes or cold weather in part kept the populations of loricariid catfish down. In 2001 a freeze produced fish kills as seen in Figure 4.11. Between 2001 and 2006, there were no such freezes, and during this time the loricariid catfish population seemed to grow. Once again in early 2007, another freeze occurred and, subsequently, commercial fishermen reported that instead of catching 1,000 or more pounds of loricariid catfish per haul, they were catching only 10 to 12 pounds.[15] Also, because the haul seines operate only in the middle of Lake Okeechobee, they are perhaps less affected by loricariid catfish populations that typically are found in the shallower areas.

Another factor that likely figures into the abundance of the loricariid catfish in Lake Okeechobee during these years (prior to 2007) is that in 2004 there were hurricanes Jeanne and Frances, which hit on the north side of Lake Okeechobee and, in 2005, hurricane Wilma hit the south end of the lake. These hurricanes damaged the habitat for native largemouth bass and black crappie.

[13] Interview with Don Fox, 13 April 2007.
[14] Florida Game and Fresh Water Fish Commission, 5/24/94, Non-Native Fish Collection Report.
[15] Interview with Don Fox, 13 April 2007.

Commercial Baitfish Fishery

The success of the world-famous largemouth bass fishery is part due to the use of shiners as bait. Commercial fishermen using cast nets have been paid well to provide shiners to the industry. At one marina in the south of the lake, large tanks sat empty in the midst of a bass tournament because there were so few shiners available. The proprietor and others explained that shiner fishermen were now traveling to central Florida to find shiners. However, just a few years earlier, the marina sold 26,000 shiners per year. When the shiner fishery in Lake Okeechobee was still functioning, these fishermen were also experiencing frustration and difficulty due to loricariid catfish populations. The catfish were caught in the nets, often damaging them. Furthermore, removing the catfish could take a lot of valuable time away from more productive fishing. The photograph in Figure 4.12 shows one frustrated cast net shiner fisherman with his haul of loricariid catfish.

Game Fish and Other Populations

Random electro-shocking throughout the lake in both 2005 and 2006 yielded between 2.76 and 4.3 catfish caught per hour per unit of effort in those years.[16] Based on the CPUE for 2005, loricariid catfish were the seventh-most frequently caught species in the lake, after white catfish, florida gar, threadfin shad, gizzard shad, inland silverside, and largemouth bass (see Table 4.3). In 2006, loricariid catfish had become the fifth-most frequently caught species, having passed inland silverside and largemouth bass. More significantly, loricariid catfish were the only fish to increase in number caught per minute between 2005 and 2006. The same obtains for the overall weight of the fish caught in the subsequent year sampling, with the catch-weight of loricariid catfish increasing 54 percent between years, while all of the other common species experienced a decline in both weight and CPUE. Black crappie and redear sunfish are included in this table because both fish have economic value: black crappie for recreational fishing and redear sunfish for commerce. The economic harm to these commercial and recreational fishing industries is significant: for instance, the revenue from the popular recreational fishery for largemouth bass and black crappies represents an estimated $100 million in revenues per year.[17]

Concurrent Factors

Although loricariid catfish have thrived while other species have declined, the economic impacts of the species itself are difficult to disassociate from concurrent water management policies and weather events. The fishery of the lake has been affected by the effect of prolonged high water levels on aquatic vegetation and the effects of hurricanes on turbidity. The following is a summary of how both types of events have affected populations of largemouth bass (LMB) in recent years:

Table 4.3. Data for Lake Okeechobee Top Species by Number per Minute (Catch per Unit of Effort, or CPUE)

Common Name	Scientific Name	Year	Number	Weight (total in grams)	Percent Change	CPUE (fish/minute)	Percent Change
White Catfish	*Ameriurus catus*	2005	272	54,783	-73%	0.275	-66%
		2006	92	14,583		0.093	
Florida Gar	*Lepisosteus platyrhincus*	2005	246	137,327	-55%	0.248	-56%
		2006	108	61,443		0.109	
Threadfin Shad	*Dorosoma petenense*	2005	241	1,659	-48%	0.243	-33%
		2006	160	861		0.162	
Gizzard Shad	*Dorosoma cepedianum*	2005	233	17,524	-60%	0.235	-31%
		2006	159	6,923		0.161	
Inland Silverside	*Menidia beryllina*	2005	19	29	-97%	0.192	-96%
		2006	8	<1		0.008	
Largemouth Bass	*Micropterus salmoides*	2005	156	99,630	-70%	0.158	-56%
		2006	69	30,108		0.070	
Orinoco Sailfin Catfish	*Pterygoplichthys multiradiatus*	2005	46	38,571	54%	0.046	57%
		2006	71	59,230		0.072	
Redear Sunfish	*Lepomis microlophus*	2005	42	8,097	-28%	0.042	-29%
		2006	30	5,801		0.030	
Black Crappie	*Pomixis nigromaculatus*	2005	40	9,502	-88%	0.040	-75%
		2006	10	1,114		0.010	

Source: Map Module 3.4 Fish Condition and Population Structure, Lake Okeechobee Lakewide Trawl, fall 2006 and fall 2005, provided by Florida Fish and Wildlife Conservation Commission.

[16] Based on results of 0.046 and 0.072 fish caught per minute (CPUE).
[17] Egbert, M.E., 2007, "Summary of Roving Creel Survey Results for Lake Okeechobee from 1977 to 2006," Symposium Platform Presentation, 27th Annual Meeting of the Florida Chapter of the American Fisheries Society.

Poor recruitment during the 1999–2001 period is attributed to habitat loss associated with excessively high lake stages during the late 1990s. A managed water-level recession in 2000 followed by a subsequent drought in 2001 resulted in historically low lake levels, which resulted in the stimulation and expansion of submerged and emergent aquatic plant communities. In response to increased and enhanced habitat, LMB exhibited greatly enhanced recruitment, which is evidenced by the high abundance of young–of-year (YOY, <20-cm) fish in 2002 and 2003. Extremely high lake stages commencing in 2003 began to impact habitat, resulting in decreased recruitment of LMB. Hurricanes Frances and Jeanne in 2004, and Hurricane Wilma in 2005, further reduced the areal coverage and quality of aquatic plant communities, resulting in very poor recruitment of YOY LMB in 2005 and 2006.[18]

This summary describes a series of high- and low-water events coupled with aquatic plant community variations and turbidity. During this period, loricariid catfish were able to survive and thrive while other populations declined. However, the catfish are also vulnerable to cold and may have already declined in numbers, as skeletons have once again been found on the banks of the lake.

Summary for Lake Okeechobee

The extent to which recent increases in loricariid catfish populations have affected the recreational fishing industry in Lake Okeechobee is unclear. The haul seine operators had complained of loricariid catfish in previous years but unfortunately few data are available on the degree to which they may have reduced wages in this fishery as they have in Polk and Lake Counties. Doubtless this has occurred in recent years, though it is not clear how much. However, it is likely that wages decreased due to loricariid catfish, and that additional fees (to discard them, costing $29/ton) and the effort required to load and transport them to the local dump were required. Also, there are eight fishing permits in operation in Lake Okeechobee and only one in Polk and Lake Counties.

Cast net fishermen have also been affected by loricariid catfish—through the additional time needed to remove them from the nets and the damage to nets themselves. However, the shiner population, which has been one of the most lucrative revenue streams for these fishermen, has also declined to the point that none are currently being caught in Lake Okeechobee.

While there has been a concurrent decline in the recreational fishery as the loricariid catfish population has increased, there is as yet no evidence that the two ecological events share a cause-effect relationship, although both may share a common cause in management alterations and hurricanes.

CROWDING OUT NATIVE FISH SPECIES

It has been argued that loricariid catfish threaten the survival of native fish species due to their large size, long lifespan, and high population densities (Hoover 2004). Their benthic nature may cause them to displace smaller and/or less aggressive benthic fishes such as darters, madtoms, and bullhead catfish. It is possible that the shiner population decline in Lake Okeechobee may be somewhat related to displacement by loricariid catfish. Furthermore, as algae feeders, loricariid catfish populations can sometimes change the composition and/or reduce the habitat quality of the algae. It has been contended that this in turn can reduce the amount of spawning habitat and/or food sources available to other species of fish that rely on them. Food competition from loricariid catfish is believed to affect the devil river minnow (federally classified as “threatened”), while habitat loss and possible egg predation by the loricariid catfish are believed to affect the endangered fountain darter (Hoover 2006). In central Florida, because some of the lake bottoms are reportedly covered with loricariid catfish, the fishermen tend to believe that this is causing reproductive habitat loss not only for tilapia, but also for species like bass that have recreational economic value.

Despite these assertions by Hoover, however, there is considerable debate among fisheries managers, fishermen, and fisheries biologists as to whether or not the loricariid catfish are taking a spot in the ecological system that would otherwise be occupied by native species, or whether the native species are able to cohabitate with the catfish and thereby increase the overall biomass of the system. In the canal system of southern Florida, researchers from the Florida Wildlife and Fish Conservation Commission are exploring this question. Preliminary evidence suggests that overall biomass of a system can increase with the introduction of loricariid catfish.[19] However, the canal system, Lake Okeechobee, and the central Florida lake systems are each unique, and in the canal system the population has not expanded rapidly as it has in Lake Okeechobee or in central Florida. Fishermen in central Florida, and some recreational fishermen at Lake Okeechobee, are of the opinion that the presence of loricariid catfish bodes ill for populations of desired target species, although again, this opinion seems derived by association rather than causation.

Conclusions

There are numerous economic realities associated with the introduction of loricariid catfish in Florida, including:

- Benefits of wild loricariid catfish egg mass collection in support of the aquaculture industry;
- Economic costs associated with bank erosion in residential developments from burrowing loricariid catfish, estimated at $1.5–$2.0 million per year;
- Torn fishing nets, and additional time required to catch the same quantity of fish in cast net fisheries throughout the state; and
- Additional labor required for same harvest level in haul seine fisheries, as well as additional costs from discard fees for loricariid catfish caught in Lake Okeechobee.

[18] Interview with Don Fox, 13 April 2007.
[19] Meeting with Kelly Gestring and Paul Shafland, Florida Wildlife and Conservation Commission, Boca Raton, Florida, 26 January 2007.

Limitations of the Research

At present, there are three fundamental sources of difficulty in quantifying the economic impacts of loricariid catfish in Florida. The first difficulty is that in several areas of recent and rapid population expansion, there are so many concurrent irregular events that have occurred (namely hurricanes and water management strategies) at the same time as the invasion, it is very difficult to disassociate the effects of the invasion from the effects of the other events. The second difficulty is that economic losses or gains are typically measured against the next best alternative. When there are plenty of alternatives or substitutes readily available, quantitative impacts are minimized. For this reason, it is difficult to measure reductions in opportunity posed by the invasions in several central Florida lakes, since numerous other lakes are still available for fishing. Finally, there is a lack of available data on the loricariid catfish that makes it difficult to assess changes in their population, and these are populations that can expand rapidly.

Questions for Further Research

This chapter has provided an overview of the current status of the loricariid catfish invasion in Florida. At the current time, these fish seem to present a threat to commercial fishing as a viable industry within the state. However, the future situation is difficult to quantify. This is due both to a lack of data and to inadequate responses to some biological questions. Questions critical to understanding the future economic risks are:

1) What factors influence the ability of loricariid catfish populations either to stabilize or to expand rapidly?
2) In areas where adverse environmental conditions have resulted in population declines among desirable fish species and concurrent increases in loricariid catfish populations, will improved environmental conditions have the opposite result?
3) If valuable recreational and commercial fish populations rebound in Lake Okeechobee and in the central Florida lakes that currently support large loricariid catfish populations, is it likely that both populations will be able to cohabitate?

Questions for ongoing biological and economic research include:

1) What are the prospects for managing loricariid catfish populations, reducing biomass, and mitigating damages?
2) What are the measured and potential impacts on economic returns in recreational fishing?
3) What are the measured and potential impacts on competitive sport fishing?
4) What are the long-term implications for commercial fishing in Central Florida?
5) Is there any way to turn harvested mature loricariid catfish into a marketable product?
6) What volumes of loricariid catfish catch are currently being incidentally captured and discarded in Lake Okeechobee, and what are the costs associated with this catch?

5

CHAPTER 5

Invasion of Armored Catfish in Infiernillo Reservoir, Michoacán-Guerrero, Mexico, Socio-economic Impact Analysis: A Tale of Two Invaders

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SUMMARY

This chapter documents the rise and fall of the tilapia fishing industry at the Infiernillo Reservoir in the states of Michoacán and Guerrero, Mexico. Initially, tilapia and carp were introduced into the reservoir to provide economic opportunities for the surrounding communities. Although the carp and the native catfish were more highly valued in the reservoir, the tilapia thrived. In its hey day, this reservoir was the most productive freshwater reservoir in Latin America, supporting over 3,500 fishermen, as well as the associated processing and distributing industries. The exotic tilapia species were the source of economic opportunities for the local communities that surpassed earlier agricultural activities in terms of revenue potential. However, inadequate fisheries management, including the harvesting of juveniles prior to reproductive maturity and over-fishing, pollution, and a general failure to regulate and enforce restrictions on timing and location of fishing, resulted in declines in the fishery.

Further affecting a fishery already in decline, invasive armored catfish from the *Loricariidae* family (hereafter referred to as "loricariids," commonly known as "plecos" (from the most familiar species, *Hypostomus plecostomus*), entered the Infiernillo Reservoir ecosystem. Loricariid catfishes, in particular those of the *Hypostomus genus*, are very common in the North American aquarium trade, and it is thought that the introduction of these catfish into the reservoir was due to repeated escapes from ornamental fish farms upstream. Loricariids compete with the tilapia for food and habitat, but as of yet, have no economic value. When caught, the loricariids damage fishing nets and poses a sanitary threat as they decompose on shorelines.

At present, loricariids constitute a major threat to the already fragile tilapia fishery. Within the community, potential negative economic impacts include losses of direct fishery revenue, losses of revenue in the related industries of fish processing and marketing, and losses of revenue in the communities that depend on the income from the fishermen. The community declines resulting from fishery losses have added international implications, as this increases the need for young Mexicans to work in the United States to support their families. Other international issues include competition from Chinese trade and the links to the American aquarium fish industry.

INTRODUCTION

Infiernillo Reservoir

The Adolfo López Mateos Reservoir, also called "El Infiernillo," is located at the boundary of the states of Michoacán and Guerrero (18º52'–18º15' North and 101º54'–102º55' West). The reservoir created by the dam has a maximum length of 120 kilometers and a maximum capacity of 11.86 billion cubic meters, representing a flooded surface of 40,000 hectares. The minimum surface area maintained at the reservoir is approximately 14,000 hectares. Its main tributaries are the Tepalcatepec River in Michoacán and the Balsas River in the state of Guerrero (Juárez 1989).

The reservoir was constructed between 1962 and 1963, and it started functioning in 1964 with the purpose of generating electrical power.

Several native species inhabit the reservoir: a cichlid (*Cichlasoma istlanum*), a cyprinid (*Notropis boucardi*), a catfish (*Ictalurus balsanus*), a poecilid (*Poeciliopsis balsas*), an atherinid (*Atherinella balsana*), a characid (*Astyanax fasciatus*), and a godeid (*Ilyodon whitei*). In 1969, four species of tilapia (*Oreochromis mossambicus*, *O. aureus*, *Tilapia rendalli*, and *T. zilli*) and four species of carp

Figure 5.1. Satellite Image of Infiernillo Reservoir

Source: Google Earth (Provided by Carlos Ramírez)

* 1-UANL; 2-CIIDIR-IPN; 3-Conabio; 4-IIS-UANL; 5-Semarnat; 6-CIIDIR-IPN); 7-consultant

(*Cyprinus carpio specularis*, *Ctenopharyngodon idella*, *Hypophthalmichthys molitrix*, and *Mylopharyngodon piceus*) were introduced to enhance the economy of the region (Jiménez-Badillo *et al*. 2000; Tomasini 1989). Sampling conducted in 2007 did not discover *M. piceus* (Orbe-Mendoza, 2007). Jiménez- Badillo (1999), states that 10 fish species were found in the reservoir; however, this document lists 15, suggesting a taxonomic revision or update of the species found in the reservoir may be needed.

The commercial fishery started in 1970 and has constituted the main economic activity of 119 communities around the dam since it began. (Torres Oseguera 2005). Many of these communities are considered by the federal and state governments to exist below the poverty level—at or below a sustained subsistence level. At present, 44,467 people depend on fish production from this reservoir system (anonymous 1998).

For a long time, the Infiernillo Reservoir hosted the most important freshwater fishery in the nation. In 1987, it was considered the most productive freshwater reservoir in Latin America, when a catch of 18,953 tons of tilapia were registered (Contreras-Balderas *et al*. 2008). After 1987, catch volumes begin to decline noticeably and, by 1999, only 4,770 tons of tilapia were caught.

The first important socio-economic damage was registered when the native catfish and the introduced carp were gradually displaced by the tilapia, to a point where they were no longer important to the local catch. The native catfish constitute a tradition and, thus, are highly appreciated by the local populations willing to pay more for them. The previously introduced carp were best known before tilapia as the most common commercial fishes captured and also demanded a higher price than the tilapia. Among the introduced populations of tilapia, *O. aureus* quickly became dominant, constituting from 90 to 99 percent of the fishery. The tilapia populations in the Infiernillo Reservoir can reproduce from six to eight times each year and are capable of spawning year-round, although activity appears to peak from May through January (Jiménez-Badillo *et al*. 2000). The fish reach reproductive maturity in about 11 months, at lengths measuring approximately 175 and 172 mm for females and males, respectively. This size class also coincides with the size when they are first considered fishable. Because the tilapia are caught in a size class that corresponds to their mature size, their population size has not increased, and the selection pressure has likely caused a shift in the population structure to favor maturity at smaller sizes, leading to potential stunting and inbreeding in the fish (Jiménez and Osuna 1998).

Food chain

Tilapia are omnivorous and their diet in the reservoir created by the Infiernillo dam consists of detritus and vascular plant residues as a primary food, unicellular algae as secondary food, and remains of insects and fishes. Grass seeds (sugar cane and corn mainly), filamentous algae, and occasional aquatic invertebrates such as cladocerans, ostracods, rotifers and copepods are also consumed (Jiménez-Badillo and Nepita-Villanueva 2000). This dietary overlap with the carps and native catfish suggests that competition from the tilapia could have contributed to the decrease in the populations of these latter species in the reservoir.

Figure 5.2. Panoramic View of Infiernillo Reservoir

Source: FLICKR- http://farm1.static.flickr.com/24/47412995_1231f9d9bdjpg%3Fv%3D0&imgrefurl= http://flickr.com/photos/vsp/47412995/&usg=u7TZT90h0h3P9Wi9qS5V92ML3ek =&h=375&w=500&sz=162&hl=en&start=2&sig2=WGUS4682Wmzk6PTB7mCZ 5A&um=1&tbnid=SmRlvsY-2fcxAM:&tbnh=98&tbnw=130&prev=/images%3Fq- %3DInfiernillo%2Bdam%26hl%3Den%26client%3Dsafari%26rls%3Den-us%26sa% 3DN%26um%3D1&ei=JErVSau8HabgtQOTss2qCg

Fishing gear

Gillnets 12 to 35 m in length and 1.75 to 3.5 m in height are commonly used to capture the tilapia in the Infiernillo Reservoir. Different mesh openings, ranging from 7.9 to 11.4 mm have been used, with 8.3 and 10.8 mm mesh sizes being the most common. Gillnets are set during the night and checked the next morning. The fishing fleet is composed of 54 percent fiberglass motorboats and 46 percent wooden rowboats (Jiménez-Badillo 1993). The number of nets per fisherman is highly variable (from 3 to 50), with sets of 10 to 20 nets most common. The catch per unit of effort with this gear varied from 16.9 to 27.7 kg/fisherman/day of small tilapia (14 to 23 cm) and 6.7 to 13.8 kg/fisherman/day of big tilapia greater than 23 cm (Jiménez-Badillo 1999).

CHRONICLE OF AN ANNOUNCED DEATH

Historical Trends

Although information is scarce and fragmentary, the historical trend of tilapia populations in Infiernillo Reservoir can be reconstructed (Fig. 5.3). Great fluctuations in tilapia harvests, ranging from nearly 3,000 to nearly 20,000 metric tons, were registered between 1981 and 2005. In 1987, with more than 3,500 fishermen and 16,150 gillnets, 18,953 tons of tilapia (22,078 tons, including carp and catfish) were caught. However, in 1988, with even greater efforts, 22,422 gillnets were used and only 15,076 tons of tilapia were caught (Jiménez-Badillo *et al*. 2000).

From 1980 to 1990, the spawning stock biomass dropped three times (Hernández-Montaño 2002). By 1992, many people had abandoned fishing, some even migrating out of the region, and only 2,343 fishermen were left in the community.

These remaining fishermen used 32,750 gillnets to obtain only 12,290 tons of tilapia that year. In 1993, the catch plummeted further to 7,964 tons of tilapia and only 1,229 fishermen were still active. In an effort to maintain their revenue, fishermen began to use more gillnets, passing from a mean of five/fisherman in 1987 to 14 or 15 in 2000 and sometimes even as many as 50 (Romero and Orbe-Mendoza 1988). In 1998, loricariids began to be caught sporadically (Escalera Barajas 2005) and from 2000 onwards they were commonly captured.

Many people had abandoned agricultural activities, encouraged by the high tilapia yields obtained initially. At the time, this seemed to represent an excellent alternative for providing food and economic resources to the communities. Unfortunately, this situation turned out to be short-lived, as the unsuccessful tilapia fishery was unable to satisfy the demands of these communities over the long-term. In fact, the introduction of tilapia, combined with other ecological impacts (e.g., eutrophication), contributed to the decline of the native species such as the Balsas catfish and local cichlids that were of higher ecological and market value (Contreras-MacBeath 1998; Huerta and Castañeda 1982; Luna Figueroa 2006).

Fishery Infrastructure

Fishermen are grouped in 48 organizations: 12 in the state of Guerrero, with a present population of 417 fishermen and 36 in the state of Michoacán, with a population of 2,069 fishermen (Torres-Oseguera 2005). Because the tilapia fishery is only artisanal, no advanced technology is used in processing the fish. However, the jobs have represented an alternative source of revenue for the families and a source of employment for women in the communities. The main processing is to produce fillets from the whole fish to sell to the national and international markets. Fillets represent a higher value product, with 1 kg of fillet resulting from 3 kg of whole fish. This spin-off activity for the women helps explain why the fishery decline affects the revenue stream of a whole family and not just that of the fishermen. Because there are no ice factories near the dam and people from the processing plants do not have refrigerated trucks, the tilapia fillets are taken to the next town, where the price is set by approximately 28 intermediaries who then transport the product to Mexico City. At the present, the beach price of newly caught tilapia is P$3–4/kg (US$0.27–0.36), while the processed fillet is bought by intermediaries at P$8/kg (US$0.73) and then is sold at P$17–22 (US$1.54–2.00) on the national market, e.g., in Monterrey. Prices have recently declined due to another problem unrelated to the smaller size of the tilapia that now are caught in Infiernillo: massive imports of the more expensive, yet often preferred, Chinese tilapia. These tilapia are individually packed for quality control, and fillets are sold at P$30–35 (US$2.72–3.18) retail. Obviously, competition from these prices does not allow any increase in the price of locally captured tilapia or, consequently, in the income of fishermen.

Administrative Measures

Due to the overexploitation of tilapia over the years and to the continuously reduced volumes available for harvest, a federal regulatory measure was adopted in 2000 (NOM-027-PESC-2000). This measure limits fishing locations, net sizes, numbers of nets per fisherman, hours of operation, and total fishing effort in the reservoir. Fishing activities are restricted in certain zones of the reservoir that are known reproductive zones; furthermore, the minimum fish size is

Figure 5.3. Fish Catch in Infiernillo Reservoir between 1981 and 2005 (Principally Tilapia, as Related to Gillnets/Man)

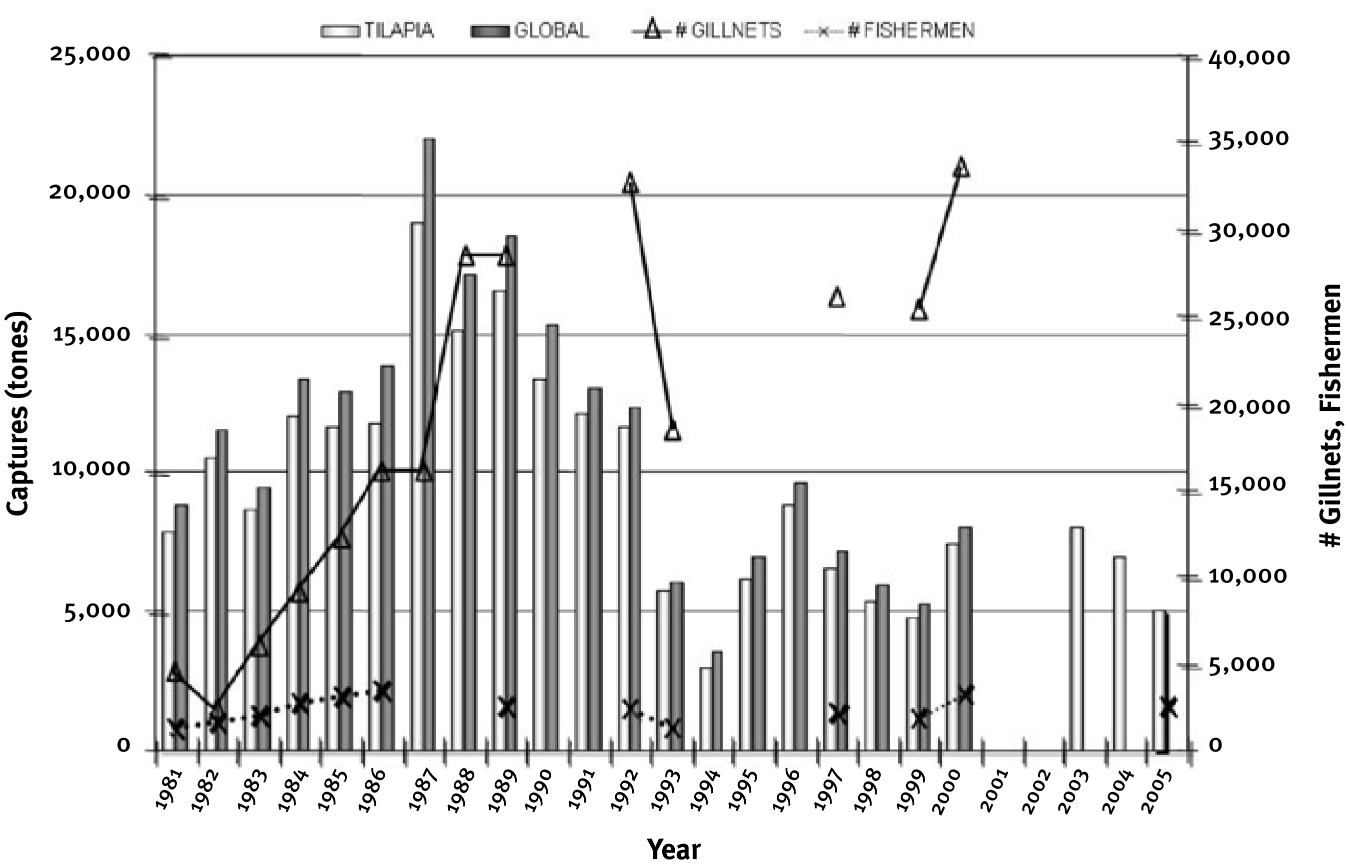

Figure 5.4. Loricariids as Bycatch in 2006

Source: Roberto Mendoza

Figure 5.5. Tilapia Processing at Infiernillo

Source: Roberto Mendoza

17 cm, and gillnets must not exceed a maximum length of 35 m and maximum height of 3 m, with a minimum mesh opening of 8.25 cm. Fishermen are limited to five nets/fisherman, with a maximum of 16,000 nets in total use throughout the reservoir, and a total maximum of 3,000 fishermen in all. The work schedule from Monday to Friday is restricted to between 6:00 AM and 3:00 PM.

Unfortunately, these restrictive measures have not been enforced adequately. Furthermore, the suggested official mesh opening still allows the capture of immature fish, thereby affecting the reproduction pattern of the population. Protected zones were also not respected because this policy affected a significant number of specific fishermen who had previously been allotted areas for fishing that became protected under the new ruling. Each fisherman has a specific site in the reservoir, and the restricted areas would mean that fishing in some of these allotted areas would now be off-limits. Instead, those fishermen would have to travel to open areas, which would require spending more fuel and time. As a result, until 2002, the tilapia fishery at Infiernillo was still considered an open resource (i.e., unlimited entry) without restrictions on how the fish were captured (Hernández-Montaño 2002).

In March 2006, a modification to this regulation was announced. The modification seeks to avoid the capture of undersized or maturing tilapia, by changing the kind of nets that are used and establishing a more restrictive legal framework—and including more severe punishments for violators. The regulatory modification was instituted because of the low competitiveness of the fishery and the repeated violations of the previous measures (e.g., up to 10,000 gillnets have been destroyed due to illegal mesh size and 51 tons of tilapia have been retained by inspectors because the fish were of illegal size, see Servin-García 2006).

RECOVERY OF THE POPULATIONS?

The fact that fishing pressure is mainly exerted on fish that are just starting their reproductive age, together with the use of illegal fishing gear such as cast nets (“tarrayas”) and smaller mesh sizes than those authorized, or the use different mesh sizes in a single net, have precipitated the decline of the population. The decline is also believed to have led to smaller size at maturity. It is common for tilapia to reproduce when they are only a few months old, often below market weight (Peña-Mendoza *et al*. 2005). However, it has been reported that early sexual maturity may have a negative influence on growth rate (Morales, 1991). Likewise, dwarfism has been reported to be a normal response in *Oreochromis* species during the first year of life (Dudley 1972). Reduction of tilapia populations has also been attributed to the incidence of parasites (Rosas 1976).

Other concerns about the tilapia in the Infiernillo Reservoir relate to their introduction initially coming from a reduced number of breeders (3,685 fingerlings from a single hatchery in Tacámbaro, Michocán, Rosas 1976), and that further restocking came from the same place. Thus, a high degree of inbreeding is likely. The lack of an adequate study of the population further confuses the situation. For example, when they were introduced, no attention was paid to the need to produce fertile hybrids. A recent study (Barriga-Sosa *et al*. 2004) has indicated a rather low genetic variability [expected heterozygosity (*He*)= 0.062] for the tilapia individuals of this dam, which could explain the slow recovery of the population.

According to García-Calderón *et al*. (2002), the construction of Caracoles Reservoir in 1987 (INE) upstream from Infiernillo also contributed to the overall decline in production. Also, because the main purpose of the dam is to generate electric power, there is a continuous fluctuation of the water level and the reservoir volume may be reduced down to 37 percent. At such levels, the tilapia spawning zones are exposed.

Mitigations

Several measures have been suggested to remedy some of the causes of tilapia population decline in the reservoir. These include restocking with genetically controlled strains of tilapia, increasing gillnet mesh size to avoid stunting, respecting protected zones, restricting capture seasons, and culturing tilapia in floating cages for export (Jiménez-Badillo 2000; Hernández-Montaño 2002; Torres Oseguera 2005). However, these measures are not likely to occur as a result of the poor socioeconomic condition of the region.

THE LORICARIID INVASION OF THE INFIERNILLO RESERVOIR

Pathway of Introduction

Loricariids were brought to the Caracoles Reservoir, located upstream from the Infiernillo Reservoir, to control and clean algae from this water body. When the sluice gates of the Caracoles dam were opened, the fish entered the Infiernillo Reservoir in large numbers (Martínez Elorriaga 2005). However, the high abundance of loricariids found in the upper Balsas basin, particularly in the environs of the state of Morelos, where most of the aquarium farms are located, would argue likelihood that continuous escapes from those farms have contributed as sources of at least six different species of loricariid populations. In addition, loricariids were massively introduced in the state of Morelos in an unsuccessful effort to control water hyacinth. The Infiernillo Reservoir presents optimum conditions for the development and establishment of loricariid populations, with its warm temperatures, high oxygen levels, low salinity, nearly neutral pH, and abundant food sources (Escalera Barajas 2005). The morphometry of the reservoir, together with the confluence of lotic and lentic ecosystems, provides different kinds of habitats for the successful adaptation and proliferation of the loricariid populations (Escalera Gallardo and Arroyo Damián 2006). This favors apportioning habitat use between large and small loricariids, as has been reported for different armored catfish species (Liang *et al*. 2005). Moreover, in this basin, the introduced loricariids lack any known natural predator. This is demonstrated in their success as invaders over the numerically and genetically depressed populations of tilapia, carp and native catfish.

Utilization

As eradication is almost impossible, the government of the state of Michoacán, in conjunction with the National Research Council of Mexico has announced the availability of funding for research directed towards the utilization of loricariids. The state government has already sponsored a project to grind loricariids into fishmeal to be used as fertilizer in agriculture and the value of this fishmeal is being evaluated as an ingredient for cattle feed (Martínez Elorriaga 2005) and for feeds for aquaculture. The results seem

Figure 5.6. Juvenile Loricariids for Sale

Figure 5.7. Discarded Gillnets after Loricariids Were Entangled

Source: Roberto Mendoza

Figure 5.8. Tool Made to Cut Loricariid Heads

Source: Roberto Mendoza

Figure 5.9. Nesting Holes Excavated in the Dam by Loricariids

Source: Roberto Mendoza

promising due to the high protein level (85 percent) of muscle and the elevated *in vitro* protein digestibility (95 percent), as well as its rich fatty acid profile (Vargas-Vázquez 2006, Escalera 2006 *pers. comm*., Escalera Gallardo and Arroyo Damián 2006). However, the possibility of human utilization, such as for human food supplements, remains to be investigated, as there are reports asserting that certain species of loricariids are prone to accumulate heavy metals, which has discouraged their consumption (Marcano and Troconis 2001; Chávez *et al.* 2005).

Socio-economic Problems caused by Loricariids in the Infiernillo Reservoir

Economic Problems

Fishery Issues

Due to their defensive posture when loricariids are caught, their raised dorsal and pelvic spines get entangled in the gillnets in such a way that nets need to be cut in order to get them out (Martínez Elorriaga 2005). The estimated price of a gillnet is P$900–1,000 (US$81.81–90.90). Fishermen have created a special tool to try to cut loricariid heads and save their nets (Fig. 5.3).

The effect of the loricariid invasion on tilapia stocks is uncertain. Fishermen claim that they are catching half of the tilapia that they used to before the invasion, whereas the local authorities minimize this figure, saying that the losses in tilapia capture are around 10 to 15 percent, and argue that pollution and the natural degradation of the reservoir are also important contributing factors (Martínez Elorriaga 2005). Other sources indicate that loricariid populations may have increased from 30 to 90 percent of the catch, depending on the fishing zone within the reservoir (Escalera Barajas 2005; Vargas-Vásquez 2006).

It is difficult to determine the exact number of loricariids that are actually captured, as many of them are thrown back in the water and only a fraction of those caught are discarded on shore. Damage has also been observed in certain sections of the reservoir embankments where loricariids have made their nesting holes and tunnels, in line with what researchers have noted in other locations (Hoover 2004, Devick 1989).

Through their foraging behavior, excretion and sediment stirring, these fish create water quality problems, microscopic algae blooms and changes in plankton nutrient availability (Escalera Barajas 2005; Novales-Flamanrique *et al.* 1993). An indirect effect of their grazing behavior is the modification of the trophic structure of the ecosystem, as suggested by Power (1990), which could be detrimental for tilapia stocks. The aggressive behavior of loricariids and tilapia during reproduction and the competition for nesting substrates, may have contributed as well (Escalera Barajas 2005, Crossland 2006). The accelerated decline of tilapia populations as a consequence of the presence of loricariids is plausible, since the invasion of loricariids and their impact on fisheries have already been documented (Chávez *et al.* 2006).

Human Health Issues

Since local fishermen refuse to consume the loricariids, instead throwing them on shore to decompose, the fish constitute a source of potential public health problems (Servin-García 2005). Also, in trying to detach loricariids from gillnets, fishermen often injure themselves (Escalera Barajas, *pers. comm.* 2005).

Socio-economic Study

A socio-economic study was conducted in one representative town, Churumuco, located on the eastern side of the reservoir that contains the largest number of communities. Churumuco is 235 km away from Morelia, the capital of the state of Michoacán.

The municipality of Churumuco covers 1,119 km^2, representing nearly two percent of the total Michoacán state. In 1995, 15,068 people were registered (*Gobierno de Michoacán* 2005). According to the most recent census in the year 2004, the municipal capital was inhabited by 14,866 people (*Periódico Oficial de Michoacán* 2005). An important aspect is that 51 percent (7,658 persons) of the communities from this municipality are considered to live under the poverty level, 13 percent (1,968 persons) in poverty and 36 percent (5,330 persons) in relative poverty.

Based on data collected from a survey of 300 persons, 15 years of age or older, conducted over a single month by Escalera (2005) and the municipal plan for 2005–2007 (*Periódico Oficial de Michoacán* 2005), several socioeconomic facts are helpful for understanding the impacts to the fishery impacts, as detailed below.

Figure 5.10. Typical Bycatch of Loricariids from Infiernillo Reservoir

Source: Roberto Mendoza

Figure 5.11. Loricariids Decomposing on Shore

Source: Roberto Mendoza

Education

There are 56 elementary schools, six junior high schools, two senior high schools and one municipal library. According to the official figures 25 percent of the population is illiterate. However, the survey indicates that 53 percent of the population is illiterate or has not finished primary school. One of the main problems when the survey was conducted is that many people could not read or fill the questionnaires and when they managed to do so, they could not understand common words such as "consumption." This aspect limits the social and economic development of the region, since many inhabitants are not able to participate in training courses or cannot apply for state assistance even when they are eligible, considering their socioeconomic status. This lack of education also inhibits the ability of the fishermen to organize and sell their products directly in the national market.

Health

The town has only one medical center and one institution providing medical diagnosis and treatment for ambulatory patients. There are seven physicians in total.

Age

Most of the population consists of adults (90 percent), with 40 percent older than 46 years of age. This age structure is due to regular migration of adults to other regions since the decline of the fishery began 18 years ago.

Figure 5.12. Location of the Municipality of Churumuco

Civil status

The married population is 89 percent of the municipal total. Due to the age structure, and the migration of younger people for employment elsewhere, only 10 percent of the resident population is within an age range of 15 to 25 years old.

Security

This is a critical issue, since the town has only 43 policemen and two patrol cars, of which only one is in good condition. It has been recognized by the local, state and federal authorities that important drug dealers operate in the region. Drug consumption has been increasing and some kidnappings have been reported (*Periódico Oficial de Michoacán* 2005). These facts have driven away potential investors.

Gender of the population related to the fishing activities

Ninety-four percent of the people who responded to the survey were males. However, the women interviewed only represent their husbands in the fisheries unions; 49 percent of the inhabitants are males and 51 percent are females; with 47 percent of these females (3,500 women) older than 12 years old, and 27 percent (2,000 women) of whom work outside the home.

Home owners

The original town of Churumuco was flooded by the reservoir created when the dam was completed in 1964. Just before the dam began functioning to generate hydroelectricity, the people were relocated and the new territory was evenly distributed. This action offered an opportunity for every family to become homeowners; 2,609 houses out of 2,703 (97 percent) are owned. However, by the year 2000, 76 percent of the houses still lacks sewer connections, 20 percent did not have electricity, and 54 percent were not provided with potable water (INEGI 2001).

Automobile owners

Only 30 percent of the questionnaire respondents own an automobile. In this context, a car is not a luxury item, but a necessary tool. Fishermen who posses a vehicle have the opportunity to bring their product to market without the intervention of intermediaries.

Seniority

At present, 23 percent of the fishermen began fishing since the dam began operation and 56 percent were incorporated into the fishery during the period from 1976 to 1990. The latter group was active, therefore, when the tilapia catch was at its highest levels and fishing was the most important activity in the region.

Time dedicated to the fishing activity

An eight-hour fishing schedule is practiced by 57 percent of the fishermen, which contravenes the officially approved regulation (from 6:00 AM to 1:00 PM). This is a normal consequence of the reduced tilapia populations existing in the reservoir. However, this practice has brought about a more complex situation; as a result of the low volumes caught during the official schedule, several fishermen, as well as unregistered fishermen, have decided to fish at night. This situation has already provoked a serious conflict that adds to the scarce security capacity, and the illiteracy and low income of the overall population, and has provided an opportunity to drug dealers of the region to offer their services to solve the problem.

Fishing gear

Fishing equipment is owned by 88 percent of the fishermen. On the other hand, 15 percent of the respondents mentioned that every now and then they use unofficial fishing gear or gillnets with a lower mesh openings than authorized.

Commercialization

As a consequence of the lack of resources to commercialize their catch, the vast majority of fishermen (92 percent) prefer to sell their product to intermediaries, and only 8 percent of them fish to satisfy their own food requirements.

Product value

Many respondents (85 percent of fishermen) complain of the low price offered for their catch, while 13 percent claim that the major problem is fish size. The rest (2 percent) feel that the quality is an impediment to improved commercialization.

Income

Ninety percent of respondents view the income they earn as unsatisfactory.

Alternative activities

The percent of fishermen who engage in fishing as a full-time activity is 44 percent, while 47 percent supplement their income with money sent from foreign nationals back to the region.

Migration

The emigration of young people to the United States who send money home is critical to the ongoing economic survival of the community (Martínez-Elorriaga 2004). In general, the emigration may be related to the hot and dry weather of the region (22.9 to 36.1ºC, with a mean annual precipitation of 639 mm) and to the lack of alternative jobs (*Periódico Oficial de Michoacán* 2005). Because of the climate, agriculture is hardly an option. The survey indicated that 44 percent of the interviewed fishermen have at least one relative living in the United States and 16 percent of respondents work in the United States on a temporary basis themselves. The paradox is that the dam was built not only for the production of electric power, but also for the conservation of the native ichthyofauna and the economic development of the region (Escalera Gallardo and Arroyo Damián 2006).

Family members

Households are crowded, with 73 percent of households composed of more than five individuals. This may explain the economic pressure felt by fishermen and explain why they may not respect current management efforts designed to restore populations.

Family gender structure

A majority, 54 percent, of the children are males. It is likely that many of these will not contribute to their family income within the region, but will eventually decide to emigrate in search of better employment opportunities.

Family income

Only eight percent of females contribute directly to their family income, in part because fishing is considered an exclusively male activity and also because the high number of children that need to be taken care of.

Loricariids

Up to 96 percent of respondents knew about the loricariids. More than 70 percent had tried to eat the catfish in different ways (mostly as a condiment just to add flavor to regular food).

Present appreciation of the fishing activity

Fishing is still considered a primary activity for 97 percent of the people in the survey. However, a growing proportion of the population is considering alternative activities or relocating elsewhere.

CONCLUSIONS

The introduction of tilapia and carp into the Infiernillo reservoir of Michoacán and Guerrero states in Mexico provided economic opportunities to local fishermen and the region through fish processing and other related industries for some years. However, the tilapia overtook the more valuable carp and native catfish as their numbers grew. Later, "tilapia populations began to decline, too, perhaps as a result of insufficient genetic diversity, pollution, and the poor management of the fishery. In recent years, the tilapia decline has been hastened by the unwelcome arrival of members of another exotic fish family, the Pleco."[20] To date, the loricariids have been found to have no economic value, but rather compete with the tilapia for food and space.

The poor socio-economic conditions in the region highlight two related conclusions about the introduction of these fishes. First, introducing an alien species, such as the tilapia and carp, can sometimes provide improved incomes and jobs in a region, but such a resource needs to be managed carefully if the economic gains are to be sustained over time. If it is not managed well, the economic gains will decline as quickly as they had developed, leaving the local communities as bad off, or worse, than before. Second, an accidental introduction, such as the loricariids in this case, can be devastating to an environmental resource, especially an unmanaged resource like the tilapia fishery at the Infiernillo Reservoir. The rapid decline of the fishery and problems associated with the introduction of the loricariids to the reservoir has had severe negative impacts on an already poor Mexican community, leaving young people with fewer and fewer alternatives other than emigrating to the United States or relocating to areas where greater economic possibilities may exist.

These facts deserve deep reflection, as the loricariids are spread throughout half of Mexican territory, thriving in waters where communities are found like those bordering the Infiernillo Reservoir. If there is any moral to this tale it is: "*never introduce an alien invasive species where there have been others*, *because it will find the road paved for invasion*."

[20] Luna Figueroa 2006.

6

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.

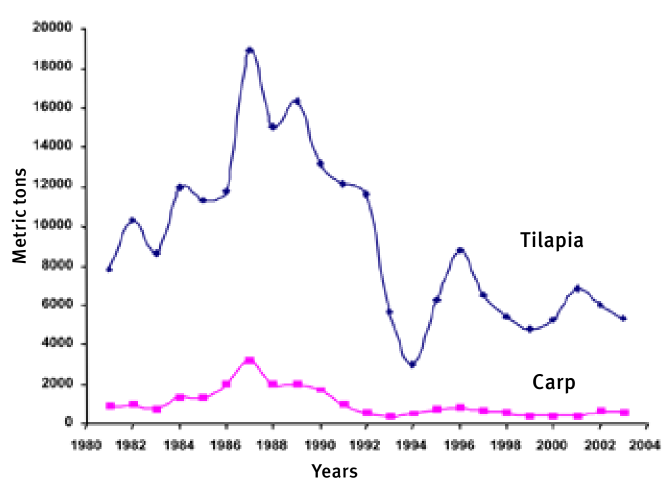
Loricariids began to appear in the reservoir in 1998, and beginning in 2001 there was an increase in their proportion of the total fish caught.[22]

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).

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.

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

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.

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.

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

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.

APPENDIX A
Organism Risk Assessment Form

ORGANISM RISK ASSESSMENT FORM
(With Uncertainty and Reference Codes)

ORGANISM ____________________ **FILE NO.** ____________________

ANALYST ____________________ **DATE** ____________________

PATHWAY ORIGIN ____________________ **ORIGIN** ____________________

I. LITERATURE REVIEW AND BACKGROUND INFORMATION

(Summary of life cycle, distribution, and natural history):

II. PATHWAY INFORMATION (include references):

III. RATING ELEMENTS: Rate statements as low, medium, or high. Place specific biological information in descending order of risk with reference(s) under each element that relates to your estimation of probability or impact. Use the reference codes at the end of the biological statement where appropriate and the Uncertainty Codes after each element rating.

PROBABILITY OF ESTABLISHMENT

Element Rating (L,M,H)	Uncertainty Code (VC - V)	
______,	______	Estimate probability of the non-indigenous organism being on, with, or in the pathway. (Supporting Data with reference codes)
______,	______	Estimate probability of the organism surviving in transit. (Supporting Data with reference codes)
______,	______	Estimate probability of the organism successfully colonizing and maintaining a population where introduced. (Supporting Data with reference codes)
______,	______	Estimate probability of the organism to spread beyond the colonized area. (Supporting Data with reference codes)

CONSEQUENCE OF ESTABLISHMENT

Element Rating (L,M,H)	Uncertainty Code (VC - VU)	
______,	______	Estimate economic impact if established. (Supporting Data with reference codes)
______,	______	Estimate environmental impact if established. (Supporting Data with reference codes)
______,	______	Estimate impact from social and/or cultural influences. (Supporting Data with reference codes)

I. ORGANISM/PATHWAY RISK POTENTIAL: (ORP/PRP) ____

Probability of Establishment	Consequence of Establishment	= ORP/PRP RISK

II. SPECIFIC MANAGEMENT QUESTIONS

III. RECOMMENDATIONS

IV. MAJOR REFERENCES

REFERENCE CODES TO ANSWERED QUESTIONS

Reference	CodeReference Type
G)	General Knowledge, no specific source
(J)	Professional Judgment
(E)	Extrapolation; information specific to pest not available; however information available on similar organisms applied
(Author, Year)	Literature Cited

UNCERTAINTY CODES TO INDIVIDUAL ELEMENTS

(based as much as possible on peer-reviewed science)

Uncertainty Code	Symbol	Description
Very Certain	VC	As certain as I am going to get
Reasonably Certain	RC	Reasonably certain
Moderately Certain	MC	More certain than not
Reasonably Uncertain	RU	Reasonably uncertain
Very Uncertain	VU	An educated guess

ATTACHMENT 1A
Organism Risk Assessment Form For Northern Snakehead (*Channa argus*)

ORGANISM RISK ASSESSMENT FORM

(With Uncertainty and Reference Codes)

ORGANISM Northern snakehead (*Channa argus*)

FILE NO.

ANALYST Becky Cudmore and Nick Mandrak

DATE May 2006

PATHWAY ORIGIN Live Food Trade

ORIGIN Manchuria, Russia, Korea (except Northeastern region), China

I. LITERATURE REVIEW AND BACKGROUND INFORMATION

The northern snakehead is golden brown to pale grey in colour when young, changing to darker brown with black splotches with age. They are superficially similar in appearance to the following native North American fishes: bowfin (*Amia calva*), burbot (*Lota lota*), and American eel (*Anguilla rostrata*). They can grow to 1.8 m and weigh up to 6.8 kg (Courtenay and Williams 2004, ISSG 2005). They are found in slow moving waters, usually close to shore with vegetated or muddy substrate (ISSG 2005). Spawning occurs in June or July in their native range when the species matures at about two years (or 30 cm in length) (ISSG 2005). This species builds cylindrical nests using pieces of macrophytes in shallow aquatic vegetation. These nests can be up to one metre in diameter (Courtenay and Williams 2004). Between 1,300 and 1,500 pelagic, non-adhesive, buoyant eggs (about 1.8 mm diameter) can be laid per spawn, with up to five spawns occurring within a year (Courtenay and Williams 2004). The Northern snakehead is most active at dusk and dawn. It feeds close to shore, typically under aquatic vegetation, and only when water temperatures are above 10°C (ISSG 2005). As an obligate air breather, this species is capable of surviving up to four days out of water. Overland migration is limited; however, juveniles can somewhat move on land if there is some water available (Courtenay and Williams 2004).

II. PATHWAY INFORMATION

Highly prized as a food fish, they are encountered in the live food trade where legal (Courtenay and Williams 2004, Cudmore and Mandrak unpub. data).

III. RATING ELEMENTS

Rate statements as low, medium, or high. Place specific biological information in descending order of risk with reference(s) under each element that relates to your estimation of probability or impact. Use the reference codes at the end of the biological statement where appropriate and the Uncertainty Codes after each element rating.

PROBABILITY OF ESTABLISHMENT

Element Rating (L,M,H)	Uncertainty Code (VC, RC, RU, VU)**	
H ,	VC	Estimate probability of the non-indigenous organism being on, with, or in the pathway. • Courtenay and Williams (2004)
H ,	VC	Estimate probability of the organism surviving in transit. • Courtenay and Williams (2004) • USGS (2004)
H ,	VC	Estimate probability of the organism successfully colonizing and maintaining a population where introduced. • Cudmore and Mandrak (unpub.data) • USGS (2004)
H ,	VC	Estimate probability of the organism to spread beyond the colonized area. • Cudmore and Mandrak (unpub.data) • USGS (2004)

* L = Low; M = Medium; H = High
** VC = Very Certain; RC = Reasonably Certain; RU = Reasonably Uncertain; VU = Very Uncertain

CONSEQUENCE OF ESTABLISHMENT

Element Rating (L,M,H)*	Uncertainty Code (VC, RC, RU, VU)**	
,		Estimate economic impact if established. (Supporting Data with reference codes)
H ,	RC	Estimate environmental impact if established. • Courtenay and Williams (2004)
,		Estimate impact from social and/or cultural influences. (Supporting Data with reference codes)

* L = Low; M = Medium; H = High
** VC = Very Certain; RC = Reasonably Certain; RU = Reasonably Uncertain; VU = Very Uncertain

I. ORGANISM/PATHWAY RISK POTENTIAL

(ORP/PRP) pending socio-economic impacts

Probability of Establishment	Consequence of Establishment	= ORP/PRP RISK

II.SPECIFIC MANAGEMENT QUESTIONS

This species has the potential to easily spread from areas it is found. Eradication of one non-native, established population (Crofton Pond, Maryland) has occurred in the United States.

ATTACHMENT 1B
Organism Risk Assessment Form for Chinese Snakehead (*Channa asiatica*)

ORGANISM RISK ASSESSMENT FORM

(With Uncertainty and Reference Codes)

ORGANISM Chinese snakehead (*Channa asiatica*)

FILE NO.

ANALYST Becky Cudmore and Nick Mandrak

DATE May 2006

PATHWAY ORIGIN Live Food and Aquarium Trade

ORIGIN China

I. LITERATURE REVIEW AND BACKGROUND INFORMATION

This is a warm temperature to subtropical species, likely utilizing riverine habitats. It grows up to 34 cm, rapidly growing in the first two years of life. This species is not a nest builder, but does provide aggressive protective care of young (there are some indications the male may be a mouth brooder). In aquaria, spawning can occur every 6 to 10 days, and generally occurs at night. This species is likely a thrust predator, consuming other fishes and invertebrates, depending on size (Courtenay and Williams 2004).

II. PATHWAY INFORMATION

Although noted in Courtenay and Williams (2004) that this species was likely to have been the first snakehead to be imported to the contiguous United States for the aquarium trade, it has since been discovered that this species has been used in the live food trade as well (W. Courtenay, ret-USGS, pers. comm.).

III. RATING ELEMENTS

Rate statements as low, medium, or high. Place specific biological information in descending order of risk with reference(s) under each element that relates to your estimation of probability or impact. Use the reference codes at the end of the biological statement, where appropriate, and the Uncertainty Codes after each element rating.

PROBABILITY OF ESTABLISHMENT

Element Rating (L,M,H)	Uncertainty Code (VC, RC, RU, VU)**	
H ,	VC	Estimate probability of the non-indigenous organism being on, with, or in the pathway. • Cudmore and Mandrak (unpub.data)
H ,	VC	Estimate probability of the organism surviving in transit. • Courtenay and Williams (2004) • Cudmore and Mandrak (unpub.data)
H ,	VC	Estimate probability of the organism successfully colonizing and maintaining a population where introduced. • Cudmore and Mandrak (unpub.data) • USGS (2004)
H ,	VC	Estimate probability of the organism to spread beyond the colonized area. • Cudmore and Mandrak (unpub.data) • USGS (2004)

* L = Low; M = Medium; H = High
** VC = Very Certain; RC = Reasonably Certain; RU = Reasonably Uncertain; VU = Very Uncertain

CONSEQUENCE OF ESTABLISHMENT

Element Rating (L,M,H)*	Uncertainty Code (VC - VU)**	
____ ,	____	Estimate economic impact if established. (Supporting Data with reference codes)
M ,	RU	Estimate environmental impact if established.
____ ,	____	Estimate impact from social and/or cultural influences. (Supporting Data with reference codes)

* L = Low; M = Medium; H = High
** VC = Very Certain; RC = Reasonably Certain; RU = Reasonably Uncertain; VU = Very Uncertain

I. ORGANISM/PATHWAY RISK POTENTIAL

(ORP/PRP) pending socio-economic impacts

Probability of Establishment	Consequence of Establishment	= ORP/PRP RISK

IV. REFERENCES

Courtenay, W.R., Jr., and J.D. Williams. 2004. Snakeheads (Pisces, Channidae) - a biological synopsis and risk assessment. United States Geological Survey Circular 1251.

Attachment 1C
Organism Risk Assessment Form For Blotched Snakehead (*Channa maculata*)

ORGANISM RISK ASSESSMENT FORM

(With Uncertainty and Reference Codes)

ORGANISM Blotched snakehead (*Channa maculata*)

FILE NO.

ANALYST Becky Cudmore and Nick Mandrak

DATE May 2006

PATHWAY ORIGIN Live Food Trade

ORIGIN Southern China, Northern Vietnam

I. LITERATURE REVIEW AND BACKGROUND INFORMATION

From Courtenay and Williams (2004): This species generally grows to 33 cm, but can reach lengths of more than one metre. The preferred habitat for blotched snakehead consists of shallow waters with vegetation in streams, lakes, ponds and ditches. It is a subtropical to warm temperature species, but has been noted to tolerate cold temperatures in Japan, where it was introduced. Blotched snakehead is cylindrical nest builders and guards the eggs floating in the nest. Spawning in Japan occurs in early summer. This species is reported to be a fierce predatory fish, consuming crustaceans, large insects, frogs and other fishes. Similar to other snakehead species, juvenile blotched snakeheads are capable of migrating overland.

II. PATHWAY INFORMATION

Blotched snakeheads are a valuable food fish and are cultured in China for export to many other countries. This species is often misidentified with northern snakehead.

III. RATING ELEMENTS

Rate statements as low, medium, or high. Place specific biological information in descending order of risk with reference(s) under each element that relates to your estimation of probability or impact. Use the reference codes at the end of the biological statement where appropriate and the Uncertainty Codes after each element rating.

PROBABILITY OF ESTABLISHMENT

Element Rating (L,M,H)	Uncertainty Code (VC, RC, RU, VU)**	
H,	VC	Estimate probability of the non-indigenous organism being on, with, or in the pathway. • (Supporting Data with reference codes) • Cudmore and Mandrak (unpub.data)
H,	VC	Estimate probability of the organism surviving in transit. • Courtenay and Williams (2004) • USGS (2004)
H,	VC	Estimate probability of the organism successfully colonizing and maintaining a population where introduced. • Cudmore and Mandrak (unpub.data) • USGS (2004)
H,	VC	Estimate probability of the organism to spread beyond the colonized area. • Cudmore and Mandrak (unpub.data) • USGS (2004)

* L = Low; M = Medium; H = High
** VC = Very Certain; RC = Reasonably Certain; RU = Reasonably Uncertain; VU = Very Uncertain

CONSEQUENCE OF ESTABLISHMENT

Element Rating (L,M,H)*	Uncertainty Code (VC, RC, RU, VU)**	
,		Estimate economic impact if established. (Supporting Data with reference codes)
M,	RU	Estimate environmental impact if established.
,		Estimate impact from social and/or cultural influences. (Supporting Data with reference codes)

* L = Low; M = Medium; H = High
** VC = Very Certain; RC = Reasonably Certain; RU = Reasonably Uncertain; VU = Very Uncertain

I. ORGANISM/PATHWAY RISK POTENTIAL

(ORP/PRP) pending socio-economic impacts

Probability of Establishment	Consequence of Establishment	= ORP/PRP RISK

IV. REFERENCES

Courtenay, W.R., Jr., and J.D. Williams. 2004. Snakeheads (*Pisces, Channidae*) - a biological synopsis and risk assessment. United States Geological Survey Circular 1251.

United States Geological Survey (USGS). 2004. Non-indigenous aquatic species database – northern snakehead (*Channa argus*). **www.nas.er.usgs.gov**.

Attachment 1D
Organism Risk Assessment Form For Bullseye Snakehead (*Channa marulius*)

ORGANISM RISK ASSESSMENT FORM

(With Uncertainty and Reference Codes)

ORGANISM Bullseye snakehead (*Channa marulius*)

FILE NO.

ANALYST Becky Cudmore and Nick Mandrak

DATE May 2006

PATHWAY ORIGIN Aquarium Trade

ORIGIN Pakistan, India, Sri Lanka, Bangladesh, Southern Nepal, Myanmar, Thailand, Mekong Basin (Laos, Cambodia), Southern China

I. LITERATURE REVIEW AND BACKGROUND INFORMATION

Bullseye snakehead is now known to be a species complex (W. Courtenay, ret-USGS, pers. comm.). From Courtenay and Williams (2004): This species is one of the largest in the snakehead family, attaining lengths of 120–122 cm (reaching a length of 30cm within one year); however, a bullseye snakehead from western India was reported at 180 cm and 30 kg. This species prefers deep, clear water with sand or rocky substrate in lakes and rivers, but have also been found in sluggish or standing waters. It is also found with submerged aquatic vegetation. Bullseye snakehead is a temperate to tropical species. Eggs are laid in the spring (some populations have another spawning period in the fall) in nests where there no vascular aquatic plants are present (only one of three snakehead species to do so). Parents guard the eggs and the young (brood size generally about 500, up to 3600) until they reach about 10 cm in length. This species consumes other fishes, crustaceans and insects.

II. PATHWAY INFORMATION (include references)

Highly valued aquarium species known as a 'cobra snakehead" in the aquarium trade. Courtenay and Williams (2004) suggested it is second in popularity to the giant snakehead (*Channa micropeltes*). It is also a popular sport fish in Thailand.

III. RATING ELEMENTS

Rate statements as low, medium, or high. Place specific biological information in descending order of risk with reference(s) under each element that relates to your estimation of probability or impact. Use the reference codes at the end of the biological statement where appropriate and the Uncertainty Codes after each element rating.

PROBABILITY OF ESTABLISHMENT

Element Rating (L,M,H)	Uncertainty Code (VC, RC, RU, VU)**	
H ,	RC	Estimate probability of the non-indigenous organism being on, with, or in the pathway. • Courtenay and Williams (2004)
H ,	VC	Estimate probability of the organism surviving in transit. • Courtenay and Williams (2004) • USGS (2004)
H ,	VC	Estimate probability of the organism successfully colonizing and maintaining a population where introduced. • Cudmore and Mandrak (unpub.data)
H ,	VC	Estimate probability of the organism to spread beyond the colonized area. • Cudmore and Mandrak (unpub.data)

* L = Low; M = Medium; H = High
** VC = Very Certain; RC = Reasonably Certain; RU = Reasonably Uncertain; VU = Very Uncertain

CONSEQUENCE OF ESTABLISHMENT

Element Rating (L,M,H)*	Uncertainty Code (VC, RC, RU, VU)**	
______ ,	______	Estimate economic impact if established. (Supporting Data with reference codes)
H ,	RC	Estimate environmental impact if established.
______ ,	______	Estimate impact from social and/or cultural influences. (Supporting Data with reference codes)

* L = Low; M = Medium; H = High
** VC = Very Certain; RC = Reasonably Certain; RU = Reasonably Uncertain; VU = Very Uncertain

I. ORGANISM/PATHWAY RISK POTENTIAL

(ORP/PRP) pending socio-economic impacts

Probability of Establishment	Consequence of Establishment	= ORP/PRP RISK

IV. REFERENCES

Courtenay, W.R., Jr., and J.D. Williams. 2004. Snakeheads (*Pisces, Channidae*) - a biological synopsis and risk assessment. United States Geological Survey Circular 1251.

United States Geological Survey (USGS). 2004. Non-indigenous aquatic species database – northern snakehead (*Channa argus*). **www.nas.er.usgs.gov.**

Attachment 1E
Organism Risk Assessment Form For Giant Snakehead (*Channa micropeltes*)

ORGANISM RISK ASSESSMENT FORM

(With Uncertainty and Reference Codes)

ORGANISM Giant snakehead (*Channa micropeltes*)

FILE NO.

ANALYST Becky Cudmore and Nick Mandrak

DATE May 2006

PATHWAY ORIGIN Aquarium and Live Food Trade

ORIGIN Southeastern Asia

I. LITERATURE REVIEW AND BACKGROUND INFORMATION

From Courtenay and Williams (2004): The giant snakehead is one of the two fastest-growing snakehead species, attaining lengths of 1 to 1.5 metres and can weigh over 20 kg. This species prefers deep waters in lakes, rivers, canals and reservoirs. It is a subtropical/tropical species. Giant snakehead clears a circular area in vegetation to spawn and guards the eggs floating in the nest. This species is a nocturnal feeder, consuming fishes, frogs, even water birds.

II. PATHWAY INFORMATION (include references)

This is the most popular aquarium species of all the species in the snakehead family. The juveniles are targeted and known as 'red' or 'redline' snakeheads in the North American aquarium trade. It is also a highly regarded food fish in southeastern Asia and has been imported into Canada for this reason.

III. RATING ELEMENTS

Rate statements as low, medium, or high. Place specific biological information in descending order of risk with reference(s) under each element that relates to your estimation of probability or impact. Use the reference codes at the end of the biological statement where appropriate and the Uncertainty Codes after each element rating.

PROBABILITY OF ESTABLISHMENT

Element Rating (L,M,H)	Uncertainty Code (VC, RC, RU, VU)**	
H ,	VC	Estimate probability of the non-indigenous organism being on, with, or in the pathway. • Courtenay and Williams (2004) • Cudmore and Mandrak (unpub.data)
H ,	VC	Estimate probability of the organism surviving in transit. • Courtenay and Williams (2004) • Cudmore and Mandrak (unpub.data) • USGS (2004)
H ,	RC	Estimate probability of the organism successfully colonizing and maintaining a population where introduced. • Cudmore and Mandrak (unpub.data)
H ,	RC	Estimate probability of the organism to spread beyond the colonized area. • Cudmore and Mandrak (unpub.data)

* L = Low; M = Medium; H = High
** VC = Very Certain; RC = Reasonably Certain; RU = Reasonably Uncertain; VU = Very Uncertain

CONSEQUENCE OF ESTABLISHMENT

Element Rating (L,M,H)*	Uncertainty Code (VC, RC, RU, VU)**	
,		Estimate economic impact if established. (Supporting Data with reference codes)
H ,	RC	Estimate environmental impact if established.
,		Estimate impact from social and/or cultural influences. (Supporting Data with reference codes)

* L = Low; M = Medium; H = High
** VC = Very Certain; RC = Reasonably Certain; RU = Reasonably Uncertain; VU = Very Uncertain

I. ORGANISM/PATHWAY RISK POTENTIAL

(ORP/PRP) pending socio-economic impacts

Probability of Establishment	Consequence of Establishment	= ORP/PRP RISK

IV. REFERENCES

Courtenay, W.R., Jr., and J.D. Williams. 2004. Snakeheads (*Pisces, Channidae)* - a biological synopsis and risk assessment. United States Geological Survey Circular 1251.

United States Geological Survey (USGS). 2004. Non-indigenous aquatic species database – northern snakehead (*Channa argus)*. **www.nas.er.usgs.gov.**

Attachment 2A
Organism Risk Assessment Form for *Loricariidae*

ORGANISM RISK ASSESSMENT FORM

(With Uncertainty and Reference Codes)

ORGANISM *Loricariidae* at Infiernillo Dam

FILE NO.

ANALYST Roberto Mendoza, Salvador Contreras, Carlos Ramírez, Patricia Koleff, Carlos Escalera, Porfirio Álvarez

DATE May 2007

PATHWAY ORIGIN Aquarium Trade

ORIGIN South America

I. LITERATURE REVIEW AND BACKGROUND INFORMATION

The fish family *Loricariidae* is the largest family of catfishes, including 825 nominal species, 709 of which are considered valid and 83 genera considered valid as of 9 January 2006 (Armbruster 2008). As the taxonomy of the *loricariid* catfishes is not fully resolved, this RA primarily considers the risks from a subset of the species of *Loricariidae* that are currently known in the aquarium trade in Mexico.

Origin	Native to Central and South American
Basic characters	Three rows of bony plates on their entire dorsal surface. Subterminal sucking mouth ("suckermouth")
Habits	Nocturnal fishes that inhabit streams, lakes, and weedy mud-bottomed channels.
Food sources	Bottom detritus and benthic algae, but they also feed on worms, insect larvae, and various bottom-dwelling aquatic animals (Gestring et al. 2006). High digestibility rates of organic matter (Yossa and Araujo-Lima 1998).

II. PATHWAY INFORMATION

Aquarium trade. Subsequent release from introduced wild stocks, either via egg masses, or adults intentionally introduced into naïve waters.

- The ornamental fish industry in Mexico operating for more than 50 years
- More than 40 million ornamental fish sold every year in Mexico.
- 44% are imported,
- 56% are raised in more than 250 ornamental fish production facilities located in several states of the nation (INEGI 2007).

Production

Increased more than 100% during the last decade

- National production provides employment for more than 1,000 persons
- There are 5,126 aquarium stores (INEGI 2005)
- Unofficial figures of 15,000 aquarium stores, employing around 30,000 persons (Ramírez and Mendoza 2005)
- The ornamental fish industry annual value is more than US $100 million dollars (retailers' price).
- Fifth position of the whole aquaculture industry in the country, similarly to the USA (Tlusty 2002).

Imports

1,000 to 1,200 boxes imported every week (Almenara 2001).

- Total import of ornamental fish from Asia, through the USA up to Mexico: 7,414,038 pcs
- Total import of ornamental fish from South America: 3,313,011 pcs
- Rest of the world (mainly Europe and Africa): 3,720,156 (INEGI 2007)
- Common practice to declare in average 25% less of the number of fish actually introduced. Therefore, it has been estimated that over 17,500,000 fish are actually imported.
- Importations from South America have increased in an important way over time due to the Treaty on Free Trade Between Colombia, Venezuela and Mexico (G3). This treaty eases the importations of goods coming from Colombia and gives this country an important advantage over the rest due to the tariff elimination

III. RATING ELEMENTS

Rate statements as low (L), medium (M), or high (H). Use the reference codes at the end of the biological statement where appropriate and the Uncertainty Codes after each element rating (VC = Very Certain; RC = Reasonably Certain; RU = Reasonably Uncertain; VU = Very Uncertain).

PROBABILITY OF ESTABLISHMENT

H, VC Estimate probability of the non-indigenous organism being on, with, or in the pathway.

Assessment of Loricariids in Pathway

- Loricaridae among the most popular fish families of the aquarium trade in Mexico
- Mexico also produces loricariids domestically for distribution through aquarium stores and other outlets
- A substantial part of this industry is supported by non-native populations established in the wild
- Fish from the loricariid family are estimated to represent 5 percent of the total official imports (Alvarez-Jasso 2004)

H, VC Estimate probability of the organism surviving in transit and the survival if deliberately or inadvertently released into the environment.

Entry Potential

- High, due to the physiological particularities of the species within the family, such as their capability of breathing air by swallowing it and extracting oxygen through the gut lining (Armbruster 1998), allowing them to withstand anoxic conditions (implying that they can stand long trips).
- Long history of successful transport of loricariid species from their countries of origin into Mexico is well established.
- Probability of survival if released is less studied, but examples of some species throughout many regions of the world indicate there is sufficient probability for survival in many tropical and subtropical regions. For example, populations have become established in the Philippines (Chávez *et al.* 2006), Taiwan (Liang *et al.* 2005), Puerto Rico (Bunkley-Williams *et al.* 1994), Panama, Trinidad, Guyana, Japan and Peru, (FishBase) and most recently in Singapore, Sumatra, Malaysia and Java (Page and Robins 2006).

M, VC Estimate probability of the organism successfully colonizing and maintaining a population where introduced.

Evidence of establishment

- Within Mexico, since 1995 a significant population of suckermouth catfishes has established in the Balsas Basin, one of the most important basins in the country draining a number of important rivers of the south of Mexico.
- In 2003 other invasions were registered, this time at the Usumacinta Basin (one of the largest of the country) and its tributaries draining into the Atlantic Ocean (Ramírez *et al.* 2005) mainly in the state of Tabasco, where fishermen have started requesting the state government to take immediate action on the matter. At least one species has spread through this watershed into Guatemala (Valdez-Moreno and Salvador Contreras, pers. comm. 2006).
- Expanding populations of *Pterygoplichthys anisitsi, P. disjunctivus*, *P. multiradiatus*, and *P. pardalis*, have also established in the Grijalva Basin (Waikida *et al.* 2005)
- Lack of information on numerous ecologically relevant parameters makes predicting colonization potential challenging for many species that are in the aquarium trade.

Biological traits

- Species that grow to larger size are aggressive about defending territory and competitive over food.
    - Extensive schooling behavior has been documented, suggesting that at high population density, when resources are less limited, agonistic behaviors may be reduced.
- Most species of loricariids are burrow spawners .
  They construct branching, horizontal burrows in stream or pond banks that are 120–150 cm deep.
    - Burrows are used as nesting tunnels and eggs are guarded by the males until free-swimming larvae leave the burrow, but also allow survival during drought. Fish can survive in the moist microhabitat even when water levels fall far below the opening to the chambers.
    - Burrowing behavior reduces the ability to eradicate populations effectively
- Growth is rapid during the first two years of life, with total lengths of many sail fin catfishes exceeding 300 mm (Hoover *et al.* 2006).
    - Some individuals have been observed to reach 70 cm (Fuller *et al.* 1999) and even more (pers. obs.)
    - Specimens in aquaria may live more than 10 years
- They start reproducing at t size of approximately 25 cm.
    - Fecundity of loricariids is moderately high, with females producing 500 to 3,000 eggs (Mazzoni and Caramaschi 1997; Escalera 2005; Gestring 2006), depending on species and size.
    - High fecundity may facilitate establishment as well as female-biased sex-ratios may facilitate expansion of newly introduced populations (Liangh and Shieh 2005; Page and Robbins 2006).
    - The reproductive season in Mexico takes place during the whole year

- Armored catfishes posses large-sized cells and large amounts of DNA per cell related to low metabolic levels and with the capacity of tolerating changes in the composition of the body fluid (Fenerich *et al.* 2004).
    - These cellular characteristics may enable their tolerance to challenging physiological stresses that may occur during drought periods (Brauner and Val 1996; McCormack *et al.* 2005).
    - Collectively, these aspects of their physiology have provided them with competitive advantage over other less tolerant fish populations (Stevens e*t al.* 2006).
- Loricariids are highly tolerant of polluted waters and can adapt readily to varying water quality conditions (Nico and Martin 2001).
    - They are often found in soft waters, but can adapt very quickly to hard waters. They also thrive in acidic to alkaline waters (pH 5.5 to 8.0). Further, some species are salt tolerant.
- The broad diversity of habitats potentially occupied/sought by species within the *Loricariidae* family would suggest that nearly all types of freshwater environments within Mexico that provide temperature conditions suitable for the species' could support some species of loricariids.
- Lack of establishment in some northwestern states indicates that these species may be thermally limited.

Table summarizes species of loricariids that have naturalized in Mexico and some of their physiological and habitat preferences

LORICARIIDAE – SPECIES	TEMP (ºC)	DH	pH	SIZE (cm)	POP (2 x Years)	SWIM SPEED (cm/s)	Mexico
Pterygoplichthys. lituratus				37	4.5–14	75	?
P. anisitsi	21–24	25	6.5–8.2	42	4.5–14	75	YES
P. disjunctivus				70	4.5–14	75	YES
P. multiradiatus	22–27	4–20	6.5–7.8	70	4.5–14	75	YES
P. pardalis	23–28	10–20	7–7.5	70	4.5–14	75	YES

Based on the wide array of conditions tolerated by the suckermouth catfishes, and their inherent biological characteristics, such as their high reproduction rate, spawning behavior in deep burrows, parental care, being fiercely territorial, being desiccation-resistant, being protected by a heavy armor, rasping teeth and dorsal spines that they use to defend themselves, and to the fact that they can utilize atmospheric oxygen thus having the possibility to survive out of water much longer than other fishes, introduced populations may become locally abundant (colonized) in a short period of time (Hoover *et al.* 2006). Within this context, it is worth noting, that the family Loricariidae has been found to have an 80% rate of establishment for introduction events outside their geographic range worldwide and has been rated with the highest risk score in other risk assessments (Bomford and Glover 2004).

M, RC Estimate probability of the organism to spread beyond the colonized area.

Environmental Characteristics of Vulnerable Receiving Waters

Environmental factors in receiving waters that prevent colonization, or hold in check the spread of introduced loricariid populations remain poorly studied.

Given the environmental similarities between the Amazons and certain riverine regions of Mexico and the fact that most of the imported fish are captured from the wild (thus more resistant than cultured fish), the probabilities of survival may be high (Ramírez and Mendoza 2008).

- Air breathing ability and cardiac hypoxia tolerance allow them to survive in hypoxic and polluted waters.
- Absolute thermal thresholds for cold tolerance are not known for many species, but they can stand 4ºC for several hours (Gestring *pers. comm.* 2006)
- Movements into thermal refugia (i.e., springs and seeps during winter) seem likely, as well as the utilization of sewage outflows, as has been demonstrated in Houston (Nico and Martin 2001, Jan Culbertson *pers. comm.* 2006).
- The variety of species in each of the genera suggests that certain taxa (or potential hybrids) in successive generations will acclimatize to subtropical and mild-temperate climates, becoming more cold tolerant over time.
- To further estimate the potential distribution of loricariid species in North America, a genetic algorithm for rule set production (GARP) analysis was used (Cudmore and Mandrak, Chapter 3).

It can be noticed that large parts of Mexico appear vulnerable to the spread of loricariids. Definitive modeling at the watershed scale is needed to consider the potential spread of specific species and GARP modeling does not support resolution at this finer scale. However, these predictions have been found to be accurate as to this date this is the actual distribution of loricariids in Mexico.

Probability of establishment = **M**	Organism with Pathway	Entry Potential	Colonization Potential	Spread Potential

CONSEQUENCES OF ESTABLISHMENT

H, VC Estimate economic impact if established.

Economic Impact Potential

- The first record of these fishes in Mexico was Liposarcus (=*Pterygoplichthys*) multiradiatus in the Balsas River in 1995 (Guzmán and Barragán 1997). In 2002 the first invasive status was registered in the basin. At present, the problem has become severe, as at least four species have already become established in the Infiernillo Reservoir, one of the largest freshwater reservoirs in the country (120 km in length and 40,000 ha surface, 11.860 billion cubic meters). This dam was the location of the largest freshwater fishery in the country (several introduced tilapia species constituted 90 percent of the fish population, accounting for 20 percent of the nation's production in continental waters). Before the invasion fishers captured nearly 20,000 tonnes of tilapia per year, more recently they have been catching between 13,000 to 15,000 tonnes of sailfin catfish. These fishes have been affecting the fishing gear and boats of fishermen, and thus their way of living. Overall, nearly 3,500 jobs have been lost from the infestation of loricariids in this one location. The loss of the incomes from persons employed either directly as fishers or indirectly through fishery support services has also affected family dependants, creating a difficult socioeconomic situation. This scenario is repeating in other places (e.g., Grijalva and Usumacinta Basin)

H, RC Estimate environmental impact if established.

Environmental Impact Potential

- Loricariid catfishes can assert serious negative impacts on those endemic species with substrate-attached eggs and species with benthic algae/detritus feeding habits.
- By grazing on benthic algae and detritus, suckermouth catfishes may alter and reduce food and physical cover available for the aquatic insects eaten by other native and non-native fishes where they are introduced (Liang *et al.* 2005; Page and Robbins 2006).
- The potential effects on altering insect community assemblages were demonstrated by Flecker (1992).
- Feeding on mud and silt could result in re-suspension of sediments causing turbidity and reduced photic zone depth, and/or could result in changes in substrate size.
- Nutrients can be prematurely diverted from the "consumer" components of food webs and transformed into feces available only to scatophags and decomposers (i.e., bacterial, fungi).
- Because they may attain large sizes, loricariid fishes may displace smaller or less aggressive benthic fishes (e.g., darters, madtoms, and bull head catfishes).
- Most species of loricariids are relatively sedentary, and may be attractive prey to fish-eating birds. Their defensive erection of dorsal and pectoral spines, however, poses mortal danger to birds, such as pelicans, attempting to swallow whole fish (Bunkley-Williams *et al.* 1994).
- Suckermouth catfishes "plow" the bottoms of streams, occasionally burying their heads in the substrate and lashing their tails. These behaviors can uproot or shear aquatic plants and impact native plant species by reducing their abundance in beds of submersed aquatic vegetation and creating floating mats that shade the benthos from sunlight (Hoover 2004).
- The nesting burrows of suckermouth catfishes are sometimes found in a large group or "spawning colony" in which several dozen occur in very close proximity to each other. These colonies can compromise shoreline stability, increasing erosion and suspended sediment loads. Siltation, bank failure, head-cutting, and elevated turbidity can occur as a result (Hoover *et al.* 2006; Ferriter *et al.* 2006).
- Loricariids can host infectious pathogens to which native species are not adapted or resistant including flukes, roundworms and protozoa. Some loricariids have been associated with *Trypanosoma danilewskyi* (carassii), a high-priority disease agent known to cause anemia, likely resulting in the death of freshwater fish such as cold water cyprinid fishes (e.g., carp, goldfish, tench) (Kailola 2004). Epizotic com mensal chironomid larvae have been found among the oral bristles of different species (not present in species lacking bristles). An unidentified dinoflagellate occurred on the skin, fins and gills of *Pterygoplichthys gibbiceps*. Mortality rates up to 100% were registered in some shipments after 7 to 14 days, and the parasite was not treatable with malachite green, formalin or changes in salinity because of the formation of protective cysts (Pearson 2005).
- Severity of impact will be site-specific and species-specific (e.g., *Hypostomus* versus *Pterygoplichthys*)

Consequences of Establishment *Economic* + *Environmental* = **H**

I. ORGANISM/PATHWAY RISK POTENTIAL (ORP/PRP)

Organism Risk Potential (ORP)

Probability of Establishment	= **M**	Consequence of (H) Establishment	= **H**

Pathway Risk Potential (PRP)
Rating (H)

II. SPECIFIC MANAGEMENT QUESTIONS

- At the present, only three eradication methods have been proved: the use of Paraquat (Tortorelli *et al.* 1990) the use of Niclosamide (Wu 2006) and the manual collection of individuals (Earth Month 2006).
- Ongoing trials using specific attractants and traps are under investigation in Mexico (Escalera *comm.. pers.*)
- Despite the potential use of loricariids as edible fishes (Carvalho 2003: Escalera y Arrollo 2006; Laguna Lake development Authority 2006), some studies point out the potential danger of ingestion due to their ability to accumulate mercury (Nico and Taphorn 1994; Chávez *et al.* 2005). Several proposals have arise lately, such as the utilization of loricariids for biofuel, soap, fishmeal (for aquafeeds or fertilizer), recovery of digestive enzymes, surimi…etc. (Intel International Science and Engineering Fair 2006, Martínez 2007).

III. RECOMMENDATIONS

- As an alternative for the aquarium trade industry black lists and white lists of loricariids were conceived
- HACCP capabilities are needed to prevent further expansion of loricariids.
- We suggest encouraging the development of technological alternative to use established populations that are affecting fisherman in different localities.

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APPENDIX B
Inferential Estimation of Organism Risk and Pathway Risk

Step 1. Calculating the elements in the Risk Assessment

The blank spaces located next to the individual elements of the risk assessment form

(Appendix A) can be rated using high, medium or low. The detailed biological statements under each element will drive the process. Choosing a high, medium or low rating, while subjective, forces the assessor to use the biological statements as the basis for his/her decision. Thus, the process remains transparent for peer review.

The high, medium and low ratings of the individual elements cannot be defined or measured--they have to remain judgmental. This is because the value of the elements contained under "Probability of Establishment" are not independent of the rating of the "Consequences of Establishment." It is important to understand that the strength of the Guidelines is not in the element-rating but in the detailed biological and other relevant information statements that supports them.

Step 2. Calculating the Organism Risk Potential

The Organism Risk Potential and the Pathway Risk Potential ratings of high, medium and low should be defined (unlike the element rating in step 1 which have to remain undefined). An example is provided of these definitions at the end of Appendix B.

To calculate the Organism Risk Potential, the following three steps must be completed:

Step 2a. Determine Probability of Establishment

Probability of establishment	Organism with Pathway	Entry Potential	Colonization Potential	Spread Potential

The probability of establishment is assigned the value of the element with the lowest risk rating (e.g., a high, low, medium and medium estimates for the above elements would result in a low rating).

Because each of the elements must occur for the organism to become established, a conservative estimate of probability of establishment is justified. In reality (assuming the individual elements are independent of each other), when combining a series of probabilities (such as medium - medium - medium) the probability will become much lower than the individual element ratings. However, the degree of biological uncertainty within the various elements is so high that a conservative approach is justified.

Step 2b. Determine Consequence of Establishment

Economic	Environmental	Perceived	Rating
H	L, M, H	L, M, H	= H
L, M, H	H	L, M, H	= H
M	M	L, M, H	= M
M	L	L, M, H	= M
L	M	L, M, H	= M
L	L	M, H	= M
L	L	L	= L

Note that the three elements that make up the "Consequence of Establishment" are not treated equally. The "Consequence of Establishment" receives the highest rating given either the Economic or Environmental element. The Perceived element does not provide input except when Economic and Environmental ratings are low (see next to the last column on the above table).

Step 2c. Determine Organism Risk Potential (ORP)

Probability	Consequence	Rating
High	High	= High
Medium	High	= High
Low	High	= Medium
High	Medium	= High
Medium	Medium	= Medium
Low	Medium	= Medium
High	Low	= Medium
Medium	Low	= Medium
Low	Low	= Low

The conservative approach is to err on the side of protection. When a borderline case is encountered, the higher rating is accepted. This approach is necessary to help counteract the high degree of uncertainty usually associated with biological situations.

Step 3. Determine the Pathway Risk Potential (PRP)

ORP		PRP
Rating	**Frequency**	**Rating**
High	1 or more	High
Medium	5 or more	High
Medium	1 to 4	Medium
Low	All	Low

The PRP reflects the highest ranking ORP. The only exception is when the number of medium risk organisms reaches a level at which the total risk of the pathway becomes high. The number, “5 or more,” used in the above table is arbitrary.

Definition of Ratings used for Organism Risk Potential and Pathway Risk Potential:

Low = acceptable risk - organism(s) of little concern (does not justify mitigation)
Medium = unacceptable risk - organisms(s) of moderate concern (mitigation is justified)
High = unacceptable risk - organisms(s) of major concern (mitigation is justified)

When assessing an individual organism, a determination that the ORP is medium or high often becomes irrelevant because both ratings justify mitigation. When evaluating a pathway, the potential “gray area” between a PRP of medium and high may not be a concern for the same reason.

APPENDIX C. Definitions

AQUATIC [ALIEN] INVASIVE SPECIES A non-indigenous species that threatens the diversity or abundance of native species, the ecological stability of infested waters, or commercial, agricultural, aquacultural or recreational activities dependent on such waters. Aquatic invasive species include non-indigenous species that may occur in inland, estuarine and marine waters, and that presently or potentially threaten ecological processes and natural resources. In addition to adversely affecting activities dependent on waters of the Canada, Mexico and/or the United States, aquatic invasive species may directly adversely affect humans, including health effects.
AQUATIC SPECIES All animals and plants, as well as pathogens or parasites of aquatic animals and plants, totally dependent on aquatic ecosystems for at least a portion of their life cycle.
BALLAST WATER Any water and associated sediments used to manipulate the trim and stability of a vessel.
CANADA (please define)
CONTROL Activities to eliminate or reduce the effects of aquatic invasive species, including efforts to eradicate infestations, reduce populations of aquatic invasive species, develop means to adapt human activities and facilities to accommodate infestations, and prevent the spread of aquatic invasive species from infested areas. Control may involve activities to protect native species likely to be adversely affected by aquatic invasive species. Preventing the spread of aquatic invasive species is addressed in the Prevention Element of the proposed Program; all other control activities are included in the Control Element.
ECONOMIC IMPACT POTENTIAL The expected net change in society's net welfare which is the sum of the producers' and consumers' surpluses arising from changes in yield and cost of production caused by the pest.
ECOSYSTEMS - In the broadest sense, organisms and the biological, chemical and physical habitat in which they live. These include natural or "wild" environments as well as human environments. In the case where the species involved is a pathogen or parasite, an ecosystem may be an animal or plant that acts as a host.
ENTRY POTENTIAL The relative ability of an organism to colonize a given area within a time interval.
ENVIRONMENTALLY SOUND Methods, efforts, actions or programs to prevent introductions, or to control infestations of aquatic invasive species that minimize adverse impacts to the structure and function of an ecosystem and adverse effects on non-target organisms and ecosystems using integrated pest management techniques and nonchemical measures.
ESTABLISHED When used in reference to a species, this term means occurring as a reproducing, self-sustaining population in an open ecosystem, i.e., in waters where the organisms are able to migrate or be transported to other waters.
HYBRIDIZATION The mating of organisms from different species, sub-species, varieties or strains resulting in offspring.
INDIGENOUS The condition of a species being within its natural range or natural zone of potential dispersal; excludes species descended from domesticated ancestors (OTA 1993).
INTENTIONAL INTRODUCTIONS The knowing import or introduction of non-indigenous species into, or transport through, an area or ecosystem where it was not previously established. Even when there is no intent to introduce an aquatic organism into an ecosystem, escapement, accidental release, improper disposal (e.g., "aquarium dumps") or similar releases are the virtual inevitable consequence of an intentional introduction, not an unintentional introduction.

Synonyms: Purposeful, Deliberate.
MEXICO (in translation)
NATIVE Indigenous.
NON-INDIGENOUS SPECIES Any species or other viable biological material that enters an ecosystem beyond its historic range, including any such organism transferred from one country into another.
ORGANISM Any active, infective, or dormant stage of life form of an entity characterized as living, including vertebrate and invertebrate animals, plants, bacteria, fungi, mycoplasmas, viroids, viruses, or any entity characterized as living, related to the foregoing.
PATHWAY The means by which aquatic species are transported between ecosystems.
PREVENTION Measures to minimize the risk of unintentional introductions of aquatic invasive species that are, or could become, aquatic invasive species into waters of Mexico, Canada and the United States.
RISK The likelihood and magnitude of an adverse event.
RISK ANALYSIS The process that includes both risk assessment and risk management.
RISK ASSESSMENT The estimation of risk.
RISK COMMUNICATION The act or process of exchanging information concerning risk.
RISK MANAGEMENT The pragmatic decision-making process concerned with what to do about the risk.
SPECIES A group of organisms, all of which have a high degree of morphological and genetic similarity, can generally interbreed only among themselves, and show persistent differences from members of allied species. Species may include subspecies, populations, stocks, or other taxonomic classifications less than full species.
UNINTENTIONAL INTRODUCTION An introduction of non-indigenous species that occurs as a result of activities other than the purposeful or intentional introduction of the species involved, such as the transport of non-indigenous species in ballast or in water used to transport fish, mollusks or crustaceans for aquaculture or other purpose. Involved is the release, often unknowingly, of non-indigenous organisms without any specific purpose. The virtually inevitable escapement, accidental release, improper disposal (e.g., "aquarium dumping') or similar releases of intentionally introduced non-indigenous species do not constitute unintentional introductions.

Synonyms: Accidental, Incidental, Inadvertent
UNITED STATES The 50 States, the District of Columbia, Puerto Rico, Guam, and all other possessions and territories of the United States of America.

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