Chapter 1

Predictive Modelling for Fisheries Management in the Colombian Amazon

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A group of Colombian indigenous communities and Amacayacu National Park are cooperating to make regulations for sustainable use of their shared natural resources, especially the fish populations. To aid this effort, we are modeling the interactions among these communities and their ecosystem with the objective of predicting the stability of regulations, identifying potential failure modes, and guiding investment of scarce resources. The goal is to improve the probability of actually achieving fair, sustainable and community-managed subsistence fishing in the region.

Our model fuses common-pool resource non-cooperative games with principles of self-organizing commons management by allowing agents to affect the existence of game rules as well as choosing wether to act within the bounds of those rules. Sustainable management is threatened by both economically rational individuals, who cheat the system when it profits them, and by malicious individuals, who wish to destroy the system for their own obscure reasons. With our model, we hope to evaluate the stability of a system of regulations in simulation by measuring the impact of malicious agents on the behavior a population of rational agents employing a strategy of measured response.

1.1 Overview

Along the Colombian section of the Amazon river, a group of small indigenous communities and Amacayacu National Park are experimenting with the design and implementation of regulations intended to recover and maintain the integrity and productivity of their shared natural resources, especially the fish populations on which they depend. We are modeling the behavior and stability of management scheme options for this system with the objective of developing guidelines for strategic future investment of time, energy, and money. The goal is to improve the probability of actually achieving fair, sustainable and community-managed subsistence fishing in the region.

Sustainable long-term use of common pool resources is an inherently difficult political challenge. The Amacayacu communities face the additional complications of complex and poorly-understood ecosystems, uncontrolled demographic growth and cultural change in the population of legitimate resource appropriators, weak and often corrupt national and regional institutions, and primitive transportation and communication infrastructure. Balanced against these are the positive factors of a relatively small and well-defined population of users, appropriation practices that can be monitored relatively effectively at relatively low cost, recognition of the legitimacy of local regulations by regional and national institutions, and an explicit commitment on the part of the appropriator population to developing fair, sustainable, and democratic ground rules for natural resource use.

We approach this problem from the perspective of self-organizing commons management principles[4] and present a first-draft model for human/fish interactions in the Amacayacu region based on common-pool resource non-cooperative games,[6] with the addition of institutional level choice to our model. Predictions from this model can be derived through simulations which introduce a small number of malicious agents, and compared against the evolving situation of the Amacayacu communities. If successful, this model can then be used as an aid for decision-making in solving the resource management problems facing the Amacayacu communities

1.2 The Amacayacu Fisheries Dilemma

There are two types of fisheries in the Amacayacu region. The majority of activity is in the subsistence fisheries. A broad range of species are involved, likely more than 100, ranging in size up to a few kilograms. Subsistence fishing takes place mostly in the two tributaries bordering the park (Q. Mata Mata and Q. Amacayacu) and in the lakes contained within the islands of Mocagua and Zaragozilla. The open river, on the other hand, is harvested primarily for commercial purposes, yielding large catfish which are sold in the city of Leticia, 50 kilometers distant. Although these command a lucrative price compared to the smaller, bonier fish from the subsistence fisheries, the subsistence fisheries are significantly more important to the viability of the communities.

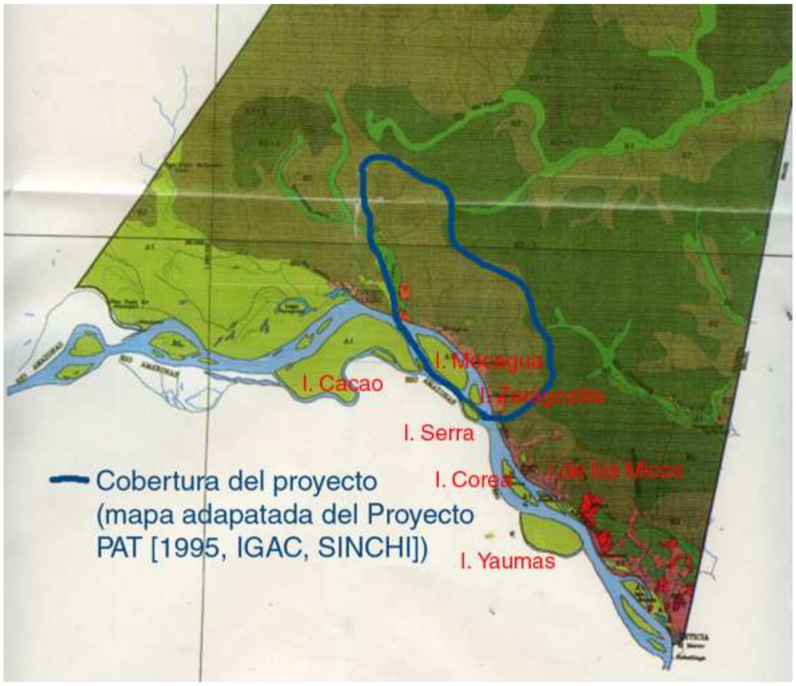

Figure 1.1: Amacayacu fisheries management project area (blue outline)

In recent years, the user communities have perceived a major decrease in the productivity of the subsistence fisheries, coincident with major demographic growth and the widespread introduction of fishing nets. The causation is unclear, and the subject of current research, although the use of nets appears to have a disproportionately large impact on the productivity of the fisheries.

Unfortunately, quantitative information about the fisheries is virtually non-existent. This presents a major challenge to any conservation effort, as there is little known about the biology or ecological interactions of the species being harvested, or indeed even exactly how species are being harvested regularly. Harvest records are only beginning to be compiled — establishing a system of records is a main objective for the management project in the coming year.

1.2.1 User Communities

The six communities which have participated in the project (Macedonia, Mocagua, Zaragoza, El Vergel, Palmeras, and San Martin de Amacayacu) are spread along 25 kilometers of the Colombian bank of the Amazon. Together they comprise approximately 2500 inhabitants, ranging from 183 in Palmeras to 826 in Macedonia.[1] Child mortality has plummeted due to improved health

[1] 2002 survey data, unpublished

care, but there is not yet a corresponding cultural change in birth-rate, so the population is growing rapidly.

Although there are no formal restrictions on where members of a given community can fish, in practice each community fishes a rough territory nearby, overlapping with its upstream and downstream neighbors. In addition, there are occasional problems with poachers from the Peruvian side of the river.

Interaction between communities is relatively scarce. This is partly due to the lack of enabling infrastructure — there are no roads, only a few occasionally functional satellite telephones, and boat motors and gasoline are expensive — and partly due to insularity on the part of the communities — it is more likely for people from non-neighboring communities to meet on excursions to the Leticia.

There is a high level of poverty in the communities, where much of the economic activity is non-monetary. Other local industries besides fishing include subsistence farming, ecotourism, and production of traditional crafts for sale.

1.2.2 Management Project History

Management of the fisheries is an outgrowth of other conservation efforts in the region. Isla Mocagua is also inhabited by the wattled curassow *(crax globulosa)*, an endangered species of bird approximately the size of a turkey. Beginning in 2000, Project Piuri (after the Spanish name for the species) enlisted local aid in data-gathering and monitoring to prevent hunting of the birds. Spurred by the apparent success of Project Piuri, members of the involved communities began wondering whether they could improve the fisheries of the island as well.

Under the fisheries management project, begun in 2002, nets are banned from use in all subsistence fisheries. To enforce the ban, round-the-clock teams of monitors are deployed in the fisheries, with the authority to confiscate and burn nets from violators. Each community is responsible for monitoring a portion of the fisheries,

After only a few months of monitoring, there was widespread agreement that the fishing had greatly improved. The project has already weathered several crises, but consensus among the communities is still fragile.

1.3 Self-Organizing CPR Management

Despite stereotypes to the contrary, many communities avoid the tragedy of the commons and develop long-term sustainable common pool resource management schemes. For example, the *huerta* of Valencia, Spain, have been operating as a self-governing irrigation system since the year 1435.[5]

Analysis of a self-organizing CPR management system proceeds on three levels: **Constitutional Choice** is the highest level, in which participants determine how to go about devising their institutions. Below that is the level of **Institutional Choice**, in which participants make collective choices about regulations for interacting with the CPR — who can draw units, how conflicts will be resolved, and what sanctions will be imposed for violations. Finally **Operational Choice** is the level at which participants actually interact with the CPR, deciding whether or not to obey or enforce the regulations.[4]

By contrast, analyses like the classical tragedy of the commons assume that the Constitutional and Institutional levels are fixed by an outside party, so that participants can only make choices at the Operational level, greatly limiting their options.

In fact tragedy of the commons situations do occur, a fact which self-organizing CPR management accounts for by identifying ways in which successful and failed CPR management systems tend to differ. Ostrom[4] identifies a set of eight design principles for successful self-organized CPR management systems:

1. Clearly defined boundaries
2. Proportional equivalence between benefits and costs
3. Collective-choice arrangements
4. Monitoring
5. Graduated sanctions
6. Conflict resolution mechanisms
7. Minimal recognition of rights to organize
8. Nested enterprises

Systems which follow all of these principles tend to be very successful, systems which only partially follow the principles tend to be fragile and unstable, and systems which follow few or none tend to fail badly.

In the case of the Amacayacu communities, all eight of these principles are on their way to being satisfied. Governmental authorities have given legal recognition and broad authority to the project, which is organized at both the community and regional level, and an ongoing process of collective choice within the communities is supporting the efforts at present. The fisheries under management are in well-defined locations, with a clearly identified population of legitimate users, and a system of monitoring established. The remaining principles (proportionality, sanctions, and conflict-resolution) are still in the process of being established.

1.4 Modeling Challenges

Modeling the Amacayacu fisheries presents major difficulties stemming from complexity and lack of knowledge about the ecosystem as well as from the shifting body of rules allowed by self-organization of the user community.

The major issues in modeling the fisheries stem from lack of information. Many different species of fish are harvested, and little to no information is known about the reproductive biology and ecological interactions of any given species. What is known is largely phenomenological information gathered by the user community: for example, cleaning surface vegetation off of the ponds significantly increases the harvestable fish population, but the mechanism is entirely unclear. Additional complexity is added by large seasonal variations in the fisheries as the river floods and retreats, and possible multi-year cycles for which historical data is sparse at best. Finally, the Amacayacu fisheries are not isolated from the larger Amazon, and the degree of interaction between them and the local, regional, and continental ecosystem is unknown.

The major issues in modeling the user community stem from the fluxing political situation. Because the national and regional institutions tend to be weak and sometimes corrupt, there is no powerful authority issuing or enforcing regulations. As a result, the main regulatory authority lies with the user community, resulting in a tight coupling of constitutional, institutional, and operational choice levels. Furthermore, the communities' general cynicism, that rules are unenforceable and that local actions cannot affect the environment, has been shaken by the success of Project Piuri and the perception of improving fisheries. Finally, with a total population of only a few thousand across all six communities, the group is small enough for actions of single users to have a large impact, particularly at the level of institutional choice, but large enough that any given user is likely to have no direct relationship with many of the other users.

A further complication comes from invading poachers from the Peruvian communities on the other side of the river. Not only do the poachers take fish, but their free-riding challenges the Amacayacu communities commitment to conservation.

1.5 System Model

Our system model is predicated on two major hypotheses:

Aggregate Biology Hypothesis: *Given the large number of species involved, the biology of individual species may be generalized and the fish resource modeled as harvestable biomass.*

System Dynamics Hypothesis: *Gross system dynamics are determined by the interaction of five factors: individual belief in regulations, economic rationality, social networking, physical geography, and observable ecological variables.*

The model consists of three components: the population of resource users, the environmental system from which units of resource can be harvested, and the rules regulating interaction between users and the environment. The specifics below represent a first draft of the model. It has been kept intentionally simple, minimizing the number of hidden variables, with the intention of simplifying synchronization with the evolving field data.

The environment is modeled as a collection of villages and fishing grounds. Traveling between any two places costs time proportional to the distance. At fishing grounds, users can choose to fish either with a net, yielding high returns at the cost of high impact, or with a spear, yielding low returns but low impact.

Our model of the fish population is fairly radical, due to the many species involved, the strong coupling with the surrounding Amazon region, and the observed rapid impact of environmental changes in the fishing grounds. Rather than model the underlying population, we model the biomass of "catchable fish". Instantaneous conditions at a fishing ground regulate the sustainable density of catchable fish (e.g. net-fishing decreases density, clear vegetation increases maximum) Catchable fish then diffuse between the larger Amazon system and each fishing ground based on the ratio of density to sustainable density.

Each game is a day. Users must begin and end their days in their home villages. In between, they expend time to try to maximize fish, by choosing a combination of travel, net-fishing, and spear-fishing that expends all of the available time.

Rules are represented by a collection of expert system IF/THEN rules. Every user interprets the set of rules with belief values, representing whether the user believes the rule is enforceable — the expected probability of enforcement is the sigmoid of the belief ($s(b) = \frac{1}{1+e^{-x}}$). Rule belief is affected by two mechanisms: observation and gossip. If a user observes the antecedents of a rule being fulfilled, then if the consequence is also fulfilled, belief increases by one. If, on the other hand, the consequence is not fulfilled, belief decreases by one. Gossip, on the other hand, acts by diffusion of belief values between users at the same location.

There are two types of users. The vast majority act economically rationally, employing a strategy of measured response[6]. Under measured response, a user determines the Nash equilibrium of a situation and the optimal strategy within bounds of the rules, then combines them proportional to the enforceability of the rules. A small minority, however, exhibit malicious behavior, collaboratively choosing actions to minimize compliance with the rules (this will usually also minimize the total value extracted from the resource).

Evaluation is on the basis of robustness against malicious users. In general, it is the case that with enough malicious users, belief in the rules will be destroyed and the system will settle to the Nash equilibrium. The higher a percentage of malicious users in the population that a system can sustain without belief in the rules collapsing, the more robust that system is.

1.6 Contributions

Preliminary results from the model suggest that it can display behavior characteristics similar to the real fisheries management system. Further testing of the hypotheses, however, is awaiting more data, particularly the harvest records from the coming year.

If the hypotheses prove justified, we can then apply the model to assist in making decisions and detecting problems in the fisheries management project.

One area of immediate applicability is cost-benefit estimates for investment of scarce resources (e.g. is it better to have more monitors, or radios to make communication between communities easier?). Simulations may also be helpful in predicting what types of problems are likely to arise, allowing better prevention. Finally, studying how systems collapse in simulation may provide diagnostics for early warning signs of serious problems and prescriptions for treatment.

The inclusion of institutional choice in the form of individual belief in regulations may be of broader interest. If it proves to be a useful model, it greatly simplifies the modeling of institutional choice, enabling better understanding and easier use of self-organizing CPR management systems.

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