Exploring Alternatives for Sustainable Development in Tamiahua Wetlands.

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Abstract

This paper presents a preliminary System Dynamics model developed to analyze sustainability of a natural reserve in Mexico: the Tamiahua wetlands. Wetlands are often referred to as nature's kidney because they filter contaminants from water. In spite of their importance, wetlands are endangered areas around the world. The preliminary model presented in this paper suggests that fishing activity in the Tamiahua wetlands, together with contaminants from human activity, have the potential to damage the diversity of species in the ecosystem, endangering the sustainability of the system. Continued work on the model is intended to explore appropriate ways of preserving Tamiahua, providing inhabitants with economic activities that promote the sustainability of the region.

Keywords

Sustainable Development, Wetlands, Mexico, Tamiahua

Introduction

This paper introduces a preliminary System Dynamics model to analyze sustainability of a natural reserve located in the Northern bound of the State of Veracruz in Mexico: the Tamiahua wetlands. The model presented in this paper is the result of initial conversations among researchers interested in regional development and the preservation of the Tamiahua protected area, and builds upon known system dynamics models like Fishbanks (Meadows). One of the authors of this initial paper has been involved in extensive field research in Tamiahua collecting information about water quality. During his fieldwork, he has observed a growth in the fishing industry followed by a decline on the activity of fishing cooperatives. The reduction in fishing appears to be the result of a combination of factors such as increased fishing activity, contamination and deterioration of the diversity of species in the wetlands region.

The paper is organized in five more sections. The second section consists of a preliminary literature review on the nature and characteristics of wetlands, and the use of System Dynamics as a tool to study sustainability of fishing. The third section describes very briefly the methods used in the paper. Sections four and five describe the model structure and some interesting behaviors of the model TAMIAHUA1. Finally, we conclude the paper with some final remarks and future work.

Literature Review

Wetlands are often referred to as nature's kidney because they readily filter contaminants from water, their intrinsic beauty, importance as habitat for rare and endangered species and role in carrying out basic ecological functions such as primary productivity, decomposition, nutrient cycling and regulation of fluxes between land and water bodies. These ecosystems can also function to remove and store nutrients and toxic pollutants in runoff from surrounding areas.

Particularly, coastal wetlands play an important role in protecting coastal water quality. They are critical ecosystems that help to regulate and maintain the hydrology by storing and releasing floodwaters. Wetlands and hard to define mainly because are transition zones. They hydrology is usually the most important factor determining its character. These regions are considered one of nature's most efficient filters and usually are important nurseries for fish, crabs, shellfish and an extensive variety of animals.

Despite their importance in the ecosystems, wetlands are endangered zones in all around the world. Only in USA, yearly loss of c.a. 1.05 million hectares of wetlands is estimated (Josephson, 1992). Additional to agricultural conversion, wetlands are continuously jeopardized as result of overfishing, burgeoning development, sediment contamination and nutrient pollution. All this as result as growing population and increasing of non-planned development in coastal counties producing, in many of the cases, overexploiting of fisheries and a increase in threatened, endangered and extinct native species.

System Dynamics has been used successfully to analyze and study fishing systems in a variety of ways (Ruth, 1995; Otto and Struben, 2004; Morecroft, 2007). Most of these previous efforts are focused on analyzing the problem known as the "Tragedy of the Commons" and policies to control over exploitation of fishing areas. The model presented in this paper builds over previous work in System Dynamics, and studies the impact of contaminants and the impacts of fishing activities on the diversity of species in Tamiahua wetlands.

Method

As mentioned early in the paper, the modeling effort is based upon the knowledge and experience of two experts, one on regional development, and the other on water and environment. Although obtaining quantitative data to build the model has proven to be difficult, knowledge from field work on the region has been used to get a better understanding of behavior over time and structural hypotheses.

Tamiahua Wetlands

The Tamiahua Lagoon is located in the northern part of the state of Veracruz, Mexico. It is a coastal lagoon and covers an extension of 217,500 acres, with 52.2 miles length, 15.5 km width, and a depth of 2.2-3.3 yards. It has two water mouths, one in the north and another in the south, and is located in between two large rivers, Panuco at the north and Tuxpam at the south (see Figure 1).

There are some valuable natural resources in the area which includes an important mangrove swamp towards the south of the lagoon and coral reef formations to the east, on the Gulf of Mexico coast.

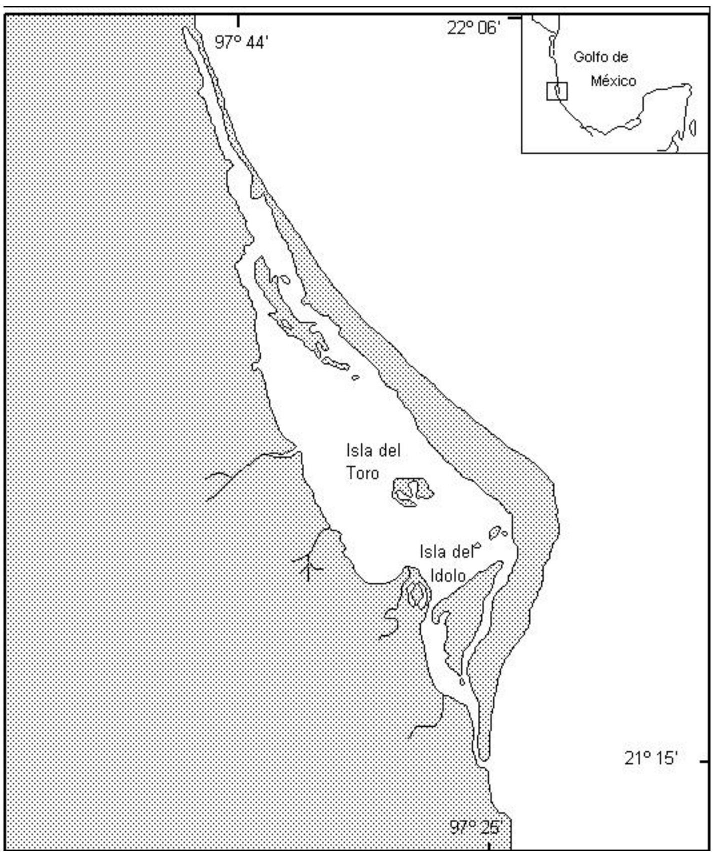

Figure 1. Tamiahua Wetlands Localization

The biodiversity of the place is rich and is inhabited by mollusk, crustacean, polychaeta, waterfowl, and a place for turtles laying eggs. Due to its ecology, botany, zoology, limnology, and hydrology richness, Tamiahua was designated as a protected wetland included in the Ramsar Treaty in November 27th, 2005. The Ramsar Convention provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources.

However, in the last ten years, a pollution problem has been affecting fishing activities in the lagoon. Industrial and residential pollutants are brought to the lagoon through 5 main rivers. The main types of pollutants are: hydrocarbon, agro-chemicals, fertilizers, metals and all sort of organic and solid waste (Albert *et al.*, 2006).

Socioecomic conditions

Surrounding Tamiahua Lagoon there are 5 municipalities with a total population of 205,000 inhabitants. The economic active population (EAP) amounts to 40 percent of total population. The main economic activity in this region is concentrated in the primary sector, mainly agriculture, as 75 per cent of the EAP is located in this sector. Only 2.5 percent is occupied in the manufacturing sector, and the rest of the EAP works in the service sector. The net rate of population growth in the region is estimated at 1.8 percent annually.

The fishing activity is carried out by approximately 4,000 people. They are grouped in 340 business units known as fishing cooperatives, with an average size of 12 people. Out of the 4,000 people, 40 percent or, or 2,400 are proprietors of the business units, and the other 1,600 fishermen work as employees. It is estimated a total fleet of 680 fishing boats that means an average of 2 boats per company.

According to recent data, yearly fish catchment is about 12,750 tons. This amounts to an average catchment per boat of 18.75 tons. a year, or 37.5 tons. per company. The estimated price per ton in the intermediary market is US$1,500.

The market price of a boat is US$10,500, and it has a usable life of 20 years. Operating cost for the each boat is estimated to run at US$10,000 per year, including wages.

Cooperatives in Mexico, as the fishing ones in Tamiahua, normally receive financial support by the Federal Government. In particular, the Ministry for Agricultural and Fishing Resources decides on fishing permits and funding for cooperatives after a feasibility economic study.

Model Description

The model Tamiahua1 consists of four main sectors. The first two sectors are similar to the ones used on the fishbanks model, and include the fish population and the fleet size. The third sector includes population dynamics in the region, and the last sector considers the contamination level in the water of the wetlands.

Figure 1 shows the basic structure of fish population and fishing. The red parts in the model are those that are unique to the model presented in this paper. The stock of diversity of the species was important to include given the key role that this diversity plays on the cleaning function of wetlands and its impact on the growth of fish population. As shown in the figure, fishing practices in Tamiahua have been recognized to have an impact on the diversity of the species. Moreover, water contaminants and the diversity of the species have also an impact on the population of fish in the lagoon.

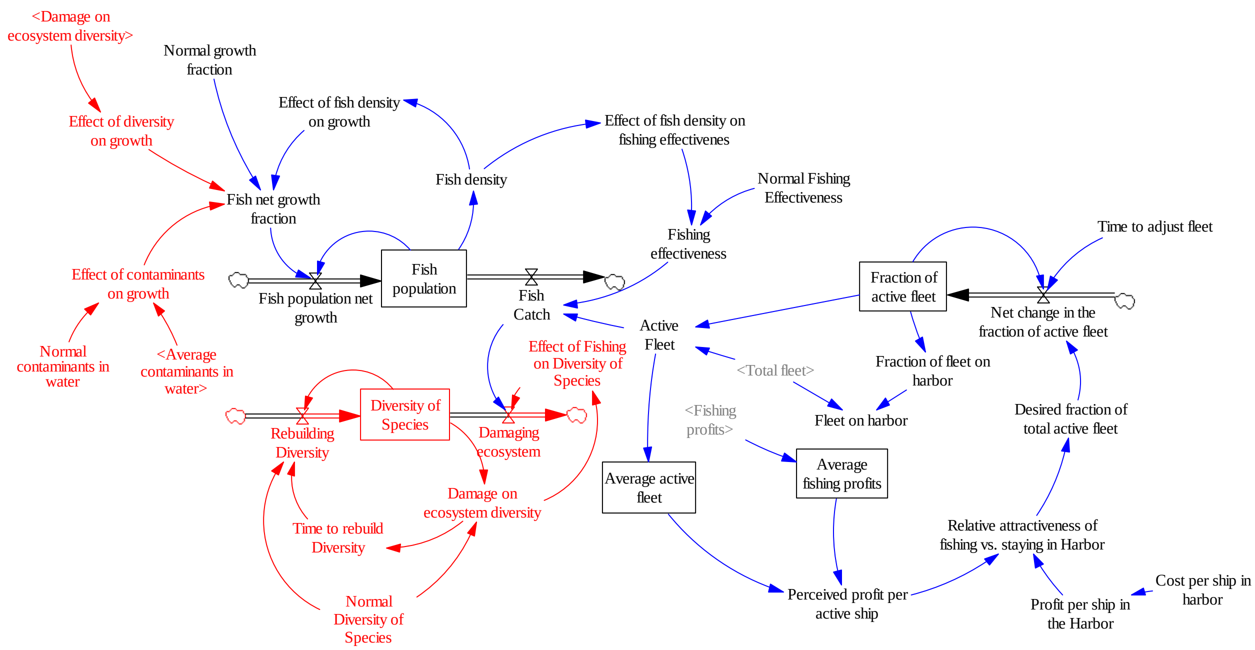

Figure 2. Fish Population and Fishing Activities.

Figures 3 and 4 represent the growth of the fishing fleet. Figure 3 includes the representation of the attractiveness of the fishing industry compared to other activities in the Tamiahua region. Profit is the result of income and costs associated to fishing, and the profitability of other economic activities was estimated using the minimum wage in Mexico. As shown in Figure 4, funding to increase fleet size does not come in this region from profits in the fishing industry, but from subsidies provided by the State government. As described by one of the experts involved in the modeling process, fishing cooperatives need to increase the fleet or replace existing boats creates a pressure on State government to provide more public funds to buy new boats.

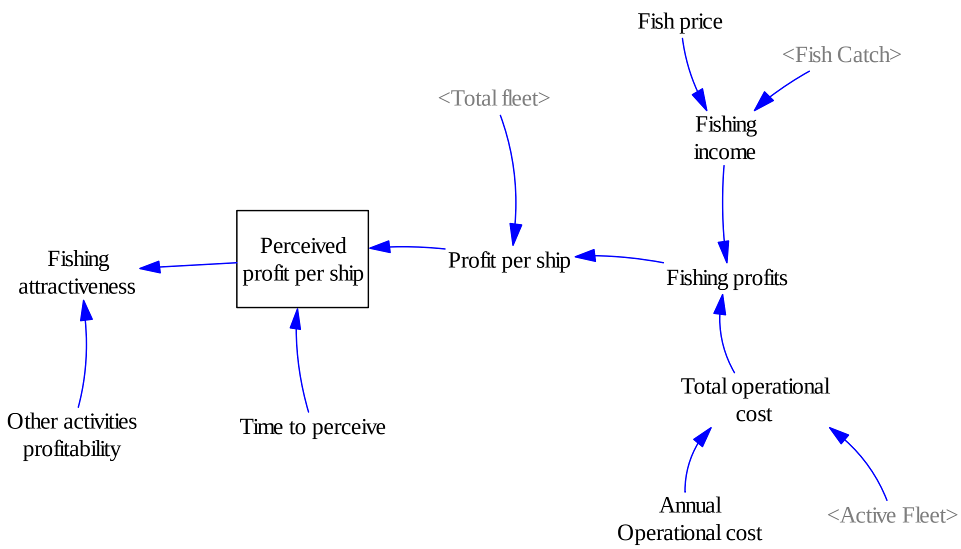

Figure 3. Fishing attractiveness.

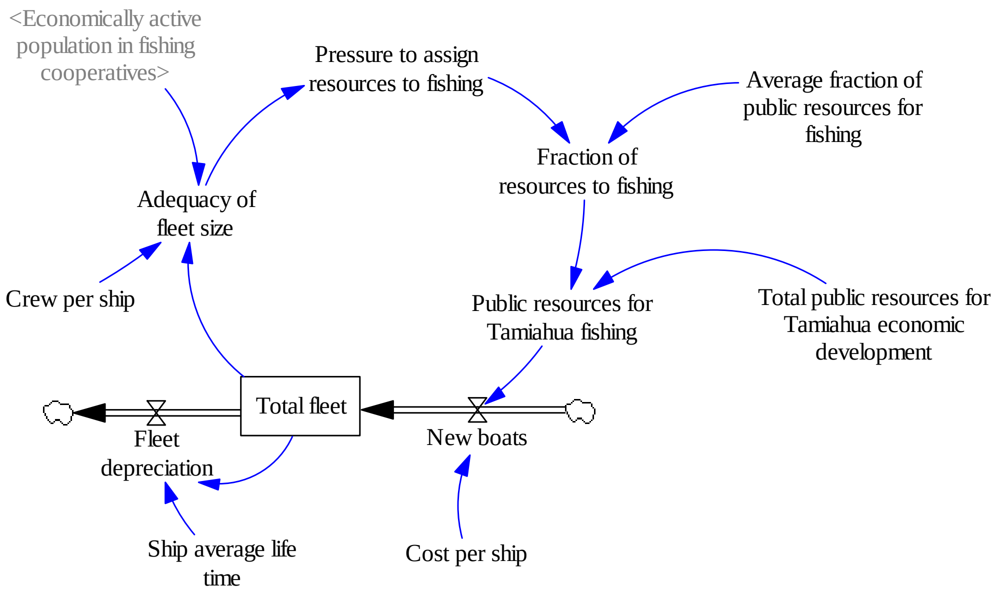

Figure 4. Fleet growth.

Figure 5 shows the way in which the attractiveness of the fishing industry attracts Tamiahua region inhabitants to join (or leave) fishing cooperatives.

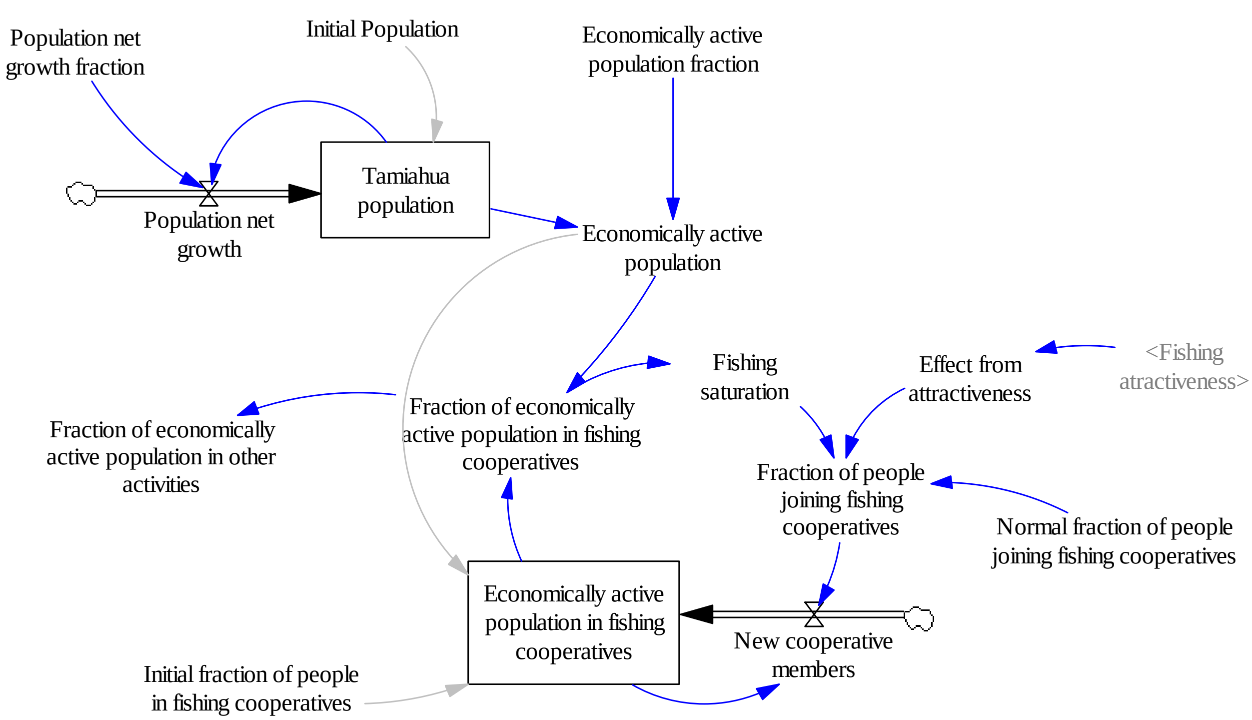

Figure 5. Tamiahua Population in Fishing activities

Finally, Figure 6 presents a theory of how contaminants come into the lagoon, and how the lagoon absorbs a fraction of these contaminants before the water reaches the sea. As shown in the figure, contaminants come from industry up in the rivers and from sewers and human activity. Damage in the diversity of the species, as well as high levels of contaminants have an impact on the absorption capacity of the Tamiahua Lagoon.

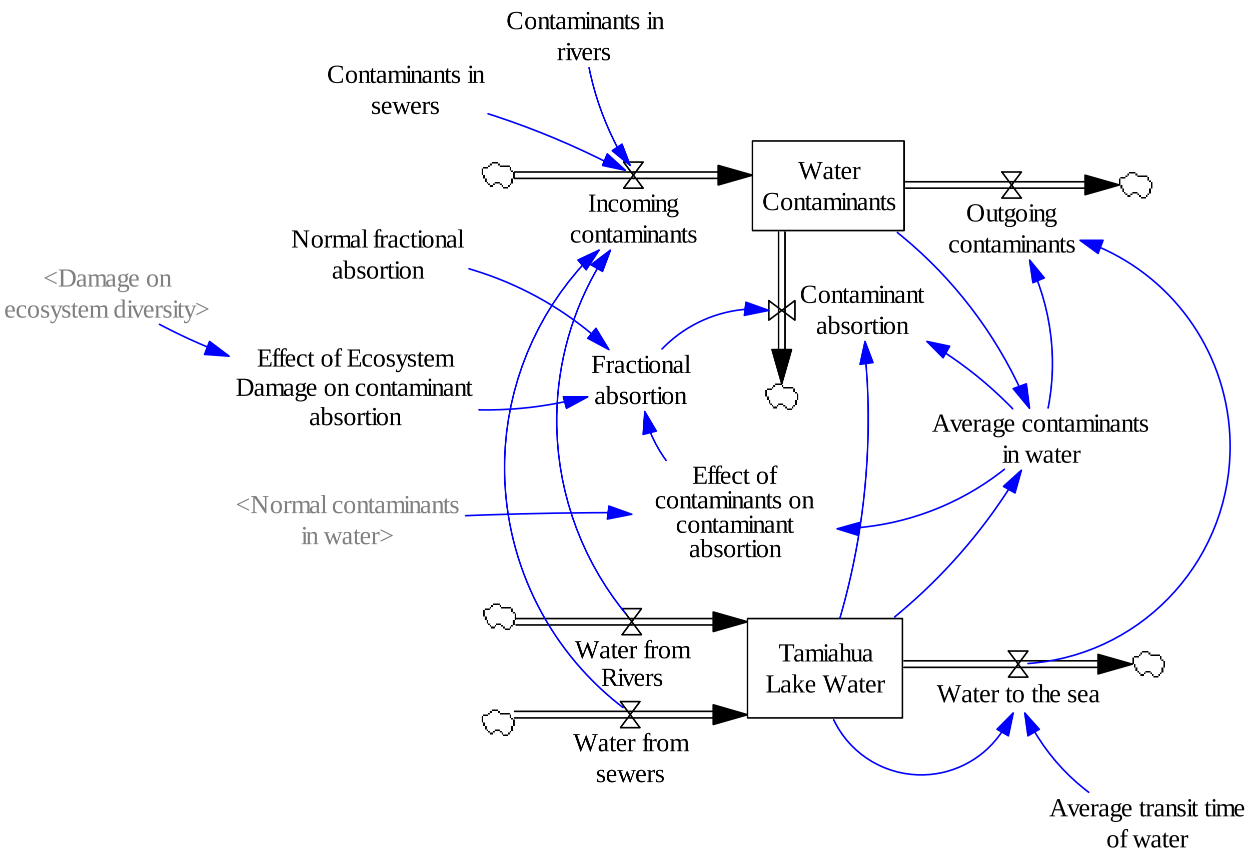

Figure 6. Contaminants in Water

Preliminary Experiments

Figures 7, 8 and 9 show some of the behaviors of the model in a base scenario. Figure 7 shows the way in which fishing activity slowly erodes the diversity of the species, eventually impacting the ability of the fish population to reproduce in a healthy way. Figure 8 shows the dynamic behavior of the fleet size, the active fleet and the fleet in harbor. As shown in the figure, the impact on the fish population promoted by contamination and the decrease on the diversity of the species is not yet enough in this model to have an impact on the fishing activities. Given that the actual fleet size is similar to the simulated fleet size, this base scenario suggests that the observed decrease on fishing activity in Tamiahua responds to the contamination of the wetlands or to the impact of the fishing techniques on the diversity of the species.

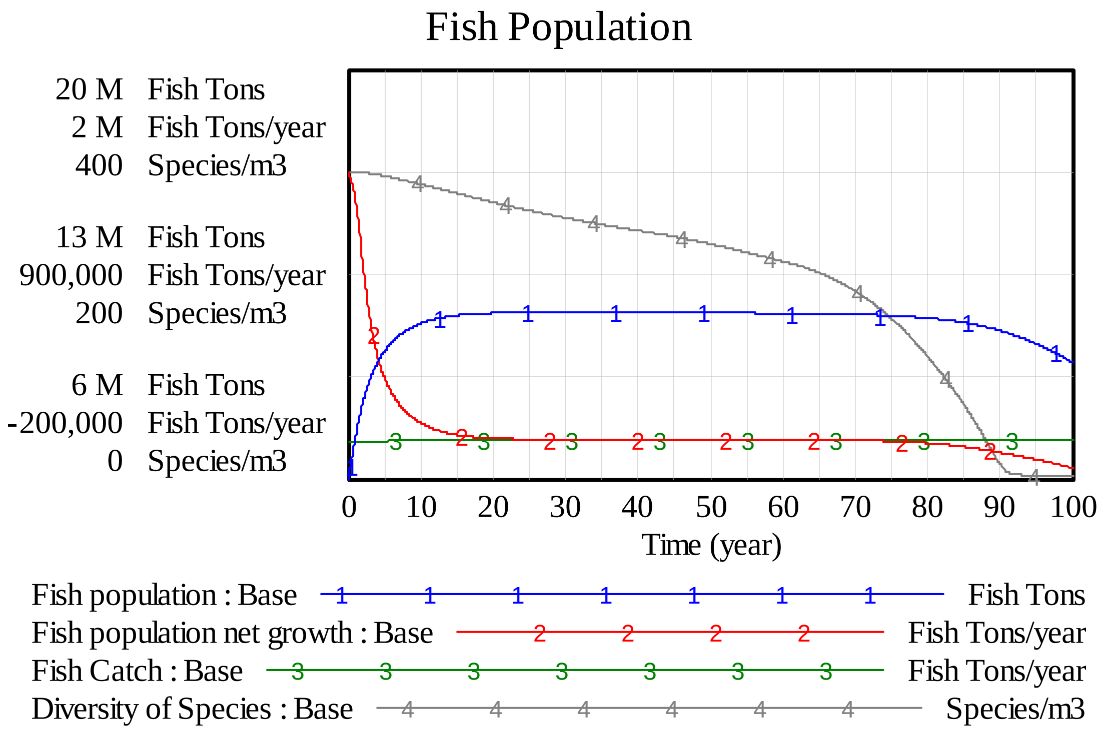

Figure 7. Fish population.

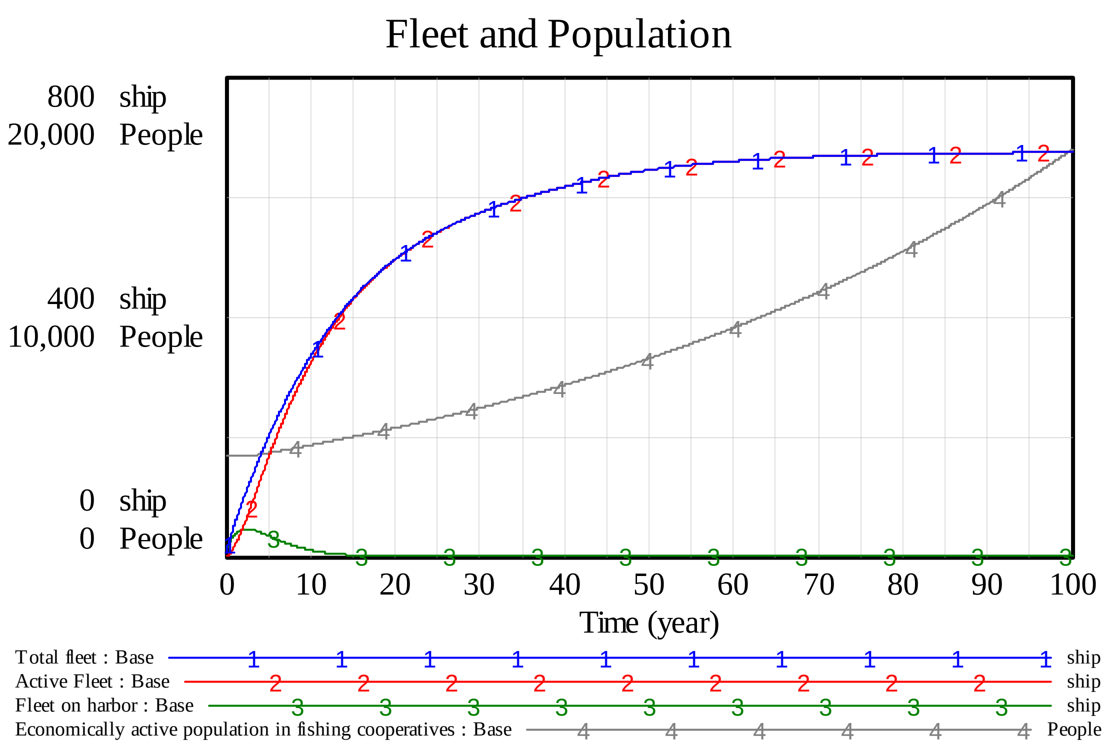

Figure 8. Fleet size and population.

Figure 9 shows some key behaviors of the ecosystem. During the last years of the simulation, it is possible to observe an important damage in the diversity of the species, which leads to an increase in contaminants in the lake, explained mainly by the reduction in the capacity of the lagoon to absorb contaminants.

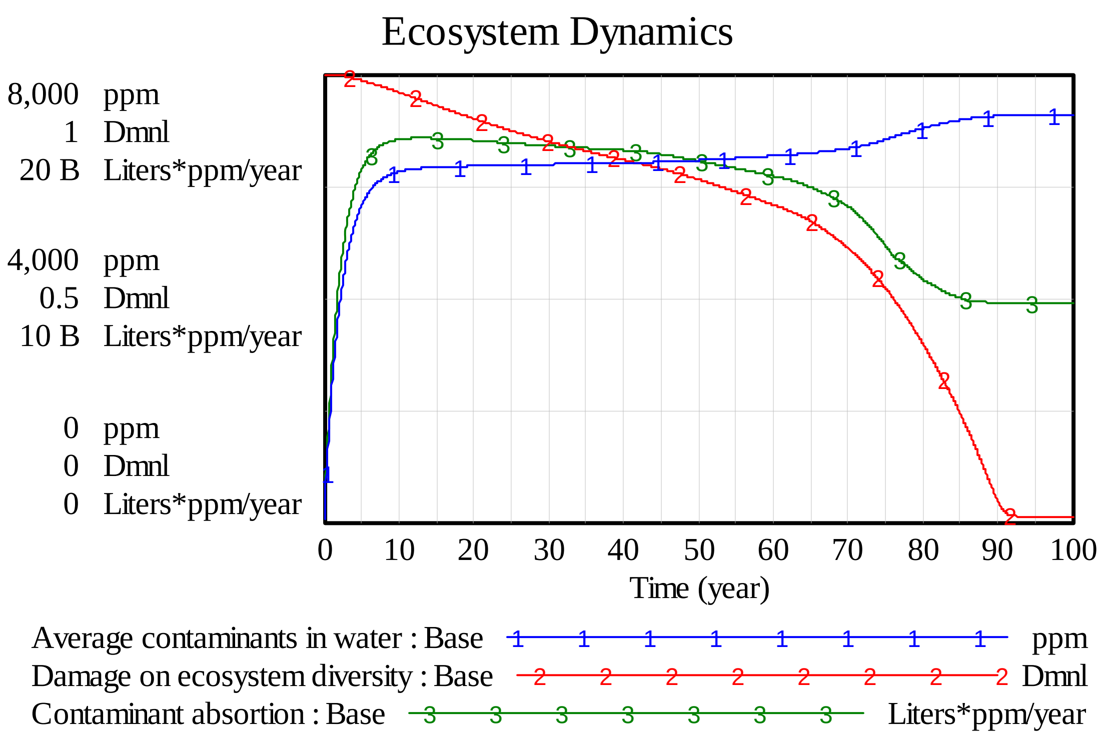

Figure 9. Contaminants and Ecosystem Diversity.

The initial explorations with the model involved 5 parameter changes producing 4 basic scenarios. In the first scenario, we increased the damage on the ecosystem produced by the fishing activity. The second scenario consists of an increase in incoming contaminants to the lagoon. The third scenario involves changes in the attractiveness of alternative economic activities, making fishing more or less attractive. The last scenario explores the impacts of increased resources from government to the fishing industry.

As shown in Figures 10 to 13, attractiveness of alternative economic activities have a very limited impact on model behavior. The main reason is that the main source of economic resources to increase the fleet size is government funds. An increase in government funds, on the other hand, does have an impact on the sustainability of the ecosystem because it allows for an increase on fleet size, accelerating damage on the ecosystem, and collapsing the fishing industry. Increasing contaminants from rivers and changes in fishing practices for ones with higher impacts on the environment have an important impact on fish population. Increased contaminants have a more continuous impact, and increased impact from fishing practices promotes a faster decline in fish population.

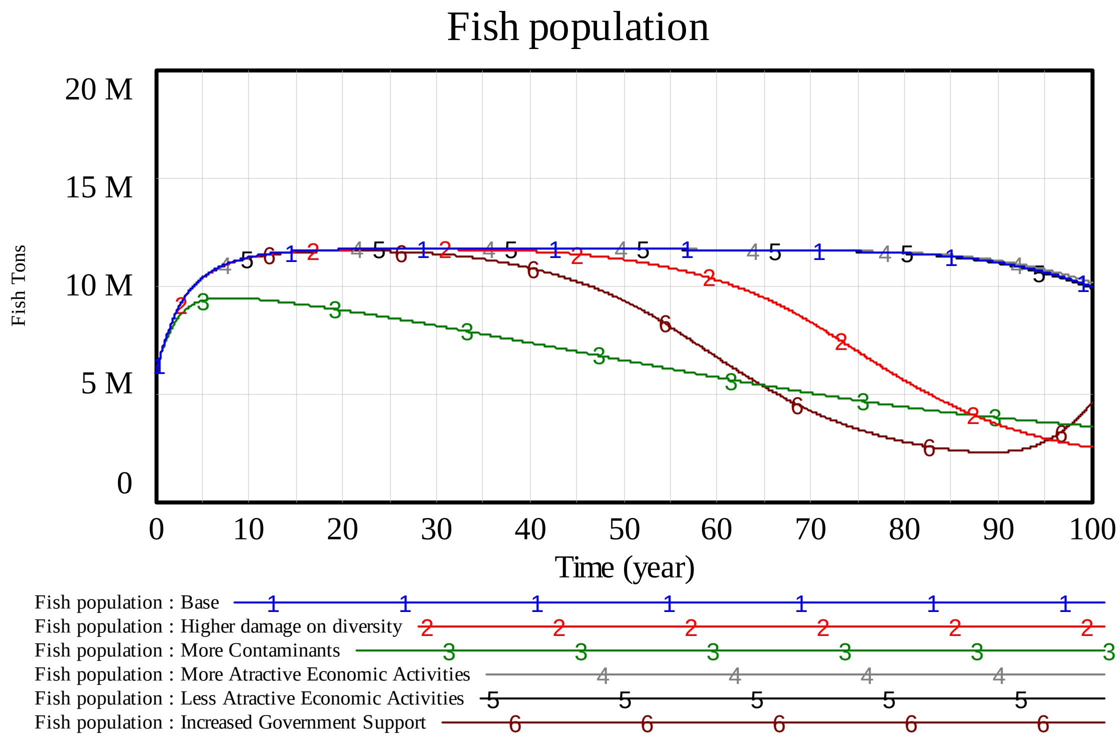

Figure 10. Comparative graph for Fish Population.

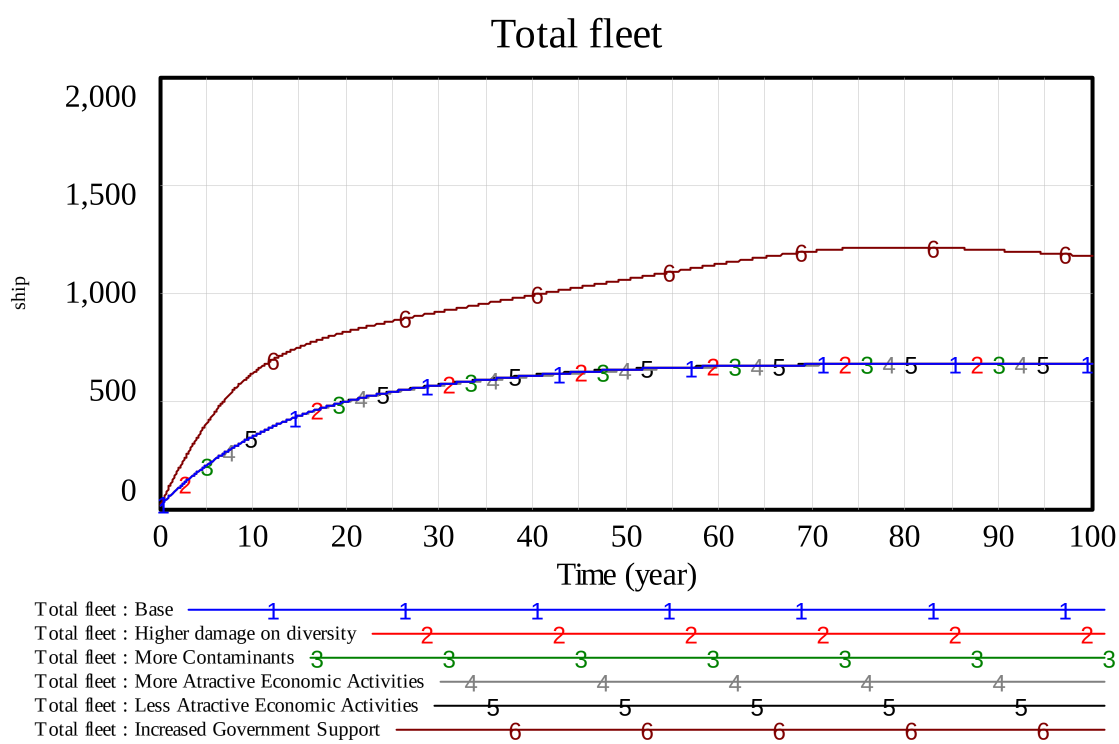

Figure 11. Comparative graph for total fleet.

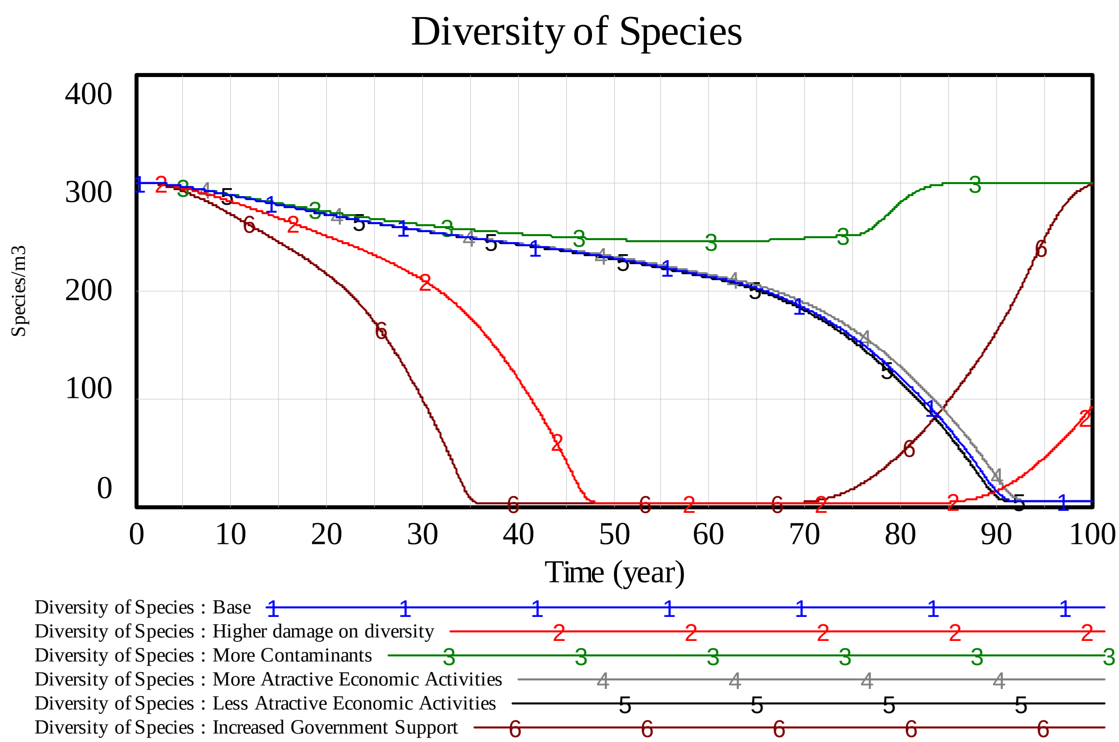

Figure 12. Comparative graph for diversity of species.

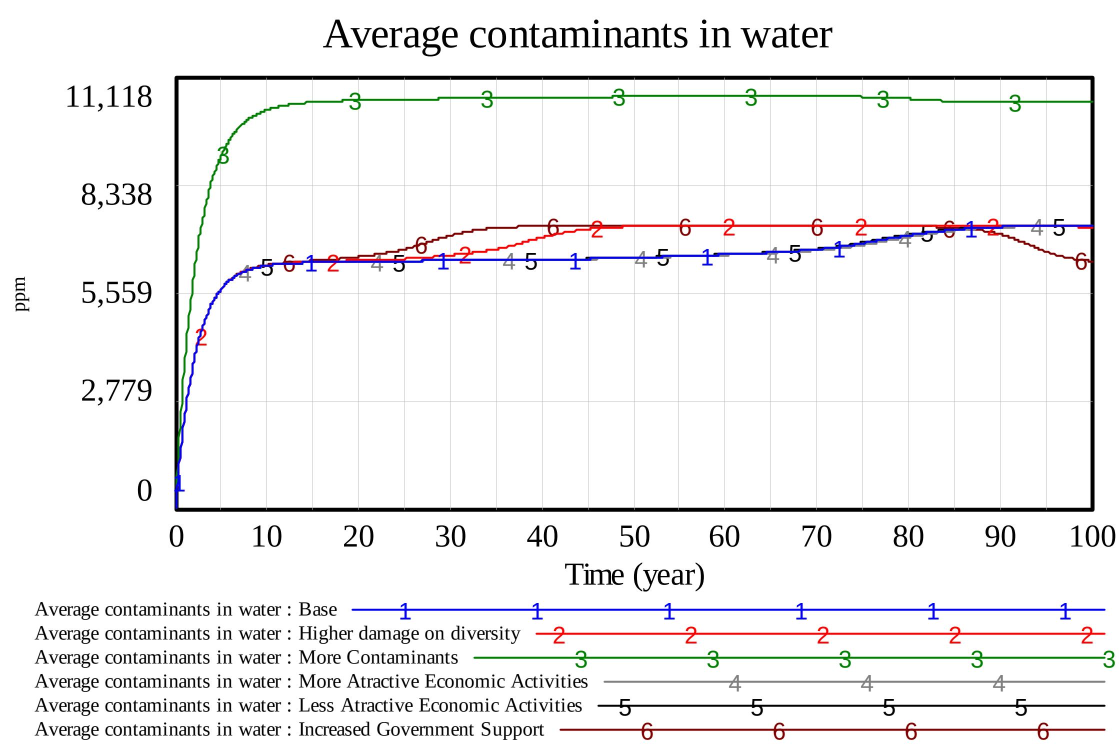

Figure 13. Comparative graph for contaminants in water.

Final Remarks

In this short paper, we presented a preliminary model to study the sustainability of the Tamiahua lagoon considering the fishing activity and the impacts of this activity on the diversity of species in the lagoon. Additionally, the model includes the impacts of contamination of the wetlands. Preliminary experiments suggest that fishing practices and contamination have the potential to create an important imbalance in the system, apparently in a more important way that the current fishing quantity.

Fishing activity is limited in an important way for the availability of government funds. In this way, government decisions on funding to the fishing activity have an impact on the stability of the system.

Although the model presented in this paper has a reasonable structure, it needs still to be refined in terms of parameter values. We will continue our experiments with the model to create a series of policy recommendations to the State Government of Veracruz in Mexico.

References

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Appendix. Model Equations.

(001) Active Fleet=
Total fleet*Fraction of active fleet
Units: ship

(002) Adequacy of fleet size=
(Economically active population in fishing cooperatives/Crew per ship)/Total fleet
Units: Dmnl

(003) Annual Operational cost=
245000
Units: pesos/ship/year

(004) Average active fleet=
SMOOTH(Active Fleet, Time to register average)
Units: ship

(005) Average contaminants in water=
Water Contaminants/Tamiahua Lake Water
Units: ppm

(006) Average fishing profits=
SMOOTH(Fishing profits, Time to register average)
Units: dollars/year

(007) Average fraction of public resources for fishing=
0.1
Units: Dmnl

(008) Average transit time of water=
3
Units: year

(009) Contaminant absortion=
Average contaminants in water*Tamiahua Lake Water*Fractional absortion
Units: Liters*ppm/year

(010) Contaminants in rivers=
5000
Units: ppm

(011) Contaminants in sewers=
12000
Units: ppm

(012) Cost per ship=
250000
Units: pesos/ship

(013) Cost per ship in harbor=
50
Units: dollars/(year*ship)

(014) Crew per ship=
6
Units: People/ship

(015) Damage constant=
0.0015
Units: Dmnl [0,1,0.001]

(016) Damage on ecosystem diversity=
Diversity of Species/Normal Diversity of Species
Units: Dmnl

(017) Damaging ecosystem=
Fish Catch*Effect of Fishing on Diversity of Species
Units: Species/(year*m3)

(018) Desired fraction of total active fleet=
DFTFC f("Relative attractiveness of fishing vs. staying in Harbor")
Units: Dmnl

(019) DFTFC f(
[(-2,0)-(2,1)],(-2,1),(-1.6,0.98),(-1.2,0.9),(-0.8,0.8),(-0.4,0.66),(0,0.5
),(0.4,0.34),(0.8,0.2),(1.2,0.1),(1.6,0.02),(2,0))
Units: Dmnl

(020) Diversity of Species= INTEG (
Rebuilding Diversity-Damaging ecosystem,
Normal Diversity of Species)
Units: Species/m3

(021) ECCA f(
[(0,0.5)-(2,1.5)],(0,1.2),(0.2,1.19737),(0.4,1.18421),(0.6,1.15789),(0.8,
1.09649),(1,1),(1.2,0.864035),(1.4,0.710526),(1.6,0.600877),(1.8,0.530702)
,(2,0.5))
Units: Dmnl

(022) ECFNG f(
[(0,-1)-(2,1)],(0,1),(0.2,0.903509),(0.4,0.719298),(0.6,0.5),(0.8,0.27193
),(1,0),(1.2,-0.192982),(1.4,-0.307018),(1.6,-0.385965),(1.8,-0.45614),(2,
-0.5))
Units: Dmnl

(023) Economically active population=
Economically active population fraction*Tamiahua population
Units: Personas

(024) Economically active population fraction=
0.3
Units: Dmnl

(025) Economically active population in fishing cooperatives= INTEG (
New cooperative members,
Initial fraction of people in fishing cooperatives*Economically active population
)
Units: People

(026) EDCFG f(
[(0,-4)-(2,2)],(0,0.8),(0.2,1.07895),(0.4,1.26316),(0.6,1.21053),(0.8,0.921053
),(1,0.394737),(1.19878,-0.0526316),(1.38226,-0.473684),(1.57187,-1.02632)
,(1.78593,-1.5),(2,-2.13158))
Units: Dmnl

(027) EDG f(
[(0,-1)-(1,1)],(0,-0.5),(0.1,-0.464912),(0.2,-0.403509),(0.3,-0.289474),(
0.4,-0.149123),(0.5,0),(0.6,0.22807),(0.7,0.491228),(0.8,0.754386),(0.9,0.903509
),(1,1))
Units: Dmnl

(028) EEDCA f(
[(0,0)-(1,1)],(0,0.5),(0.1,0.504386),(0.2,0.508772),(0.3,0.530702),(0.4,0.570175
),(0.5,0.635965),(0.6,0.763158),(0.7,0.855263),(0.8,0.938596),(0.9,0.973684

),(1,1))
Units: Dmnl

(029) EFA f(
[(0,-1)-(2,1.2)],(0,-0.5),(0.2,-0.150877),(0.4,0.157895),(0.6,0.466667),(
0.8,0.727193),(1,1),(1.2,1.13246),(1.4,1.1807),(1.6,1.1807),(1.8,1.1807),(
2,1.2))
Units: Dmnl

(030) EFDS f(
[(0,0)-(1,1.2)],(0,0),(0.025,0.6),(0.05,0.8),(0.075,0.95),(0.1,0.99),(0.2
,1),(0.3,1),(0.4,1),(0.5,1),(0.6,1),(0.7,1),(0.8,1),(0.9,1),(1,1))
Units: Dmnl

(031) Effect from attractiveness=
EFA f(Fishing attractiveness)
Units: Dmnl

(032) Effect of contaminants on contaminant absortion=
ECCA f(Average contaminants in water/Normal contaminants in water)
Units: Dmnl

(033) Effect of contaminants on growth=
ECFNG f(Average contaminants in water/Normal contaminants in water)
Units: Dmnl

(034) Effect of diversity on growth=
EDG f(Damage on ecosystem diversity)
Units: Dmnl

(035) Effect of Ecosystem Damage on contaminant absortion=
EEDCA f(Damage on ecosystem diversity)
Units: Dmnl

(036) Effect of fish density on fishing effectivenes=
SEDC f(Fish density)
Units: Dmnl

(037) Effect of fish density on growth=
EDCFG f(Fish density)
Units: Dmnl

(038) Effect of Fishing on Diversity of Species=
Damage constant*EFDS f(Damage on ecosystem diversity)
Units: Species/Fish Tons

(039) FINAL TIME = 100
Units: year
The final time for the simulation.

(040) Fish Catch=
Active Fleet*Fishing effectiveness
Units: Fish Tons/year

(041) Fish density=

Fish population/Tamiahua lake carrying capacity
Units: Dmnl

(042) Fish net growth fraction=
Effect of fish density on growth*Effect of contaminants on growth*Effect of diversity on growth *Normal growth fraction
Units: 1/year

(043) Fish population= INTEG (
Fish population net growth-Fish Catch,
6e+006)
Units: Fish Tons

(044) Fish population net growth=
Fish population*Fish net growth fraction
Units: Fish Tons/year

(045) Fish price=
15000
Units: pesos/Fish Tons

(046) Fishing attractiveness=
Perceived profit per ship/Other activities profitability
Units: Dmnl

(047) Fishing effectiveness=
Normal Fishing Effectiveness*Effect of fish density on fishing effectivenes
Units: Fish/ship/year

(048) Fishing income=
Fish Catch*Fish price
Units: pesos/year

(049) Fishing profits=
Fishing income-Total operational cost
Units: pesos/year

(050) Fishing saturation=
FS f(Fraction of economically active population in fishing cooperatives)
Units: Dmnl

(051) Fleet depreciation=
Total fleet/Ship average life time
Units: ship/year

(052) Fleet on harbor=
Total fleet*Fraction of fleet on harbor
Units: ship

(053) Fraction of active fleet= INTEG (
Net change in the fraction of active fleet,
0.05)
Units: Dmnl

(054) Fraction of economically active population in fishing cooperatives=

Economically active population in fishing cooperatives/Economically active population
Units: Dmnl

(055) Fraction of economically active population in other activities=
1-Fraction of economically active population in fishing cooperatives
Units: Dmnl

(056) Fraction of fleet on harbor=
1-Fraction of active fleet
Units: Dmnl

(057) Fraction of people joining fishing cooperatives=
Effect from attractiveness*Fishing saturation*Normal fraction of people joining fishing cooperatives
Units: 1/year

(058) Fraction of resources to fishing=
Average fraction of public resources for fishing*Pressure to assign resources to fishing
Units: Dmnl

(059) Fractional absortion=
Effect of contaminants on contaminant absortion*Effect of Ecosystem Damage on contaminant absortion
*Normal fractional absortion
Units: 1/year

(060) FS f(
[(0,0)-(1,1.3)],(0,1.2),(0.1,1.2),(0.2,1.2),(0.3,1.19167),(0.4,1.15746),(
0.5,1.11184),(0.6,1.04912),(0.7,0.992105),(0.8,0.87807),(0.9,0.615789),(1,
0))
Units: Dmnl

(061) Incoming contaminants=
Contaminants in rivers*Water from Rivers+Contaminants in sewers*Water from sewers
Units: Liters*ppm/year

(062) Initial fraction of people in fishing cooperatives=
0.07
Units: Dmnl

(063) Initial Population=
200000
Units: People

(064) INITIAL TIME = 0
Units: year
The initial time for the simulation.

(065) Net change in the fraction of active fleet=
(Desired fraction of total active fleet-Fraction of active fleet)/Time to adjust fleet
Units: 1/year

(066) New boats=
Public resources for Tamiahua fishing/Cost per ship
Units: ship/year

(067) New cooperative members=
Fraction of people joining fishing cooperatives*Economically active population in fishing cooperatives
Units: People/year

(068) Normal contaminants in water=
10000
Units: ppm

(069) Normal Diversity of Species=
300
Units: Species/m3

(070) Normal Fishing Effectiveness=
20
Units: Fish Tons/(year*ship)

(071) Normal fraction of people joining fishing cooperatives=
0.01
Units: 1/year

(072) Normal fractional absortion=
0.1
Units: 1/year

(073) Normal growth fraction=
0.2
Units: 1/year

(074) Other activities profitability=
20000
Units: pesos/year

(075) Outgoing contaminants=
Water to the sea*Average contaminants in water
Units: Liters*ppm/year

(076) PARF f(
[(0,0)-(2,2)],(0,0),(0.2,0.105263),(0.4,0.298246),(0.6,0.517544),(0.8,0.77193
),(1,1),(1.2,1.2193),(1.4,1.37719),(1.6,1.4386),(1.8,1.45614),(2,1.5))
Units: Dmnl

(077) Perceived profit per active ship=
Average fishing profits/Average active fleet
Units: dollars/(year*ship)

(078) Perceived profit per ship=
SMOOTH(Profit per ship, Time to perceive)
Units: pesos/(year*ship)

(079) Population net growth=
Population net growth fraction*Tamiahua population
Units: Personas/year

(080) Population net growth fraction=
0.015
Units: 1/year

(081) Pressure to assign resources to fishing=
PARF f(Adequacy of fleet size)
Units: Dmnl

(082) Profit per ship=
Fishing profits/Total fleet
Units: pesos/year/ship

(083) Profit per ship in the Harbor=
0-Cost per ship in harbor
Units: dollars/(year*ship)

(084) Public resources for Tamiahua fishing=
Fraction of resources to fishing*Total public resources for Tamiahua economic development
Units: dollars/year

(085) Rebuilding Diversity=
(Normal Diversity of Species-Diversity of Species)/Time to rebuild Diversity
Units: Species/m3/year

(086) "Relative attractiveness of fishing vs. staying in Harbor"=
Perceived profit per active ship/Profit per ship in the Harbor
Units: Dmnl

(087) SAVEPER =
TIME STEP
Units: year
The frequency with which output is stored.

(088) SEDC f(
[(0,0)-(2,1.5)],(0,0),(0.149847,0.447368),(0.388379,0.754386),(0.599388,0.912281
),(0.798165,0.960526),(1,1),(1.19878,1.03947),(1.41896,1.08553),(1.59633,1.16447
),(1.8,1.2),(2,1.2))
Units: Dmnl

(089) Ship average life time=
15
Units: year

(090) Tamiahua lake carrying capacity=
1e+007
Units: Fish Tons

(091) Tamiahua Lake Water= INTEG (
Water from Rivers+Water from sewers-Water to the sea,
2.4e+007)
Units: Liters

(092) Tamiahua population= INTEG (
Population net growth,
Initial Population)

Units: People

(093) TIME STEP = 0.0625
Units: year
The time step for the simulation.

(094) Time to adjust fleet=
3
Units: year

(095) Time to perceive=
2
Units: year

(096) Time to rebuild Diversity = WITH LOOKUP (
Damage on ecosystem diversity,
([(0,0)-(1,50)],(0,50),(0.1,34.6491),(0.2,25.4386),(0.3,18.6404),(0.4,14.693
),(0.5,10.7456),(0.6,7.45614),(0.7,4.82456),(0.8,3.28947),(0.9,2.19298),(1
,1)))
Units: year

(097) Time to register average=
1
Units: year

(098) Total fleet= INTEG (
New boats-Fleet depreciation,
10)
Units: ship

(099) Total operational cost=
Annual Operational cost*Active Fleet
Units: pesos/year

(100) Total public resources for Tamiahua economic development=
7.5e+007
Units: dollars/year

(101) Water Contaminants= INTEG (
Incoming contaminants-Contaminant absortion-Outgoing contaminants,
1e+009)
Units: Liters*ppm

(102) Water from Rivers=
4e+006
Units: Liters/year

(103) Water from sewers=
4e+006
Units: Liters/year

(104) Water to the sea=
Tamiahua Lake Water/Average transit time of water
Units: Liters/year