Building the Fish Banks Model

and

Renewable Resource Depletion

Prepared for
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***Note: This paper is a combination of Building the Fish Banks Model (D-4543) and Renewable Resource Depletion (D-4263-3). The previous version was D-4448.

This paper is meant to accompany the **Fish Banks Exercises** model on the disk provided with Road Maps.

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Building the Fish Banks Model

Renewable Resource Depletion

This paper comes with a disk labeled “Fish Banks Exercises”. If you do not have this disk, it can be obtained free of charge from The Creative Learning Exchange.

The exercises in this paper require a Macintosh[1] Computer with 2 Mb of RAM if running System 6.0.4 and at least 4 Mb of RAM if running System 7 or higher. Also required is the STELLA[2] II software package. If you do not have STELLA, contact High Performance Systems.

***Note: The instructions given in this paper are directed toward readers using STELLA II version 3.0.1 or higher. If you have some familiarity with STELLA, you will be able to complete the modeling using an older version of the software.

The Fishing Game disk that comes with this paper contains three models. “The Fishing Game v1.02” is for STELLA II v1.02, “The Fishing Game v2.2.1” is for STELLA II v2.2.1, and “The Fishing Game v3.0.1” is for STELLA II v3.0.1 and higher. Appendices 2 and 3 explain the differences between the three versions of the game and gives some instructions specific to STELLA II v1.02 and v2.2.1. Do not open the older version of the game (v1.02 or v2.2.1) with the newer version of the software (v3.0.1) as the model will be altered.

[1]Macintosh is a registered trademark of Apple Computer, Inc.
[2]STELLA is a registered trademark of High Performance Systems, Inc..

1 INTRODUCTION

Fish Banks, Ltd.[3] is a role-playing game developed by Dennis L. Meadows at the University of New Hampshire. Dr. Meadows developed the game to inform people about using natural resources effectively and prudently. Although the game originally targeted corporate managers and public officials, anyone can benefit from the insights gained by playing the game.

In the Fish Banks, Ltd. game, teams of players manage their own fishing companies. At the beginning of the game, each fishing company has equal amounts of money and fishing ships. Each company has the same operating costs and technology. At the beginning of every simulated year, the teams make decisions about buying or selling ships, whether to fish or not, and where to fish. The object of the game for each company is to maximize profits.

In this paper, you will play The Fishing Game, a one-player game similar to Fish Banks, Ltd. by Dennis Meadows. The Fishing Game uses a system dynamics computer model. Your computer is your opponent. After playing The Fishing Game, you will build a model of a fishing system similar to that used for the game. The fishing system model can be segmented into three subsystems. You will build the three subsystems separately and observe the behavior of each subsystem. Then, you will combine the three models to form the final fishing system model.[4]

After building the final model, you will proceed to use this model to perform some policy analysis exercises to evaluate various strategies for avoiding the abuse of renewable resources.

The Fish Banks, Ltd. material, including the game board, pieces, and directions, can be purchased from:

Dennis L. Meadows, Director
Institute for Policy and Social Science Research
Hood House
Durham, NH 03824-3577

[3]Dennis L. Meadows, Institute for Policy and Social Science Research, Hood House, University of New Hampshire, Durham, NH 03824.
[4]Note: Although The Fishing Game can only be played on STELLA v2.2.1, the model can be built on any version of STELLA.

2 PLAYING THE FISHING GAME

The numerical values used in The Fishing Game as well as in the model you will build are not realistic. The values were chosen to maintain consistency with the original Fish Banks, Ltd. game developed by Dennis Meadows as well as with *Renewable Resource Depletion* (D-4263) which is the second half of this document. Nevertheless, the numbers used are altogether consistent and do not affect the qualitative behavior of the model. It may be helpful to consider the numbers as representing their values in thousands.

2.1 Role Description

You will be fishing in an area that has an optimal fish population of 1200. A natural restriction occurs once the fish population reaches 1200, so that overcrowding doesn't occur. The restriction is a reduced reproduction rate so that the population remains at 1200 while the natural habitat of the fish stays unchanged.

The presence of a fishing industry in the area disturbs the natural habitat of the fish. When the fishing industry takes only small amounts of fish from the population, the fish are able to quickly regenerate and regain their optimal population of 1200 fish. If the small depletions by the fishing industry continue steadily over time, the fish will never reach 1200, but will establish a new optimal population at less than 1200. However, if the fish population drops dramatically, the number of fish laying eggs is so small that the population takes a very long time to recover even when undisturbed by the fishing industry during the regeneration period.

The fish population is able to regenerate as shown in Figure 1 below.

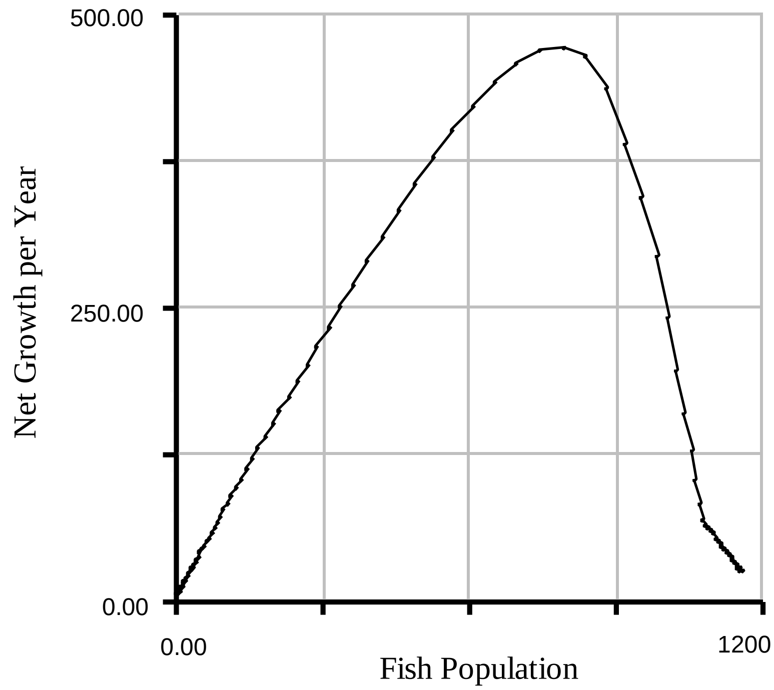

Figure 1: Net Growth per Year of Fish Population vs. Fish Population

This graph shows the net growth rate of the fish population as it varies with the size of the population. The capacity of the fish population to regenerate increases with the size of the population. As the population approaches its optimal size, the net growth of the population decreases to zero.

Your fishing ships (as well as your competitor's) are equipped with the latest in fish tracking and catching technology. As a result, you will be able to catch nearly a full load of fish even if the fish density drops by 30 or 40 percent. This characteristic of your fish catch is a result of a simplification of the model. This model assumes that your ships go out to sea once per day, catch a full load of fish and return. In real life, fishing companies would most likely increase the number of runs per day if the fish density was very high. To model this we would also have to vary the operating cost per ship. This level of complexity is unnecessary to simulate this system accurately. Figure 2 shows how your ability to catch fish varies with the fish population density.

Your goal is to maximize profits and make more money than your competitor, the computer. The game lasts for 10 years, from 1980 to 1990. The fish population at the beginning of the game is 1000 fish. Both companies begin with zero net profit, and may go into debt to build ships. Each company begins with 2 ships each.

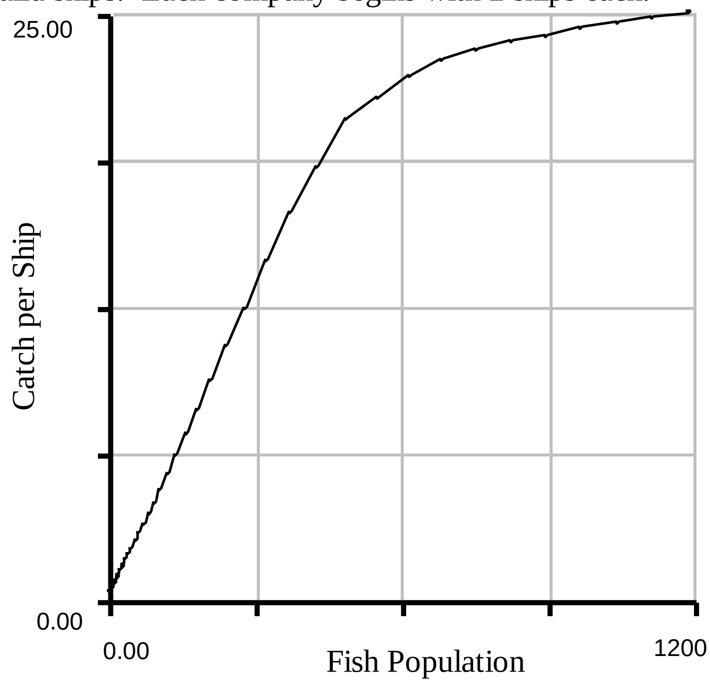

Figure 2: Catch per Ship vs. Fish Population

This graph shows the Catch per Ship as it varies with the size of the fish population. The ability of the fishing ships to catch fish does not decrease dramatically until the fish population density drops dangerously low.

2.2 Playing the Game

***Note: The Fish Banks Exercises disk that came with this paper contains three models. "The Fishing Game v1.02" is for STELLA II v1.02, "The Fishing Game v2.2.1" is for STELLA II v2.2.1 and v2.2.2, and "The Fishing Game v3.0.1" is for STELLA II v3.0.1.

Section 2.2 (this section) gives the instructions for playing the game on STELLA II v3.0.1. If you are using earlier versions of STELLA II, you should still read this section, but you should also refer to Appendices 2 and 3. Appendix 2 gives instructions specific to STELLA II v.2.2.1 and v2.2.2, and Appendix 3 gives instructions specific to STELLA II v1.02. Do not open the older version of the game (v1.02, v2.2.1 or v2.2.2) with the newer version of the software (v3.0.1) as the model will be altered. All specific instructions are given in bold.

At the beginning of each simulated year you will choose for your company how many ships either to build or to sell. You will then run the model for one year and observe the effects of your fishing on the fish population and on both players' profits. Each time you run the game, the model runs for one year and then pauses. You make your decisions for that year, and run the model for another year.

? **Make sure that STELLA II v3.0.1 is installed on your hard disk.**

? **Insert the disk labeled "Fish Banks Exercises" into your disk drive.**

? **Double-click on the disk icon labeled "The Fishing Game."**

? **In the window that appears, double-click on the icon labeled "The Fishing Game v3.0.1."**

If you have the STELLA II v3.0.1 program installed on your hard drive, the model you selected will open on your screen. If the model does not open, you need to open the STELLA program first and then open the model from within the program.

Once the model is open, you will see three sectors, each labeled “The Fish,” “You,” and “Competitor.” If the model is open and you do not see the top level of the sectors, use the arrow at the top right corner of the STELLA window to scroll up until you see it.

Figure 3: Top Level of the Three Sectors

The three sectors are the main players in the game, and the arrows with brief explanations show the relationships among them. Referring to Section 2.1 as needed, try to understand how each sector affects and is affected by the other two.

? **Looking at the three sectors, devise a plan which would maximize your profits.**

? **Using the downward arrow at the bottom right corner of the window, scroll down until you see a graph pad.**

This graph pad is where you view the progress and the final outcome of your game. It contains four graphs, one on each page, and the page number is on the bottom edge of the window. You can click on the lower left corner of the graph pad to view the different pages, one at a time. These four graphs will allow you to track your own progress as well as that of your competitor. Figure 4 contains a list of the available graphs and their contents. At the end of every simulated year, STELLA updates these graphs with current information. Please note that in graphs 3 and 4, the scales for the two elements are different.

Page:	Graph:	Contents:
1	Annual Profits	*Competitor Profit Each Year* *Your Profit Each Year*
2	Total Profits	*Competitor Total Profits* *Your Total Profits*
3	Your Catch	*Catch per Ship* *Your Total Catch*
4	Your Ships	*Your Ships* *Your Building Rate*

Figure 4: The Graphs contained in the Graph Pad

These are the graphs that are available to you as you play The Fishing Game. With these graphs you can track your performance and re-evaluate your strategy.

? **Using the downward arrow at the lower right corner, scroll down until you see a table and a slide bar.**

The table displays the current values of the following six variables: *Your Ships, Your Total Profits, Your Profit Each Year, Catch per Ship, Your Total Assets, and Competitor's Total Asset*. To complement the graphical outputs on the graph pad, this table shows numerical values. The slide bar is an input device. It lets you select a value between -10 and +10 for *Your Building Rate*.

Implement your strategy for the game by setting a value for *Your Building Rate*. Before starting the next round of the game, specify how many ships you wish to build. If you wish to decrease the size of your fleet, you may sell ships by choosing a negative number. If you do not set a value at the beginning of a year, it will automatically reset to 0, and you will not build or sell any ships. You may track your previous decisions for *Your Building Rate* by looking at page 4 of the graph pad. Figure 4 contains a list of all available graphs and their contents.

? **Develop a strategy for maximizing your profits and beating your competitor.** (You may wish to re-read section 2.1 which briefs you on the game scenario.)

? **Click and hold on the button located between -10 and +10 on the slide bar.**

? **Slide the button until the desired number of ships you wish to build the first year shows to the right of *Your Building Rate* = .**

? **Select "Run" from the Run menu or press ? -R.** The model will run for 1 year.

? **Look at the four pages of the graph and the table below the graph pad to observe the behavior of the model.**

***Note: After the first year, the Run menu will no longer contain the option "Run." Instead, you should select "Resume."

? **Continue entering values for *Your Building Rate* and running the model until the end of the simulation in 1990.**

? **Play the game a few times, revising your strategy each time to increase your profits.**

The game will automatically reset at the end of each 10 year simulation. You do not need to reset anything.

- ? **When you finish playing the game, select "Close" from the file menu.**
- ? **Click on "Don't Save."**

After playing the game a few times you may notice that if you try to beat your competitor, by the end of the game, you have nearly destroyed the fish population and thus your yearly profit is very low. In the next part of this paper, you will go through the process of building a model similar to the one used for the game. You should gain some insight into why the fish population is so depleted and how you can avoid this catastrophe.

The depletion of the fish population did not occur because you didn't play the game correctly. The problem is that you cannot maximize your profits if your only goal is to beat your competitor. Thousands of people from all over the world have played Fish Banks. Each time, the result is the same as yours: every company falls far short of its profit potential because the players harvest the entire fish population too quickly for the fish to regenerate. The companies focus on maximizing profits and making the most money. Each company tries to build as many ships as possible to catch more fish than any other company. This leads to quick short-term profit but, as companies soon find out, the future is ultimately unprofitable.

3 BUILDING THE MODEL

Part 3 of this paper challenges your modeling skills. At the beginning of each section you will read a brief written description of the subsystem you are to build. It is possible, and you should attempt, to build the model based solely on the information given in the description. Following the description are step-by-step instructions on how to build the model. If you have difficulty, skip to the end of the section and look at the picture of the model. If you still have trouble, refer to the final model with equations in Appendix 4.

In order for your model to run properly, you need to change the value of the solution interval, DT. The reason is that the default value of DT (0.25) is too large for the unusually high values for the hatch and death rates of the fish population. Since the fish population system is changing very quickly, you need to instruct STELLA to calculate the values of the model more frequently. Changing the value of DT from the default value of 0.25 to 0.1 will do just that and consequently result in a more accurate model.

The hatch and death rates are set high so that we will be able to observe the dynamics of the fish population in the time frame of the simulation. Although the values of these rates are unrealistic, they are consistent with the other variables in the model and do not affect the qualitative behavior of the model.

? **Begin a new model in STELLA.**
? **Select "Time Specs" from the Run menu.**
? **Change DT to 0.1.**
? **Select "Years" in the Unit of Time column.**
? **Click on OK.**

There is an icon in the upper-left corner of your STELLA window that has in it either a picture of a globe, or X^2. If you do not see any one of these two icons, click on the upside down triangle at the upper-left corner, and you will see, right below the two triangles, a globe, or X^2. This is the Map/Model mode toggle button. You must be in model mode to define model elements as described in this paper.

- **Click on the Map/Model mode toggle button until it looks like X^2.**

Now you are ready to model the fish population, and the next section will take you through it step by step.

3.1 Modeling the Fish Population Subsystem

3.1.1 Description

The fish population is a simple S-shaped growth system. Without a fishing industry, fish hatch, grow to maturity, lay eggs and die. The size of the population naturally remains in dynamic equilibrium at the maximum sustainable number. If the population is decreased for unnatural reasons, it will return to the equilibrium level exhibiting S-shaped growth.

The first step in building a model is to identify the stocks present in the system. In the case of the fish population subsystem, the only stock present is the size of the fish population, called *FISH*.

Once you have identified the stock, you must recognize the flows which affect it. *Fish Hatch Rate* and *Fish Death Rate* are the two flows that affect the fish population stock. The *Fish Hatch Rate* is proportional to *FISH*. On average, one female fish produces 12 offsprings per year. This means that if 50% of the fish population is female, six fish hatch each year for every living fish. In other words, the number of fish hatched per year for each member of the fish population, or the *Hatch Fraction*, is six.

The *Fish Death Rate* does not remain proportional to the fish population. The fraction of the fish population that dies each year depends on the degree of crowding of the fish population. The *Death Fraction* increases as crowding increases. When the fish population is below the *Carrying Capacity* of the area, *Death Fraction* is lower than the *Hatch Fraction*, so the population increases. As the population increases and approaches the *Carrying Capacity*, the *Death Fraction* increases and approaches the value of the *Hatch Fraction*. When the fish population is at the carrying capacity, the population enters into dynamic equilibrium. If the fish population becomes greater than the *Carrying Capacity*, the *Death Fraction* is greater than the *Hatch Fraction*, and *FISH* decreases to the equilibrium level. The *Death Fraction* in this model will be a function of the ratio between the fish population *FISH* and the *Carrying Capacity*.

3.1.2 Building the Model

? **Create the stock *FISH* in your STELLA window.**

? **Create the flow *Fish Hatch Rate* going into the *FISH* stock and the flow *Fish Death Rate* going out of the stock.**

? **Place the converters *Death Fraction* and *Hatch Fraction* next to their corresponding flows.**

? **Make connections from *FISH* and *Hatch Fraction* to *Fish Hatch Rate* and from *FISH* and *Death Fraction* to *Fish Death Rate*.**

? **Define *Fish Hatch Rate* and *Fish Death Rate:***

Fish Hatch Rate = FISH * Hatch Fraction

Fish Death Rate = FISH * Death Fraction

? **Enter initial values for FISH (10) and Hatch Fraction (6).**

? **Place a converter called *Carrying Capacity* next to *Death Fraction*.**

? **Set *Carrying Capacity* = 1200 (fish).**

? **Place connectors from the *FISH* stock and the *Carrying Capacity* converter to the *Death Fraction*.**

? **Double click on *Death Fraction* and enter *FISH/Carrying Capacity***

? **Click on *Become Graph***

? **Enter the proper values for the Input and Output as shown in Figure 6.**

? **Change the upper and lower limits of *Death Fraction* from 0 and 100 to 5 and 11, and *FISH/Carrying Capacity* from 0 and 100 to 0 and 2.**

? **Click on OK.**

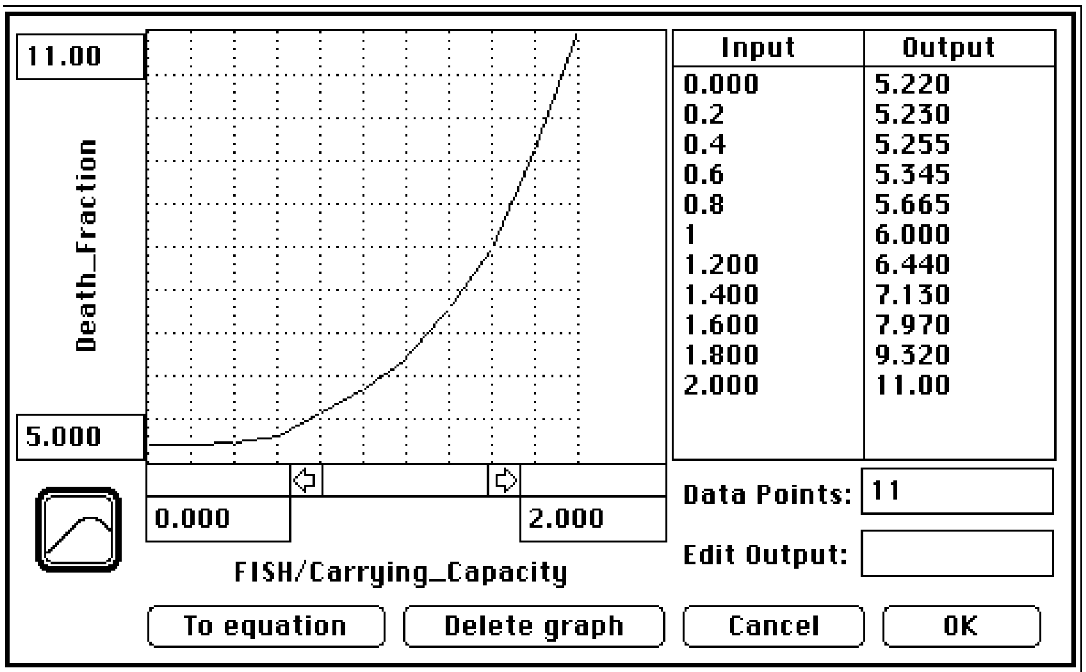

Figure 6: Graph of Death Fraction

This figure shows the graph that defines the relationship between *Death Fraction* and the fish crowding factor (*FISH/Carrying Capacity*).

The graph shown in Figure 6 covers a range extending from a fish population of zero to a fish population that is twice as large as the carrying capacity. Although it may seem extraneous to define such a large range , it is a good practice to follow. It is unlikely that the fish population will rise much above the maximum carrying capacity, but to test your assumptions about the model, you should test a few points well outside the expected operating range and see if your assumptions remain valid. In this model, we assumed that the *Death Fraction* would rise quickly as the number of fish increased above the carrying capacity. Using STELLA, we can create a simulation to test this assumption. If you dump 1000 extra fish into the area, the death rate will surge and quickly bring the population back to equilibrium at maximum capacity. This behavior makes sense, so our assumption is probably correct.

- **Remember to set the value of DT = 0.1 before you run the model.**

Your model should now look similar to the one shown in Figure 7. The feedback loops present in the system are highlighted in Figure 7 and will not look the same in your diagram. The negative and positive signs indicate the polarities of the loops and are only for your information. They do not show on your model.

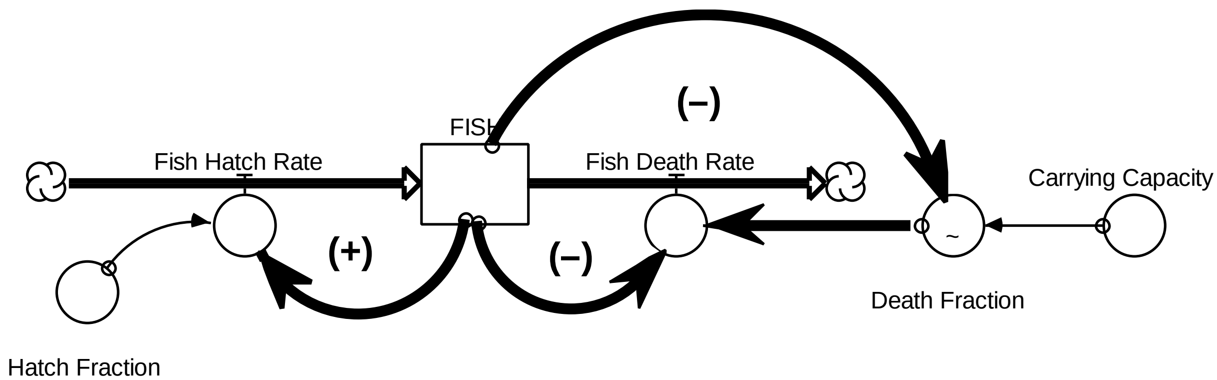

Figure 7: Modified STELLA diagram of The Fish Population Model

This modified STELLA diagram shows the model of the fish population. It has been modified to highlight the feedback present in the model.

You have now completely modeled the fish population as it behaves in the absence of a fishing industry. The questions below will help you to understand the model more insightfully. Go through the questions carefully and then compare your answers with suggested answers in Appendix 1.

3.1.3 Questions

1. Trace out the feedback loops shown in Figure 7. Which is positive? Negative? Why?

2. Do you recognize the S-shaped growth structure in the model? Can you think of other situations where similar behavior occurs?

3. Run the model. Create a graph and observe the behavior of the *FISH* stock. What is the shape of the curve? Which loop is dominant after three years? After nine years? When does the transition occur?

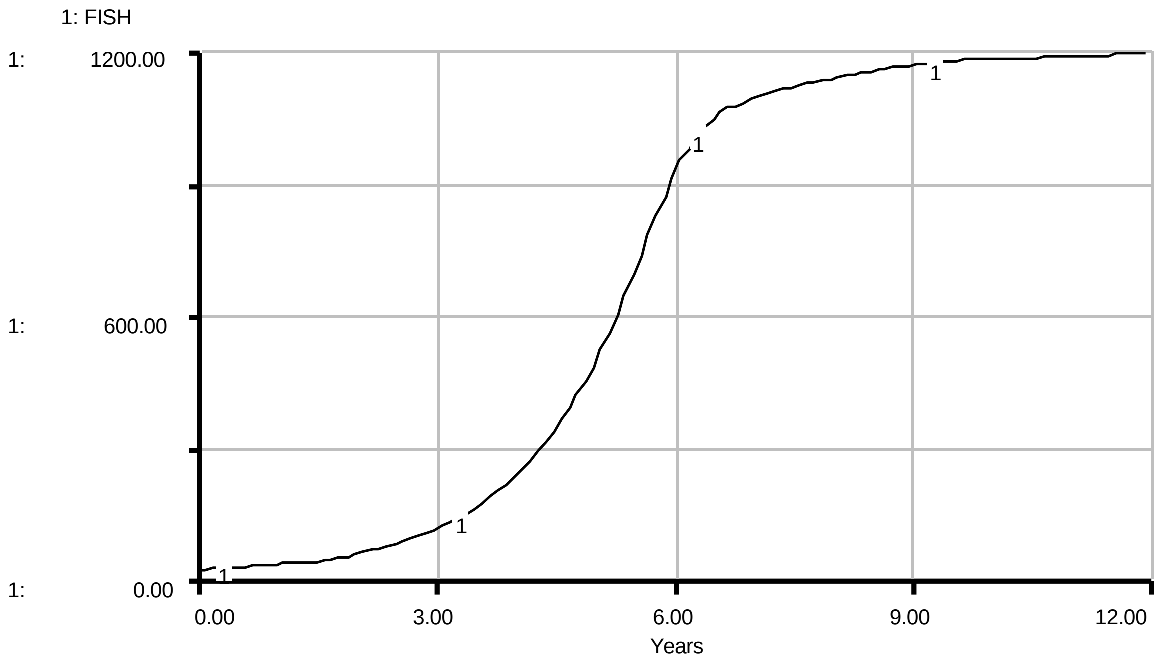

Figure 8: The Behavior of the Fish Population over time

This graph shows the S-shaped growth of the fish population as it grows from 10 fish to the maximum limit of 1200 fish in the absence of a fishing industry.

3.2 Modeling the Ship Subsystem

***Note: To facilitate the process of combining the models, you should build the Ship subsystem on the same STELLA diagram pad as the Fish Population subsystem.

3.2.1 Description

***Note: For simplicity, this model will combine all the individual fishing companies into one aggregate company. Also, we have made assumptions about the buying strategy of the fishing companies.

Each year, the company harvests the fish and reinvests 20% of its *Yearly Profits* into building more *SHIPS* at $300 apiece. The *Ship Building Rate* is the number of ships the company can build with the fraction of the *Yearly Profits* being reinvested into ship building. The company will begin with 10 *SHIPS* and increase its fleet as long as *Yearly Profits* are positive. If the *Catch per Ship* is low, the company's *Operating Costs* may exceed the income from fishing, and the net profit for that year will be negative. *Yearly Profits* are determined by subtracting the company's *Operating Costs* from the *Revenues*. The *Operating Costs* of the company depend on the number of ships in its fleet. It costs $250 per ship to operate for one year. The company sells the *Total Catch per Year* at $20 per fish to produce *Revenues.* For this model, assume that the *Catch per Ship* is 15 fish.

Two feedback loops affect the *SHIPS* stock. The relationship between *SHIPS* and *Revenues* generates the first loop. That is, fishing with more ships leads to a larger *Total Catch per Year*, which in turn leads to larger *Revenues* and increased *Yearly Profits*. The increase in *Yearly Profits* results in an <u>increase</u> in the amount of money reinvested into building more ships. This is a positive feedback loop.

The relationship between the number of *SHIPS* and *Operating Costs* generates the second feedback loop. Increasing the number of *SHIPS* in operation increases *Operating Costs* which then causes *Yearly Profits* to decrease. This decrease in profits results in a <u>decrease</u> in the amount of money reinvested into building more ships. This is a negative feedback loop.

***Note: Since later we will be connecting this model to the Fish Population model, create *Total Catch per Year* as a flow. For now, leave it as an unconnected flow (with *Catch per Ship* and *SHIPS* as inputs.)

<u>3.2.2 Building the Model</u>

? **Create the stock *SHIPS* with the *Ship Building Rate* flowing into it.**
? **Set the initial value of *SHIPS* = 10 (ships).**

The *Ship Building Rate* is the number of ships the company can build with the fraction of the yearly profits being reinvested into ship building. This leads to the following equation:

*Ship Building Rate = Yearly Profits * Fraction Invested / Ship Cost*

? **Create the following converters in your model:**

  ***Ship Cost* = 300 ($)**

  ***Fraction Invested* = 0.2 (dimensionless)**

  ***Yearly Profits* (leave undefined)**

? **Connect the three new converters to *Ship Building Rate*.**

? **Define *Ship Building Rate.***

Yearly Profits are equal to *Revenues* minus *Operating Costs*. *Operating Costs* are simply the number of *SHIPS* multiplied by $250. Fish sales produce *Revenues*.

? **Create the following converters:**

  ***Operating Costs = SHIPS* * 250**

  Fish Price = 20 ($)

? **Create the flow *Total Catch per Year*, but leave it unconnected.**

? **Create the converter *Revenues.***

? **Connect *Fish Price* and *Total Catch per Year* to *Revenues.***

? **Define *Revenues:***

  Revenues = Total Catch per Year * Fish Price

? **Connect *Revenues* and *Operating Costs* to *Yearly Profits*.**

? **Define *Yearly Profits*:**

  Yearly Profits = Revenues - Operating Costs

The *Total Catch per Year* is simply the number of fishing ships present in the area times the number of fish that each ship catches.

? **Create the converter *Catch per Ship.***

? **Connect *SHIPS* and *Catch per Ship* to *Total Catch per Year.***

? **Define *Catch per Ship* and *Total Catch per Year:***

  ***Catch per Ship* = 15 (fish)**

  Total Catch per Year = SHIPS * Catch per Ship

After building the entire ship subsystem model on STELLA, compare your model to the one shown in Figure 9. If your model is the same, please continue with the rest of the paper. If it is not, correct your model and check it with the relevant equations in Appendix 4.

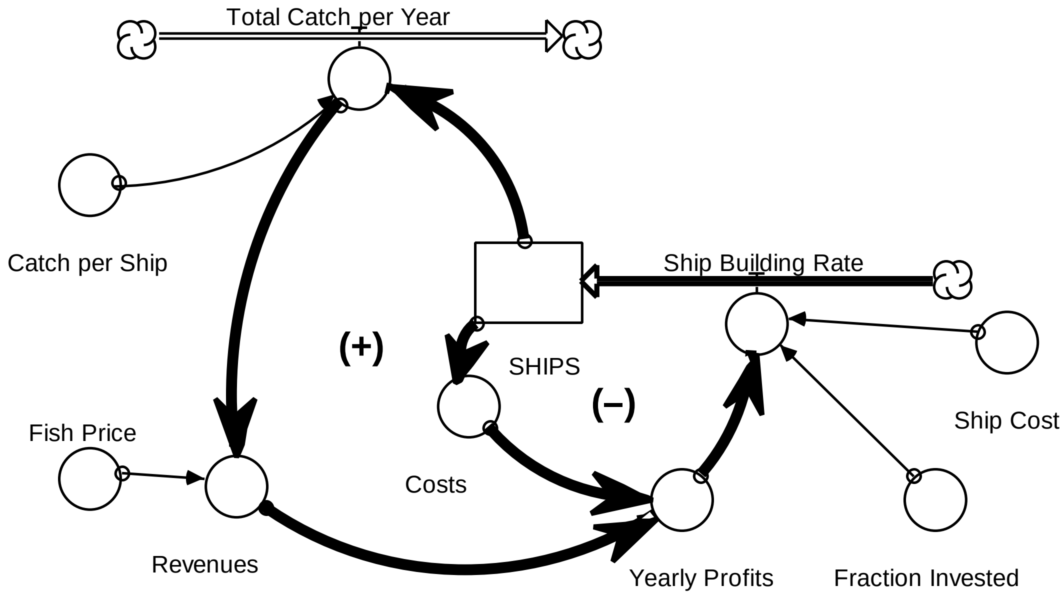

Figure 9: Modified STELLA diagram of The Ship Subsystem

This modified STELLA diagram shows the model used to represent the Ship subsystem. It has been modified to highlight the feedback loops present in the model.

3.2.3 Questions

1. Trace the feedback loops on the model in Figure 9. Which loop is positive feedback? Which is negative? Why?

2. Run the model. Look at the graphs for *SHIPS* and *Yearly Profits*. Why are they the same shape? Will they always look like this?

3. Change *Catch per Ship* to 10. What happens? Can you make *Yearly Profits* zero? What would the value of *Catch per Ship* be?

3.3 Modeling The Connection Subsystem

You have just modeled both the fish population and the fishing companies. Now it is time to put those two subsystems together into one complete model. We will analyze the connection between the two previous subsystems separately as its own subsystem.

This subsystem is perhaps the most important piece of the whole system. Its behavior is one of the main reasons why the fish population is depleted every time.

The model of this subsystem contains some of the elements that you have already included in the fish and the ships models. Since you cannot use the same element twice in STELLA, you must save the models that you have already built and begin a new model.

? **Select “Save” from the File menu.**
? **Click on “Desktop” in the Save dialogue box.**
? **Name your model and save it. (Be sure to remember the name!)**
? **Select “Close Model” from the File menu.**
? **Select “New” from the File menu to begin a new model.**

3.3.1 Description

The connection subsystem contains the link between the FISH and the SHIPS stocks. The major characteristic of this subsystem is the delay between *FISH* and *Catch per Ship*. Modern fishing ships have sonar tracking and other high tech equipment to aid in finding and catching fish. As a result, the ships are able to return with nearly a full load even if the fish population begins to drop. It is not until the fish population has dropped dangerously low that fishing companies detect any significant decline in the catch. To represent this fact in a model we will need to redefine *Catch per Ship* and have it depend on a new factor: *Density*. *Density* is the number of *FISH* in the 100 square mile *Area* where the fish population lives. The *Catch per Ship* will be 0 when *Density* is 0. As *Density* increases, *Catch per Ship* will increase sharply, leveling off at 25 fish per ship when the population is at maximum density.

This model introduces a new flow affecting the *FISH* population, *Total Catch per Year*. This flow was defined in the previous section, but it was left unconnected. In this model, and in the final model, connect *Total Catch per Year* to *FISH* as an outflow. For this model, set the initial value of *FISH* = 1000 (fish) and *SHIPS* = 10 (ships).

There is a feedback loop present in this subsystem. An initial increase in the *Total Catch per Year* increases the depletion rate of the *FISH* population. As a result, fish *Density* is lower than it would have been, and so is *Catch per Ship*. Finally, the *Total Catch per Year* decreases. This is a negative feedback loop.

3.3.2 Building the Model

? **Create the *FISH* and *SHIPS* stocks.**

? **Create *Total Catch per Year* as an outflow to the *FISH* stock.**

? **Create the following converters:**

Area = 100 (square miles)

Density = FISH / Area

Catch per Ship (Leave undefined)

? **Define the flow Total Catch per Year:**

Total Catch per Year = SHIPS * Catch per Ship

? **Set the initial value of *FISH* (1000 fish) and *SHIPS* (10 ships).**

? **Connect *Density* to *Catch per Ship.***

? **Double-click on *Catch per Ship*.**

? **Select *Density* from the Allowable list.**

? **Click once on Become Graph, then enter the proper ranges, Inputs and Outputs as shown in Figure 10.**

? **Click on OK.**

Make sure that your model is correct by comparing with Figure 11. If your model is structurally the same, then go on to the next section. If not, please refer to Appendix 4 and correct your model.

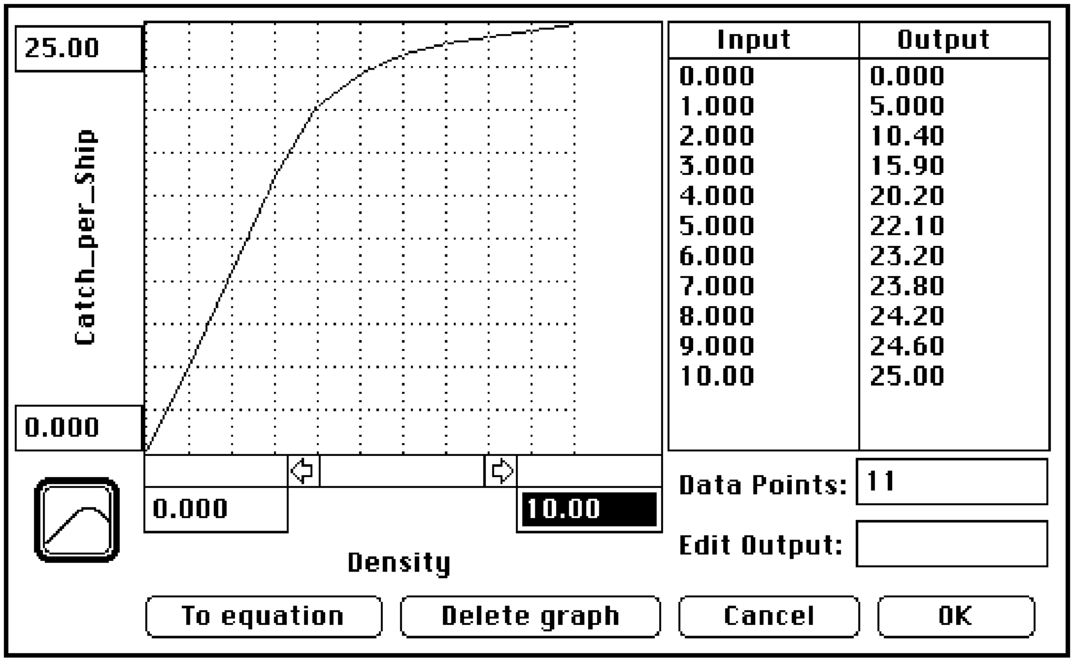

Figure 10: Catch per Ship graph

This figure shows the graph which you must enter into your STELLA model to define the relationship between *Catch per Ship* and fish *Density*.

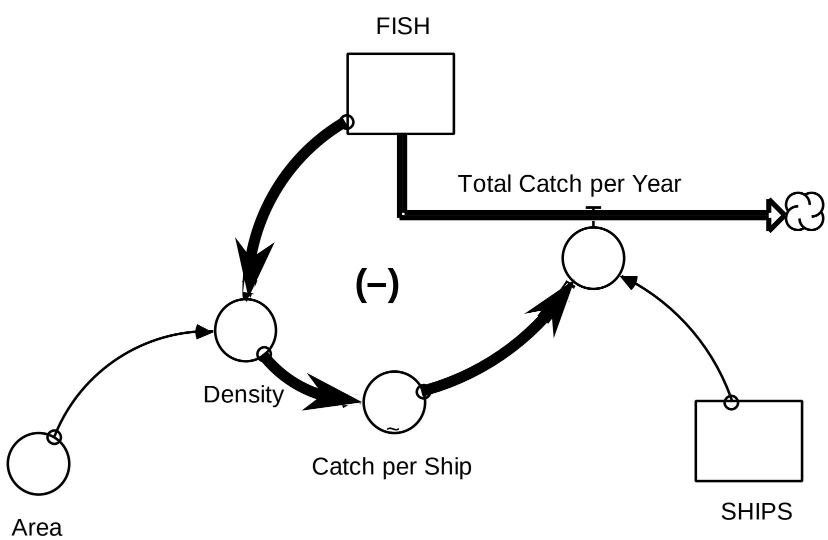

Figure 11: Modified STELLA diagram of The Connection Subsystem

This modified STELLA diagram shows the model of the feedback loop which connects the Fish and the SHIPS subsystems.

3.3.3 Questions

1. Why is this a negative loop?

2. Run the model and observe the behavior of *Total Catch per Year* and *FISH*. Notice that the fish population drops significantly before any noticeable change occurs in the catch. After one year, the *Catch per Ship* dropped by only 4% while nearly 1/4 of the fish population was eliminated. After two years, there is only a 10% drop in the *Catch per Ship*, and almost 1/2 of the fish population is gone. What is the major implication of this in the fishing industry?

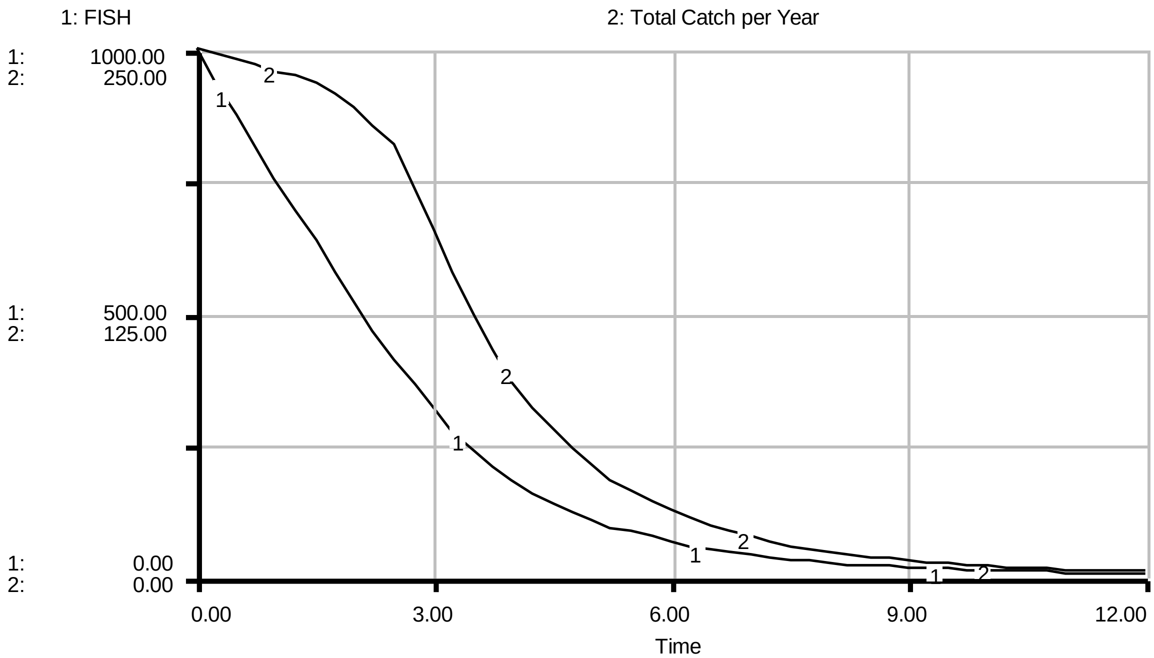

Figure 12: Graph of the Connection System behavior

This graph shows the behavior of the connection subsystem. The graph shows the delay between the *FISH* population and the *Total Catch per Year*.

3.4 Combining the Systems

You will need to close your model of the connection subsystem and open your saved model of the fish and ships subsystems. It may be helpful to tear off the Appendix and keep the picture of the final model handy for this part.

- **Select "Close Model" from the File menu.**
- **Click on "Don't Save" in the dialogue box which appears.**
- **Select "Open" from the STELLA File menu.**
- **Click on "Desktop" in the Save window.**
- **Select your saved model and open it.**
- **Highlight the entire Ship system by clicking and dragging the mouse to form a dotted outline around the system.**
- **Align the two models so that the *Total Catch per Year* is below the *Fish Death Rate*.**
- **Click on the cloud opposite the arrow of the *Total Catch per Year* flow and drag it until it is inside the *FISH* stock.**
- **Release the mouse button and click on the *FISH* stock.**
- **Move the mouse slightly until the cloud hidden by the stock becomes highlighted as well. Release the button.**
- **Click on the arrow in the upper-left corner of the STELLA window to display the equations. The *FISH* stock should now have *Total Catch per Year* listed as an outflow**
- **Click on the arrow in the upper-left corner again.**
- **Place the *Area* and *Density* converters in their proper places in the model and make their connections.**

Now that you have completed the model of a fishing industry system, feel free to play around with it and see what happens. You should check your model equations with those included in Appendix 4 to make sure they are identical. Notice that the model you have built, unlike the one-player game, does not allow for any user input other than to run the model. In your model, the profits from the previous year determine the *Ship Building Rate*. Although the reinvestment of a constant percentage of the profits into building more ships may seem oversimplified, this is similar to the growth strategy of many fishing companies. Some of the more interesting elements to observe may be *FISH*, *Yearly Profits* and *Total Profits*. After building the model you should have a good idea why it behaves the way it does. The next section of the paper will take you through a policy analysis exercise using the model you have just created. The goal of the policy analysis is to find a solution to the fish resource problem.

4 THE TRAGEDY OF THE COMMONS

As the fish population decreased, your fishing ships began returning a smaller and smaller profit. The natural reaction to this is to increase your fishing fleet to keep making the same net profit. Even if you realize the danger of over fishing the area, there are no guarantees about your competitors realizing the same thing. Short-term individual profits motivate many fishing companies. They give little concern for the resource involved. As long as this is the case, the companies will overuse the resource and greatly diminish or destroy it. This phenomenon is very common in real life, so common that it has a name: Tragedy of the Commons.[5]

Tragedy of the commons occurs when several individuals share a limited resource. It is described as follows:

> *"Individuals use a commonly available but limited resource solely on the basis of individual need. At first they are rewarded for using it; eventually, they get diminishing returns, which causes them to intensify their efforts. Eventually, the resource is either significantly depleted, eroded, or entirely used up."*[6]

This phenomenon shows up in many fields other than resource extraction. Tragedy of the commons affects companies with shared secretarial pools, departments competing for funds, businesses competing for a small number of specialized clients and many other systems.

5 DEBRIEFING

The seas have been a source of wealth for centuries. During those centuries, fishermen have been in constant battle with the seas in order to provide for their very survival. However, over the past century, man has taken the upper hand in this age-old battle. Through the use of superior harvesting technology, man has been able to rob the

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[5] Hardin, Garrett. "The Tragedy of the Commons", Science. Vol.162, December 13, 1968. pp. 1243-1248.

[6] Senge, Peter M., 1990. *The Fifth Discipline: The Art and Practice of the Learning Organization*, New York, Doubleday.

seas of greater and greater numbers of fish. As a result, there are many fisheries which have been totally destroyed or are near destruction because of over-harvesting. Man's superior intellect has destroyed stocks of renewable resources which could have remained harvestable for hundreds of generations.

The model you built in this paper is based on the game Fish Banks, Ltd. developed by Dennis L. Meadows.[7] Dr. Meadows developed the original game to address the problems inherent in the use of natural resources. The original game requires a large group of people. The model you have built gives individuals the opportunity to learn about the natural resource depletion dilemma.

The interaction between the fish population and the fishing companies is only one of the many systems that include and affect these entities. You can build models to describe the effect of weather patterns, natural predators for the fish, the local economy and many other factors. It is important to realize that the model created in this paper cannot be used to analyze the behavior of those other systems. This model addresses a specific problem: the effects of a fishing industry on an otherwise stable fish population. When used for this purpose the model describes very accurately the actual behavior of similar real-life systems.

The following quote illustrates the result of overexploitation of a fish population in real life.

> *"The Pacific Coast sardine industry had its beginnings back in 1915 and reached its peak in 1936-1937 when the fishing netted 800,000 tons. It was first in the nation in numbers of pounds of fish caught, and ranked third in the commercial fishing industry, growing $10 million annually. The fish went into canned sardines, fish bait, dog food, oil, and fertilizer. The prosperity of the industry was supported by over exploitation. The declines in the catch per ship and success per unit of fishing were compensated for by adding more ships to the fleet. The fishing industry rejected all forms of regulation. In 1947-1948 the Washington-Oregon fishery failed. Then, in 1951, the San Francisco fleet returned with only eighty tons. The fishery closed down and has never recovered..." Ecologist Robert Leo Smith.*[8]

[7]See Footnote 3.
[8]Owen, Oliver, 1985. *Natural Resource Conservation: An Ecological Approach*, New York, MacMillan.

Now we introduce you to a paper which deals with policy analysis. Please read and do the exercises in the following pages.

Renewable Resource Depletion:

A Systems Approach to the Tragedy of the Commons
“Supplemental Materials for Fish Banks, Ltd.”

This section of the paper is a shortened version of:

Halbower, Matthew C., 1992. *Renewable Resource Depletion* (D-4263-2), System Dynamics in Education Project, System Dynamics Group, Sloan School of Management, Massachusetts Institute of Technology, January 28, 37 pp.

In this section, you will continue to use the fish banks model you just built. The model will be used to test several strategies for renewable resource management.

6. PURPOSE OF LESSON

The purposes of the Fish Banks, Ltd. role-playing simulation and the Fish Banks computer simulation are complementary. The purpose of the role-playing simulation is to give students an understanding of the economic incentives and environmental realities from the perspective of a manager of a fishing company. From this view, the goal is to have students understand how the system can drive rational fishermen to the point of elimination of their fish supply. General knowledge of the feedback which controls the system behavior should be learned as well as the deeper understanding taken away by the firsthand experience of living through the huge initial profits followed by the sudden collapse and destruction of the fishing industry.

Beginning with the debriefing stage of the role-playing simulation and continuing through the computer simulation stage, students assume the role of scientists. Their job is to brainstorm and model (with the teacher's guidance) the feedback present in the system. The goal here is to go beyond a superficial understanding of the reasons causing the tragedy of the commons. Students can explicitly develop the structure with the help of a computer and test their model to determine whether their structure produces the behavior observed during the role-playing simulation.

Once students have developed a model which represents the system, they can assume the role of ministers in the National Fishery and Wildlife Service. In this part of their work, they conduct policy analysis on the system by changing its structure to conform to a number of regulatory policy formulations. Their responsibility and goal is to formulate a regulatory policy which will sustain a thriving national fishing industry, while keeping in mind the political, practical, and economic obstacles of various policy paths. This policy can be reinforced by computer simulation as well as written arguments supporting the policy choice and the reasons why other competing policies were not chosen.

With these general goals in mind, there are a number of specific subject areas emphasized throughout the lesson plan. The diversity of the plan hints of the interdisciplinary nature of simulations such as Fish Banks.

The main theme of the simulation stresses the necessity to understand and practice renewable resource management. From the systems perspective, this requires an understanding of the tragedy of the commons phenomenon from both an economic and environmental viewpoint. Stated simply, tragedy of the commons is a phenomenon whereby individuals, sharing a common limited resource, each try to maximize his/her share of the resource until the resource is depleted and eventually destroyed.

Understanding the mechanics of tragedy of the commons requires knowledge of the interactions between the environmental and economic characteristics of the system. An environmental analysis can include population dynamics, carrying capacity, and maximum sustainable harvesting rate which helps explain that the earth's seemingly boundless natural resources are indeed limited. An economic analysis can show how the collective use of a renewable resource gives individuals an incentive to maximize their own profits in the short run rather than looking at the bigger picture and attempting to maximize everyone's profits, including their own. Combining the economic and environmental analysis points out why fishermen cannot see the effects of their actions on the system in the beginning. They can only see these effects after the destruction is complete.

Thus, students conduct computer simulation experiments to investigate the effectiveness of a range of regulatory policies. Policies can vary from taxation to the limitation of ships. The results of the implementation displays the effectiveness of each policy. Therefore, each student can discover, on his own, the solutions to the tragedy of the commons effect.

One of the most interesting regulatory policies deals with imposing restrictions on fishing technology.[9] Students can explore the effects of such limits on the sustainability of a fishing industry as well as ask in-depth questions concerning the effects of man's technological innovations.

Other regulatory policies include imposing taxes on ship construction, taxes on fish, forced dry-docking of ships over a certain age, ship building regulations and limits, market fish price regulation, and government fish price regulation. Of course students must always consider the political consequences of the regulatory decisions as well as the feasibility of carrying out those regulations.

In addition to exploring those computer simulation policies, the Fish Banks curriculum provides many opportunities for exploration away from the model. One of the most interesting areas to explore is the legal relationships between the economics and environmental consequences of renewable resource depletion. How does one set up a regulatory agency controlled by the state? What effects might proposed regulatory plans

[9] Such policies are already established in places like Alaska where fishing regulations require the use of gill nets which the fish can see underwater rather than the undetectable gill nets in order to reduce overharvesting.

have on individual liberty or property rights? Would assigning property rights to portions of the sea cut down on the tragedy of the commons?[10]

Finally, no matter what particular issues you wish to emphasize throughout this lesson, the nature of the work requires your students to develop group interaction and communication skills. This is true in two particular aspects. First, the computer exercises allow students to work together on the Macintosh and learn from each other. In this situation, the teacher fades into the background as the students explore the system with each other. Second, during the role-playing portion of the simulation, students must express their strategies and ideas and convince others through sound arguments. These two aspects of group interaction encourage the students to form mental models of the fishing system, to brainstorm solutions, and to verbalize complete ideas. These techniques show students how to work with complex problems and can later be applied to situations other than Fish Banks.

Dennis Meadows summed up its general purpose the best when he said, “This curriculum is specifically designed to convey the fundamental insights required for corporate managers, public officials, and private citizens to use their region’s natural resources intensively without deteriorating the long-term productivity of their resource endowment.”[11]

[10] On the Virginia side of the Chesapeake Bay, the state has assigned property rights to portions of the bay for the havesting of oysters in an attempt to control the problem of Tragedy of the Commons.

[11] Meadows, Dennis, Thomas Fiddaman, and Diana Shannon. Fish Banks, Ltd. A Microcomputer Assisted Simulation That Teaches Principles for Sustainable Management of Renewable Resources. p. 1.

7. FISH BANKS MODEL REVIEW

This section contains a brief review of the model you built earlier in the first part of this packet.

Model Assumptions:

The computer model contains two assumptions which are different from the assumptions in the role playing simulation. First, unlike the role-playing simulation, there is only a single fishery present within this model. All ships fish in the deep sea, and operating costs are computed accordingly.

Second, unlike the role-playing simulation, the model aggregates all shipping companies into a single stock of ships. The purpose of this is to allow the student to conduct a holistic study of the entire industry through the aggregation of the various fishing fleets. Both assumptions are meant to reduce the complexity and redundancy present within the role playing simulation.

Model Description:

Figure 13 on the next page shows the final result of combining the ship subsystem with the fish subsystem. The ships drive the depletion of the fish resource. Simple economics drives the increase in the number of ships. As the total catch per year increases, the total revenues increase since more fish are sold. Profits increase as revenues increase because more money is being made. When deciding whether or not to purchase a ship, the fisherman looks at his profits and invests some fraction of those profits in new ships thus increasing the total number of ships. This forms a positive feedback loop since an increase in ships will lead to an increase in total catch per year which leads to more revenues, more profits and ships, thus increasing the stock of ships.

The only force counteracting this positive feedback loop is the negative feedback loop formed between ships, costs, profits, and new ships. As the number of ships increases, the cost of operating those ships increases which decreases profits, new ships, and then the number of ships. This feedback loop is much less dominant than the positive feedback loop at the beginning of the simulation when a great deal of money is being made.

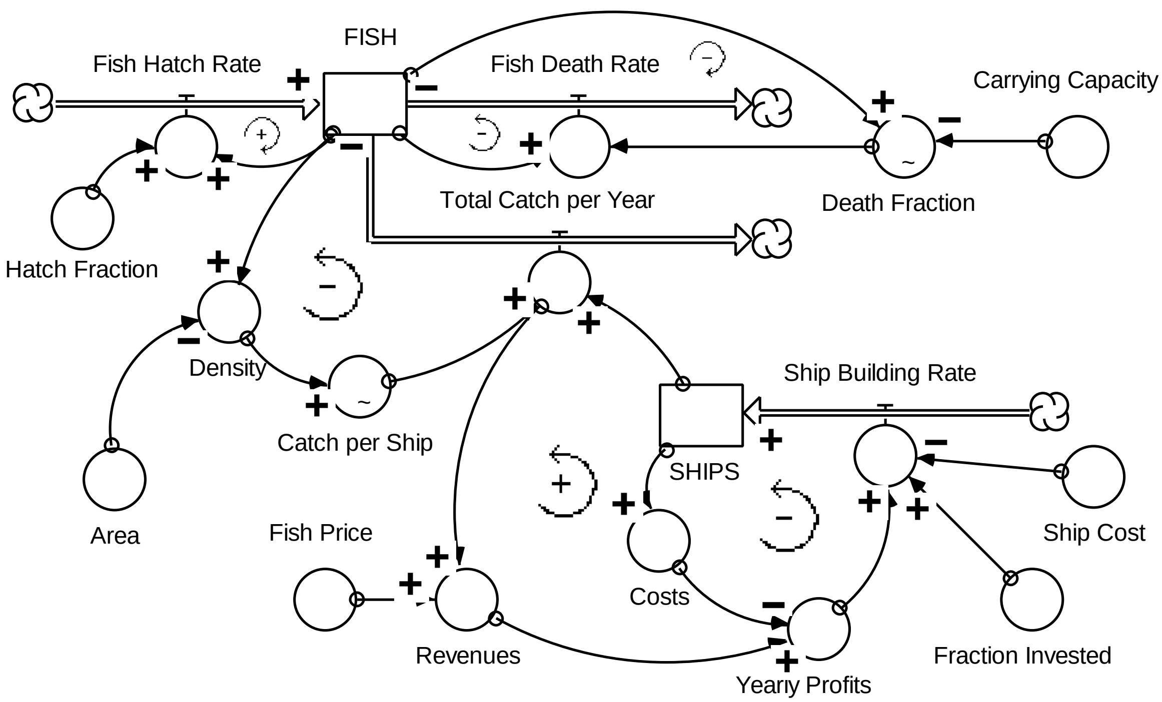


Figure 13: STELLA Diagram Depicting Structure of Fish Banks Model

8. POLICY ANALYSIS EXERCISE

The following exercises are for your students. No answer key is included because the answers vary depending on the emphasis of the lesson. Therefore, the exercises should be examined before presentation to the students so that areas of focus can be determined and original answers created. The length of time required to complete the exercises is approximately three hours, so you may wish to delete some of them. The students should work in pairs or groups of three to encourage communication and interaction. Let the students learn from each other; you may be surprised by some of their innovative suggestions.

System Dynamics in Education Project

Fish Banks Policy Analysis Exercise

Name ________________

The year is 1970.

You are a manager in the national fish and wildlife service. You are charged with the responsibility of making policy suggestions regarding the management of a fishery surrounding your national borders. Fishing is an important source of economic income for your country so your decisions must insure the healthy maintenance of the fish population and fishing industry.

Luckily, you have retained some expensive consultants from MIT (paid with government money, of course). The consultants have built a model of the fish population and fishing industry in your nation. They claim that you can use the model to test the impact of different regulatory policies on the fish population and fishing economy. A diagram of the model is shown below in Figure 1.

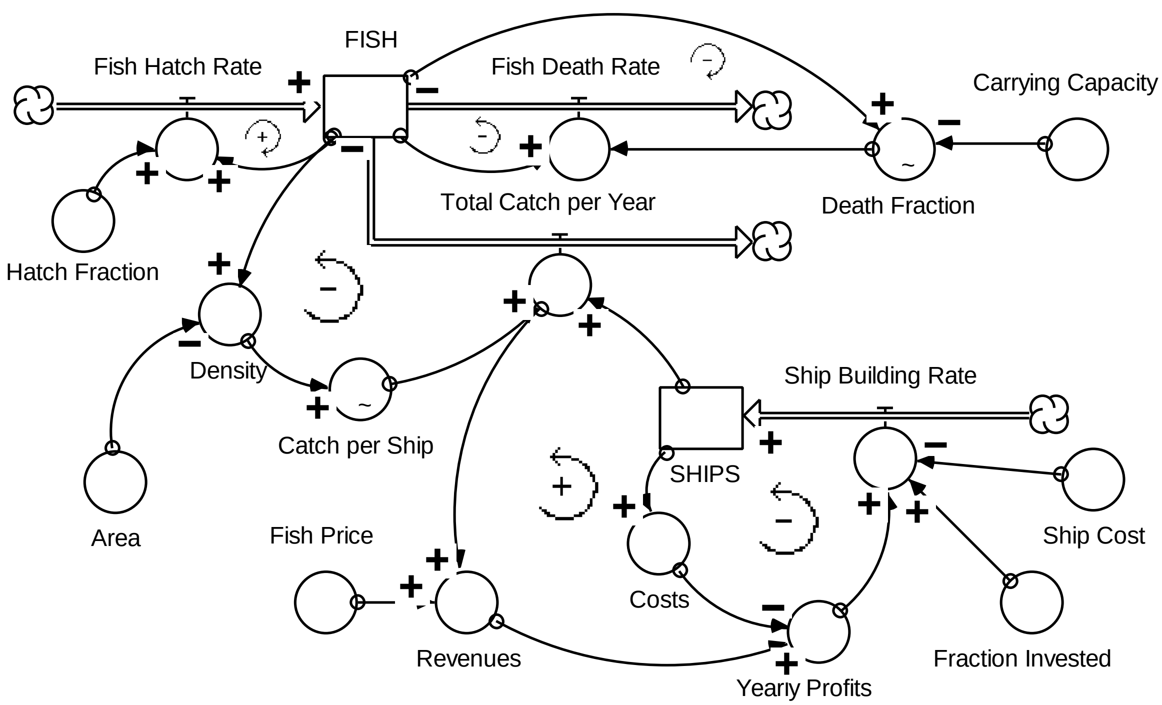


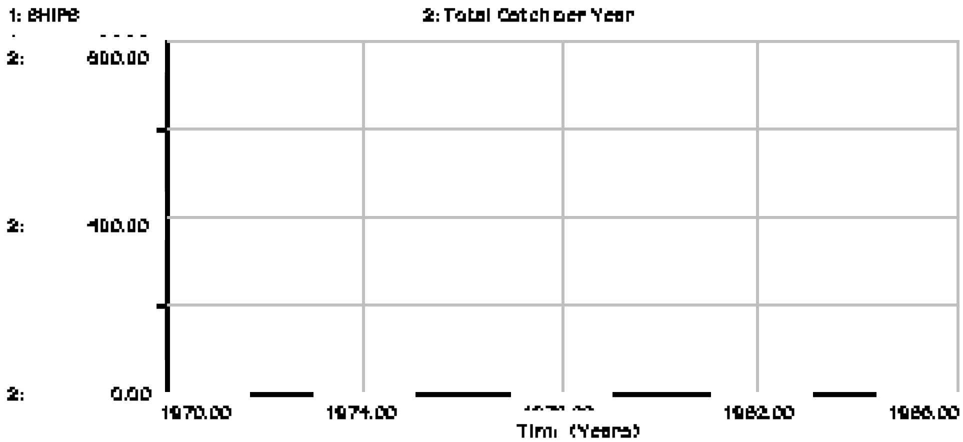
Figure 1: STELLA Diagram of Fish Banks Model

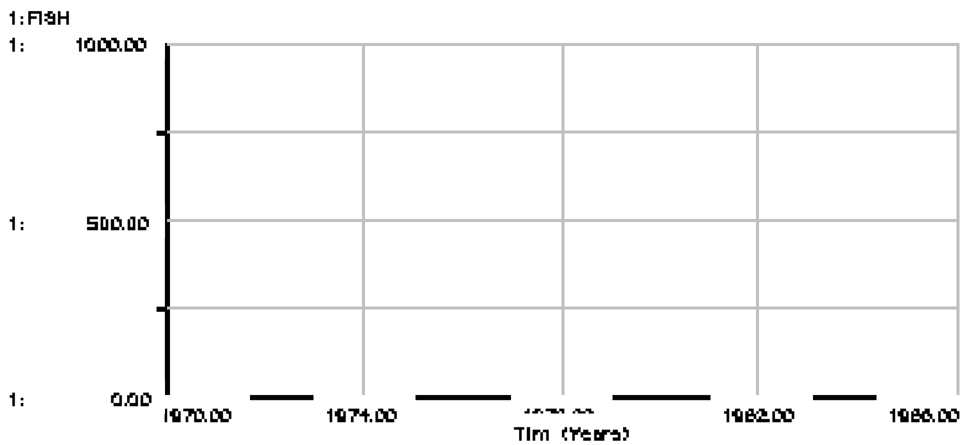
YOUR TASKS:

1. The model is currently set up to simulate the regulatory situation present within the national fishing industry as of 1970 (no regulation). To simulate the system:

- **Select Graph Pad from the Windows Menu**
- **Select Run from the Run Menu**

Observe the behavior of the number of ships, catch per year, fish population, and total accumulated profits on the different pages of the graph pad. The pages may be changed by clicking on the page numbers on the top right of the graph pad window. Sketch the graphs of ships, catch per year, and fish population on the axes below.

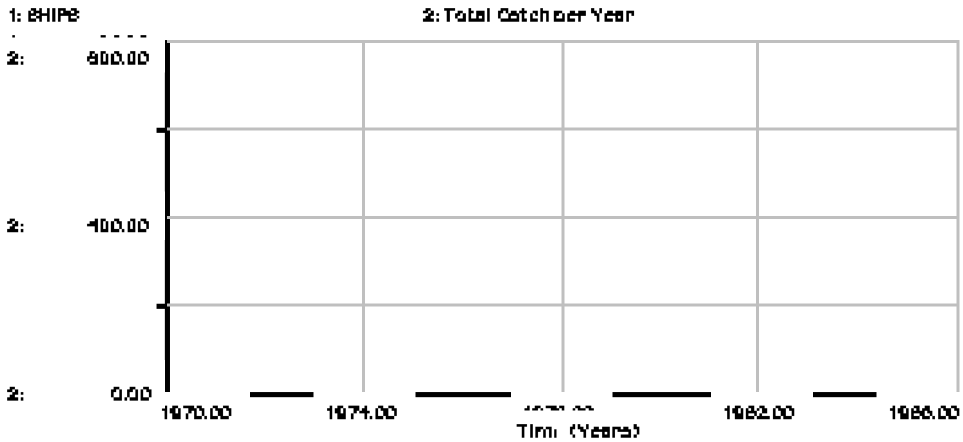


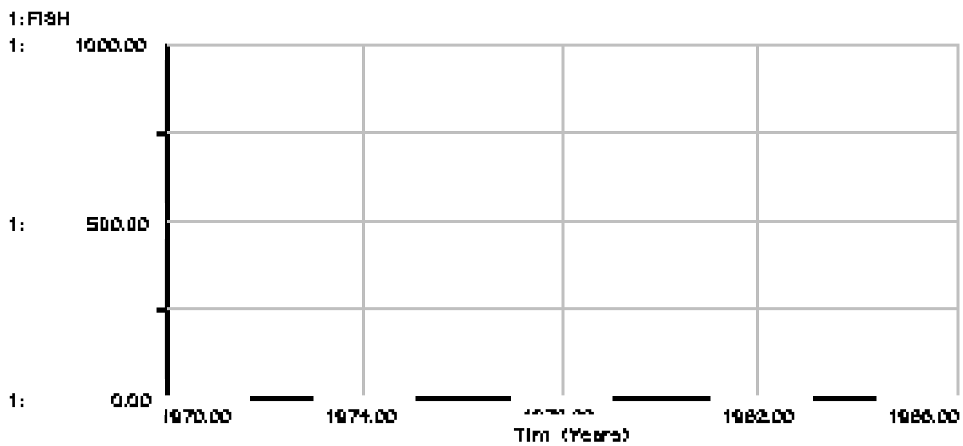


Explain in a few sentences why the system generated the exhibited behavior. Try to tell the story of what happened in the Fish Banks simulation by making reference to the feedback loops describing the system.

2. Clearly, leaving the present system undisturbed is an unacceptable situation. The fish population is decimated, the fishing industry dies, and you lose your job.

One regulatory policy which might help to avoid this situation is to levy a large tax on new ships (say $200 per ship), thereby raising the price and curtailing purchases. Sketch on the axes below the effect you believe that this policy will have on the number of ships, total catch per year, and fish population.





Try running this policy by changing the ship cost from $300 to $500.

- **Select Diagram from the Windows Menu**
- **Double-click on the converter labeled "Ship Cost"**
- **Type "500"**
- **Click the OK Button**

Once you have changed the ship cost, simulate the system:

- **Select Graph Pad from the Windows Menu**
- **Select Run from the Run Menu**

Using either a dashed line or different colored pen, sketch on these same axes: the computer simulated graphs of ships, total catch per year, and fish population.

Was this policy successful? How does the behavior generated in this simulation compare with the previous behavior? Explain the differences in behavior.

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Vary the amount of the tax and re-simulate to observe the effects on behavior. What behavior is exhibited if the tax is too high?

3. It is clear that a tax on ships seems to do nothing more than delay the destruction of the fish population. Another possible policy alternative is to keep building ships until there is a noticeable problem with the fish population. Since the only feedback signal from the fish population that fishermen receive is from the fish catch, the policy could make building ships illegal once the catch per ship decreases to an unacceptable rate.
To implement this policy, first change the ship cost back to 300 dollars per ship.

- **Select Diagram from the Windows Menu**
- **Double-click on the converter labeled "Ship Cost"**
- **Type "300"**
- **Click the OK Button**

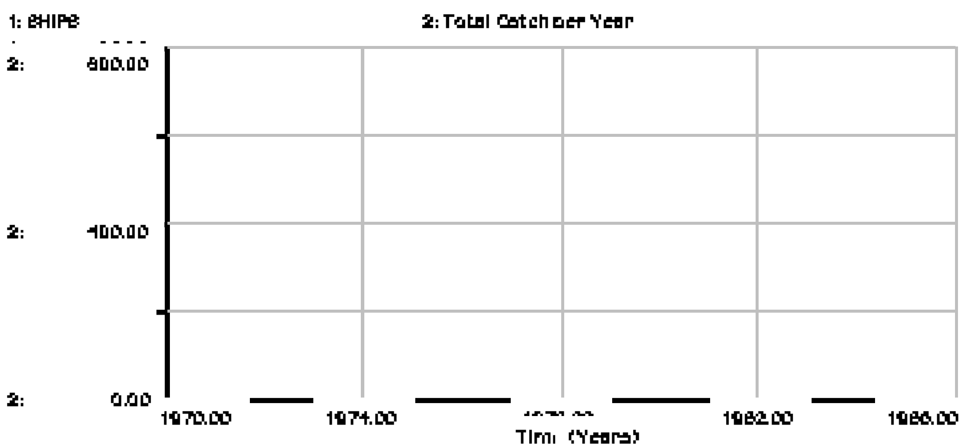
Next insert the feedback from Catch per Ship to Ship Building Rate. During good fishing, the average ship will catch 25 fish per year. See what happens when the ship building is limited after the catch drops below 22 fish per year.

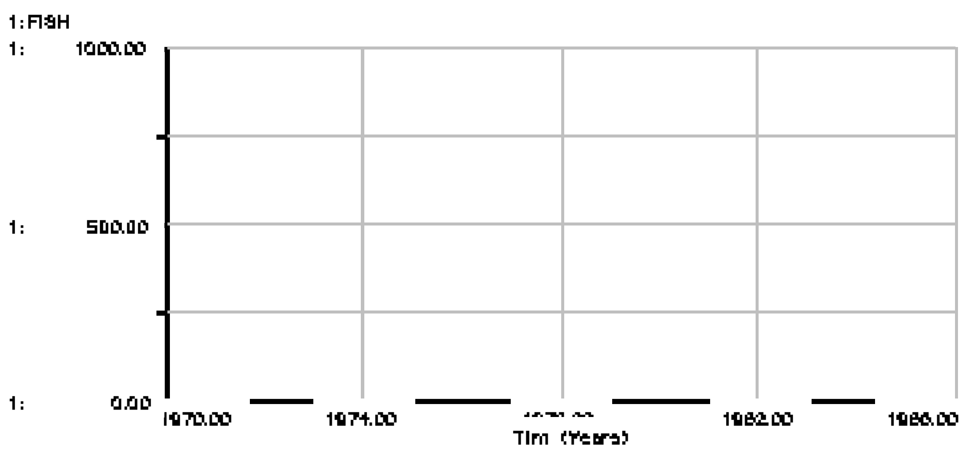
- **Draw a causal connection from Catch per Ship to Ship Building Rate**
- **Insert the following equation into the Ship Building Rate:**

if Catch_per_Ship>22 then Yearly_Profits*Fraction_Invested/Ship_Cost else 0

This equation says that if the catch per ship is greater than 22 fish per year then purchase the normal number of ships (Profits*Fraction Invested/Ship Cost). However, if the catch per ship falls below 22, then build zero ships.

Graph on the axes below the effect you believe this regulation will have on the system.





Run the model and sketch the behavior on the axes above using either dashed lines or a different-colored pen.

Were your predictions correct? How does the behavior generated based on the new regulation differ from a system with no regulation? Explain any differences or lack of differences.

Was this policy successful? If not, try increasing the threshold on Catch per Ship from 22 to a higher number. At what number does the system produce a stable fish population?

What factors not present within the model might affect the catch per ship?

How easy do you think it will be for the government to collect data on the catch per ship? What problems might be encountered?

Write down a plan outlining how you would collect the data in order to decide when to limit the ship building rate.

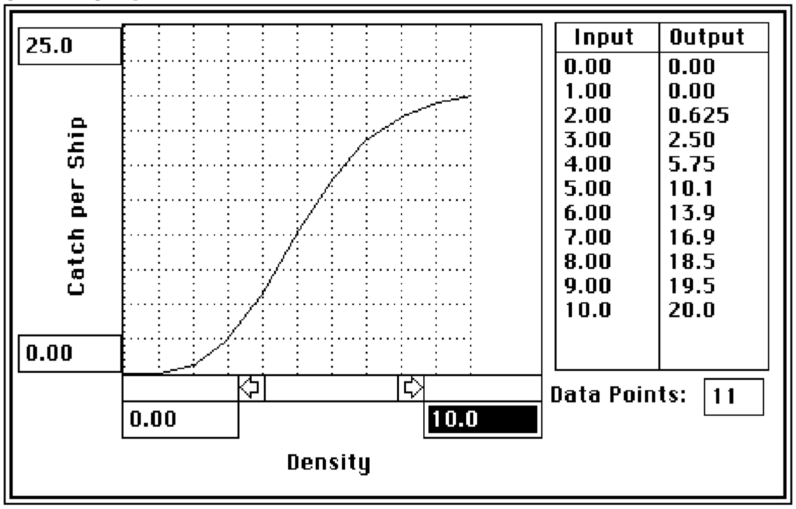
Do you get the impression that fishing systems tend to give a great deal of warning before a catastrophe or do you feel these catastrophes come on more suddenly? Is the catch per ship an accurate indication of the fish population? Explain your reasoning by referring to the graph of Fish Catch per Ship and its relationship to fishing technology.

4. Another policy alternative is to make certain fishing technologies illegal by making it more difficult for ships to catch fish. Fewer fish caught means that the fish population has a better chance for survival. To implement this policy, first return the model to its original state:

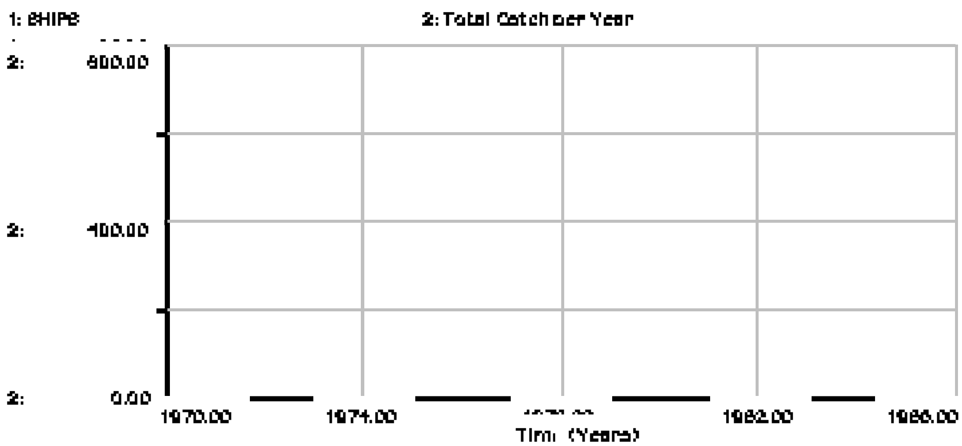
- **Select "Revert to Saved" under the file menu**

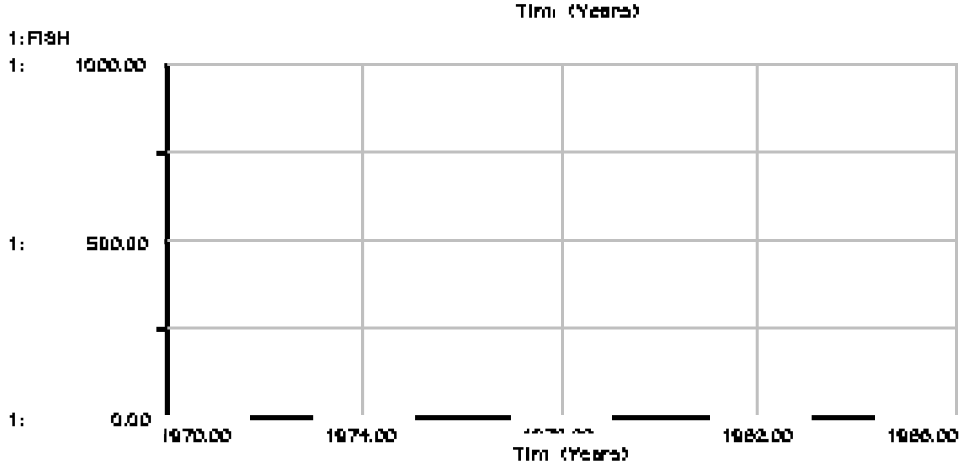
Next, change the graph defining Catch per Ship to model low fishing technology.

- **Double-click on the converter labeled Catch per Ship**
- **Change the graph so that it matches the one found below**



Once again try to predict how this policy will affect the number of ships, catch per year, and fish population by sketching on the axes below.





Run the model and sketch the computer simulated behavior on the previous axes using either dashed lines or a different colored pen.

How does this policy alternative seem to work? Were your predictions correct? If not, why were they incorrect? If you would like to run the time axis out further:

• **Select Simulation Time under the run menu and change the final time value.**

What are your accumulated profits here as compared to previous simulations? Explain why the fishermen's accumulated profits are more or less under this regulation.

Comment on the likelihood of being able to implement regulation of fishing technology. What groups would be opposed to or in support of such regulation? Do you think that your job would be in jeopardy if you proposed such a regulation?

5. Another policy might be to force all boats over a certain age have to be dry docked for safety reasons. This would create an outflow from the stock of ships. To implement this policy, first return the model to its original state:

- **Select "Revert to Saved" under the file menu**

To model the policy:

- **Select the Flow icon on the upper left portion of the STELLA Diagram Window**
- **Place the Flow icon on top of the stock labeled SHIPS**
- **Hold the mouse button down and drag the mouse an inch to the left**
- **Release the Mouse Button**
- **Type "Ship Scrapping Rate"**

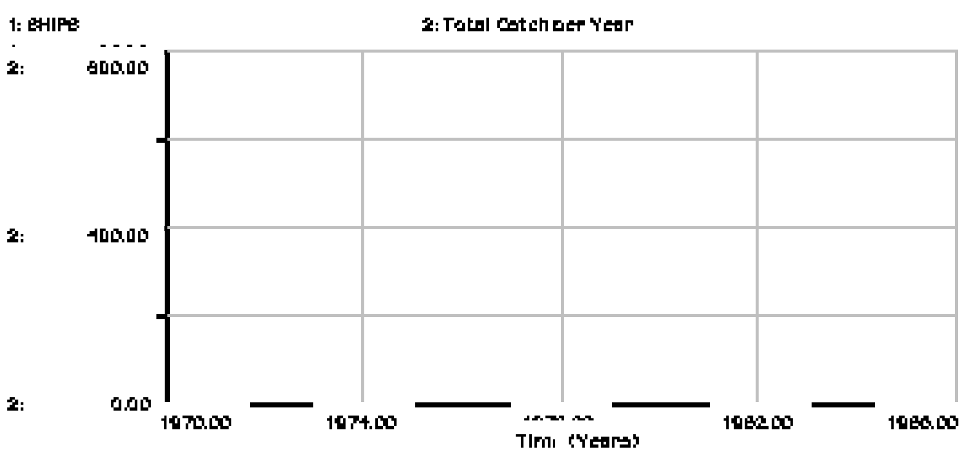
To define the flow, it is necessary to have a converter specifying the maximum age of ships:

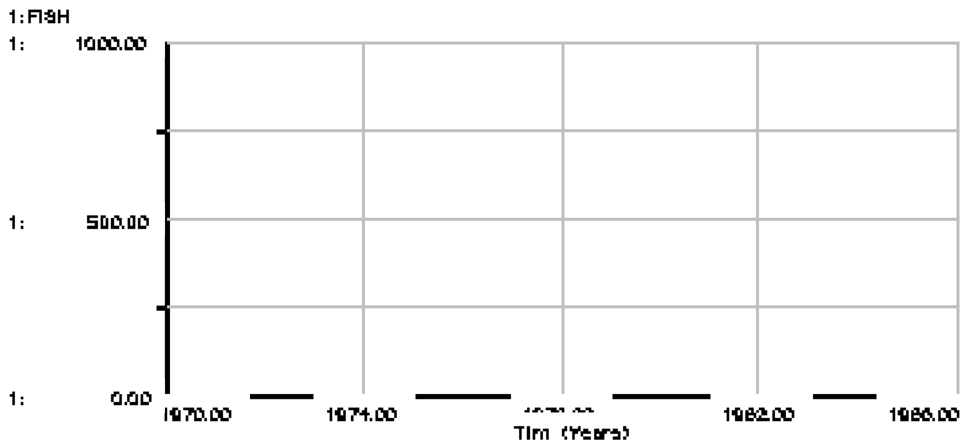
- **Select the Converter icon on the upper left portion of the STELLA Diagram Window**
- **Place the Converter icon just underneath the Ship Scrapping Rate flow**
- **Click the Mouse Button**
- **Type "Maximum Ship Lifetime"**
- **Double-click on Maximum Ship Lifetime and give it a value of 12 years**

All that remains is to determine the equation for the Ship Scrapping Rate. Assuming that the age of the ships is evenly distributed from young to old, about one-twelfth of the ships are scrapped each year due to old age. The equation defining ship scrapping rate is therefore the number of ships divided by the maximum age. To model this:

Draw a converter from SHIPS to Ship Scrapping Rate
Draw a converter from Maximum Ship Lifetime to Ship Scrapping Rate
Double-click on Ship Scrapping Rate
Define Ship Scrapping Rate to be SHIPS/Maximum Ship Lifetime

Once again try to predict how this policy will affect the number of ships, catch per year, and fish population by sketching on the axes below.





Run the model and sketch the behavior on the previous axes using either dashed lines or a different-colored pen.

Were your predictions correct? How does the behavior generated based on the new regulation differ from a system with no regulation? Try to tell the story of the differences between the two simulations by making reference to the feedback loops describing the system.

Continue to simulate the model with different maximum ship lifetimes. What happens if the maximum ship lifetime is made too short? Why?

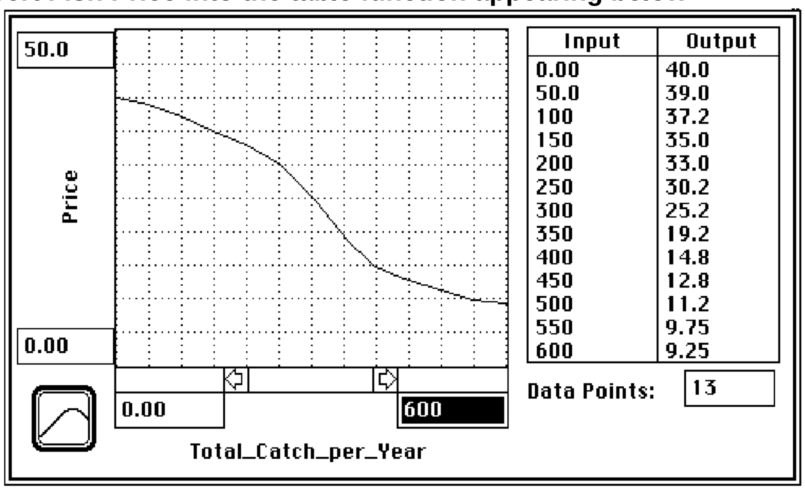
Do you think a regulatory policy such as this would be fair to the fishermen? Why?

6. Thus far, the fish price has always remained inelastic or constant relative to the actual supply of fish. In real life economics, the price of fish changes relative to the supply of fish. Thus, the price of fish will decrease if the total catch per year (supply) is higher for a particular year or increase if the total catch per year is smaller. To see how this affects the behavior of the system, first return the model to its original state:

- **Select "Revert to Saved" under the file menu**

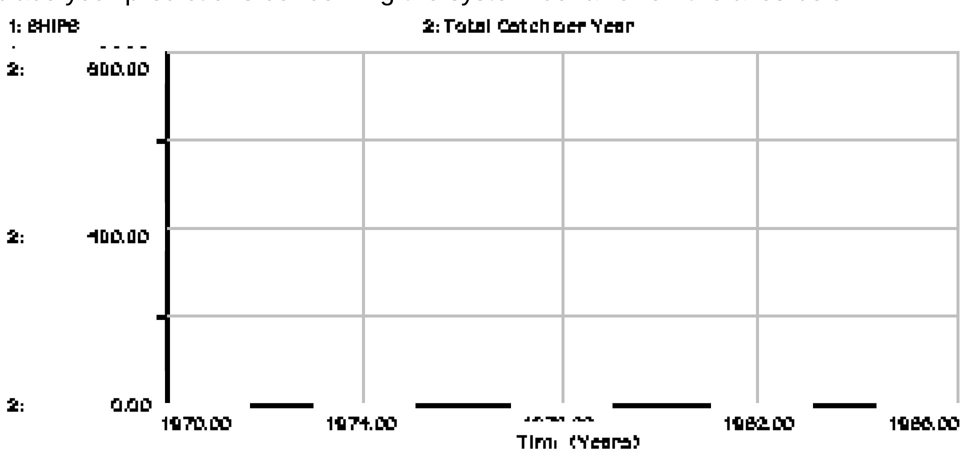
To implement the change:

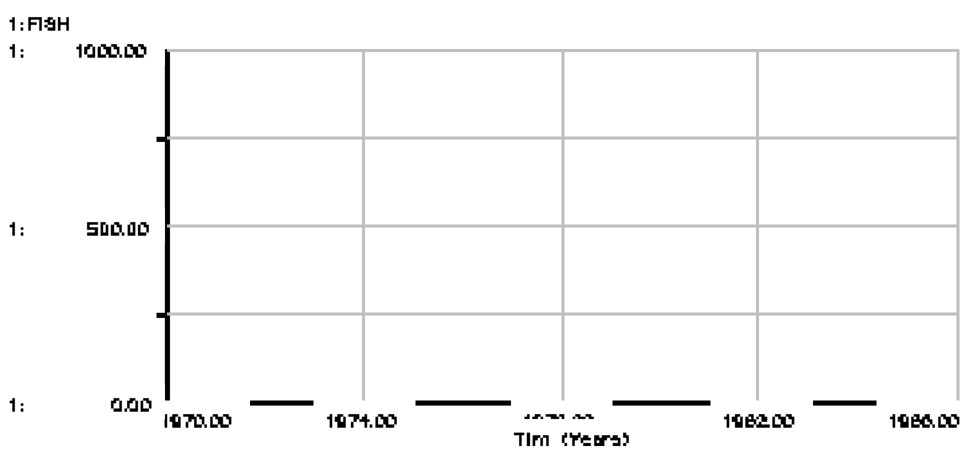
- **Draw a causal connection between the Total Catch per Year and the Fish Price**
- **Convert Fish Price into the table function appearing below**



Input	Output
0.00	40.0
50.0	39.0
100	37.2
150	35.0
200	33.0
250	30.2
300	25.2
350	19.2
400	14.8
450	12.8
500	11.2
550	9.75
600	9.25

Again, place your predictions concerning the system behavior on the axes below.





Run the model and sketch the computer simulated behavior on the previous axes using either dashed lines or a different colored pen.

Were your predictions correct? Explain why the simulation generated this behavior.

Examine the graph showing the yearly profits of the fishermen. Does an extremely elastic price curve seem to be an acceptable solution?

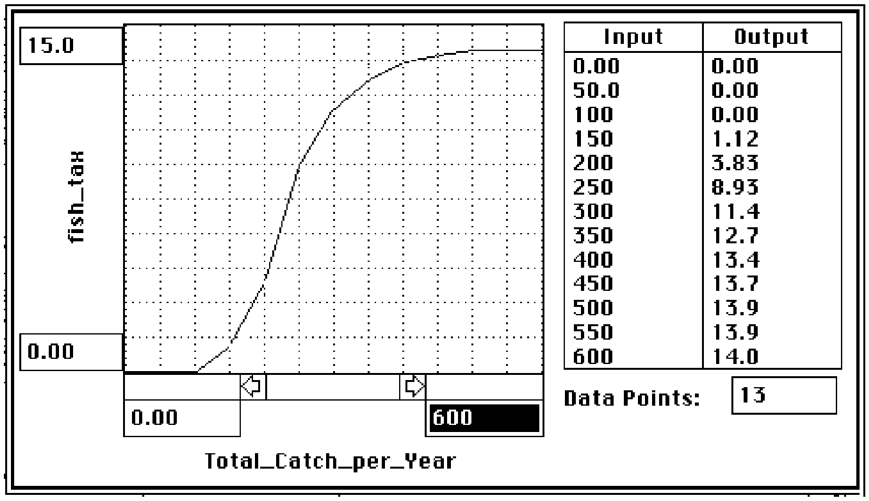
Change the price curve and re-simulate.

7. Suppose that we design an environmental tax which will tax the fishermen on a per fish basis based on the total number of fish which are caught each year. To implement this policy, first return the model to its original state:

- **Select "Revert to Saved" under the file menu**

To model the policy:

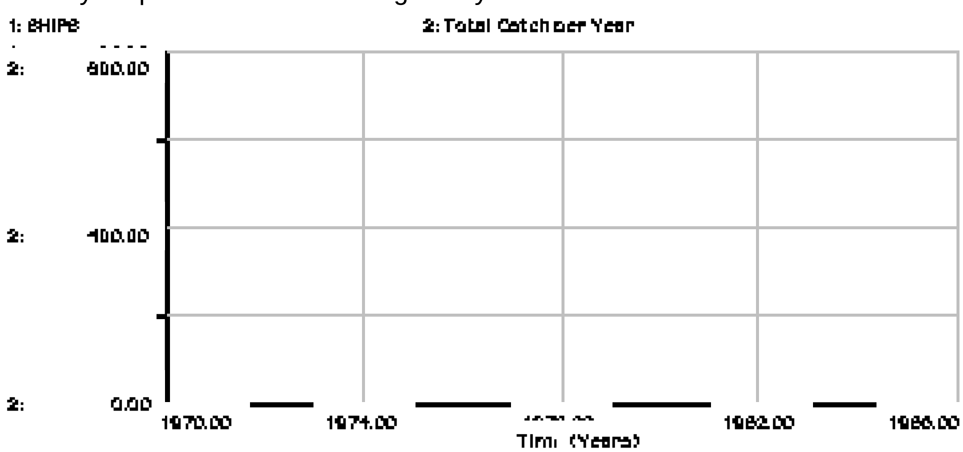
- **Create a new converter called Fish Tax**
- **Draw a causal connection from Total Catch per Year to Fish Tax**
- **Define Fish Tax as the table function shown below**

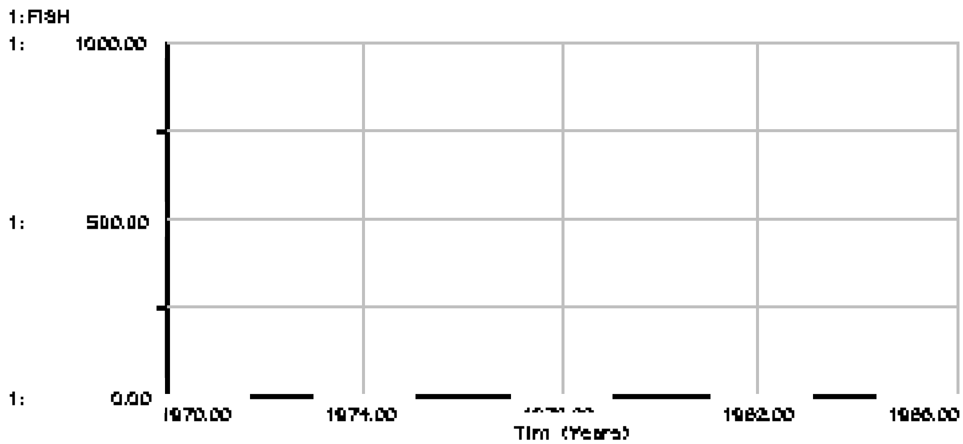


Input	Output
0.00	0.00
50.0	0.00
100	0.00
150	1.12
200	3.83
250	8.93
300	11.4
350	12.7
400	13.4
450	13.7
500	13.9
550	13.9
600	14.0

- **Draw a causal connection from Fish Tax to Costs**
- **Define Costs as "SHIPS*200 + Fish Tax"**

Again, sketch your predictions concerning the system behavior on the axes below.





Run the model and sketch the behavior on the previous axes using either dashed lines or a different-colored pen.

Were your predictions correct? How and why does such a policy affect the fishermen's profits? Is this an acceptable policy solution?

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8. Can you come up with any policies which have not been tried above? If so, list them below and attempt to model them if you have time.

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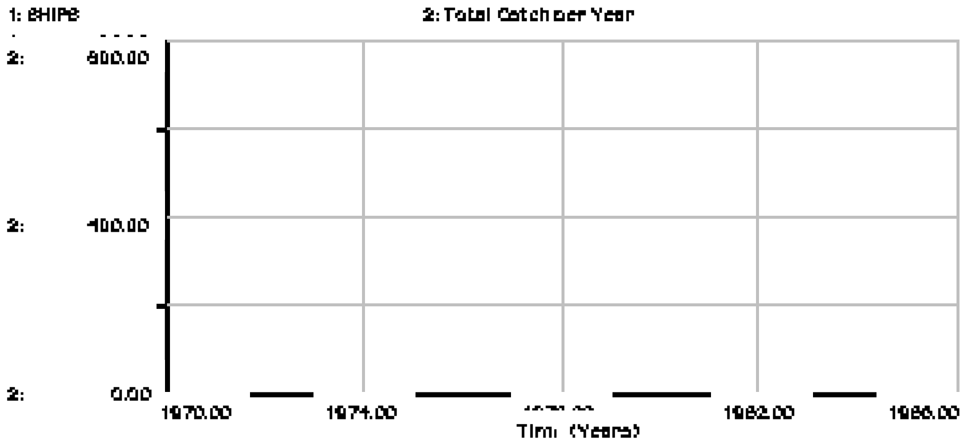
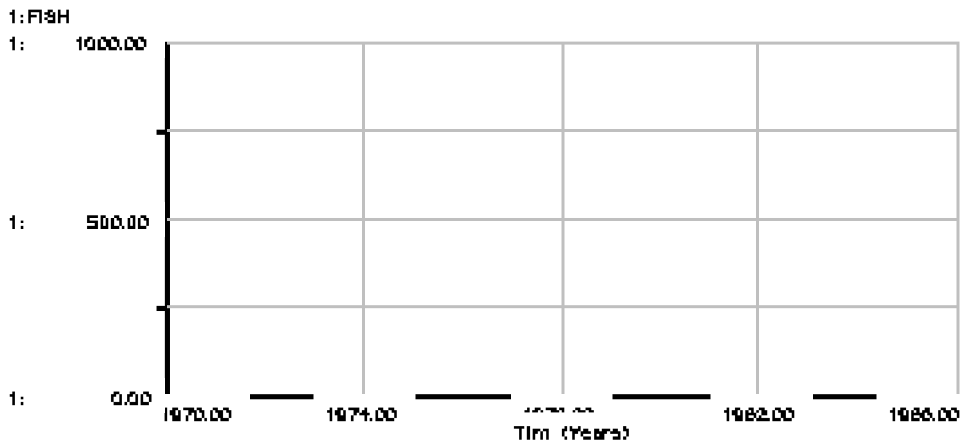
9. Devise your own regulatory plan incorporating any or all of the regulatory policies tested above. Implement your plan on the model, and record the results on the graphs below.





What final policy plan would you recommend to the Wildlife and Fisheries Service? Clearly state the goals you are trying to meet and describe what an effective policy should accomplish? Justify your choice, and explain how it will work. Give your predictions regarding how your policy plan will be accepted by fishermen, politicians, and the public. Describe any possible difficulties associated with the implementation of your plan.

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9 APPENDIX

9.1 Appendix 1: Selected Answers to Questions

<u>3.1.3 Modeling the Fish Population Subsystem: Page 16</u>

1. A positive or reinforcing loop is a loop where an initial change in an element of the loop will result in a change in the same direction of that element. Negative or balancing loops have the opposite effect. An initial change in the value of an element will result in a change in the opposite direction of that same element.

2. S-shaped growth occurs when you have a reinforcing growth process that is eventually brought under control by some growth constraint. An S-shaped growth structure consists of a positive growth loop and a negative balancing loop. Some real world examples include the spread of a rumor, infection of a population and growth of an economy.

3. The positive feedback loop is dominant for approximately four years. During this period the graph of the fish population seems to show pure exponential growth. After about five years, the dominance is shifted to the negative feedback loop. The dominance of the negative feedback loop causes the goal seeking behavior demonstrated in the last few years of the simulation.

<u>3.2.3 Modeling the Ship Subsystem: Page 19.</u>

1. The feedback loops are described in the explanation of the system.

2. As long as the *Catch per Ship* remains constant, as it does here, *Yearly Profits* and *SHIPS* will have the same shape curve. In the final model, they do not.

3. When *Catch per Ship* is 10, the company loses money each year, because the cost of maintaining a ship is greater than the revenue it produces. A *Catch per Ship* of about 12.5 is needed to break even. (i.e., *Yearly Profits* = 0)

<u>3.3.3 Modeling The Connection Subsystem: Page 23.</u>

1. The feedback loop is described in the explanation of the system.

2. The fishing companies are unaware of the plight of the fish population until it has been severely depleted. Because of this, it is impossible to protect the fish population with a reactive strategy. A proactive strategy is necessary. You will help design such a strategy in the Renewable Resource Depletion exercise. (D-4263)

9.2 Appendix 2: The Fishing Game on STELLA II version 2.2

Fishing Game v2.2.1 looks very much different from v3.0.5., but the basic ideas are exactly the same.

- ? **Make sure that STELLA II v2.2.1 is installed on your hard disk.**
- ? **Insert the disk labeled "Fish Banks Exercises" into your computer.**
- ? **Double-click on the disk icon labeled "The Fishing Game."**
- ? **In the window that appears, double-click on the icon labeled "The Fishing Game v2.2.1"**

If you have the STELLA II v2.2.1 program installed on your hard drive, the model you selected will open on your screen. If the model doesn't open, you need to open the STELLA program first and then open the model from within the program.

Your interface for the game is in a separate sector labeled "Control Panel." Figure 3 shows a picture of the control panel. The sector shown in Figure 3 is located in the upper-left corner of your STELLA diagram pad. If you do not see the sector shown in Figure 3, use the arrow bars on the bottom and right edges of the STELLA window to scroll the window until you see it.

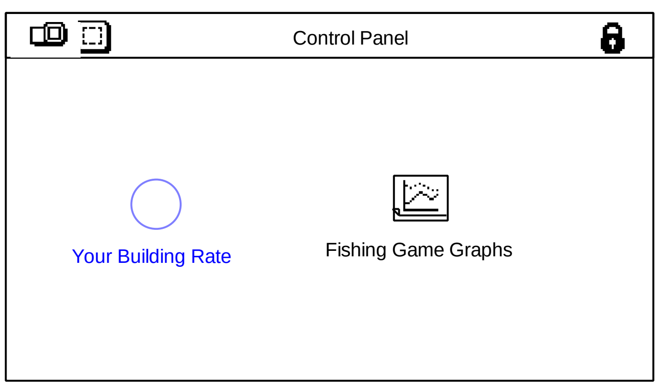


Figure 3: The Control Panel

This is the control panel through which you will control your fishing company in The Fishing Game. You can alter *Your Building Rate* each turn and observe the effects in the *FishingGame Graphs*.

? **Double-click on the icon labeled "Fishing Game Graphs" in the Control Panel.**

A graph window will appear on your screen. This window is called the graph pad, and it contains four graphs. At the top of the window is the title of the graph. The page number is on the bottom edge of the window. You can click on the lower-left corner of the graph pad to view the different pages, one at a time. These four graphs will allow you to track your own progress as well as that of your competitor. See Figure 4 on Page 8 for a list of the available graphs and the information each graph contains. At the end of each year, STELLA updates these graphs with current information. Please note that in graphs 3 and 4, the scales for the two elements are different.

? **Double-click on *Your Building Rate*.**

The dialogue box shown in Figure 5 should appear on your screen. The value for *Your Building Rate* from the previous year is highlighted. At the beginning of the game, this value will be zero.

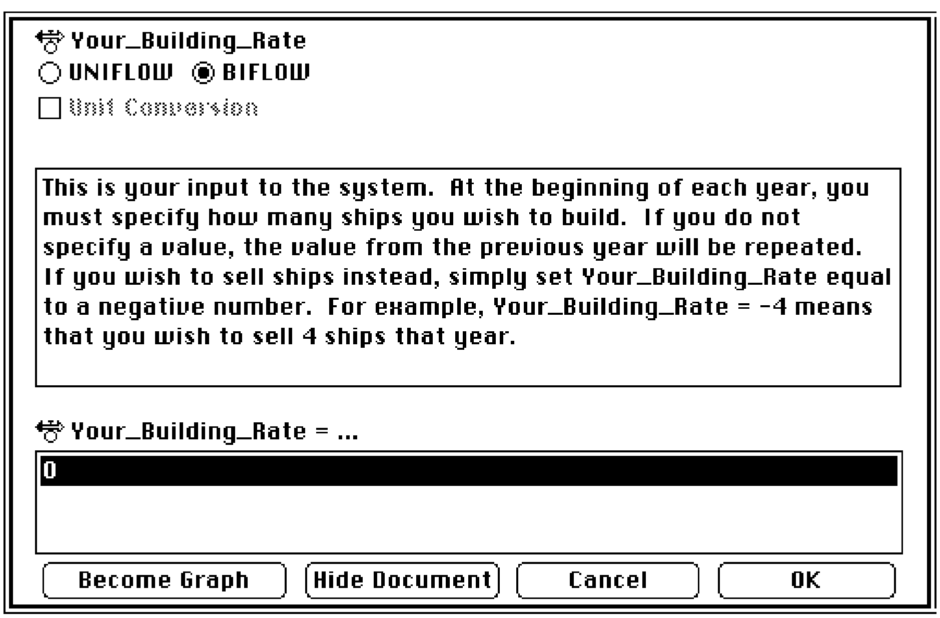


Figure 5: The input screen for *Your Building Rate*

This figure shows the dialogue box that will appear when you double-click on the *Your Building Rate* icon in the control panel. At the beginning of each round, set a value for *Your Building Rate* and then click on OK.

Implement your strategy for the game by setting a value for *Your Building Rate*. Before starting the next round of the game, specify how many ships you wish to build. If you wish to decrease the size of your fleet, you may sell ships by entering a negative number. If you do not set a value at the beginning of a year, you will build (or sell) the same number of ships as the previous year. You may track your previous decisions for *Your Building Rate* by looking at page 4 of the graph pad. Figure 4 contains a list of all available graphs and their contents.

? **Develop a strategy for maximizing your profits and beating your competitor.** (You may wish to re-read section 2.1 which briefs you on the game scenario.)
? **Enter the number of ships you wish to build the first year.**
? **Click on OK.**
? **Select "Run" from the Run menu or press Command-R.** The model will run for 1 year.
? **Double-click on the Fishing Game Graphs icon.**
? **Look at the four pages of the graph and observe the behavior of the model.**

***Note: After the first year, the Run menu will no longer contain the option “Run.” Instead, you should select “Resume.”

? **Continue entering values for *Your Building Rate* and running the model until the end of the simulation in 1990.**
? **Play the game a few times, revising your strategy each time to increase your profits.**

The game will automatically reset at the end of each 10 year simulation. You do not need to reset anything.

? **When you finish playing the game, select “Close” from the file menu.**
? **Click on “Don’t Save.”**

Please go to Section 3 now.

9.3 Appendix 3: The Fishing Game on STELLA II version 1

The Fishing Game on STELLA II version 1 is very similar to the game on version 2 because the model is the same, but playing the game is slightly different. The main reason for the difference is that STELLA II version 1 does not allow the user to input a pause interval as does version 2. Because of this, you will need to input your entire strategy for the game at the beginning, then run through all ten years of the simulation at once.

- **Insert The Fish Banks Exercises disk into your disk drive.**
- **Double-click on The Fishing Game disk icon.**
- **Open the Fishing Game v1.02 model by double-clicking on it.**

If you have STELLA II version 1 installed on your computer, the model will open. If the model doesn't open, you need to open the STELLA II program first, then open the model from within the program.

A small circular icon labeled "Your Building Rate" should appear in your STELLA window. This icon is located in the upper-left corner of the STELLA diagram pad. If you do not see it, use the scroll bars on the bottom and right edges of the STELLA window to scroll until you see it.

- **Double-click on *Your Building Rate.***

The dialogue box shown in Figure 14 should appear on your screen. The dialogue box allows you to enter your strategy for the entire simulation before running the model. Before running the simulation, set a value for *Your Building Rate* for each year of the game. You may do this directly on the graph with the mouse, or by clicking on the numbers in the right-hand column and entering new values with the keyboard. The default value is zero for each year.

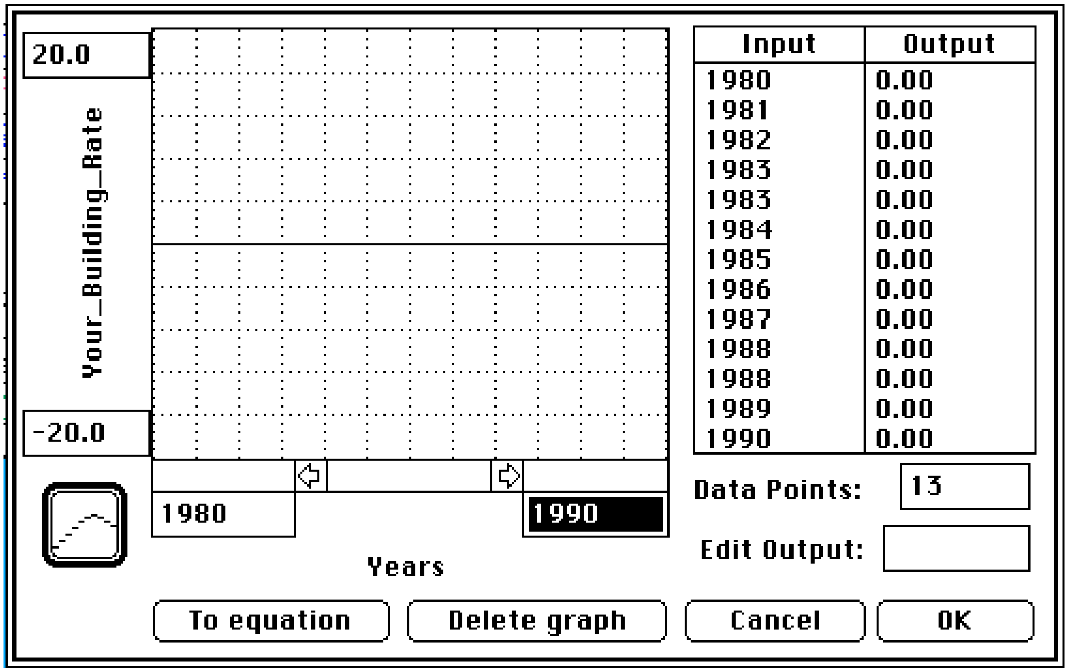


Figure 14: *Your Building Rate* dialogue box

This dialogue box allows you to enter your strategy for each year before running the simulation. Right now, it is set to build zero ships each year from 1980 to 1990.

? **Set the value of *Your Building Rate* for each year.**

? **Click on OK**

? **Run the model by selecting “Run” from the Run menu or by pressing Command-R.**

STELLA II version 1 does not use the graph icon. Instead, there is something called a “Graph Pad.” The same graphs are included in both versions of the fishing game.

? **Select “Graph Pad” from the Windows menu to open the Graph Pad.**

? **Click on the numbered boxes in the upper-right corner of the Graph Pad window to view the other graphs.**

? **See Figure 4 on page 8 for a description of the available graphs.**

? **Select “Diagram” from the Windows menu to return to the model.**

9.4 Appendix 4: The Fish Banks Model

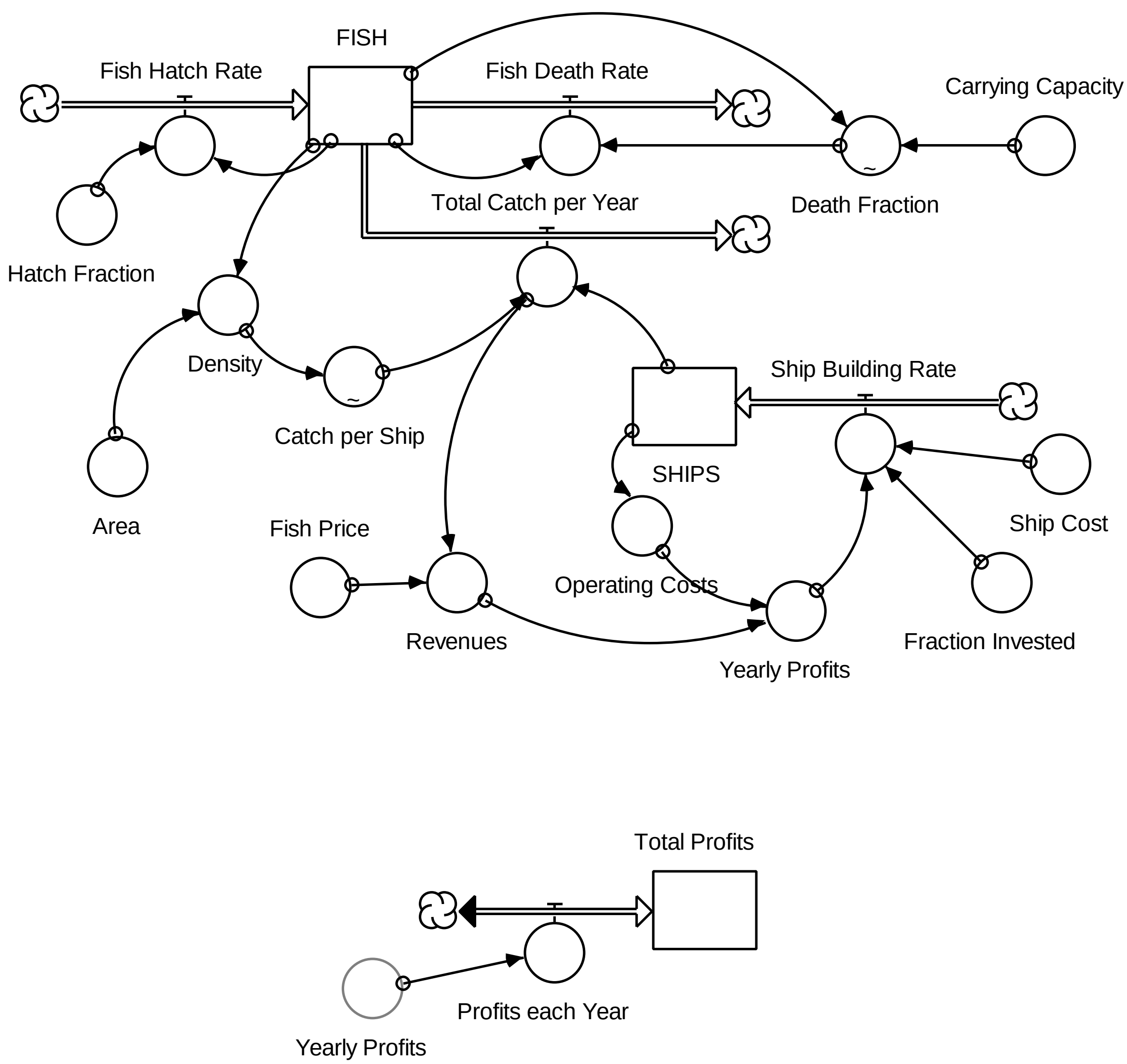


Figure 15: STELLA model of the Fish Banks system

This is the final model created by the reader. This model simulates the behavior of a fish population being depleted by a fishing industry.

The Fish Banks Model Equations:

FISH(t) = FISH(t-dt) + (Fish_Hatch_Rate- Fish_Death_Rate - Total_Catch_per_Year) * dt

INITIAL FISH = 1000

DOCUMENT: Fish are the number of fish alive within the fishing bed which is being modeled. At the beginning of the simulation there are initially 1000 fish alive in the bed.
UNITS: fish

INFLOWS:

Fish_Hatch_Rate = FISH*Hatch_Fraction
DOCUMENT: The fish hatch rate is the number of fish hatched per year. It is computed by multiplying the total fish population by a hatch fraction. The hatch fraction is the average number of offspring per year per fish.
UNITS: Fish/year

OUTFLOWS:

Fish_Death_Rate = FISH*Death_Fraction
DOCUMENT: Fish Death Rate is the number of fish per year which die from causes other than fish harvesting.
UNITS: fish/year

Total_Catch_per_Year = SHIPS*Catch_per_Ship
DOCUMENT: Total Catch per Year is the total number of fish which are harvested from the fishing waters each year. It is computed by multiplying the number of ships by the catch per ship.
UNITS: fish/year

SHIPS(t) = SHIPS(t - dt) + (Ship_Building_Rate) * dt
INITIAL SHIPS = 10
DOCUMENT: There are initially 10 ships at the beginning of simulation.
UNITS: ships

INFLOWS:

Ship_Building_Rate = Yearly_Profits*Fraction_Invested/Ship_Cost
DOCUMENT: The Ship Building Rate is the number of new ships which are built each year. It is determined by the amount of money invested each year in new ships (profits_each_year*fraction_invested) divided by the ship cost. The units are ($/year)/($/ship)=(ship/year).
UNITS: ships/year

Total_Profits(t) = Total_Profits(t - dt) + (Profits_each_Year) * dt
INITIAL Total_Profits = 0

INFLOW:

Profits_each_Year = Yearly_Profits

Area = 100
DOCUMENT: The Area is the size of the fish bed in square miles.
UNITS: square miles

Hatch_Fraction = 6
DOCUMENT: Hatch fraction is the average number of offspring per year per fish. It is the fractional increase in the population per year. A hatch fraction of 6 means that every female fish (half the fish population) will have an average of 12 offspring per year.
UNITS: 1/years

Carrying_Capacity = 1200
DOCUMENT: The carrying capacity is the total number of fish which the ocean environment can support.
UNITS: Fish

Operating Costs = SHIPS*250
DOCUMENT: The Total Cost is the number of ships times the operating cost per year of each ship. The cost per ship per year is 250 dollars.
UNITS: $/year

Density = FISH/Area
DOCUMENT: Density is the number of fish found per square mile within the fish bed.
UNITS: fish/square mile

Fish_Price = 20
DOCUMENT: Fish Price is the amount of money a fisherman can sell a fish for as soon as it is caught.
UNITS: $/fish

Fraction_Invested = .2
DOCUMENT: The Fraction Invested is the fraction of the profits each year which are invested in the building of new ships.
UNITS: (unitless)

Revenues = Total_Catch_per_Year*Fish_Price

DOCUMENT: Revenues are the moneys made each year through the sale of fish. Revenues are the number of fish sold each year times the price per fish.
UNITS: $/year

Ship_Cost = 300
DOCUMENT: The Ship Cost is the amount of money it costs to build a new fishing ship.
UNITS: $/ship

Yearly_Profits = Revenues-Costs
DOCUMENT: Profits each year are the difference between revenues and costs.
UNITS: $/year

Catch_per_Ship = GRAPH(Density)
(0.00, 0.00), (1.00, 5.00), (2.00, 10.4), (3.00, 15.9), (4.00, 20.2), (5.00, 22.1), (6.00, 23.2), (7.00, 23.8), (8.00, 24.2), (9.00, 24.6), (10.0, 25.0), (11.0, 25.3), (12.0, 25.5)
UNITS: fish/ship

Death_Fraction = GRAPH(FISH/Carrying_Capacity)
(0.00, 5.22), (0.1, 5.22), (0.2, 5.23), (0.3, 5.24), (0.4, 5.26), (0.5, 5.29), (0.6, 5.34), (0.7, 5.45), (0.8, 5.66), (0.9, 5.94), (1.00, 6.00)
UNITS: 1/years

Vensim Examples: Building the Fish Banks Model And Renewable Resource Depletion

By Aaron Diamond
October 2001

3.1.2 Building the Fish Population Subsystem model

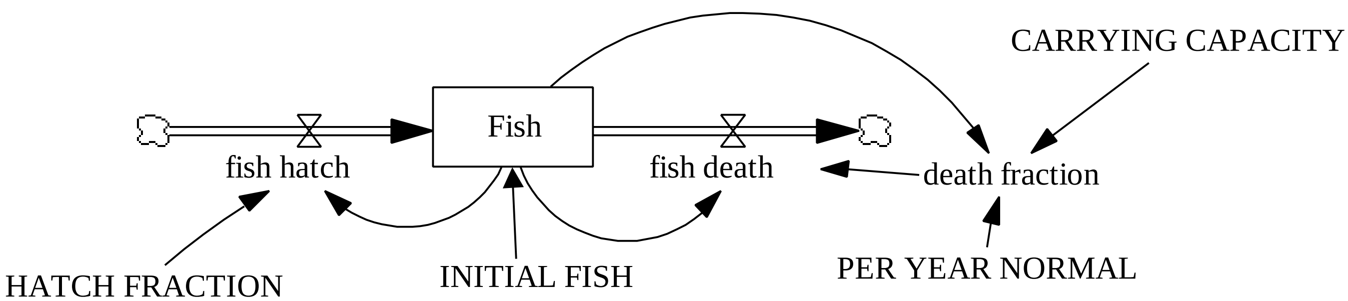


Figure 16: Vensim equivalent of Figure 7: Modified diagram of The Fish Population Model

Documentation for the Fish Population Model

(01) CARRYING CAPACITY=1200
Units: fish

(02) death fraction=Fish/CARRYING CAPACITY*PER YEAR NORMAL
Units: 1/year

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

(04) Fish= INTEG (+fish hatch rate-fish death rate,
INITIAL FISH)
Units: fish

(05) fish death rate=Fish*death fraction
Units: fish/year

(06) fish hatch rate=Fish*HATCH FRACTION
Units: fish/year

(07) HATCH FRACTION=6
Units: 1/year

(08) INITIAL FISH=10
Units: fish

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

(10) PER YEAR NORMAL=1
Units: 1/year

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

(12) TIME STEP = .0625
Units: year
The time step for the simulation.

3.2.2. Building the Ship Subsystem model

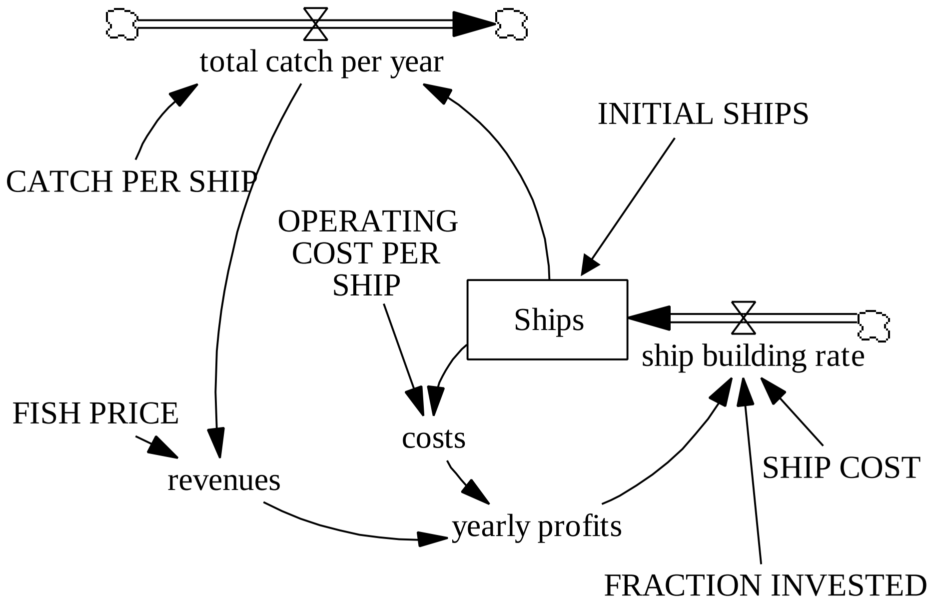


Figure 17: Vensim equivalent of Figure 9: Modified diagram of The Ship Subsystem

Documentation for the Ship Subsystem Model

(01) CATCH PER SHIP=15
Units: fish/ship

(02) costs=Ships*OPERATING COST PER SHIP
Units: $

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

(04) FISH PRICE=20
Units: $/fish

(05) FRACTION INVESTED=0.2
Units: 1/year

(06) INITIAL SHIPS=10

Units: ship

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

(08) OPERATING COST PER SHIP=250
Units: $/ship

(09) revenues=FISH PRICE*total catch per year
Units: $

(10) SAVEPER = 1
Units: year
The frequency with which output is stored.

(11) ship building rate=yearly profits*FRACTION INVESTED/SHIP COST
Units: ship/year

(12) SHIP COST=300
Units: $/ship

(13) Ships= INTEG (ship building rate, INITIAL SHIPS)
Units: ship

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

(15) total catch per year=Ships*CATCH PER SHIP
Units: fish

(16) yearly profits=revenues-costs
Units: $

3.3.2 Building the Connection Subsystem model

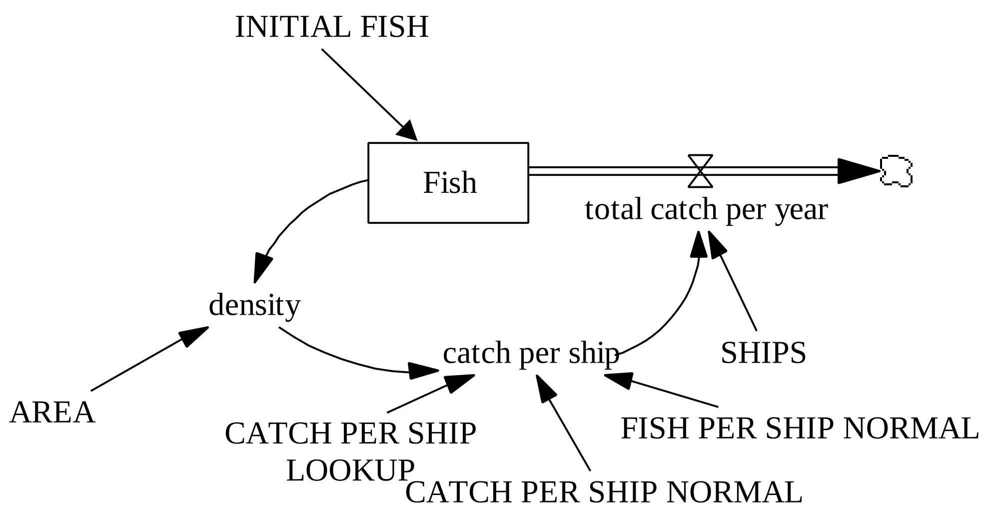


Figure 18: Vensim equivalent of Figure 11: Modified diagram of The Connection Subsystem

Documentation for the Connection Subsystem Model

(01) AREA=100
Units: square miles

(02) catch per ship=CATCH PER SHIP LOOKUP (density*CATCH PER SHIP NORMAL)*FISH PER SHIP NORMAL
Units: fish/(ship*year)

(03) CATCH PER SHIP LOOKUP=([(0,0)(10,40)],(0,0), (1,5),(2,10.4),(3,15.9),(4,20.2),(5,22.1), (6,23.2),(7,23.8),(8,24.2),(9,24.6),(10,25))
Units: dmnl

(04) CATCH PER SHIP NORMAL=1
Units: square miles/fish

(05) density=Fish/AREA
Units: fish/square miles

(06) FINAL TIME = 12
Units: year
The final time for the simulation.

(07) Fish= INTEG (-total catch per year,
INITIAL FISH)

Units: fish

(08) FISH PER SHIP NORMAL=1
Units: fish/(ship*year)

(09) INITIAL FISH=1000
Units: fish

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

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

(12) SHIPS=10
Units: ship

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

(14) total catch per year=SHIPS*catch per ship
Units: fish/year

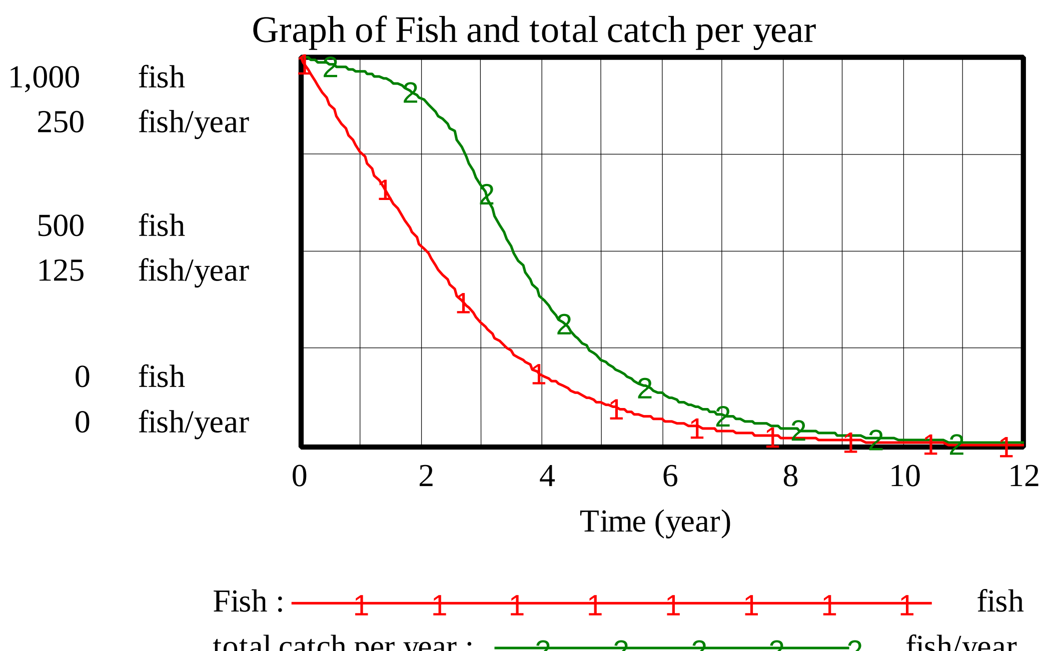


Figure 19: Vensim equivalent of Figure 12: Graph of the Connection System Behavior

7. Fish Banks Model Review

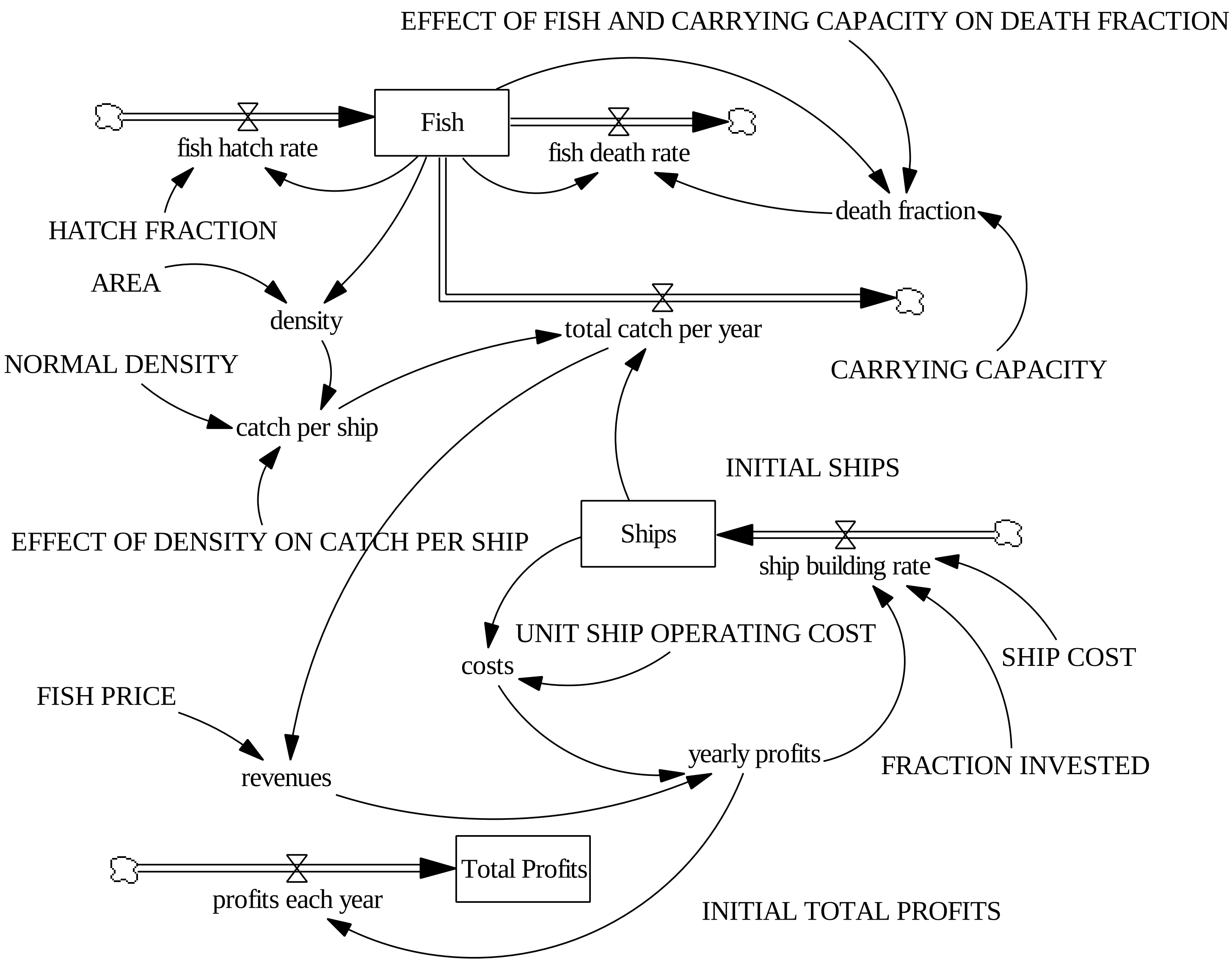


Figure 20: Vensim equivalent of Figure 13, Figure 15, and Figure 1 of the Fish Banks Policy Analysis Exercise: Vensim final model of the Fish Banks system

Documentation for Fish Banks Final Model

(01) AREA=100
Units: square mile
The Area is the size of the fish bed in square miles.

(02) CARRYING CAPACITY=1200
Units: fish
The carrying capacity is the total number of fish which the ocean environment can support.

(03) catch per ship=EFFECT OF DENSITY ON CATCH PER SHIP(density/NORMAL DENSITY)
Units: fish/ship/Year
The amount of fish caught per year.

(04) costs=Ships*UNIT SHIP OPERATING COST
Units: $/Year
The Total Cost is the number of ships times the operating cost per year of each ship.

(05) death fraction=EFFECT OF FISH AND CARRYING CAPACITY ON DEATH FRACTION(Fish/CARRYING CAPACITY)
Units: 1/Year

(06) density=Fish/AREA
Units: fish/square mile
Density is the number of fish found per square mile within the fish bed.

(07) EFFECT OF DENSITY ON CATCH PER SHIP([(0,0)-(12,26)], (0,0), (1,5), (2,10.38), (3,15.88), (4,20.25),(5,22.13),(6,23.25),(7,23.75),(8,24.25),(9,24.63),(10,25),(11,25.35),(12,25.48))
Units: fish/ship/Year

(08) EFFECT OF FISH AND CARRYING CAPACITY ON DEATH FRACTION([(0,5)(1,6)],(0,5.22),(0.1,5.225),(0.2,5.23),(0.3,5.24),(0.4,5.255),(0.5,5.29),(0.6,5.345),(0.7,5.45),(0.8,5.665),(0.9,5.94),(1,6))
Units: 1/Year

(09) FINAL TIME = 1986
Units: Year
The final time for the simulation.

(10) Fish= INTEG (fish hatch rate-fish death rate-total catch per year,

INITIAL FISH)
Units: fish
Fish are the number of fish alive within the fishing bed which is being modeled. At the beginning of the simulation there are initially 1000 fish alive in the bed.

(11) fish death rate=death fraction*Fish
Units: fish/Year
Fish Death Rate is the number of fish per year which die from causes other than fish harvesting.

(12) fish hatch rate=Fish*HATCH FRACTION
Units: fish/Year
The fish birth rate is the number of fish born per year. It is computed by multiplying the total fish population by a birth fraction. The birth fraction is the average number of offspring per year per fish.

(13) FISH PRICE=20
Units: $/fish
Fish Price is the amount of money a fisherman can sell a fish for as soon as it is caught.

(14) FRACTION INVESTED=0.2
Units: dimensionless
The Fraction Invested is the fraction of the profits each year which are invested in the purchase of new boats.

(15) HATCH FRACTION=6
Units: 1/Year
Birth fraction is the average number of offspring per year per fish. It is the fractional increase in the population per year. A birth fraction of 6 means that every female fish (half the fish population) will have an average of 12 offspring per year.

(16) INITIAL FISH=1000
Units: fish

(17) INITIAL SHIPS=10
Units: ship

(18) INITIAL TIME = 1970
Units: Year
The initial time for the simulation.

(19) INITIAL TOTAL PROFITS=0
Units: $

(20) NORMAL DENSITY=1
Units: fish/square mile

(21) Profits each Year=yearly profits
Units: $/Year
The amount of money made per year.

(22) revenues=FISH PRICE*total catch per year
Units: $/Year
Revenues are the moneys made each year through the sale of fish.
Revenues are the number of fish sold each year times the price
per fish. units: $/year

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

(24) ship building rate=MAX(0,yearly profits*FRACTION INVESTED/SHIP COST)
Units: ship/Year
The Ship Building Rate is the number of new ships which are
built each year. It is determined by the amount of money
invested each year in new ships
(profits_each_year*fraction_invested) divided by the ship cost.
The units are ($/year)/($/ship)=(ship/year).

(25) SHIP COST=300
Units: $/ship
The Ship Cost is the amount of money it costs to build a new
fishing ship.

(26) Ships= INTEG (ship building rate, INITIAL SHIPS)
Units: ship
There are initially 10 ships at the beginning of simulation.

(27) TIME STEP = 0.25
Units: Year
The time step for the simulation.

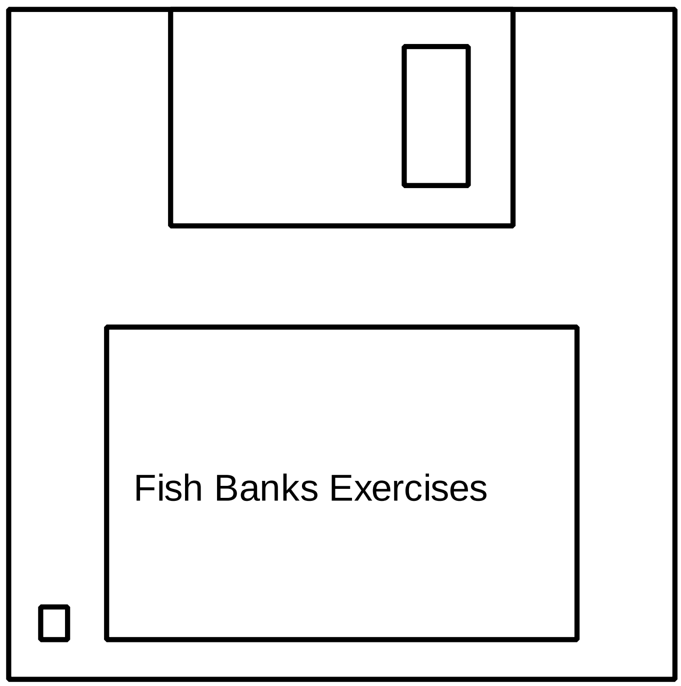
(28) total catch per year=Ships*catch per ship
Units: fish/Year
Total Catch per Year is the total number of fish which are
harvested from the fishing waters each year. It is computed by
multiplying the number of ships by the catch per ship.

(29) Total Profits= INTEG (Profits each Year,
INITIAL TOTAL PROFITS)

Units: $
Total Profit is the total amount of money made.

(30) UNIT SHIP OPERATING COST=250
Units: $/ship/Year
The unit ship operating cost is the cost of maintaining one ship for one year.

(31) yearly profits=revenues-costs
Units: $/Year
Profit each year are the difference between revenues and costs.



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