The ANCHOVY Simulation

Introduction:
So You Think You Can Do Better?

The ANCHOVY simulation gives you a chance to try your skills at fisheries management. You can invest in fishing boats and fishmeal plants, decide how many fish to catch and how many months of the year to keep the fishery open, and turn on random variations in recruitment and natural mortality to see how these environmental uncertainties affect the potential yields from the fishery. Finally, you can allow El Niños to occur and determine their impact on the fishery yields.

The economic constraints reflect conditions that prevailed during the 1960s. The simulation is designed to illustrate the folly of overcapitalization and the importance of not fishing down the stock to the point where recruitment is seriously compromised.

By running the simulation you can determine the maximum sustainable yield from the fishery under steady-state conditions, and you can determine the relationship between sustainable yield and the size of the adult stock. The simulation program was written using Matlab and can be run on either Macintosh or PC desktop computers.

Getting Set Up

You begin the simulation by typing in the word ANCHOVY and hitting the return key.

COMPUTER: WELCOME TO THE ANCHOVY GAME

COMPUTER: HOW MANY YEARS WOULD YOU LIKE THE SIMULATION TO RUN?

The simulation assumes that you begin with the virgin stock of anchovies, and it will of course take a few years to fish down that stock and settle down. A good running time is 100 years, but you can use shorter or longer times if you like.

ACTION: Type in the number of years and press the enter key.

COMPUTER: HOW MANY INDUSTRY UNITS DO YOU WANT TO BUY?

In ANCHOVY one fishing boat can catch about 50 tonnes of anchovies per day, and it takes 32 boats to supply enough anchovies for each fishmeal plant, which can process about 1,600 tonnes of anchovies per 20-hour day (down time at the plant is assumed to average 4 hours per day). One fishmeal plant and 32 fishing boats constitute one unit of the industry.

Each fishing boat has a crew of 13, and each fishmeal plant employs 50. So each industry unit employs $50 + 32 \times 13 = 466$ people. The variable costs (salaries, fuel, etc.) for a unit of the industry average $14,000$ per operating day, or about $14,000/466 = $30 per person-day. Fixed costs for one unit of the industry are assumed to be $180,000$ per month.

About 5.3 tonnes of anchovies are required to produce 1.0 tonne of fishmeal. The wholesale value of the fishmeal is about $110$ per tonne. So 1,600 tonnes of anchovies yield 302 tonnes of fishmeal worth $33,200$. You can catch about 0.42 Mt of anchovies per year with one industry unit operated at full capacity, and you will make a profit of about $2.9$ million.

In summary, for each industry unit:
Fishing boats = 32
Fishmeal plant = 1
Personnel = 466
Fixed costs = $180,000 per month
Variable costs = $14,000 per operating day
Revenue = $33,220 per operating day

A workweek is assumed to consist of seven days (sorry, no time off in the fishing industry), and all months are assumed to contain 365/12 days. If you invest in 20 industry units, you have the capability of catching 20 x 365 x 1,600 = 11.68 Mt per year or almost 1 Mt per month. The game does not allow you to catch more anchovies in a month than your investment in fishing boats and fishmeal plants will permit.

**ACTION: Type the number of industry units you want to buy and press enter. (You cannot buy fractional parts of industry units because you cannot build part of a fishmeal plant. If you try to invest in 8.7 industry units, for example, the computer will ignore the 0.7 and give you 8.0 units.)**

Controlling the Catch

ANCHOVY assumes that prior to your entry into the industry there has been no anchovy fishing. The virgin stock of adults (age five or more months) averages 14 Mt over the course of a year but varies a bit from month to month because recruitment is not constant. Your job is to set the catch quotas for as long as you choose to play the game.

There are several ways to control the catch. First, you can set an upper bound on the catch. Obviously that upper bound must be no greater than the maximum possible catch implied by the number of industry units you have purchased. Second, you can shut down the fishery for a month at a time if the biomass of anchovies has dropped below a level that you specify. The fishery will remain closed until the biomass has increased above your threshold value. A third built-in control is the fact that the game shuts down the fishery for a month at a time if your requested catch for the month exceeds the biomass of all the anchovies. In other words, not only are you forbidden to wipe out the stock of anchovies, but your catch will be set to zero for any month in which your requested catch would produce that result. Finally, you are given the option of arbitrarily closing the fishery during certain months of each year.

**COMPUTER: DO YOU WANT TO HAVE ANY CLOSED SEASONS (NO = 0, YES = 1)**

**ACTION: Type 1 for yes or 0 for no and press enter.**

If you responded yes, you will then be asked: **LIST THE MONTHS THE FISHERY IS TO BE CLOSED; JAN = 1, FEB = 2, ETC., IN MATRIX FORMAT, E.G., [1 2 7 10]**

For example, if you want the fishery to be closed during May, June, and July, you would type [5 6 7] and press enter. The months do not have to be consecutive, and you can enter them in any order. For example, typing [6 3 8] would cause the fishery to be closed during the months of March, June, and August.

**COMPUTER: AT WHAT LEVEL OF ANCHOVY BIOMASS WOULD YOU LIKE TO TEMPORARILY CLOSE THE FISHERY (ANSWER IN MILLION TONNES)?**

**ACTION: Type in the anchovy biomass below which you want the fishing to stop and press enter. You can type in zero if you**
like. As noted, the biomass will never drop
to zero, because the simulation will always
shut down the fishery if the requested catch
for the month exceeds the biomass at that
time.

At this point the computer will tell you
your maximum allowable catch in Mt. For
example, if you invested in 20 industry units
and specified no closed seasons, your
maximum allowable annual catch is 11.68
Mt. If you specified a closure during two
months, then your maximum allowable
catch would be \((10/12) \times 11.68 = 9.73\) Mt.

**COMPUTER**: WHAT WOULD YOU
LIKE THE ANNUAL CATCH TO BE IN
MILLION TONNES?

You can specify any catch less than or
equal to the maximum allowable. (If you
specify a larger number, the computer will
set the catch equal to the maximum.) Why
would you want to specify a catch less than
the maximum? By adding industry units one
at a time you increase the allowable catch by
0.584 Mt (if the fishery is open year round).
Economically it is unwise to specify a catch
that is not an integral multiple of 0.584 Mt.
For example, if you want to try to catch 5.0
Mt of fish per year, then you would need to
invest in at least nine industry units, which
would allow you to catch 5.256 Mt at full
capacity. However, keep in mind that the
more your capacity to catch fish exceeds
your actual catch, the less money you will
make. Idle boats and fishmeal plants cost
you money.

**ACTION**: Type in a number and press
enter.

The computer will tell you what your
maximum annual catch will be, your
estimated operating costs, your maximum
annual revenue, and your maximum annual
profit. The actual numbers at the end of the
simulation may be less than these if the
fishery is forced to shut down from time to
time because the anchovy biomass has
dropped below the threshold you specified
or because your requested catch has
threatened to wipe out the stock during some
months.

**Random Variability**

The problems that will confront you in
achieving your catch goals are
environmental variability and uncertainty.
You can reduce the uncertainty to a
minimum by requesting that recruitment and
natural mortality be nonrandom and that
there be no El Niños. The natural mortality
rate will be 16% per month, and the
relationship between recruitment and adult
population size will follow the curve shown
in Figure 14.

**COMPUTER**: DO YOU WANT
RANDOM RECRUITMENT AND
NATURAL MORTALITY? (NO = 0, YES
= 1)

If you request random recruitment and
natural mortality, then recruitment will on
the average follow Figure 14 but will vary in
a random manner between a minimum equal
to \(2/3\) and a maximum equal to \(4/3\) of the
value predicted by the curve. Similarly,
natural mortality will average 16% per
month but will vary in a random manner
from a minimum of 6.4% to a maximum of
25.6% per month (a factor of four). This
range of variability is consistent with field
observations (see Figure 7).

**ACTION**: If you want random recruitment
and natural mortality, respond yes by typing
1. If not, type 0.
The sequence of El Niños is taken from a 470-year record dating back to 1520. During this time there were a total of 110 El Niños, 62 classified as moderate, 33 as strong, 10 as strong/very strong, and 9 as very strong. If you elect to subject your fishery to El Niños, the program starts you out at a random point in the historical record and continues for as many years as you choose to play the game. The cycle repeats itself every 470 years. All El Niños begin in January and last for one year.

During El Niños the growth rates of anchovies are reduced by an amount directly proportional to the strength of the El Niño. El Niños are assumed to affect the productivity of the anchovy stock, but there is no consistent correlation between El Niños and either natural mortality or recruitment. El Niños do depress photosynthetic rates off the coast of Peru. During the months of peak intensity the depression may amount to a factor of 10 or more, but annual average photosynthetic rates do not fluctuate as much. The lowest annual photosynthetic rates are about 60% of the maximum rates. ANCHOVY assumes that the lowest rates are associated with very severe El Niños and that the extent of the depression is linearly related to the intensity of the El Niño. So El Niños are assigned to one of four categories: moderate, strong, strong/very strong, and very strong. The growth rates of the anchovies are assumed to be directly proportional to the photosynthetic rates and hence are assumed to be depressed by 10%, 20%, 30%, and 40%, respectively.

ACTION: As before, 0 means no, and 1 means yes.

Once you push the enter key, the simulation will run for the number of years you have specified. The computer will print out the average annual catch in Mt, and the average annual profit, cost, and revenue, all in millions of dollars. The computer will also generate four graphs: annual catch of anchovies in Mt, annual profit in millions of dollars, average annual anchovy biomass in Mt, and annual recruitment (R) and fishing mortality (F) in trillions of fish.

Some Tips

When you are first becoming familiar with the game, set the catch to zero so that you can study the behavior of the anchovy population in the absence of fishing. With random recruitment and natural mortality, you will find that the anchovy stock goes through some perhaps surprising fluctuations. Over the course of 100 years, the biomass may be as high as 3040 Mt and as low as 5 Mt. This natural variability is what makes management of the fishery difficult. If you invest in enough industry units to take full advantage of the good years, you will lose money during bad years, because your boats and fishmeal plants will be idle much of the time during bad years. On the other hand, if you invest in only a few industry units to avoid losing money during the bad years, you will be unable to take full advantage of the years when the anchovies are abundant.

You will find that one of the critical determinants of success in managing the fishery is the size of the stock when the fishery is shut down. If you make that cutoff too low, recruitment to the adult stock will be poor, and the fishery will remain unproductive for the rest of the game. This is known as recruitment overfishing. On the other hand, if you make the cutoff too high, the fishery will be shut down so much of the
time that your average catch will again be small. This is underfishing.

There are several interesting questions you can explore with the game. First, try managing an industry of the size that actually existed in the late 1960s: 1,450 boats (45 industry units). Can you make a long-term profit with 45 industry units? Second, is the strategy that maximizes the long-term profit the same strategy that maximizes the long-term catch? Third, is there any advantage to having closed seasons, and if so, does it make any difference at what time of year you close the fishery?