A Simple Example of How System Dynamics Modeling Can Clarify, and Improve Discussion and Modification, of Model Structure[1]

Richard G. Dudley[2] and Chris S. Soderquist[3]

The field of system dynamics grew out of engineering feedback control systems and electronics and, over the past 40 years, use of this approach has spread to a number of other fields. Within the past 10 years further use of this approach has been aided by the development of graphical modeling environments such as Stella, VenSim, and PowerSim. While mathematical and computer modeling have long been an integral part of fisheries management, use of system dynamics modeling in fisheries is relatively rare. The biomass dynamic model of Schaefer is a simple model familiar to fisheries professionals, and forms the basis of several similar models. It provides a simple example of how system dynamics modeling encourages an explicit representation of model structure, and mediates discussion and modification of a model.

Introductory Comments

Ecological and natural resource systems have been subjects of interest for fifty years or more. Over this same period techniques for the analysis of system structure and dynamics have been refined. Approaches for the study of systems emerged as a distinct field within engineering: system dynamics. Subsequently system dynamics was applied to management science and other fields. Most system dynamics workers recognize Jay W. Forrester as the father of system dynamics and his classic, *Industrial Dynamics* (Forrester 1961), was probably the first highly detailed application of system dynamics techniques to non-engineering problems. This was later followed by *Urban Dynamics* (Forrester 1969) and by *World Dynamics* (Forrester 1971) which was a precursor to the well known *Limits to Growth* models (Meadows et al 1972)[4]. These and other works helped to establish the idea that system dynamics modeling not only helps us describe and understand systems, but can be useful in exploring possible scenarios to solve complex real world problems, including those involving human behavior and soft variables.

Various systems approaches have been used in ecology and natural resource management for many years (e.g. Watt 1968, Patten 1971, Holling 1978, Walters 1986). The need for, and utility of, these approaches have recently been summarized by Grant (1998). Academic interest in systems approaches to natural resource management seems inconsistent with the relative scarcity of actual application of these approaches for solving fishery management problems. Increased application of the relatively standardized, simple, yet rigorous approach of Forrester may help alleviate this scarcity. Some recent examples of application of the system dynamics modeling approach to fisheries management are Ruth and Lindholm (1996) and Holland and Brazee (1996).

The importance of improving our ability to manage dynamic natural resource systems has been recently pointed out by Moxnes (1998a, b). In simulation settings he found that would-be managers, including those well trained in population dynamics, consistently overharvested a model stock even when given cash rewards for proper management.

In some senses system dynamics can be viewed as a quasi- standardized framework (i.e. the stock flow modeling paradigm and associated rules) within which systems, and the human

---

[1] For presentation at the 129th Annual Meeting of the American Fisheries Society, Charlotte, North Carolina. August 1999.

[2] Jalan Pangrango 6, Bogor, Indonesia. rdudley@indo.net.id

[3] One Smith Road, Hanover, NH 03755 Chris.S.Soderquist@@pontifexconsulting.com

[4] Which, more recently, was followed up with *Beyond the Limits* (Meadows et al 1992).

policies that drive many of them, can be rigorously examined. By stretching this point a bit we could say that, just as statistics provides a framework for examining data, system dynamics could provide a framework for examining systems.

Forrester's system dynamics approach utilizes stock and flow modeling which follows variables over time. Calculations are accomplished via numerical integration over short solution intervals (e.g. Δt) which requires computing power and appropriate software. During the 60's and 70's the software used was usually DYNAMO. During the 1980's system dynamics software developers took advantage of the new computing capabilities. Current software allows onscreen creation of the model structure of stocks, flows and auxiliary variables, and has convenient user interfaces allowing detailed examination of very complex model structures and output.[5] These improvements have drastically improved the accessibility of this modeling approach.

An Example Using the Schaefer Model

The Schaefer biomass dynamic model provides a simple example, with which we are all familiar, of how a system dynamics modeling approach can help to:

1) clarify the structure of a model and
2) lead to a clearer discussion of possible model modifications.

The typical formulation of the Schaefer model (Schaefer 1954) equates the rate of change of population biomass to inflows of biomass minus biomass outflows. It is typically presented as follows:

$$\frac{dB}{dt} = rB\left(1 - \frac{B}{k}\right) - qEB$$

Where *B* is population biomass, *r* is intrinsic rate of increase, *k* is biomass of the un-fished stock. The expression *qEB* (often presented as *C*) is the catch where *q* is the fraction of the stock caught by one unit of effort and *E* is the number of units of effort.

But even if presented as follows:

$$\frac{dB}{dt} = rB - \frac{rB^2}{k} - qEB$$

this simplest of models is not something we could present profitably in a public forum for discussion.

This illustrates one way in which system dynamics modeling differs from many other forms of modeling: the system dynamics modeler generally tries to formulate each component of a model separately, defines the structure linking components and then "lets the software do the talking". Mathematical modelers, on the other hand strive to develop one summary "elegant" equation that will calculate the answer for a particular set of inputs. Other forms of modeling are, perhaps, somewhere in between. While other forms of computer modeling appear to

[5] Some examples of such software are:
Stella - High Performance Systems, Inc., 45 Lyme Road, Suite 200, Hanover, NH 03755, USA. http://www.hps-inc.com
VenSim - Ventana Systems, Inc., 60 Jacob Gates Road, Harvard MA 01451, USA. http://www.vensim.com
PowerSim - Powersim Corporation, 1175 Herndon Parkway, Suite 600, Herndon, VA 20170 http://www.powersim.com/

parallel the above approach, they emphasize step by step programming which often takes precedence over a careful examination of system structure.

We have all seen the above equation, and probably have examined the underlying logic. We recall that the rate of increase with respect to time is equal to biomass times the constant r. That *-qEB* represents the removal of biomass as catch is also obvious. But why is that extra r in the outflow side, and what exactly is the meaning of B^2?

Presented in a typical system dynamics stock and flow diagram (Figure 1) the biomass dynamic model seems much clearer and the mathematical formulation of each component is explicitly stated.[6]

In answer to the questions posed above, firstly we can clearly see that *r*, the rate of increase, also equals the rate of decrease in the absence of fishing. That is, the inflow to biomass must equal normal outflow when there is no catch.

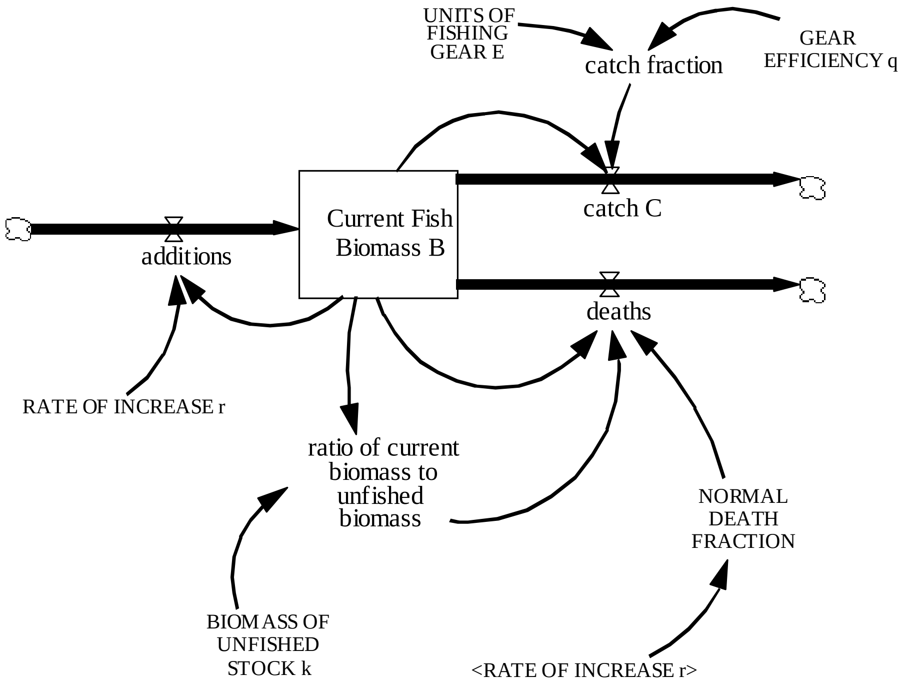


Figure 1. A system dynamics model formulation (here the Schaefer biomass dynamic model) facilitates examination of model structure and assumptions. The rectangle labeled Current Fish Biomass B is a stock, or accumulation. Metaphorically, it is similar to a bathtub containing all the biomass. The thick arrows are flows. Whatever accumulates in the bathtub flows in and out via these pipes. For example, the "additions" flow adds biomass to the stock by flowing into the Current Fish Biomass B stock at a rate of some amount of biomass per unit time (where time is the chosen time interval, Δt).

To someone not familiar with the model it becomes clearer that in this model we have assumed a proportional effect of fish biomass on deaths. That is , we have assumed that the effect of current biomass on death fraction is equal to the biomass ratio *B/k*. In other words we assume that natural death of biomass from the population is equal to the normal death fraction *r* multiplied by *B* further multiplied by *B/k*.

So the origin of $\frac{rB^2}{k}$ becomes apparent as

"normal deaths" *rB* times the "effect of biomass on death" $\frac{B}{k}$.

[6] See page 13 for model equations.

Of course this model was originally developed to calculate equilibrium yields under certain conditions. System dynamics models, on the other hand, are typically used to gain an understanding of system behavior over time. Looking at this familiar model with a system dynamics approach helps us understand its structure better. A selection of fishing pressures for the above model result in the following graph (Figure 2). Note that the traditional parabolic curve of equilibrium yield vs. biomass can also be produced from the various equilibrium yields and corresponding biomass levels (Figure 3).

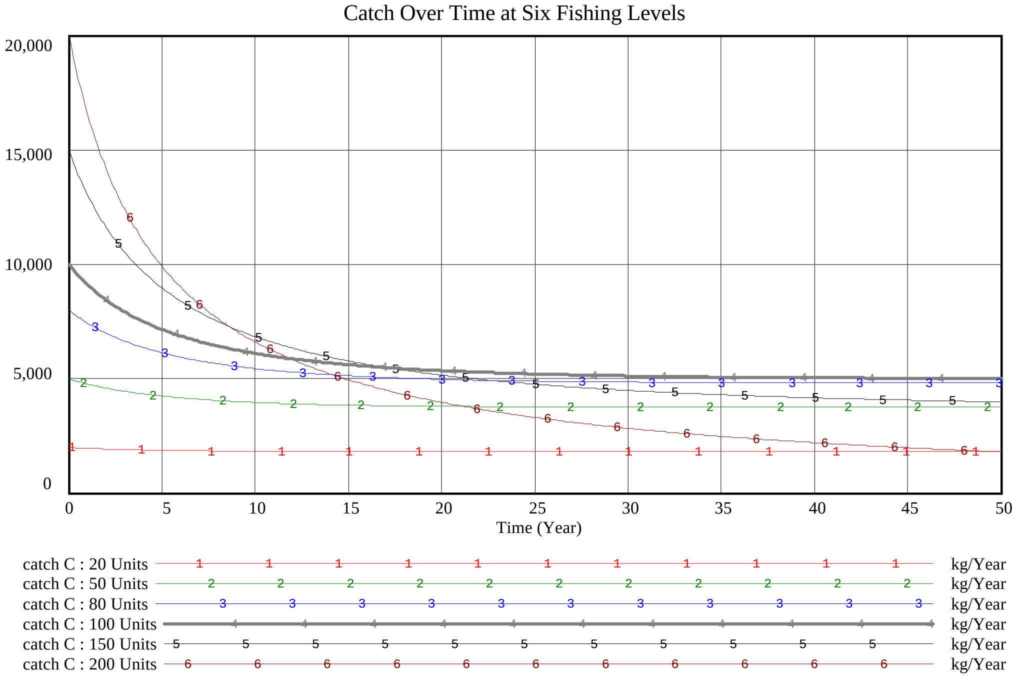


Figure 2. Example output from the Schaefer model for 6 fishing levels emphasizes the fact that system dynamics models typically follow model variables over time.

This is a predictable result: the model is not dynamic, the rates do not change (except when the user changes them). As expected, for each selected "units of fishing gear" an equilibrium yield is reached, and as expected there is a maximum equilibrium yield obtained when the stock biomass is 50% of the un-fished biomass.

While this result is not particularly surprising, it nevertheless, leads us to three important points about this modeling approach:

1) Current system dynamics modeling tools present a format that encourages discussion and suggestions for model construction both from specialists and non-specialists. This is because:
   (a) The visual layout encourages an overall understanding of the system being modeled.
   (b) Each component is clearly identified.
   (c) The relationships among components are clearly specified.
   (d) Programming is handled by the software, leaving the developer to work on model, rather than programming, logic.

2) System dynamics modeling techniques, which use computer-based numerical integration, allow us to easily examine complex systems that do not have explicit mathematical solutions.

3) Consequently, such models are easily modified to examine both changes in model parameters as well as changes to model structure.

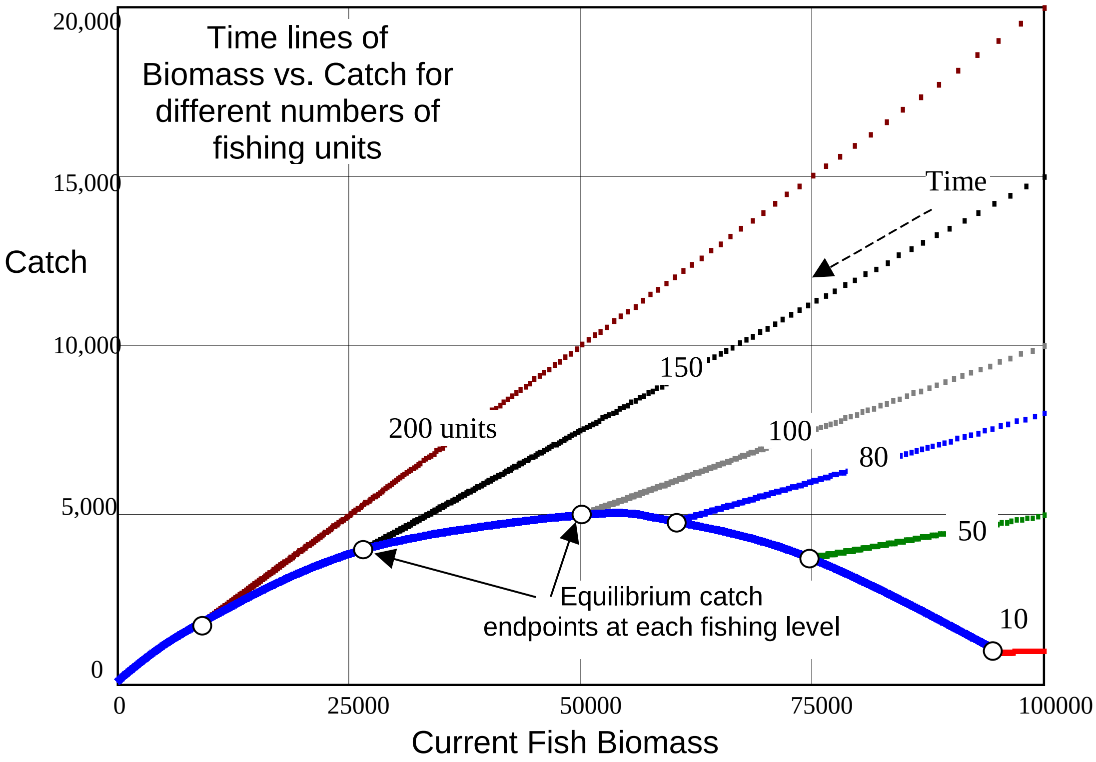


Figure 3. Of course, data can also be presented in other formats. Here, time lines for each fishing level terminate at each equilibrium catch. The traditional format of the model illustrates that equilibrium catch is maximized at an intermediate biomass.

A model is comprised of cause-and-effect assumptions. Pure mathematical models are difficult to interpret regarding what particular assumptions have been made in their formulation. System dynamics models make those assumptions visible. Looking at the model again we can see several areas for possible improvement that might not be obvious in the mathematical formulation. In a classroom situation, for example, it might be possible to ask students for suggestions for improving the model, which will also encourage thought about how fishery management works.

One might ask, for example:

1) Might biomass ratio also have an effect on inflow to the stock? Perhaps as the stock drops further from k then the intrinsic rate of increase would increase? Or is the density dependency of the deaths a sufficient description of the system?

2) In the model the number of fishing units is fixed by the model operator. What happens in the real world? Perhaps number of fishing units could be modeled as being dependent on catch per unit?

3) How might one model agency decisions about numbers of fishing permits to be issued in a limited entry fishery?

Model Modification 1: Catch per Unit Effort Affects Vessel Entry and Exit from the Fishery

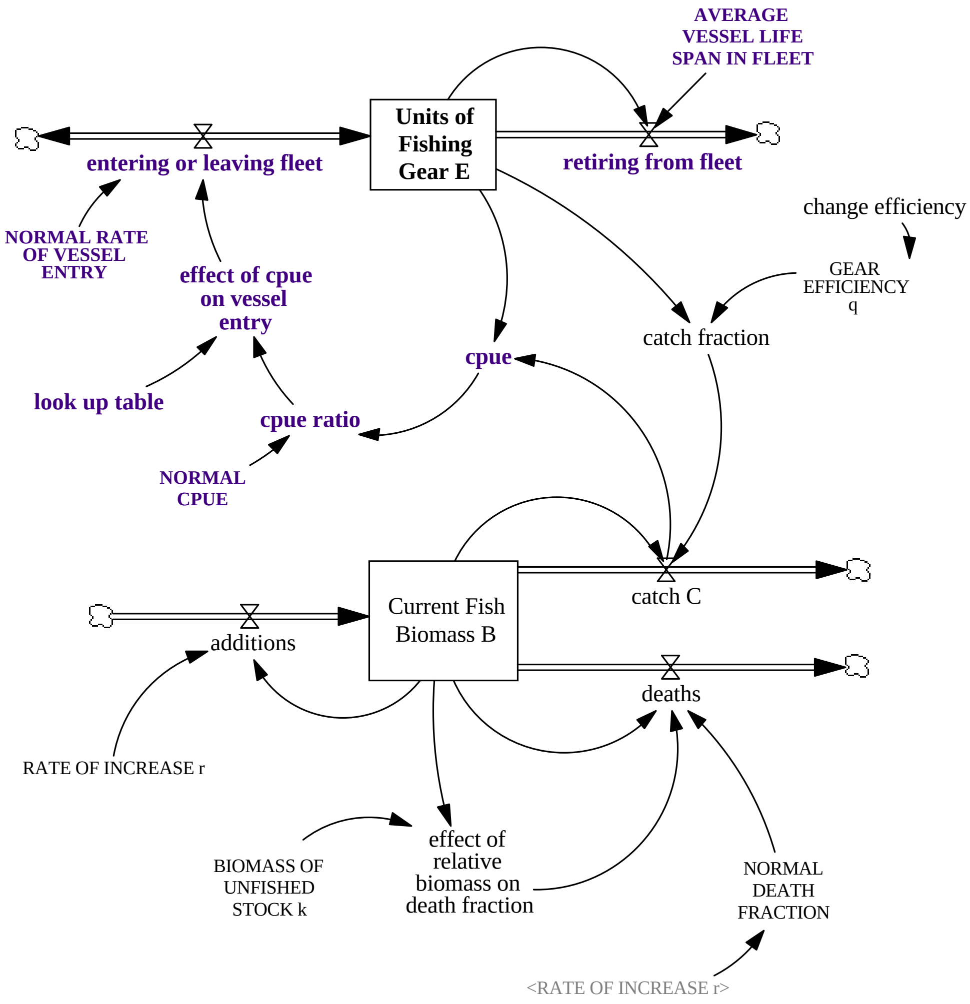


Figure 4. A modification of the original model to reformulate "Units of fishing Gear E" as a stock which grows more rapidly if cpue (catch per unit effort) is high.

This second suggestion (above) could be formulated as presented in Figure 4.[7] Here we have substituted a small sub-model in place of "units of fishing gear" which appeared in the original model. In this sub-model "units of fishing gear" has been made dependent on catch per unit effort (cpue). While we could use the actual ratio (of current cpue to that at maximum equilibrium) or some multiplier, we chose instead to use a "lookup table or graph input" which is presented in Figure 5.

Such graphs can be adjusted by the model user to indicate how the user thinks cpue (for example) might affect the entry of new units of fishing gear into the fishery. This can make the model clearer and facilitates increased participation from non-specialists. The lookup table also reminds us that system dynamics modeling frees us from reliance on mathematically tractable formulations.

[7] See page 15 for model equations.

Of course, in addition to the insights gained from building and modifying models, there is the usual benefit to be gained from examining the consequences of changing model parameters. As an example we have presented some scenarios using the modified model.

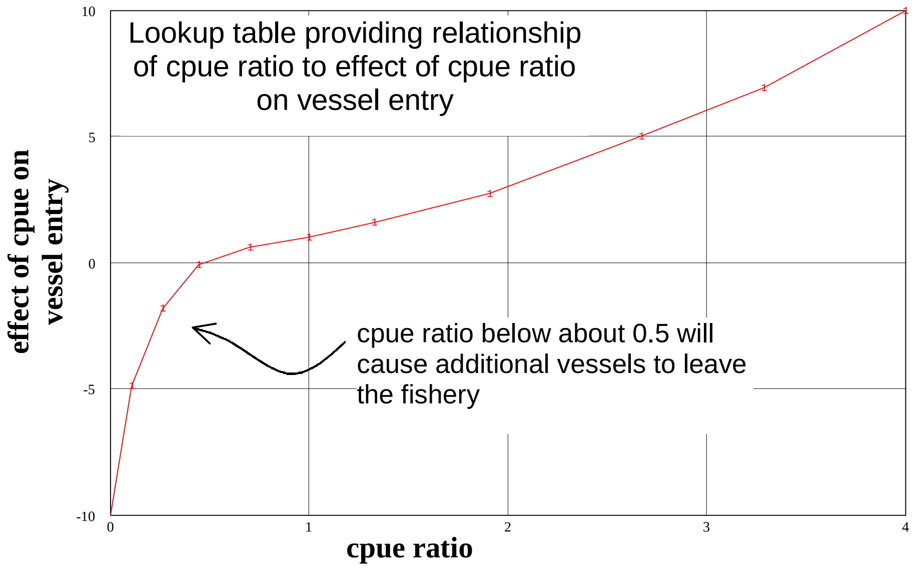


Figure 5. A lookup "table" showing the proposed relation between "cpue ratio" (x) and "effect of cpue on vessel entry " (y). As with most lookup functions the point (1,1) defines the normal value; in this case where there is no additional effect of cpue. Explicit statements regarding how each model component is calculated allow improved discussion of the model by all stakeholders. Values of points in the lookup function are provided in the model equation for "look up table " on page 15.

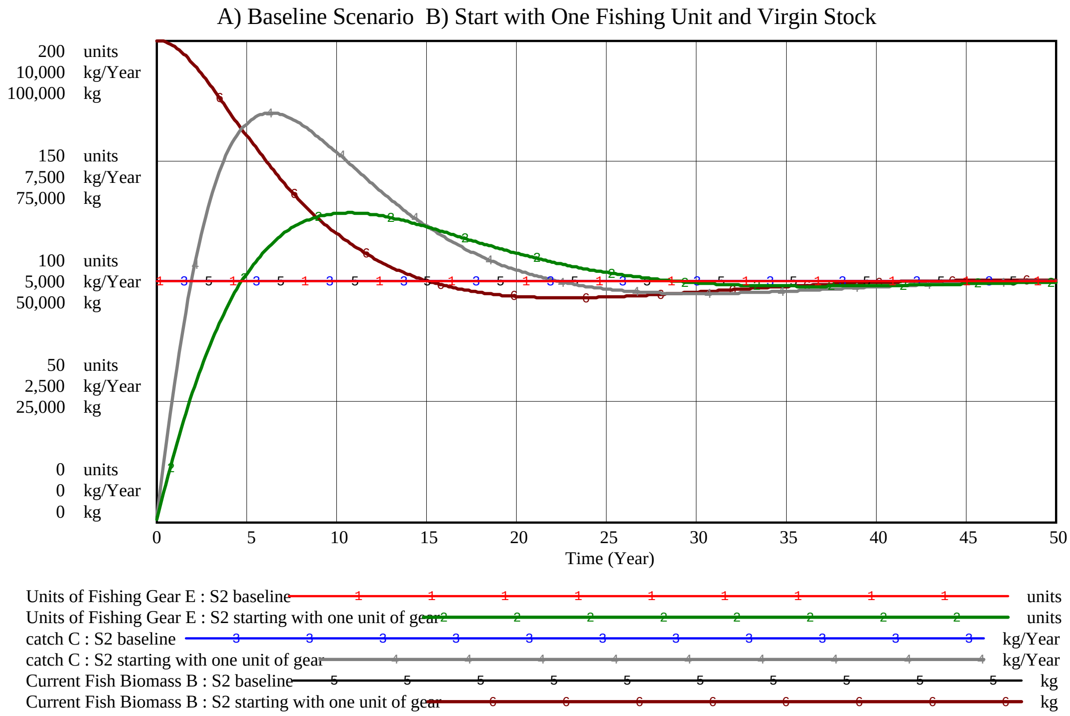


Figure 6. Two scenarios of the modified model showing the "baseline" (the straight lines), and a scenario starting with one boat and a virgin stock of 100,000 kg. In the latter case the model will (as currently structured) ultimately stabilize at the maximum equilibrium yield but only after overshooting this goal by a considerable amount in terms of both catch and numbers of gear units.

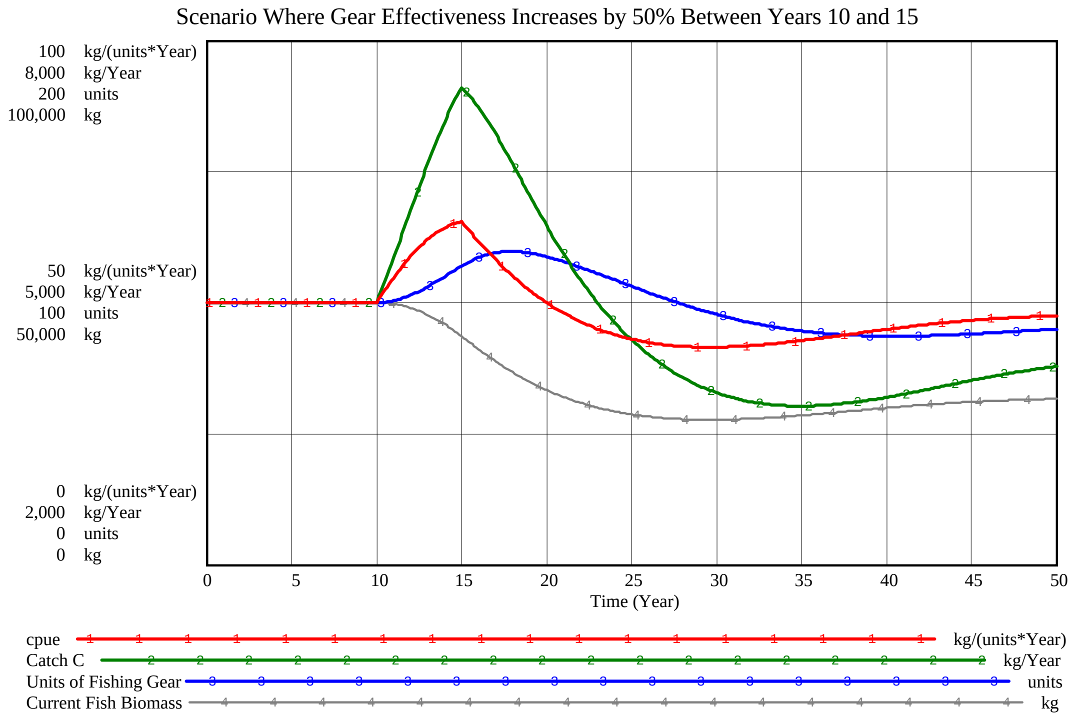


Figure 7. This figure illustrates a scenario where the stock in in equilibrium with 50 vessels. Between years 10 and 15 the effectiveness of the gear gradually increases by 50%. Here catch and number of vessels initially increase, but of course eventually drop below the original value and eventually approach a new equilibrium.

The baseline scenario uses equilibrium baseline values where the model is started with 100 vessels, and a stock size of 50,000 kg. This results in the straight lines shown in Figure 6. Also presented in Figure 6 is a scenario of a new fishery where the model starts with one vessel and a virgin stock. In this case the fishery grows beyond its maximum capacity and later stabilizes.

In Figure 7 is another scenario, where the fish stock begins in equilibrium, but then, between years 10 and 15, the gear effectiveness is increased by a total of 50%. As cpue rises more vessels enter the fishery which, after a short peak, drive down the cpue, the overall catch, and the fish population.

Even this simple model can be useful in gaining an understanding of how a fishery works. A number of different scenarios could be investigated, and model structure could be modified. How would product price effect the entry of vessels into the fishery? What about competing products? What about other factors causing fluctuations in stock size?

Model Modification 2: Decisions by a Fishery Management Entity

Rather than having the number of vessels entering and leaving the fishery determined by the cpue, we could assume that a management agency compares the actual stock to optimal stock density and adjusts the number of units in the fishery accordingly. Such a model might be formulated as in Figure 8.

In this formulation we assume that data are collected about the stock size which is compared to the optimum stock size (or goal) which, in the basic model, is assumed to be 0.5 of the maximum stock size. We assume that the agency considers changes as they occur and forms a perception of the stock's status. This perception is the basis of new decisions about numbers

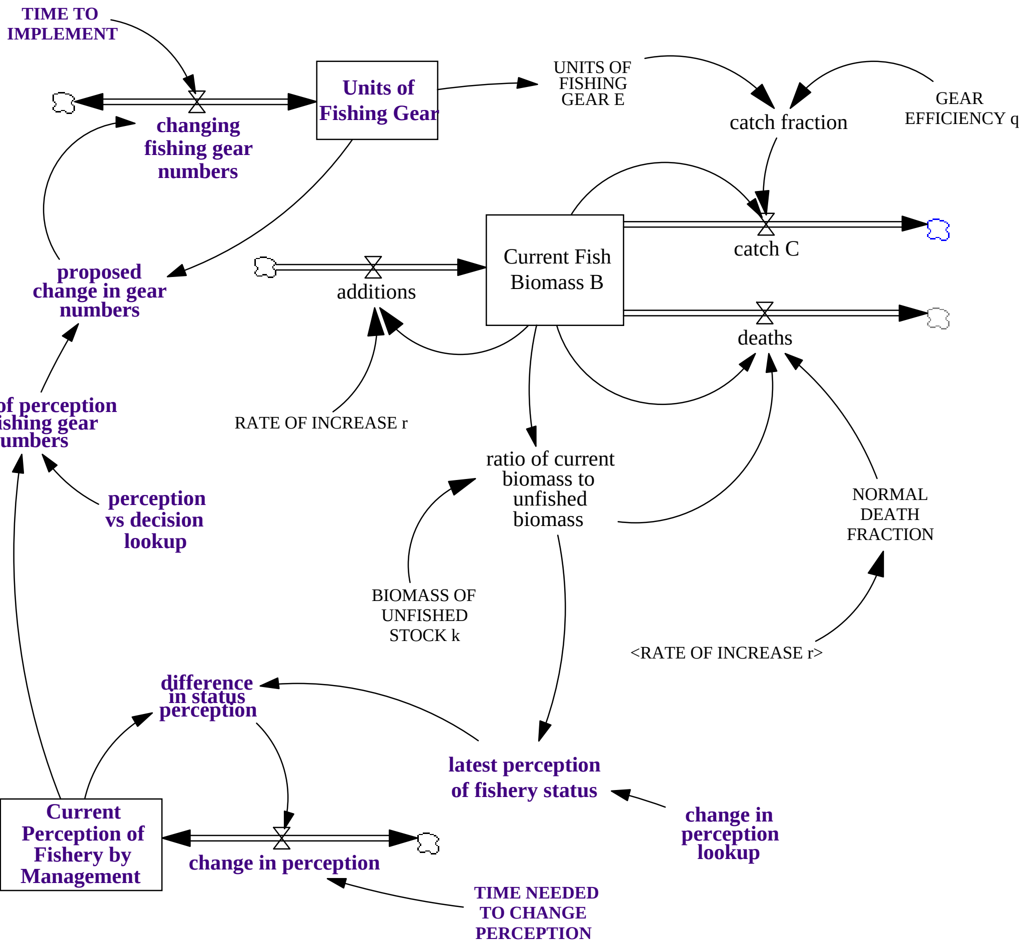


Figure 8. Additions (shown in bold) to the original model simulate adjustment to fishing gear numbers by a management entity. In this case the management entity reviews population status and then makes appropriate adjustments in fishing gear numbers.

of fishing units, and these decisions are eventually implemented. Two stocks are added to the model: one specifying the "current perception by fishery management" and the other specifying the current "units of fishing gear". The times over which perception and the units of fishing gear gradually change are also specified.

In this model there are two look-up functions which are presented in the equations on page 16 and graphically on page 18.

If this model is started with one fishing gear unit and a virgin stock the scenario evolves as presented in Figure 9.

A second scenario, where fishing gear effectiveness is gradually increased 50% between years 10 and 15, is presented in Figure 10. (This is the same scenario that was used in the first model modification presented in Figure 7). As larger amounts of fish are removed from the population by the improved gear the population ratio decreases and management adjusts the fishing gear numbers accordingly. Unlike the first model modification, this structure eventually returns the stock to the point of maximum equilibrium yield. Even with such constant adjustment, however, the population takes many years to return to equilibrium.

One might feel that a faster response time by the management entity in changing its perception and in implementing the new fishing gear numbers would improve the response of the system. As indicated in Figure 11 this is only partially true. Shortening the two management response times increases the amplitude of the damped oscillations that are inherent in the system. Although these keep the stock nearer to the target level, an unexpected consequence is that larger fluctuations in fishing gear numbers also result.

Conclusions

Our point here is not that these models are particularly appropriate or special. In fact they are merely simple examples. Our point is that the system dynamics approach is simple and convenient for looking at a variety of complex issues facing fishery scientists. When used for this purpose unexpected consequences of our decisions become clear, and reasons for these consequences are revealed. The system dynamics approach provides a somewhat standardized framework for developing models of many types. The approach is not limited to biological systems and is ideal for interdisciplinary teamwork. Several authors have provided guidelines for developing such models in group environments (e.g. Andersen and Richardson 1994, Richardson and Andersen 1995).

In today's world fishery management is often carried out by agencies with a mandate to obtain and use input from a variety of stakeholders. Interested elements of the public and special interest groups insist on having input into the fishery management decision making. Enmeshed in this reality we have a real need to develop mechanisms which allow these interest groups or stakeholders to participate in the overall management scheme, even when this scheme is complex. System dynamics modeling provides one such mechanism where modeling can be made more transparent to a variety of stakeholders, and will permit the incorporation of their ideas and desires into management planning and execution.

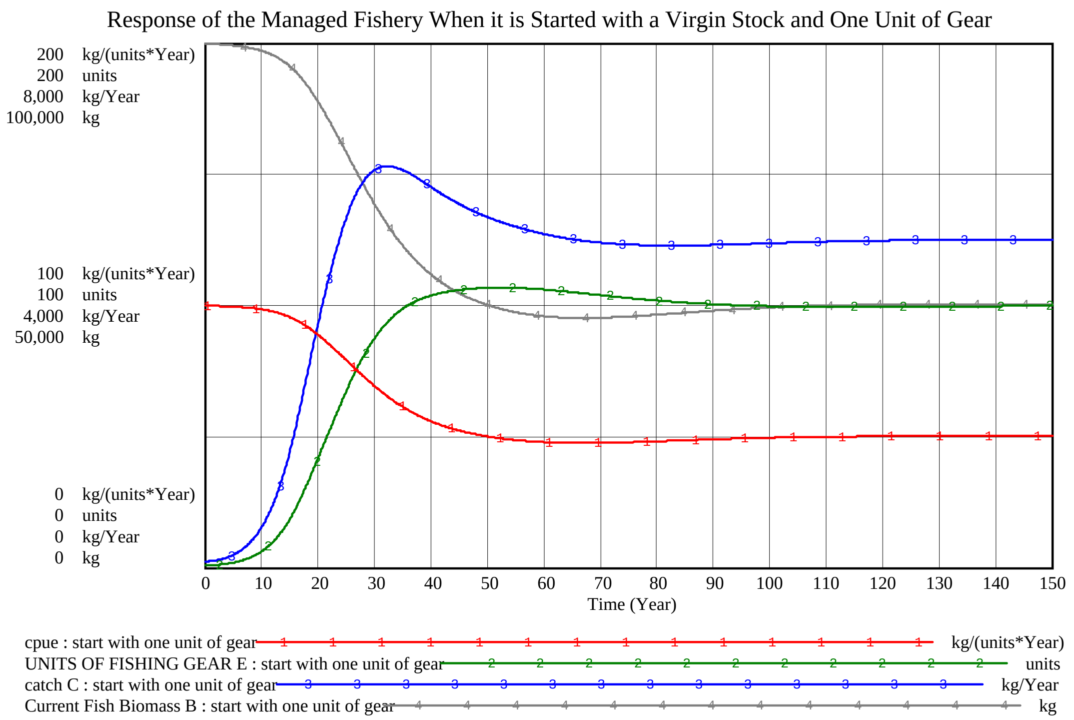


Figure 9. When started with a single unit of gear and a virgin stock (100,000 kg) the Managed Fishery formulation of the model approaches the expected equilibrium with only minimal overshoot of the ultimate number of fishing gear (line 2).

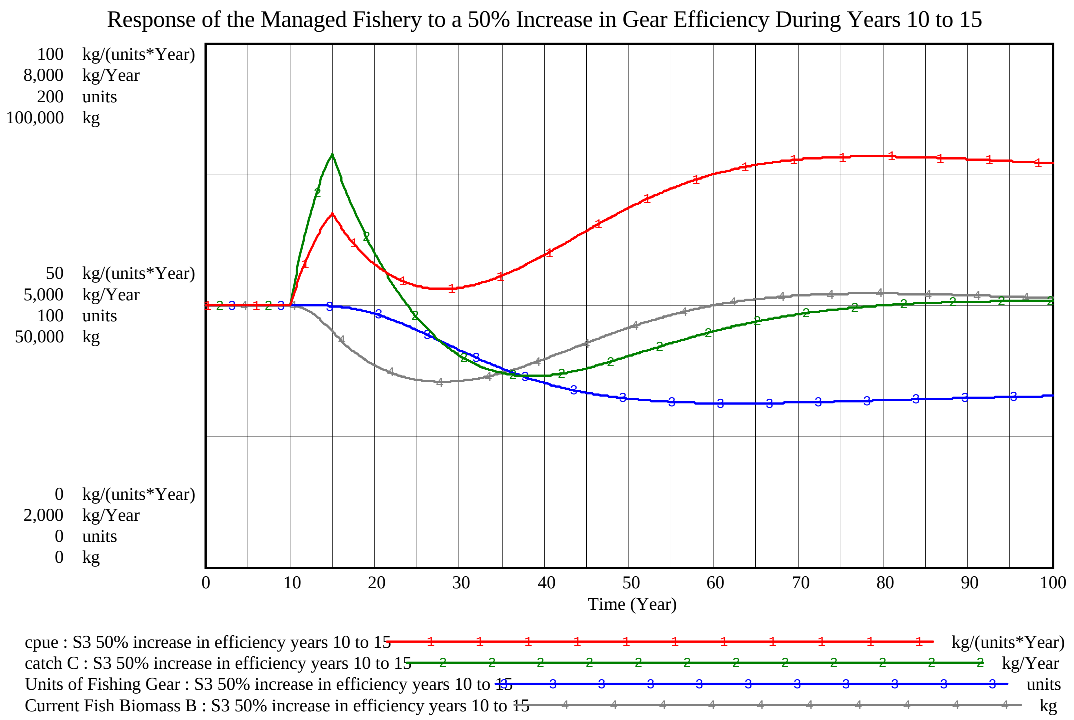


Figure 10. The represents the response of the managed fishery when fishing gear effectiveness increases by 50% over a five year period. Even though management regularly monitors the population and adjusts fishing gear numbers, biomass and catch return to their original maximum equilibrium values only after a considerable delay.

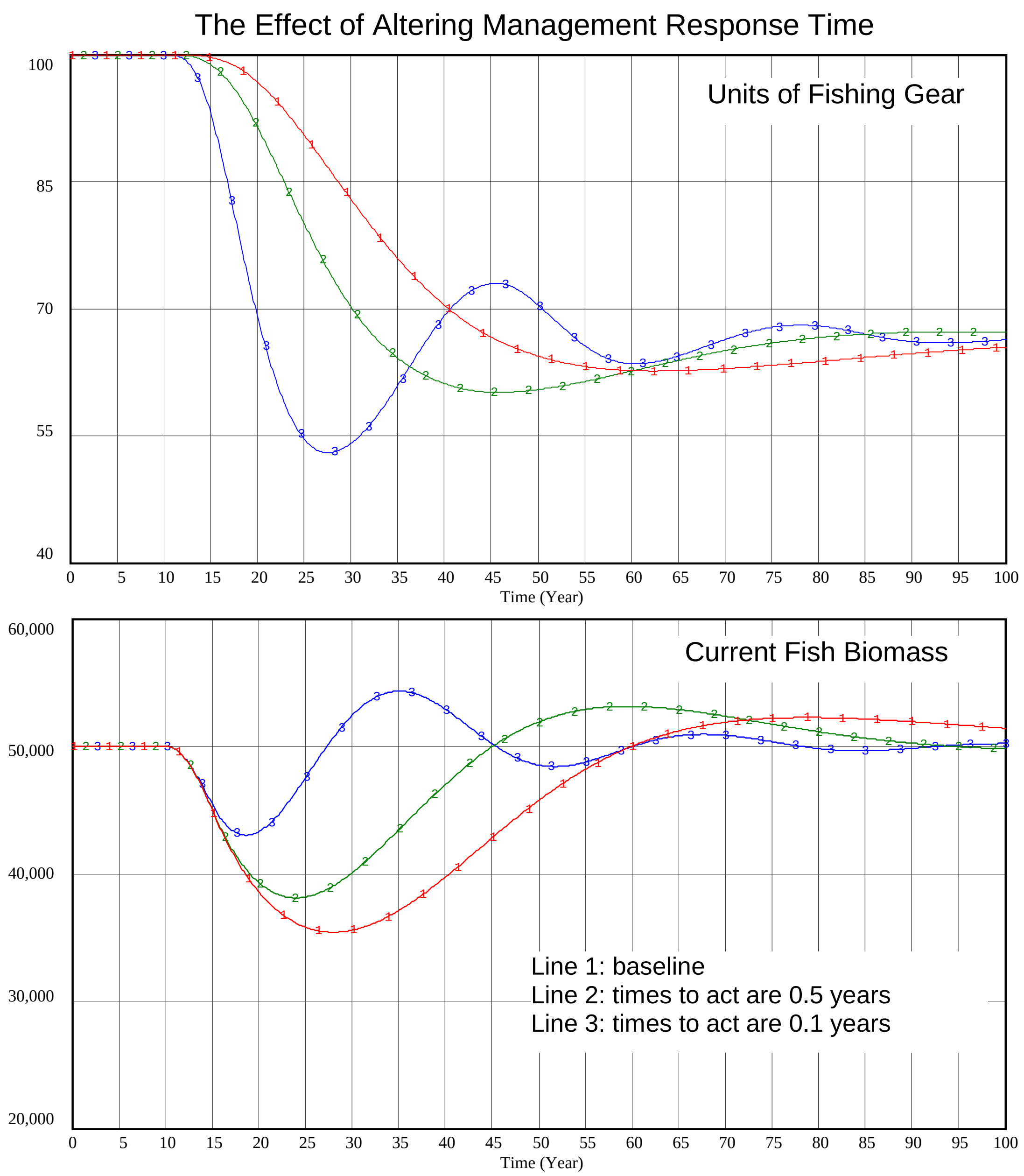


Figure 11. The effect of changing the management response times: "time needed to change perception", and "time to implement." In the baseline scenario these are 2 years and 1 year respectively. In the test scenarios these are both set to 0.5 years (line 2) and 0.1 years (line 3). A more rapid response time maintains the current fish biomass nearer to the target level, but induces unexpected larger oscillations in units of fishing gear.

Literature Cited

Andersen, David F., Richardson, George P. 1994. Scripts for Group Model Building. International System Dynamics Conference Sterling, Scotland.

Forrester, Jay W. 1961. Industrial Dynamics. Portland, OR: Productivity Press. 464 pp.

Forrester, Jay W. 1969. Urban Dynamics. Portland, OR: Productivity Press. 285 pp.

Forrester, Jay W. 1971. World Dynamics. Portland, OR: Productivity Press. 144 pp.

Grant, W. E. 1998. Ecology and natural resource management: reflections from a systems perspective. Ecological Modelling 108(1998) 67-76.

Holland, Daniel S. and Richard J. Brazee. 1996. Marine Reserves for Fisheries Management. Marine Resource Economics. 11(3):157-171.

Holling, C.S. 1978. Adaptive environmental assessment and management. Wiley, New York, 377 pp.

Meadows, Donella H., Dennis L. Meadows, Jorgen Randers, and William W. Behrens III. 1972. The Limits to Growth. New York: Universe Books. 205 pp.

Meadows, Donella H., Dennis L. Meadows, Jorgen Randers, 1992. Beyond the Limits: Confronting Global Collapse, Envisioning a Sustainable Future. Post Mills, VT: Chelsea Green Publishing Co., 300 pp.

Moxnes, E. 1998a. Not only the tragedy of the commons, misperceptions

of bioeconomics. Management Science 44(9):1234-1248.

Moxnes, E. 1998b. Overexploitation of renewable resources: The role of

misperceptions. Journal of Economic Behavior and Organization 37(1):107-127.

Patten, B.C. (Ed) 1971. Systems analysis and simulation in ecology. Academic Press, New York. 607 pp.

Richardson, George P., and Andersen, David F. 1995. Teamwork in Group Model Building. System Dynamics Review 2(11) 113-137.

Ruth, Matthias, and James Lindholm. 1996. Dynamic modelling of multispecies fisheries for consensus building and management. Environmental Conservation 23(4): 332-342.

Schaefer, M. B. 1954. Some aspects of the dynamics of populations important to the management of commercial marine fisheries. Bull. Inter-Am. Trop. Tuna Comm. 1:27-56.

Walters, C.W. 1986. Adaptive management of renewable resources. Macmillan, New York, 374 pp.

Watt, K.E.F. 1968. Ecology and resource management. McGraw-Hill, New York, 450 p.

Formulation of Schaefer Model (alphabetical order by component name):

(01) additions = Current Fish Biomass B*RATE OF INCREASE r
Units: kg/Year
Amount of biomass added to the population each year.

(02) BIOMASS OF UNFISHED STOCK k= 100000
Units: kg
Biomass that the stock has when no fishing takes place.

(03) catch C= catch fraction*Current Fish Biomass B
Units: kg/Year

(04) catch fraction = GEAR EFFICIENCY q*UNITS OF FISHING GEAR E
Units: 1/Year
Fraction of the current fish biomass caught.

(05) Current Fish Biomass B= INTEG (additions-catch C-deaths, 100000)
Units: kg
The current biomass of the fish population.

(06) deaths = Current Fish Biomass B*NORMAL DEATH FRACTION *
ratio of current biomass to unfished biomass
Units: kg/Year
Biomass of fish dying.

(07) FINAL TIME = 50
Units: Year
The final time for the simulation.

(08) GEAR EFFICIENCY q= 0.001
Units: 1/units/Year
Fraction of the current fish biomass caught by each fishing gear unit.

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

(10) NORMAL DEATH FRACTION = RATE OF INCREASE r
Units: 1/Year
This is the normal death fraction if the current fish biomass is equal to the biomass of the un-fished stock. In that case it is the same as the rate of increase r.

(11) RATE OF INCREASE r = 0.2
Units: 1/Year
The intrinsic rate of growth in biomass.

(12) ratio of current biomass to unfished biomass =
Current Fish Biomass B/BIOMASS OF UNFISHED STOCK k
Units: dmnl
The effect of current fish biomass on the death fraction is the ratio of the current fish biomass to the biomass of the stock of fish if no fishing too place.

(13) SAVEPER = TIME STEP
Units: Year

The frequency with which output is stored.

(14) TIME STEP = 0.125
Units: Year
The time step for the simulation.

(15) UNITS OF FISHING GEAR E = 0
Units: units
Number of fishing gear units. Number can be specified by the user.

Components added for model where cpue affects fishing gear entry and exit

(01) AVERAGE VESSEL LIFE SPAN IN FLEET = 10
Units: Year
Life-time of vessels in the fishery.

(02) change efficiency = 0
Units: dmnl
An added convenience to turn on a change in gear efficiency. 0 is off, 1 is on.

(03) cpue = catch C/Units of Fishing Gear E
Units: kg/Year/units
This is the catch obtained by each unit of fishing gear.

(04) cpue ratio = cpue/NORMAL CPUE
Units: dmnl
The ratio of the current cpue to the normal cpue.

(05) effect of cpue on vessel entry = look up table(cpue ratio)
Units: dmnl
The effect that the cpue ratio has on the entry of gear units into the fishery.
When this ratio is 1 there is no effect.

(06) entering or leaving fleet = NORMAL RATE OF VESSEL ENTRY *
effect of cpue on vessel entry
Units: units/Year
number of vessels (or gear units) entering the fishery.

(07) GEAR EFFICIENCY q = 0.001+change efficiency*RAMP(2.5e-005, 10, 30)
Units: 1/units/Year
Fraction of the current fish biomass caught by each fishing gear unit. The ramp function is used to examine different scenarios.

(08) look up table([(0,-10)-(4,10)],(0,-10),(0.108761,-4.91228), (0.265861,-1.84211),
(0.44713,-0.0877193), (0.700906,0.614035), (1,1),(1.32931,1.57895),
(1.90937,2.7193), (2.67069,5),(3.28701,6.92982),(4,10))
Units: dmnl
This is a graphical function which takes as x the cpue ratio and
produces as y the effect on gear entry into the fishery.

(09) NORMAL CPUE = 50
Units: kg/(Year*units)
This the the catch obtained by each unit of fishing gear under normal conditions.
Which here have been defined as the catch per unit obtained at maximum

equilibrium yield with 50 units fishing.

(10) NORMAL RATE OF VESSEL ENTRY = 10
Units: units/Year
This is the normal rate of entry at start of the model (at max equilibrium yield in this case).

(11) retiring from fleet = Units of Fishing Gear E / AVERAGE VESSEL LIFE SPAN IN FLEET
Units: units/Year
Number of vessels retiring from the fishery.

(12) Units of Fishing Gear E= INTEG (entering or leaving fleet-retiring from fleet, 1)
Units: units
Number of units of fishing gear in the fishery.

Components added for model where a management entity determines fishing gear numbers.

(01) change in perception = difference in status perception / TIME NEEDED TO CHANGE PERCEPTION
Units: dmnl/Year
Changing perception of the fishery

(02) change in perception lookup([(0,-10)-(1,10)],(0,-10), (0.0996979,-5), (0.247734,-2.19298),(0.338369,-0.789474),(0.425982,-0.263158),(0.5,0), (0.58006,0.263158),(0.655589,0.789474),(0.752266,1.92982), (0.897281,4.91228),(1,10))
Units: dmnl
A graphical lookup function describing the relationship between biomass ratio and perception of fishery status.

(03) changing fishing gear numbers = proposed change in gear numbers/TIME TO IMPLEMENT
Units: units/Year
Change in fishing gear numbers.

(04) cpue = catch C/UNITS OF FISHING GEAR E
Units: kg/units/Year
Catch fishing gear unit (note: not shown on diagram)

(05) Current Perception of Fishery by Management = INTEG (change in perception, 0)
Units: dmnl
The currently held perception of the fishery by the management entity.

(06) difference in status perception = latest perception of fishery status-Current Perception of Fishery by Management
Units: dmnl
The difference between the current perception of the fishery and the new perception.

(07) effect of perception on fishing gear numbers =
perception vs decision lookup(Current Perception of Fishery by Management)
Units: dmnl
The effect that the management entity's perception has on fishing gear numbers.

(08) latest perception of fishery status =
change in perception lookup(ratio of current biomass to unfished biomass)
Units: dmnl
The management entity's perception of fishery status as based on biomass ratio.

(09) perception vs decision lookup([(-10,0)-(10,2)],(-10,0.1),(-8.54985,0.482456), (-6.85801,0.745614),(-4.98489,0.868421), (0,1),(5,1.1),(7,1.15),(10,1.25))
Units: dmnl
A graphical function describing the relationship between the current perception of the fishery and the effect on fishing gear numbers.

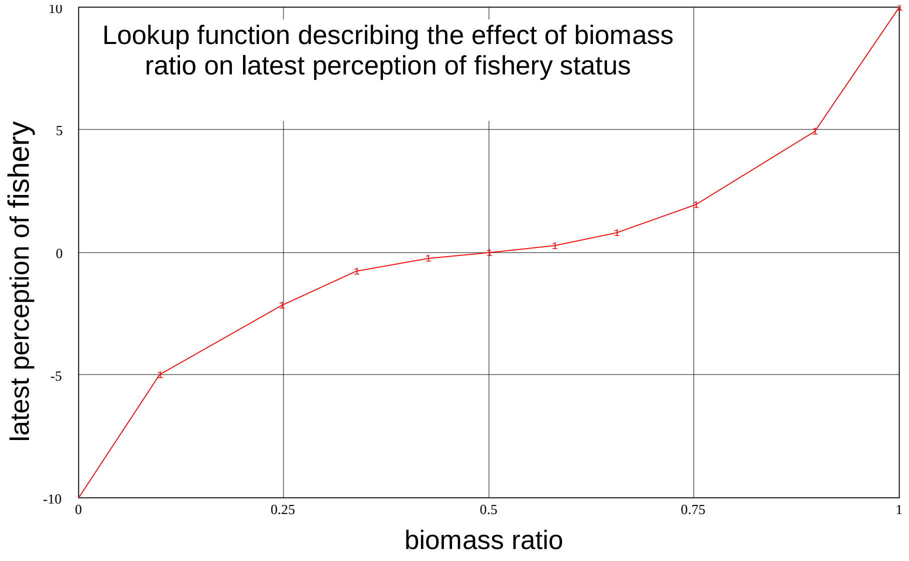
(10) proposed change in gear numbers= (Units of Fishing Gear * effect of perception on fishing gear numbers)-Units of Fishing Gear
Units: units
The change in fishing gear numbers proposed by the management entity.

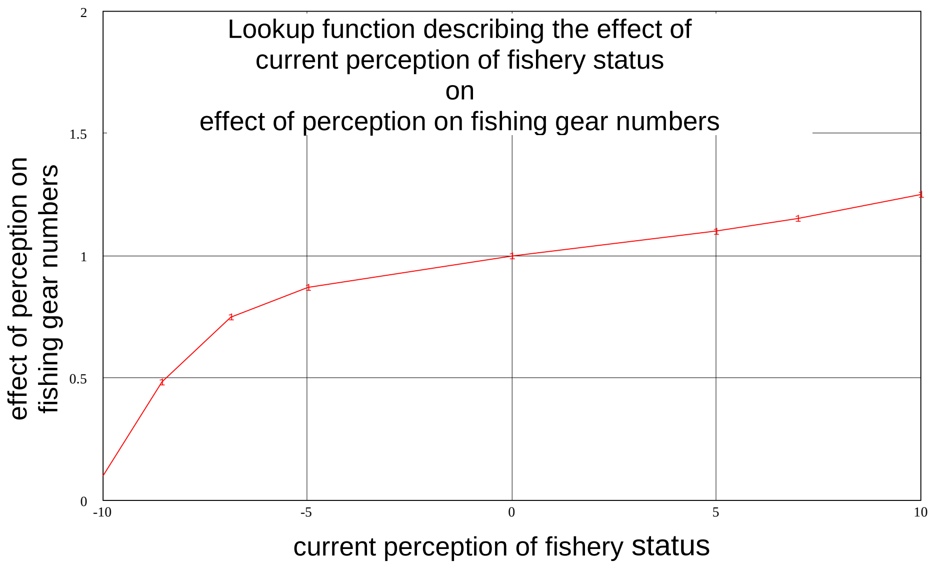
(11) TIME NEEDED TO CHANGE PERCEPTION = 2
Units: Year
The time needed for the management entity to change its perception of the fishery status.

(12) TIME TO IMPLEMENT = 1
Units: Year
Time needed to implement the new fishing gear numbers.

(13) Units of Fishing Gear= INTEG (changing fishing gear numbers, INITIAL NUMBERS OF GEAR)
Units: units
Number of units of fishing gear in the fishery.

(14) UNITS OF FISHING GEAR E = Units of Fishing Gear
Units: units
Number of fishing gear units.


Lookup function describing the effect of biomass ratio on latest perception of fishery status
latest perception of fishery
biomass ratio
10
5
0
-5
-10
0
0.25
0.5
0.75
1


Lookup function describing the effect of current perception of fishery status on effect of perception on fishing gear numbers
effect of perception on fishing gear numbers
current perception of fishery status
2
1.5
1
0.5
0
-10
-5
0
5
10