A system dynamics perspective on a global fishing enterprise:
The case of tuna ranching in Mexico

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Donald D. Robadue, Jr.
Coastal Resources Center, University of Rhode Island
Department of Informatics, University at Albany
220 South Ferry Road, Narragansett, Rhode Island 02882
401.787.8665
robadue@gso.uri.edu, don@robadue.com

Raul del Moral Simanek
Universidad Autónoma Baja California,
Apdo. Postal 453
Ensenada, Baja California,
C.P. 22800, México
R1319@prodigy.net.mx

Abstract

Tuna ranching is a value-added economic activity along the coast of Baja California in Mexico involving the live capture and transport of migrating juvenile tuna to pens located near shore, where they are fed for a period of months then harvested and shipped fresh to Japan for the high-end sushi market. It is nested within the global business of tuna fishing and processing for the fresh seafood, in particular sushi market, centered in Japan but expanding elsewhere. This is turn is nested in the entire fishery and global business of tuna. Little is known outside the industry about the functioning of Mexican tuna ranching, however it differs in important ways compared to its Australian and controversial Mediterranean competitors that indicate relative stability, most notably that it does not involve the harvest of reproducing age animals. Our analysis and exploratory modeling exercise reveals no cause for complacency however. There are several factors and issues, most of which are not the typical concerns found in popular descriptions of tuna ranching world wide, that a system dynamics model suggests examining more closely in helping determine whether Mexican ranching activities have the potential to become sustainable.

Background

Fin and shellfish aquaculture is a major and growing use of the world's coastal and marine zones, with species cultivated to meet protein needs for local populations including the poor, for export to global mass markets (salmon, shrimp) as well as species such as bluefin tuna, highly prized fish for sashimi in Japan and other Asian countries. "Aquaculture, probably the fastest growing food-producing sector, now accounts for almost 50 percent of the world's food fish and is perceived as having the greatest potential to meet the growing demand for aquatic food." (United Nations Food and Agriculture Organization, State of World Aquaculture, 2006)

A recent NY Times article covering the United Nations Food and Agriculture (FAO) report "State of World Aquaculture 2006" notes: "Fish farms are close to matching fishing fleets in

supplying seafood to expanding global markets… The main impediments to aquaculture are a lack of sufficient investment capital in poorer countries, limited land and fresh water and concerns about environmental impact." (Revkin, 2006) Bluefin tuna is a prized fresh fish in Japan, fetching a wholesale price of nearly $17 per kg in 2006.

	2004	2005	2006
	ALL SOURCES		
Fresh Bluefin tuna Metric tonnes	9,966	9,882	7,395
Million Yen	21,163	19,209	14,945
Million US Dollars	201.5	164.1	125.5
Frozen Bluefin tuna Metric tonnes	6,626	4,220	5,355
Million Yen	10,782	7,632	11,143
Million US Dollars	102.6	65.2	93.6
Exchange rate	105	117	119

Table 1 Japanese imports of fresh and frozen Bluefin tuna, all species from all sources, Source: Sonu, 2007

The demand for seafood is expected to outstrip supply from wild and aquaculture sources. The lead author of the FAO report, Rohana Subasinghe (2006), states: "It is apparent that the aquaculture sector continues to intensify and diversify, is continuing to use new species and is modifying its systems and practices. This is being achieved with the growing awareness that the resources upon which it and society in general depend must be used responsibly. Effective regulation is only possible with an effective information system."

Is bluefin tuna ranching in Mexico sustainable? Does the Mexican industry and government have all the policy tools and levers at its disposal to insure this? What kind of information system could be helpful in contributing to adequate planning, regulation and monitoring of mariculture so it can provide sustained benefits? Marine and coastal mariculture is diverse and complex in terms of the species utilized, technology employed, locations selected, ecosystems affected, governmental authorities potentially involved and markets served. We are presently developing a policy modeling approach based upon system dynamics methods for one particular type of a rapidly increasing form of mariculture: ranching or fattening of marine finfish, in particular the relatively small but rapidly increasing practice of fattening Bluefin tuna. This case is on its face simple enough, and of strong current interest, to allow for developing and validating a policy level model drawing upon the mental models of a variety of actors presently engaged from a business and public policy viewpoints.

Bluefin tuna ranching is practiced at a larger scale in the Meditteranean, especially in Spain and Morocco, and Australia in the Port Lincoln region. In effect there are three separate global stocks (*Thunnus thynnus,* or the Atlantic Bluefin Tuna; *Thunnus maccoyii*, the Southern Bluefin Tuna, and *Thunnus thynnus orientalis,*the Pacific Bluefin Tuna, which are managed under different legal regimes, but all serving the Japanese fresh and frozen sushi grade tuna market.

Year	2003	2004	2005	Jan-Nov 2005	Jan-Nov 2006
Metric tonnes of Fresh Pacific Bluefin Tuna imported from Mexico by Japan	2769	3849	4097	3318	2359

Table 2 Reported annual production of fresh tuna from offshore "ranches" in Mexico, Source: FISH INFOnetwork (2007)

Assembling accurate, consistent data on sale volume and price of Mexican ranched tuna is not straightforward, nor is a steady horizon of increasingly high production guaranteed, since many factors influence output, as described below. As Table 3 indicates as an example, the wholesale price (equivalent to the price received at the Mexican border before transshipment to Japan) for a lot of 38 fresh tuna from the ranches averaged $22.74 kg and ranged from $20.66 to $25.61 per kg on January 18, 2007. This compared to a price of $39.66 for a wild caught Atlantic bluefin caught off the coast of North Carolina. (Source: Sonu, 2007).

WHOLESALE PRICES AT TOKYO CENTRAL WHOLESALE MARKET BLUEFIN TUNA, fresh

Date of sale	Sales volume	Origin	High yen/USD per kg	Average yen/USD per kg	Low yen/USD per kg
01/18/2007	38 fish	Mexico	3,100 $25.61	2,752 $22.74	2,500 $20.66
01/18/2007	5 fish	New York	7,500 $61.98	5,250 $43.38	4,300 $35.53
01/18/2007	4 fish	North Carolina			4,800 $39.66

Wild

118-121 yen = U.S.$1.00

07/19/2007	24 fish	Mexico			2,500 $20.32

Captured

121-123 yen = U.S.$1.00
Source: Southwest Regional Office, National Marine Fisheries Service
http://swr.nmfs.noaa.gov/fmd/sunee/twprice/twp51807.htm

Table 3 Market Prices of Wild and Ranched Bluefin Tuna

The industry in Mexico was inspired in part by the early experience in Australia, and in turn may be affected in a variety of ways by developments in both regions. Globally there is a high level of concern over the status and sustainability of the wild tuna stocks and the activity of tuna ranching. Greenpeace (2005) and the WWF (Tudela and Garcia, 2004; ATRT, 2006) among many other critiques have decried the ineffectiveness of fishing quotas and tuna export restrictions in preventing the imminent collapse of both the ranching industry and the Atlantic Bluefin fishery itself. The Australian tuna fishery was on the verge of collapse in the early

1990s, with tuna ranching introduced and now tightly regulated as part of overall Australian initiative to maintain sustainable fisheries and fish export businesses. (PIRSA Aquaculture, 2003).

Popular articles on tuna ranching sometimes take a skeptical perspective, conjuring up the exaggerated imagery of a lawless maritime Wild West with ranchers, fishers, and the government embroiled in rough-and-tumble conflict. (Montgomery, M. 2005). Such a metaphor widely misses the mark when applied to Mexican tuna ranching in our view, although perhaps the use of purse seines to capture juvenile tuna and transport them to pens close to the coast has something in common with a "round-up", and perhaps the divers who inspect and collect the fattened tuna are "wranglers". In fact, the Discovery Channel broadcast a two part series in August, 2007, on the Australian tuna ranching industry titled "Tuna Wranglers".

Sasha Issenberg's recent journalist account of world trade in fish for raw consumption "The Sushi Economy" (Issenberg, 2007), offers a different metaphor, placing tuna ranching at the center of the global fishing industry. In describing Australian tuna ranching he points out: "The most successful of Port Lincoln's (Australia) ranchers have made their money by identifying the optimal level of investment. They need to know when to stop feeding and to kill, the point at which they have created the highest value fish (per weight) as possible, and their investment begins to exceed the return." (Issenberg, 2007). The results of our work to date also suggest that tuna ranching is a sophisticated and well organized economic activity, and tuna ranching in Mexico also contains an element of *maquila*, the value-added production of goods with technical and material inputs from foreign investors, in this case principally the Japanese, with some local economic benefit, but organized mainly to serve the needs of the investing nation. Anthropologist Theodore Bestor's multifaceted study of Tokyo's Tsukiji fish market, broadens the perspective of Japan's system for providing fish to its population even further: "The structure of a commodity chain – the links, stages, phases, and hands through which a particular product passes…is a highly contingent social formation….Tsukiji serves as a central node—a command and control center--- for this global trade, and the market's activities have wide influence…" (Bestor, 2004).

Key Questions

The core question from a policy perspective is whether and at what level is tuna ranching in Mexico is sustainable, and from a methodological perspective, can a policy level SD modeling serve as a bridge between scientific assessments and policy dialogue among stakeholders? Is Mexican tuna ranching utilizing Pacific Bluefin uniquely resilient, compared to the highly criticized Mediterranean based on Atlantic stocks, and higher-cost Australian ranching based on southern Pacific stocks? What policies are suggested when all aspects of the value chain of the industry are taken into account, including variability in migrating stock, limitations on coastal siting, alternative technologies, local economic impacts? How vulnerable are management decisions to information flow problems within the ranching industry, and what might be the advantages of more transparent information practices?

Approach

The story presented in this paper is the result of an ongoing collaboration between an environmental planner/ intermediate level system dynamics modeler with no previous contact or awareness with the tuna fishing industry, and a scientist with considerable experience in fishing, fisheries business investment and with confidential contacts within the tuna ranching industry in Mexico. It combines the elicitation, simulation and refinement of the evolving mental model of the scientist with content analysis of the limited literature on the Mexican case, and generalized data that is used to calibrate and validate the various builds of the model. In this sense, a modeling exercise can be viewed within the framework of action research.

Analysis of available literature also provides useful input and raises important questions about dynamics of parts of the value chain that require interviews with key actors to verify, as well as interaction with the project team, representatives of the tuna industry, as well as government and NGO actors to specify and test model scenarios. For example, one environmentalist warns that tuna ranching is unsustainable because of the risk of overproduction driving prices lower, which has happened in both shrimp and salmon farming. (Dalton, 2004) By contrast, an interview with the largest tuna rancher in Mexico addresses this price fluctuation as well, noting that it occurred early on during the emergence of tuna ranching, threatening the financial feasibility of the new business. (Panorama Acuicola, 2005).However, the issue related to price that each stakeholder is concerned with differs. The environmentalist is interested in slowing the growth of new sites and seeks to avoid higher levels of tuna fishing, while the businessman is concerned about having a stable regulatory climate, few new restrictions, and getting all Bluefin tuna allocated to the ranching industry.

In the following sections the exposition begins with a comparison of textbook and mental model versions of Mexican tuna ranching. It is followed by a brief comparison of variations on the basic textbook model that appear through content analysis of the few popularly available descriptions of the industry. A formal simulation model was then developed, based on both these sources, and is presently undergoing continuous revision as the quest for information to calibrate and validate earlier build of the model leads to hypothesized and confirmed aspects of structure and behavior that need to be included. We have tried to preserve the iterative, detective-like nature of this exploration in the narrative.

What is tuna ranching in Mexico?

This investigation begins with a simple question that was told in story-like form and recorded in the following causal loop diagram shown in Figure 1. Tuna ranching nests within other, larger fisheries and economic activities, including the overall tuna fishing industry and the sardine fisheries. To begin with, Bluefin tuna are merely visitors to the northern Pacific coast of Mexico and the western United States. They travel in schools as juveniles from the stock located off the Japanese coast, arriving around May and departing Mexican waters in August. Coincidently there is a sardine population that overlaps the area occupied by the Bluefin tuna, making it easy and economical to feed the captured tuna fresh sardines. The object of tuna ranching is fairly straightforward: capture, hold and feed tuna for several months until they increase the proportion of fat to the preference of the Japanese buyers, in other words, a marbled effect, so that a higher price can be obtained.

Since Mexican tuna ranching occurs around the City of Ensenada, less than two hours from the U.S. border city of San Diego, it is quite feasible to select, kill, process, pack and ship fresh chilled tuna to Los Angeles, where it boards an air cargo flight to Japan. Fresh Bluefin tuna is also available from wild fisheries and to some degree from the Atlantic, Australian and Mediterranean fisheries. Current freezing technology is so efficient that it allows for comparatively good prices for frozen Bluefin tuna, although the Japanese market offers a price premium for fresh.

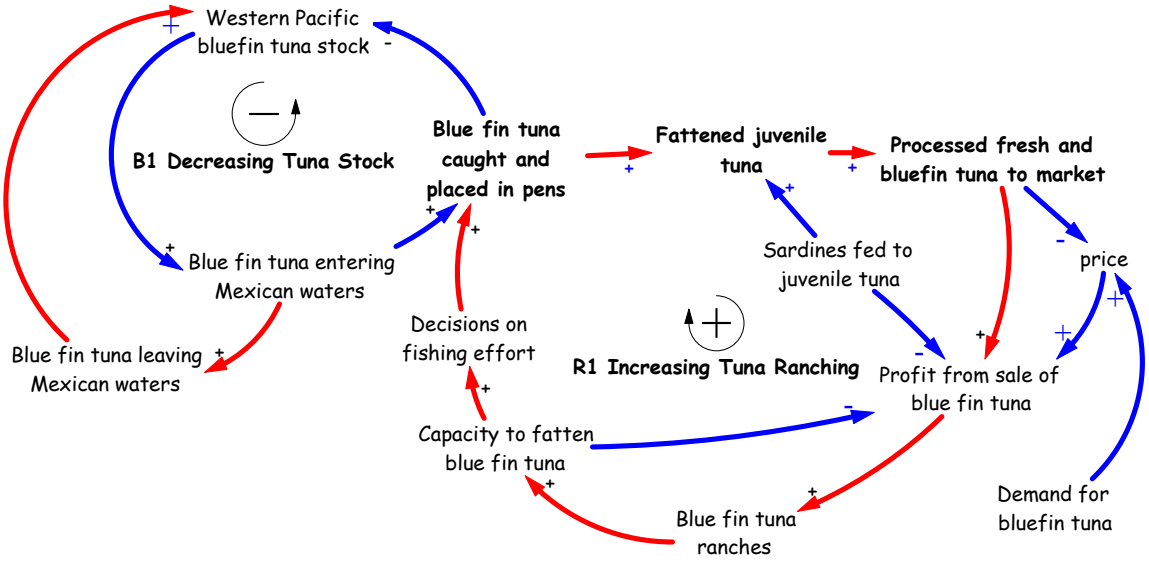

Figure 1 Simple mental model overview of tuna ranching in Mexico

The expert view of tuna ranching

A more elaborate conceptual model of tuna ranching is depicted using stock and flow notation in Figure 2, drawn from a content analysis of a recently published comprehensive text book on aquaculture (Pillay and Kutty, 2006) This concept map elaborates considerably on a few key aspects of the simple mental model, and it is also notable for treating tuna ranching as a supply chain with no explicit feed back loops, however several are implied. This and subsequent model diagrams and simulations were created using Vensim DSS.

Moving from left to right in Figure 2, Pillay and Kutty imply there is a feedback loop between catching juvenile tuna and the need for fishing quotas, although in the case of Mexico, tuna is a migrating stock from the western Pacific, in particular Japan. In practice, Australia also closely manages the southern Bluefin tuna stock. Fishing for tuna is done using purse seines, and the fish are transferred and carefully towed to fish pens located in open water near the coast. A number of practical issues come into play in terms of finding schools of tuna, the towing process,

the siting of ranches, which are comprises of collections of pens near shore. It is also at this point that research on closed cycle tuna ranching is noted, which would substitute wild caught tuna with juveniles spawned in captivity. Once placed in pens, the tuna must be fed continuously in order to gain the fat content that increases their value in the fish market, for example with fresh or frozen sardines. Managers then determine when to begin selecting tuna to be processed, packed and shipped by air freight in the case of fresh tuna, or by ship in the case of frozen, not unlike wild caught tuna. Since both are important, the conceptual framework of Pillay and Kutty addresses issues unique to each.

Critiques of tuna ranching

By way of comparison, and to indicate the potential of modeling exercises which incorporate detailed analysis of document content, John Volpe wrote a highly critical piece in BioScience. (Volpe, 2005) This is depicted in Figure 3 as an annotated version of the stock and flow diagram extracted from Kutty and Pillay. Volpe's major critiques are shown moving from right to left on the diagram in the form of major feedback loops linking the notion that a high price differential between ranched and wild caught tuna is required to make the operation viable. Price drops from oversupply of ranched tuna will lead to an industry collapse. A second major feedback loop following from price drops relates to Volpe's claim that a concentration of firms in tuna ranching will lead to weaker regulation and low compliance. He draws from the example of the Atlantic Bluefin tuna to highlight problems with poor documentation of catch, known as IUU or " illegal, unreported, unregulated" tuna fishing, which has plagued Mediterranean tuna ranching and the fishery in general. This criticism is echoed strongly by Greenpeace and WWF. More broadly the stock assessment study group of the International Commission for the Conservation of Atlantic Tuna (ICCAT) found recently that:

> the available information strengthens the opinion held by the Group that harvests of bluefin tuna from the eastern Atlantic and Mediterranean have been seriously under reported in recent years, particularly those from the Mediterranean. The volume of catch taken in recent years likely significantly exceeds the current TAC (total allowable catch) and is likely close to the levels reported in the mid-1990s, i.e. about 50,000 t in the East Atlantic and Mediterranean. (ICCAT, 2006)

Noting that accurate catch data is essential for managing the bluefin fishery, "our inability to obtain reliable information on catch and catch at age seriously undermines the credibility of conducting analytical evaluations of stock status which rely on this information." The ICCAT researchers also point out that fishing technology is changing rapidly in the Mediterranean as a consequence of Bluefin tuna ranching, in particular the modernization of fleets using purse seines for live capture of juvenile tuna. "This worrying development in a context of overexploitation potential has further led to a tremendous spatial expansion of the PS fleets in the Mediterranean, ...Consequently, the Mediterranean nowadays supports BFT (Bluefin tuna) fishing over its entire surface; a situation that has never been encountered in the past and that is of high concern since there appears to no longer exist any refuge for BFT in the Mediterranean during the spawning season."

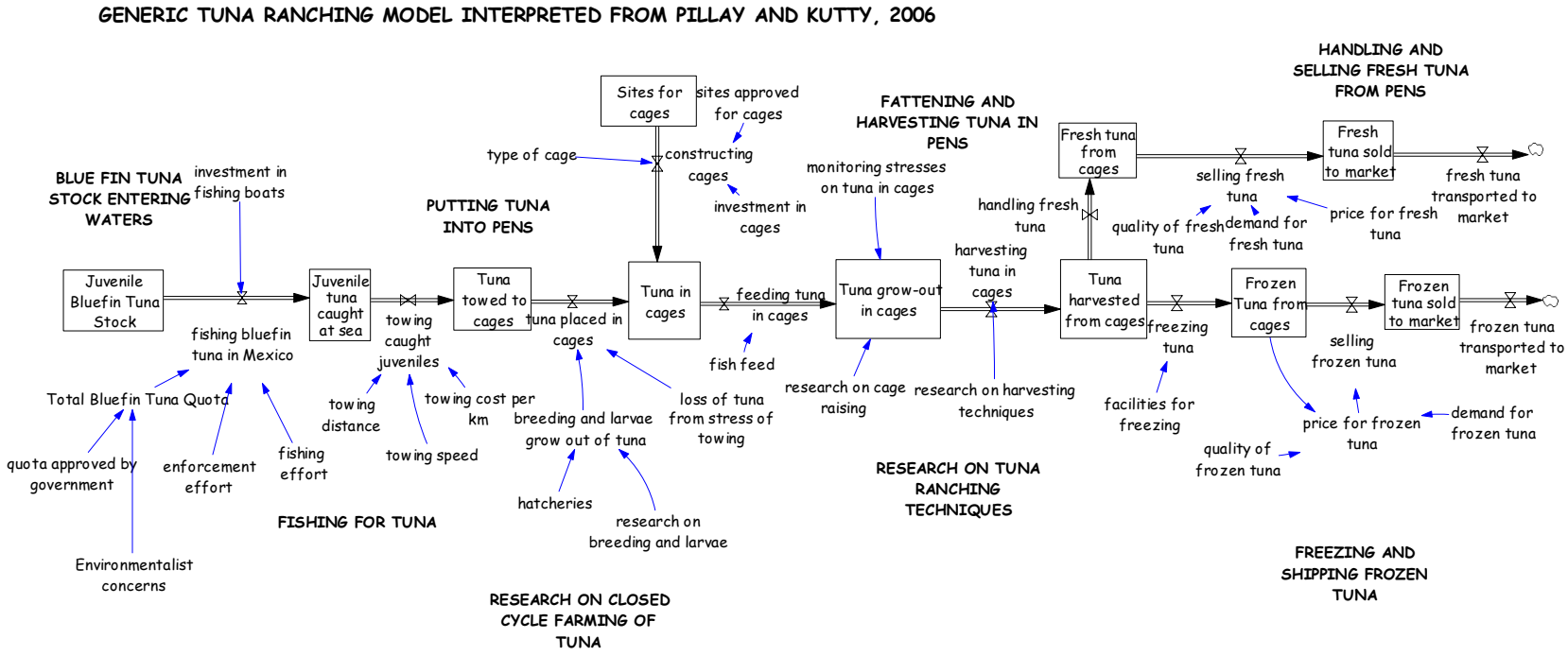

Figure 2 Generic tuna ranching conceptual model extracted from content analysis of Pillay and Kutty, 2006.

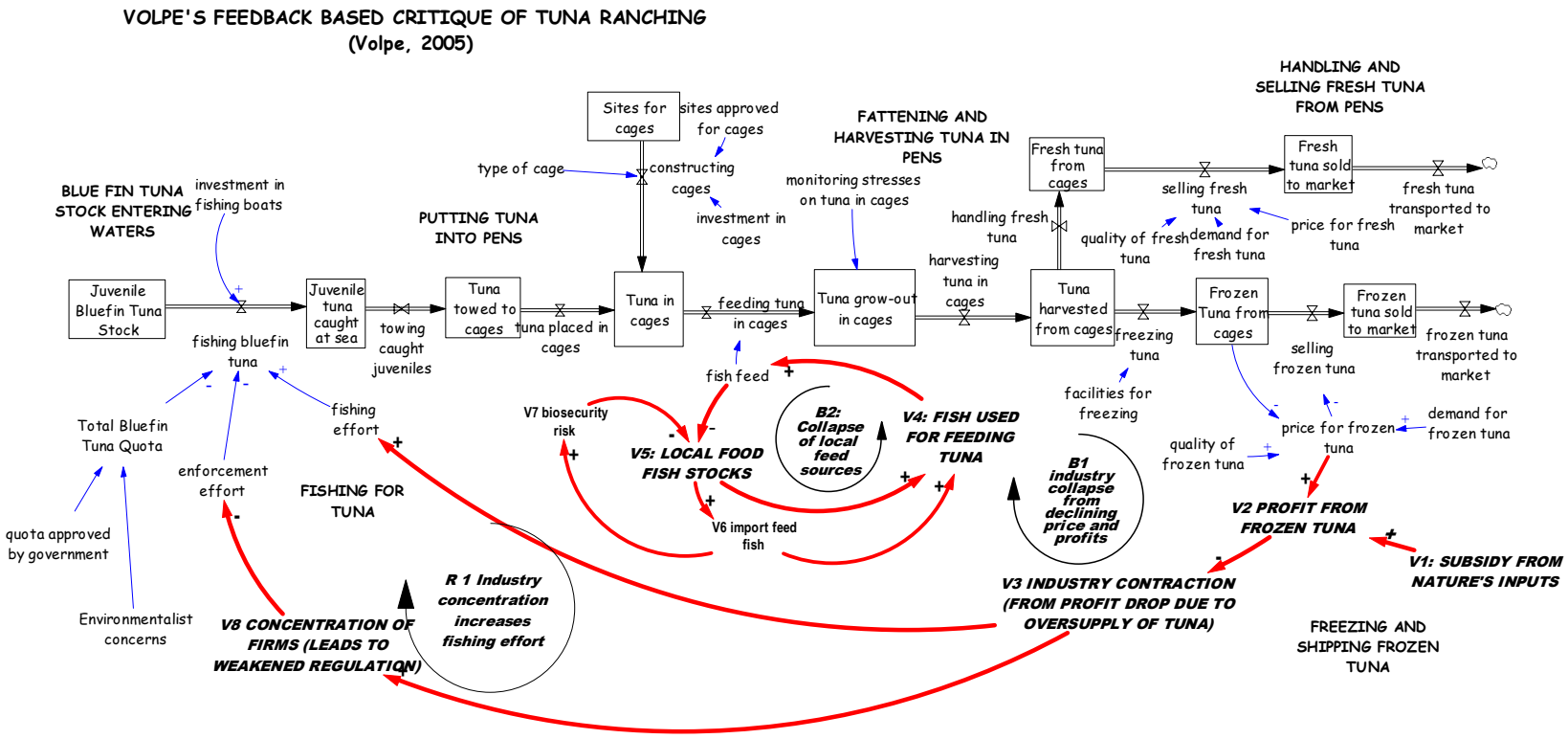

Figure 3 Critique of Tuna Ranching by Volpe, 2005, in stock and flow format. Red arrows and variables in italic san serif font indicate areas of criticism,

Notes to Figure 3:
Balancing Loop 1 "Mediterranean ranches are flooding world markets, resulting in a decline in value of ranch tuna by 50 percent from 2003 to 2004. Tuna ranching is viable only as long as the premium price of its product is protected, which in turn demands scarcity of supply. The industry is showing every sign of becoming a victim of its own success. If present rates of growth are maintained, an industry wide collapse is imminent."

Reinforcing Loop 1 "As companies approach collapse, motivation to offload production costs will grow, resulting in more violations of the emaciated regulation regime. This is sure to make the current bad situation worse. From the ashes, a handful of large multinational players will most likely emerge to supply markets in an OPEC-like quota supply model."

Balancing Loop 2 "Ranched tuna eat a lot of fish—so much, in fact, that the local environment can rarely keep pace, necessitating the import of feed fish from other regions.... this potentially opens a Pandora's box of epidemiological problems."

Variables added to Pillay and Kutty generic tuna ranching model

- V1 Subsidy from nature's inputs
- V2 Profit from frozen tuna
- V3 Industry contraction (from profit drop due to oversupply of tuna)
- V4 Fish used for feeding
- V5 Imported feed fish
- V6 Local food fish stocks
- V7 Biosecurity Risk
- V8 Concentration of firms (leads to weakened regulation)

Source: Volpe, 2005.

To what extent do the global concerns about Bluefin tuna ranching serve as a guide to the Mexican case?

Fisheries management perspective

In sharp contrast to the Mediterranean and Australian cases, very little is written or disseminated about the Mexican tuna ranching industry. This is first of all reflected in official publications of the Mexican government itself. The Mexican Diario Oficial (August 25, 2006) publishes the policies and analyses of the Instituto Nacional de Pesca. Tuna aquaculture receives barely two pages, with a simple bar graph acknowledging the growth of Bluefin tuna capacity to 11 ranches and production increasing from virtually nothing in 1997 to nearly 3000 tonnes in 2003. The document also notes that there are no regulations for tuna aquaculture, and that at some point it might be useful to have an official guideline published on the correct treatment of the live tuna fishery. The two main issues requiring research are the need for a "balanced" feed to supplement natural foods (such as sardines) and sanitation, for example parasites and infections. In terms of

management policies, the national policy notes that it might be good in the future to separate out the management of yellow fin from Bluefin tuna, given that the latter are an extremely small fishery. Also, the tuna fishing fleet in general should not be allowed to increase. Finally, the bluefin tuna stocks are categorized as "overexploited".

León and Ruiz (2006) add little to this discussion except to suggest that it might be worthwhile to require that all Bluefin tuna be assigned exclusively to tuna ranching, since "using the captured Bluefin tuna in any other process would be to lose its economic potential, especially given its scarcity".

The OECD (2006) conducted a comprehensive study of Mexico's fisheries policies including marine, aquaculture and inland, striking the theme of the globalization of fisheries and its impact on Mexico. Tuna ranching does not figure very large in the overall set of reforms required to place Mexican fisheries on the path to sustainability, greater political visibility and a range of administrative reforms to strength enforcement, cooperation and research, and reduce unhelpful subsidies and overinvestment on the other. The OECD points out that "there is very little work done in Mexico on the economic and social aspects of fisheries management policies and the literature in this area is very small" (2006:230). It goes on to note that "the interest in these studies at the policy level appears slight, yet it is these types of studies which will provide essential information on the socio-economic impacts of fisheries policy changes".

A new general fisheries law was in fact adopted in Mexico in 2006 and Mexico has been actively engaged in international discussions, including the effort to create a code of responsible fisheries. It also successfully negotiated a trade agreement with Japan in 2005, including the reduction of tariffs for fresh tuna imports among many other products. An article at the time quoted Philippe Charat, the largest tuna rancher, as saying "Sure, if Japan removes tariffs on it (Bluefin tuna), we will export 50% more" (Asia Pacific News, 2004).

Among the specific concerns, the OECD found that "there is limited information on the economic profitability of commercial fisheries" (2006:312) As part of creating greater certainty in the aquaculture sector, the study recommends "maintenance of long term concessions for aquaculture and tuna ranching", which are transferable. Overall, the OECD urges Mexico to create longer term plans for fisheries, and draw on concepts of self-regulation and market mechanisms, including individual transferable quotas rather than limited entry schemes that allow for over-exploitation through "technological creep". The OECD concludes that "...it is important to recall that fisheries are a dynamic system with many integrated components. Changing one component of the system will have consequences for other parts of the system; some consequences will be anticipated and well understood, while others will be unexpected" (2006:318).

A modeling approach to understanding Mexican tuna ranching issues and policy discussions

This section begins with a description of the first stock and flow working model that emerged in November 2006 during a work session with the authors, and its structure preceded the

preparation of the graphical representations of Pillay and Kutty, and Volpe shown in Figures 2 and 3.

A glimpse of the core structure of the Mexico tuna ranching value chain model developed so far is presented in Figure 4. This is consistent with the aquaculture literature on tuna ranching, as represented by Pillay and Kutty in Figure 2, but without reference to closing the biological cycle and spawning Bluefin tuna, nor to freezing the fattened tuna, since Mexico mainly produces fresh bluefin. While the critic Volpe (Figure 3) uses feedback thinking by discussing larger feedback loops that he believes pose a challenge to the tuna ranching industry, these extended loops are not yet included in the running model. A simple price feedback loop influences the rate of processing, since market prices do vary (in a way described by Bestor (2004) that is far more complex than represented here) as well as influences ranch size.

The working stock and flow model captures the basic value adding production chain of tuna ranching within the Mexican context, and appears to have a measure of face validity. It simplifies various aspects of each stage, since it is not the goal at the outset to simulate the activities and financial situations of the constituent firms rather to prepare an aggregate model that captures overall behavior and dynamics of importance to industry sustainability.

The boundaries of the working model are set at the stock of the Pacific Bluefin tuna *Thunnus thynnus orientalis*, that in this version is assumed to be in equilibrium and unaffected by fishing in Mexico and the Pacific. It is also limited at the sardine fishery, which is assumed to be unaffected by fishing or sales of sardine to the tuna ranches. The economics and support industry, as well as financial transactions and pricing of the tuna, are not incorporated in this version. All of these components and possible additions are discussed in more detail below and will be added and extended in future versions as the ideas, parameters and scenarios suggested by project team members are identified and incorporated.

The core scenario and basic parameters are drawn from the known and estimated characteristics of the industry in Mexico, however the model runs shown here illustrate the functionally and plausibility of the structure and emphasize creative inquiry as to the sustainability of the activity from economic, social and environmental perspectives. Calibration and more detailed validation remains to be carried out.

Key uncertainties exist about the tonnage of tuna actually captured and transferred to pens, the number of pens put into operation each year, the amount of juvenile tuna in pens, the feeding rate practices of different ranchers, the conversion factor for transforming a kg of sardines into added fat. The amount of tuna fattened in ranches and sold and exported from Mexico is accurately tracked by the supply chain but real data for model validation on the exact production levels is not consistent with information obtained to date on the fattening process. The base case presented here runs use general parameters suggested by key informants, but which require verification and validation, as small changes in some of these parameters cause large behavior changes in the model output. The assumed goal of tuna ranching is to add enough fat to tuna to maximize market value of the processed product.

Additional key assumptions in the scenarios shown below include: each ranch has 10 pens, each pen holds 40-80 tonnes of tuna, and all pens are filled each year, with the implication that nine fully operating tuna ranchers seek to acquire 3600-7200 tonnes of juvenile tuna. The shows as a look up graph an approximation of the Mexico ranch construction history, tracing information on the number of ranches put into operation since 2001, up to 9 total ranches.

A second set of key assumptions are feeding and food conversion rates. It is assumed that each pen in operation requires (40 or 80 tonnes fish/pen x 80kg/ton/day) =3.2 to 6.4 tonnes of sardines per day per pen, or 96 to 192 tonnes per pen per month or 15552 to 31104 tonnes of sardines per season for 54 pens. The runs assumes that one tonne of sardines is 5 % efficient in adding fat to tuna, that is per month each tonne of juvenile tuna gains 120 kg of fat from eating 2.4 tonnes of sardines.

Overall, just doing simple spreadsheet math, if tuna ranchers had purchased 4320 tonnes of tuna in a given season, and fed their tuna on average for three months before harvesting, they would have been able to ship 5875 tonnes of fresh tuna to Japan, having operated 54 pens for 3 months. The value added as determined by fat content gained would be 1555 tonnes or 35%. The amount shipped should also be corrected to account for the weight loss from removing gills and guts.

In discussions during model structure design and formulation of reference modes, it was assumed that the tuna would be in pens continuously for three months, then harvesting and processing would begin. The current structure attempts to capture this by allowing tuna to be harvested in less than three months as well as much longer than three months.

In sum, this first build of the model, derived mainly from co-author Simanek's mental model of the industry, generates plausible results for key aspects of the Mexico portion of the Pacific bluefin tuna supply chain.

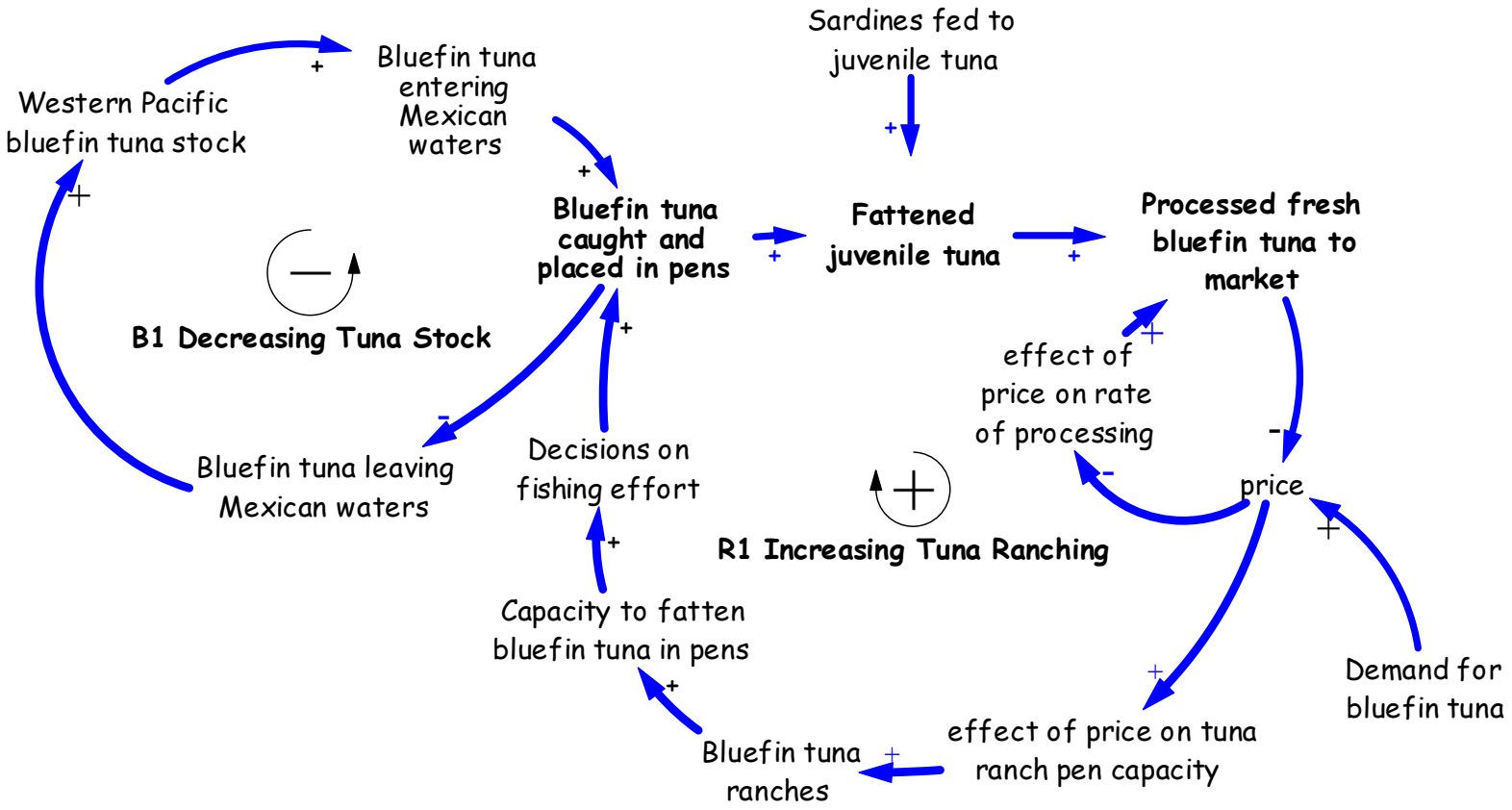

Figure 4 Overview of initial build of Mexico Tuna Ranching model

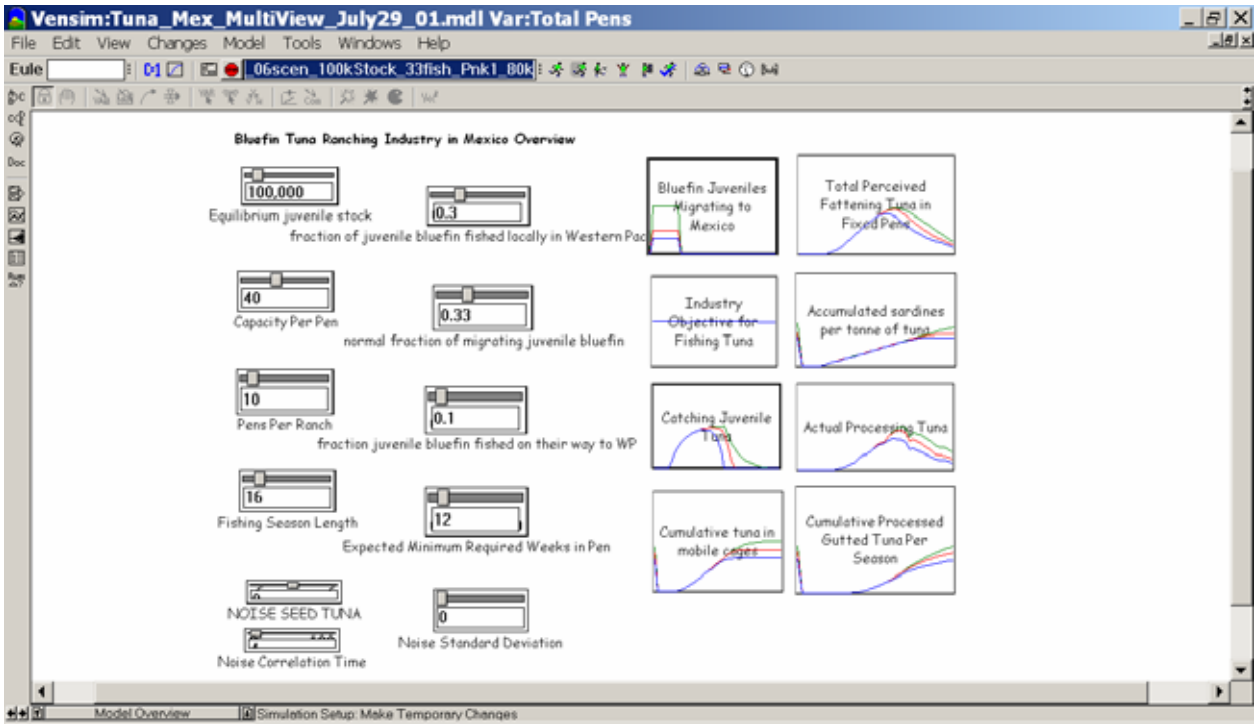

Figure 5 View of the control panel of the Mexican Tuna Ranch Model

The following three graphs show some of the basic behaviors tracked in the model. The model catches, moves, tracks and fattens Bluefin tuna. The weight of processed tuna includes the added fat minus the removed components such as gills and guts.

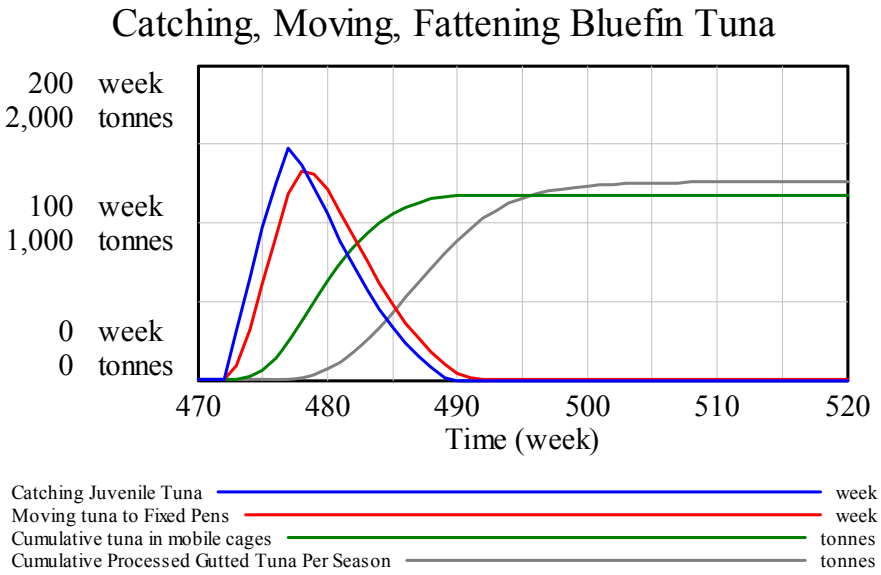

Figure 6 Catching, moving and processing tuna

The model also tracks the deployment and removal of pens at the end of the season, in part as a possible way to monitor activity in the ranches.

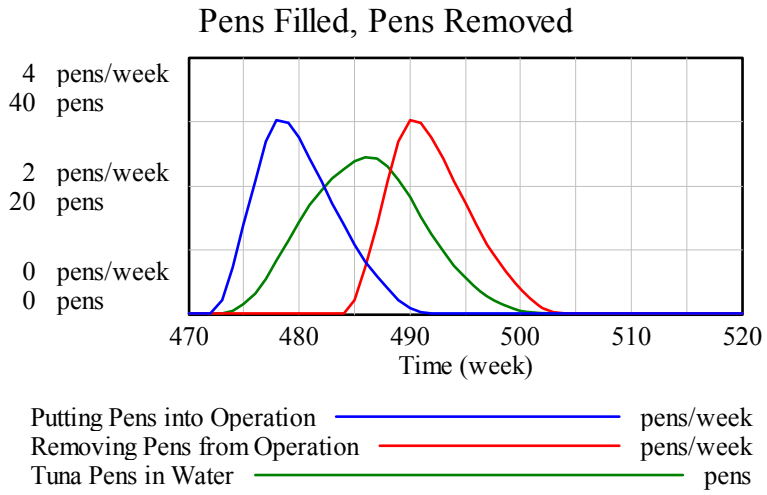

Figure 7 Deploying and removing tuna pens

Finally, as Figure 8 indicates, the model feeds, fattens and then processes tuna, with noise used to introduce variation in pricing that affects exact harvest timing. However, this graph also suggests problems in the model structure and parameters, since it implies that tuna keep fattening when feeding has largely stopped, and that some tuna (those processed in the last part of the season) are starved.

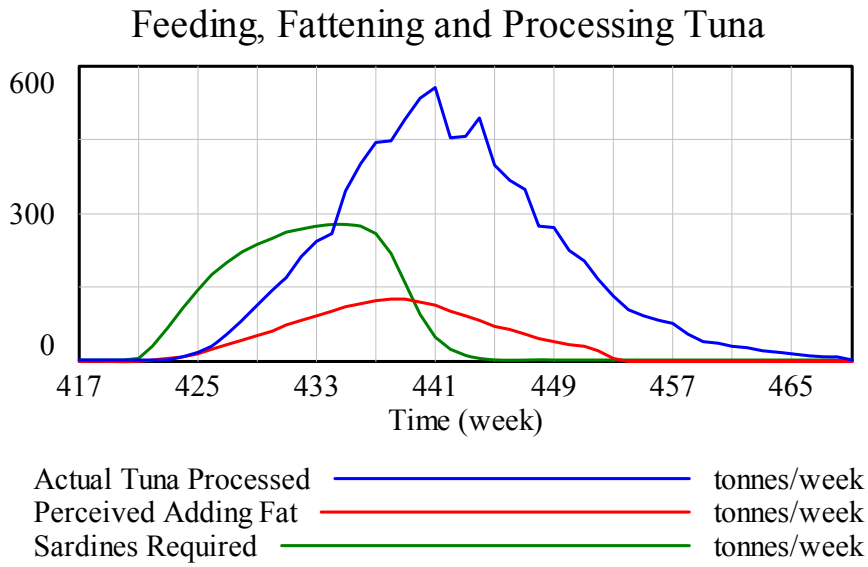

Figure 8 Feeding, fattening and processing tuna

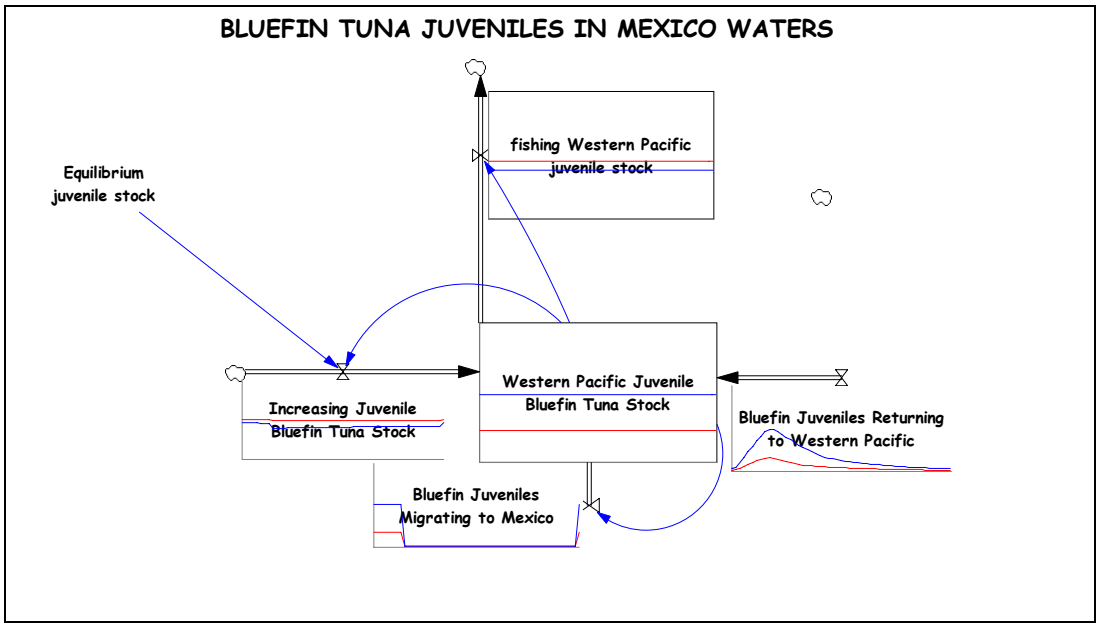

Figure 9 Non-biological fisheries component of the tuna ranching model

Figures 9-14 show key elements of model structure. The red and blue output lines represent the lower and upper limits of several scenarios discussed below, which are indicative of but specifically NOT intended to replicate the Mexican situation, as there is too much calibration and validate remaining to be done. The time frame show is a 52 week long season, however the model runs in the scenarios run for 520 weeks.

Figure 9 shows a portion of the fisheries elements of the simple Mexico tuna ranching model, which is explicitly non-biological. The model assumes that the juvenile Bluefin stock located in the Western Pacific is in equilibrium but the model contains feedback loops between the Mexican Bluefin tuna fishery and the originating stocks, in contradiction to the concept map shown in Figure 1. Perhaps the Mexican fisheries authorities are correct in concluding that this small, irregular stock should be held to its current level of harvest. In fact this viewpoint seems to be confirmed by the Inter-American Tropical Tuna Commission (2006:95), which states that a "strong recruitment event (for the Pacific Bluefin tuna) that may have occurred in 2001 would maintain spawning stock biomass above recent levels until about 2010." This is possible good news for tuna ranchers. The IATTC goes on to declare that "spawner-recruit analyses do not indicate that the recruitment of Pacific bluefin could be increased by permitting more fish to spawn." In other words, none of the tuna which migrate to the eastern Pacific need to return to Japan in order to sustain the stocks. The catches of Bluefin tuna in the eastern and western ocean are highly variable and irregular, reflecting peaks and valleys in the biomass of the spawning stock. Table 3 indicates that Mexico is responsible for a substantial fraction of that catch.

	2002	2003	2004	2005
Total catch Pacific Bluefin	17,459	15,920	21,707	13,512
Mexican	1,714	3,257	8,891	4,542
Fraction Mexico	.098	.204	.409	.336

Table 3 Reported catch of pacific bluefin tuna
Source: ICCAT (2006).

Alternative report of annual production of fresh tuna from capture-based aquaculture in Mexico

Year	2001	2002	2003	2004	2005
Tonnes, Thunnus Orientalis	521	517	517	4,193	7,869
Dollars per kg	$13.46	$14.08	$13.51	$13.78	$15.19
Value, thousands USD	7,014	7,281	6,985	57,821	119,575

Source: United Nations Food and Agriculture Organization, FIGIS Data Base.
http://www.fao.org/figis/servlet/SQServlet?file=/usr/local/tomcat/FI/5.5.23/figis/webapps/figis/temp/hqp_55755.xml&outtype=html

Table 4 Alternate information on Pacific bluefin tuna sale to Japan

The fraction Mexico is catching of the total stock varies significantly by year. Matsukawa (2006) finds an evolutionary response in that "the population excess over the carrying capacity (in the Western Pacific) causes the migration in each life stage". Furthermore, "migration of the tuna into the eastern Pacific increased in years when the abundance of sardines was declining". These sources of variation are normal. The tuna model should probe the tuna ranching system in Mexico to see the effects of such variations. It also turns out that the Western and Central Pacific Fisheries Commission has formed a Northern Committee, which is already in place and meeting, led by Japan (WCPFC, 2006). Several Americans attend the meetings, indeed the first meeting was held just across the border in La Jolla.

Figure 10 shows the movement of Bluefin tuna into Mexican waters, capture of a fraction, and then the fact that some tuna remain in the eastern Pacific and return to Mexico the next season.

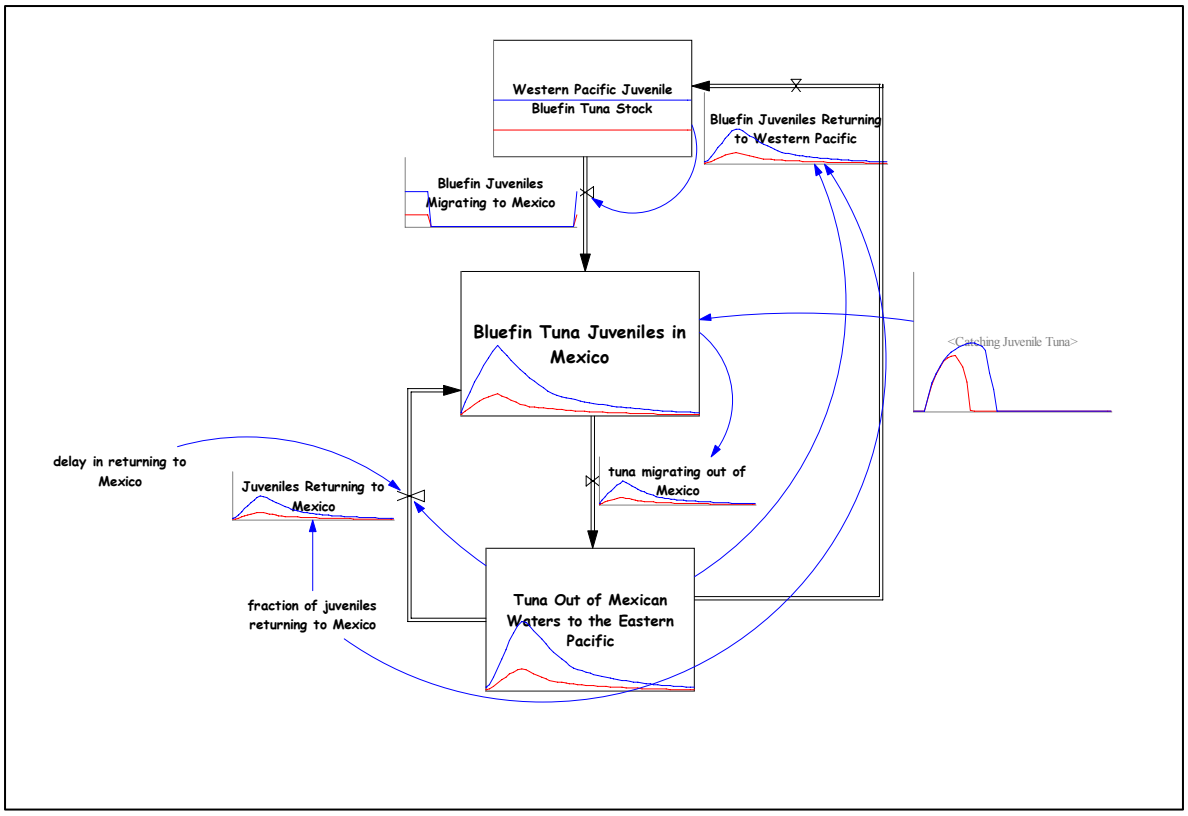

Figure 10 Bluefin tuna in Mexican waters

A key aspect that is not revealed in the model is the extent of foreign participation in the technology, supervision, financing and quality control of Mexican tuna production. Swartz (2004) maps out the changing way in which Japan, as both consumer and producer of fish products is able to participate through non-fisheries methods in assuring a steady supply of high quality products.

Production component details

A key missing piece in the Mexican tuna ranching model is the closed cycle. The abundance of fresh sardines just at the time when the Bluefin tuna arrive off the coast of Baja California makes tuna ranching simpler than in the Mediterranean or Australia. However, the questions raised by reflecting on the fisheries component led us to check whether in fact the life cycle of the Bluefin tuna had been successfully closed such that juveniles could be raised and fattened with little regard for the future of the ocean fishery. In fact, as Sawada, Okada, Miyashita, Murata and Kumai (2005) report, Japan has successfully closed the cycle. Australian ranchers also claim to have closed the cycle for *Thunnus maccoyii.* including one highly publicized operation with several adult females placed in a special environment in anticipation of spawning. (Treadgold, 2005)

In the model, only wild captured tuna is involved. In Figure 11, ranches are established and their capacity established. While permits may limit the maximum number of pens, the ranchers can decide how many pens to deploy in a season. In Figure 12 the captured tuna are towed to the

pens. Note that the term "perceived tuna in pens" is used, since many ranchers do not have a precise estimate of how many tuna are actually obtained and transferred.

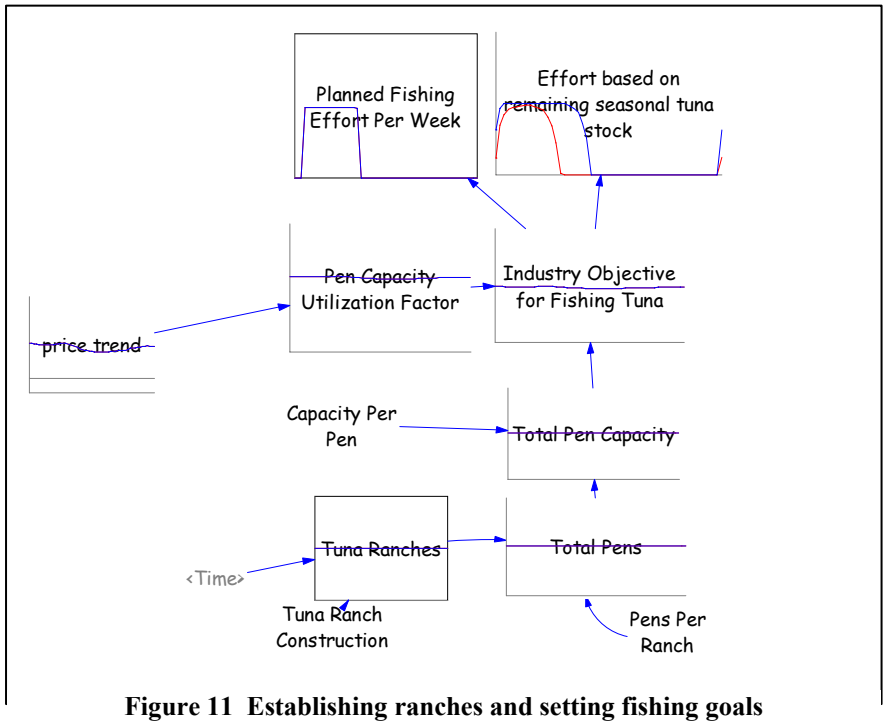

Figure 11 Establishing ranches and setting fishing goals

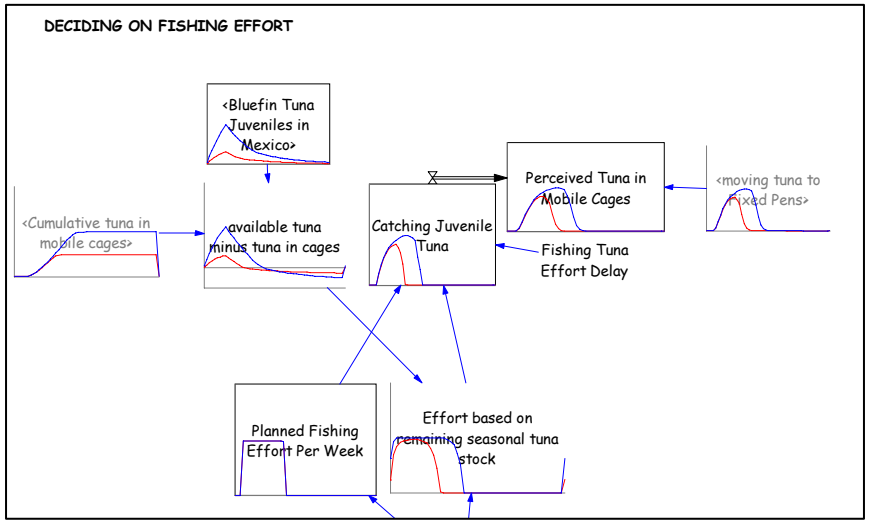

Figure 12 Deciding on how much effort to catch tuna
The model includes a simple mechanism that adjusts effort to the dwindling amount of Bluefin in Mexican waters

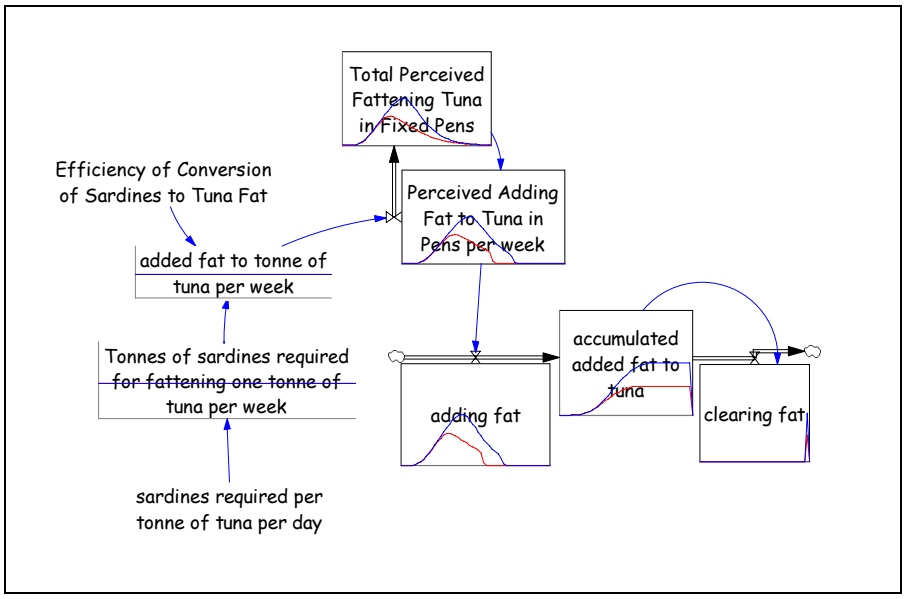

Figure 13 Feeding and Fattening Tuna
Some ranchers feed based on the perception of how many tuna are in the pens

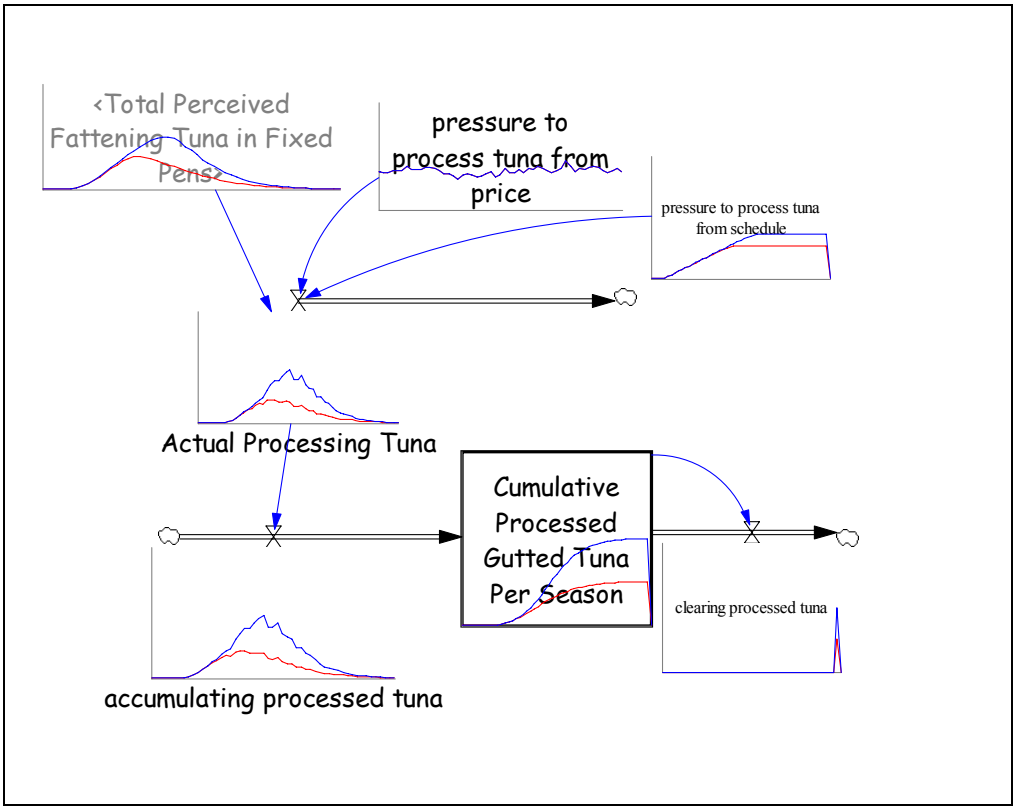

Figure 14 Processing Tuna
Processing is a balance between increasing cost of production due to feeding and market price

Another question tied to the fisheries component of tuna ranching, is the source of food. Figure 13 shows that sardines are fed at a certain rate per day and this adds the fat content to create

more valuable bluefin for use in sushi. Tuna ranchers are in a position to pay a premium for fresh sardines compared to alternative uses, such as fish meal or frozen or canned. What might happen in an extreme case when the tuna and the sardines were not in the same place at the same time? This is the case now in Australia, which relies on frozen sardines including from the United States. There are other large stocks of sardines in the Pacific and Gulf of California that could be obtained. Another key question, both from the modeling and management perspectives is the degree of information forthcoming about the actual feeding and fattening ratios, waste management and the potential for disease, in part to be able to better assess and predict industry performance related to management practices.

Finally, tuna is processed carefully to maintain a high quality, and flown chilled and fresh from Los Angeles to Tokyo. As noted by Issenberg, the rancher must balance the costs of fattening with the market price and choose the processing carefully to maximize profits.

Scenarios

To examine the potential usefulness in asking questions about sustainability, several scenarios were formulated. Table 5 shows the variations in a few parameters that are used to set up 10 year runs, and the final outcome in terms of tonnes of Bluefin tuna to the market.

Constant	Scenario 1 base case	Scenario 2 tuna stock is reduced	Scenario 3 despite reduction, effort is maximized	Scenario 4 Base case plus maximized effort
Equilibrium Stock of Juvenile Tuna in Western Pacific (tonnes)	100000 tonnes	50000 tonnes	50000 tonnes	100000 tonnes
Fraction fished locally in Western Pacific (dmnl)	**.3**	.76	.76	.3
Ranches/# Pens in Mexico at Buildout (ranches, pens)	**9 / 90**	9 / 90	9 / 90	9 / 90
Assumed total capacity of pens (40-80 tonnes/pen)	**3600 tonnes**	3600 tonnes	7200 tonnes	7200 tonnes
Tonnes of tuna to market	**3940 tonnes**	3210 tonnes	4005 tonnes	7851 tonnes

Table 5 Simulation output from model runs similar in nature to the Mexican situation

Scenario 1: The base case

Figures 15-19 summarize the model run in Year 10, leading to production of 3940 tonnes of fattened and processed tuna. Figure 15 shows the functioning of the production chain on the ranches, and Figure 16 shows the accumulations of captured tuna and tuna production. There is perfect knowledge of production, but many ranches do not have full knowledge of how many tuna of what sizes are in the pens.

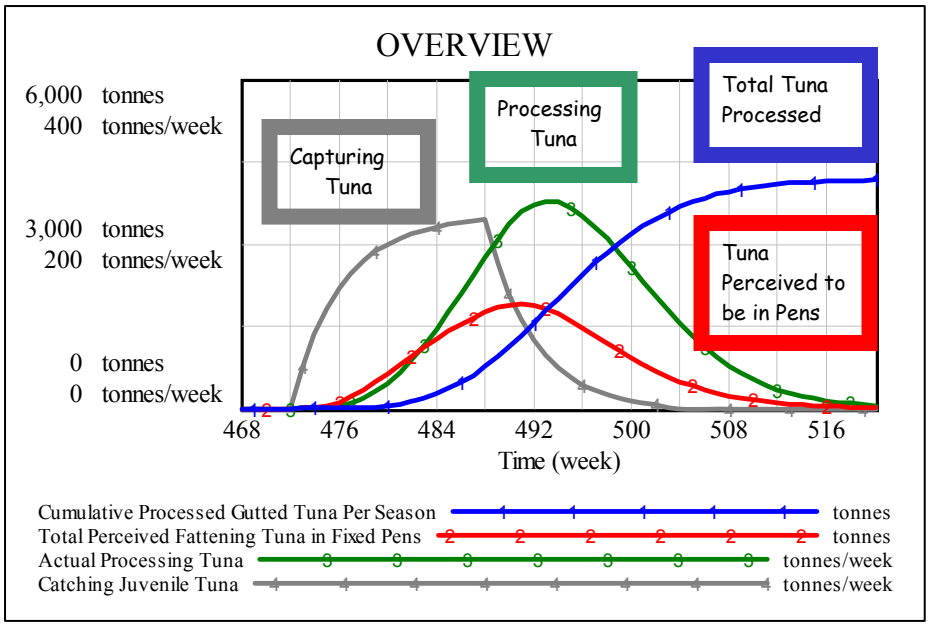

Figure 15 Scenario 1 Overview, at Year 10

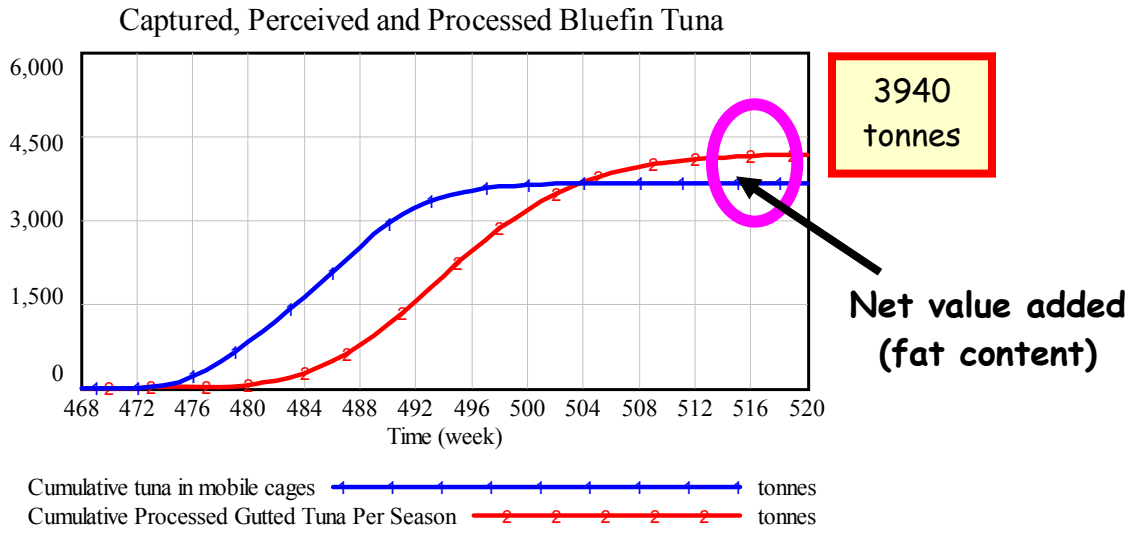

Figure 16 Scenario 1 final output comparing cumulative tuna captured and shipping weight of tuna processed

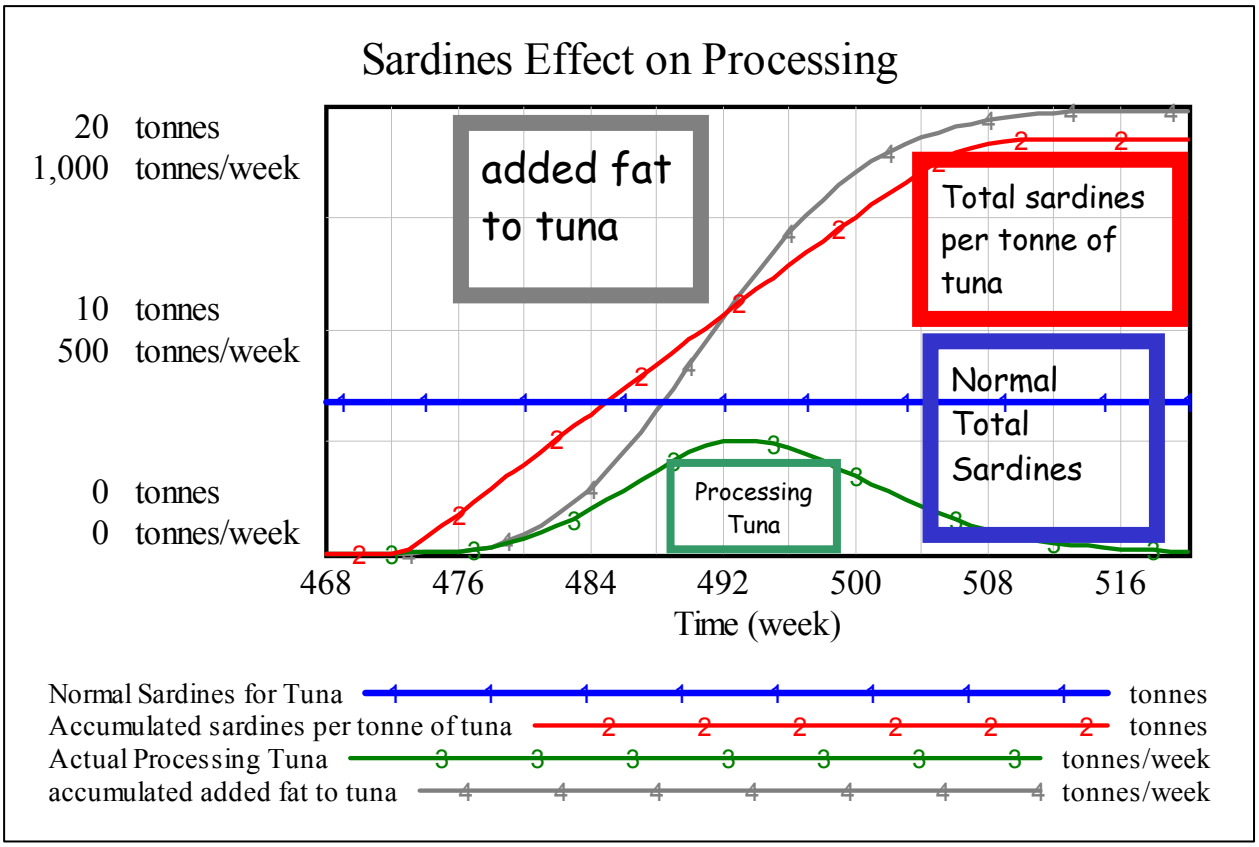

Figure 17 Pressure to harvest balances need to ship all tuna before costs overshoot price, and the advantage of delay to gain a price increase

The consequence is that ranchers are feeding "perceived tuna". The model structure, as noted earlier, attempts to indicate that the cost of continued feeding creates a pressure to harvest, while the situation in the market place in Japan may justify waiting until the price reaches the most profitable point.

Figure 18 shows that the model structure allows some exploration of the effect of profit on ranch operations. The impact on profit is the decision to purchase more captured bluefin.

Scenario 2: Suppose the Bluefin tuna stock declines to half the base case level
Scenario 2 simply reduces the assumed size of the overall Western Pacific tuna stock, keeping all else equal, with the result that a lower stock, even if very large, will reduce the amount of tuna fattened. This might be the equivalent of events such as poor year classes in the Western Pacific, or offshore Bluefin fishing increasing greatly, intercepting the juvenile tuna before they reach Mexico. The model does this with a lookup graph that has fishers become less efficient as the end of the bluefin tuna season in Mexico approaches so that at a certain point it is no longer worth setting nets. This is shown in Figure 19.

Scenario 3 assumes that ranchers decide to double their fishing effort to get as many tuna as they can, and assumes the pens can accommodate the extra tuna or more pens are deployed. The result is compared with the other scenarios in Figure 20. The blue line represents the lower capture of tuna, even though, as Figure 21 indicates, the initial pulse of captured tuna occurs

because of doubled effort. However, the intuition is that because there are fewer tuna overall, each setting of the nets will be less and less productive. The model employs very simple structure to produce this effect.

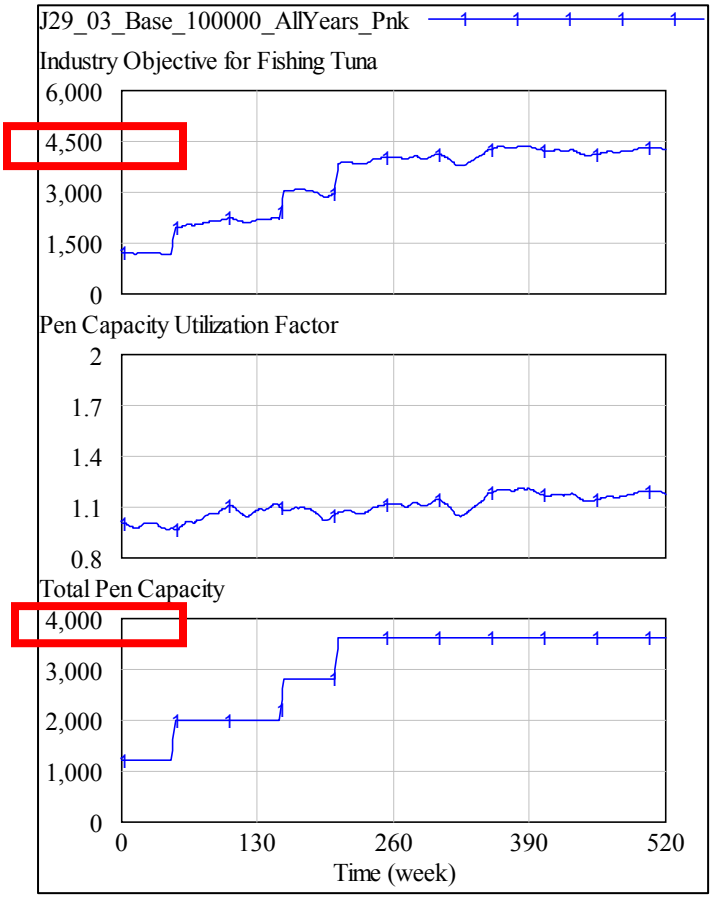

Figure 18 Price signal used to influence investment in ranches and pens. A pink noise based long term price rise influences decisions to expand capacity correspondingly

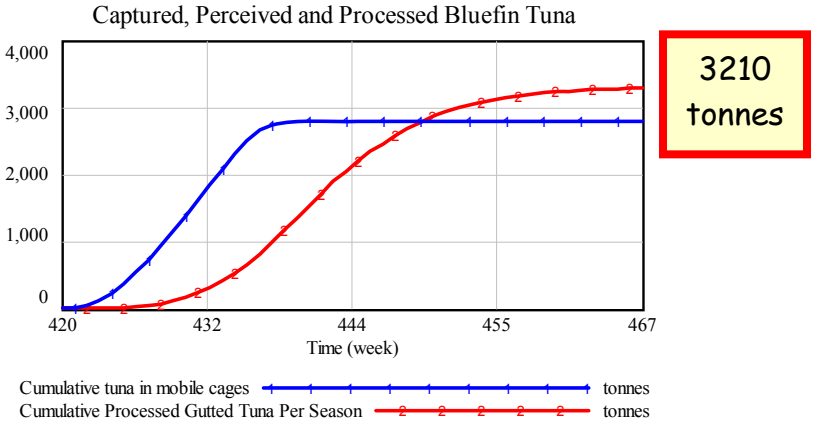

Figure 19 Scenario 2 output shows reduced production because Bluefin tuna are more scarce

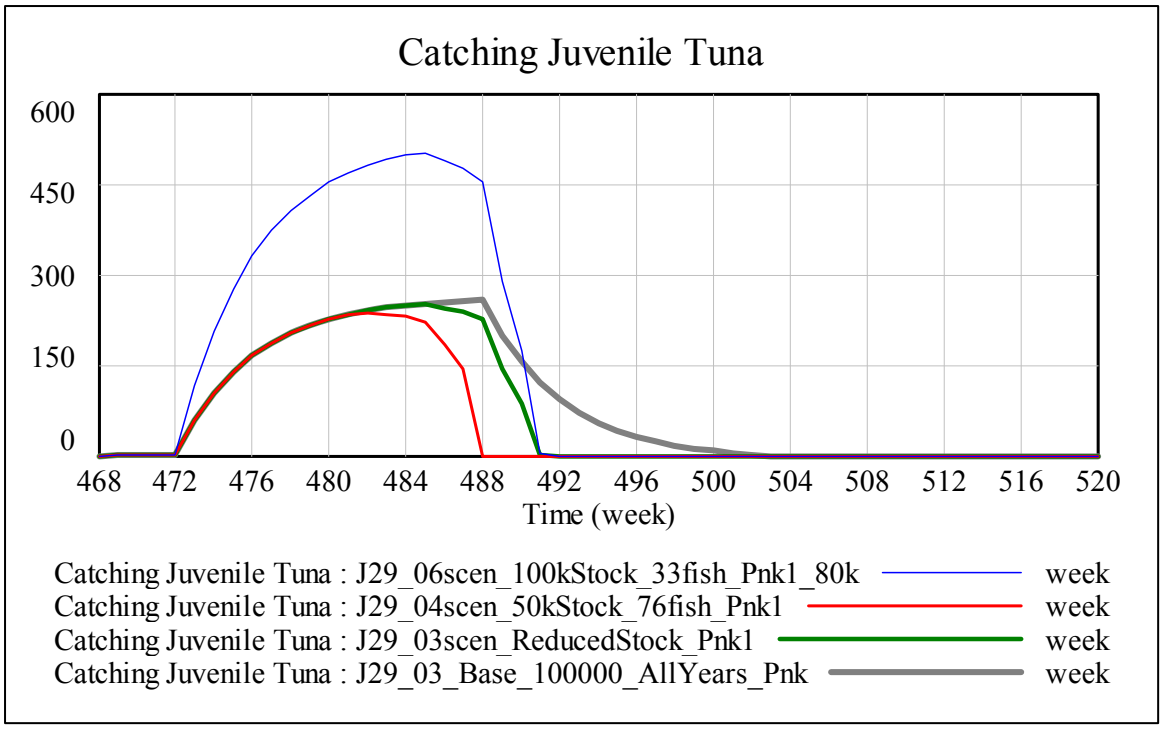

Figure 20 Comparison of four scenarios based on fish stock and fishing effort.

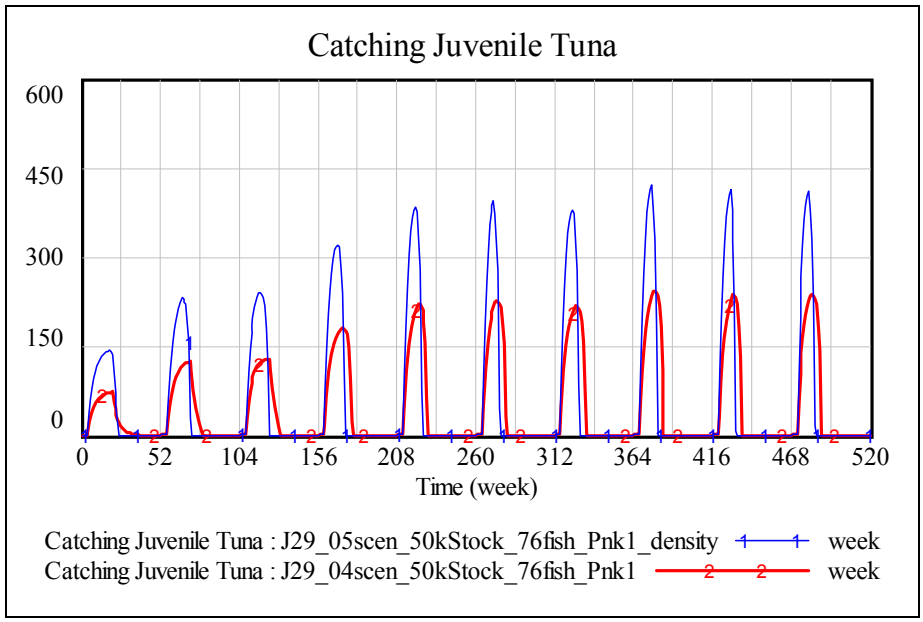

Figure 21 Initial result of scenario 3: more fishing effort creates a dramatic initial pulse of capture

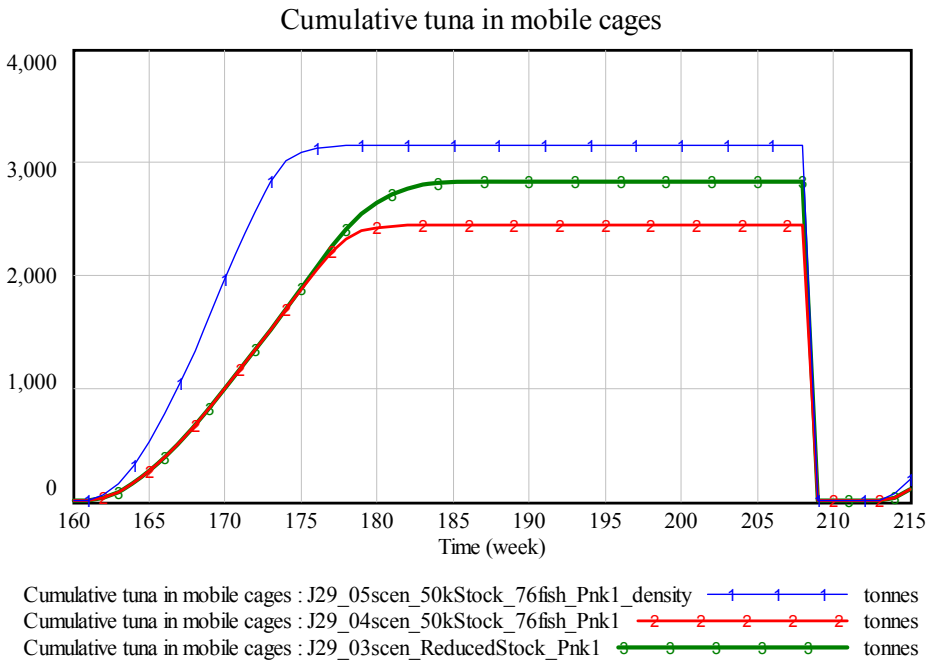

Figure 22 Comparison of scenarios...doubling fishing effort does not double capture nor production

Scenario 4, shown below in Figure 23, represents the optimistic view of tuna ranching that does not recognize any internal or external constraints, and thus supports the assumption that tuna ranching is sustainable in the Eastern Pacific. As the model is validated, the various scenarios will likely fall below the level of this optimistic view.

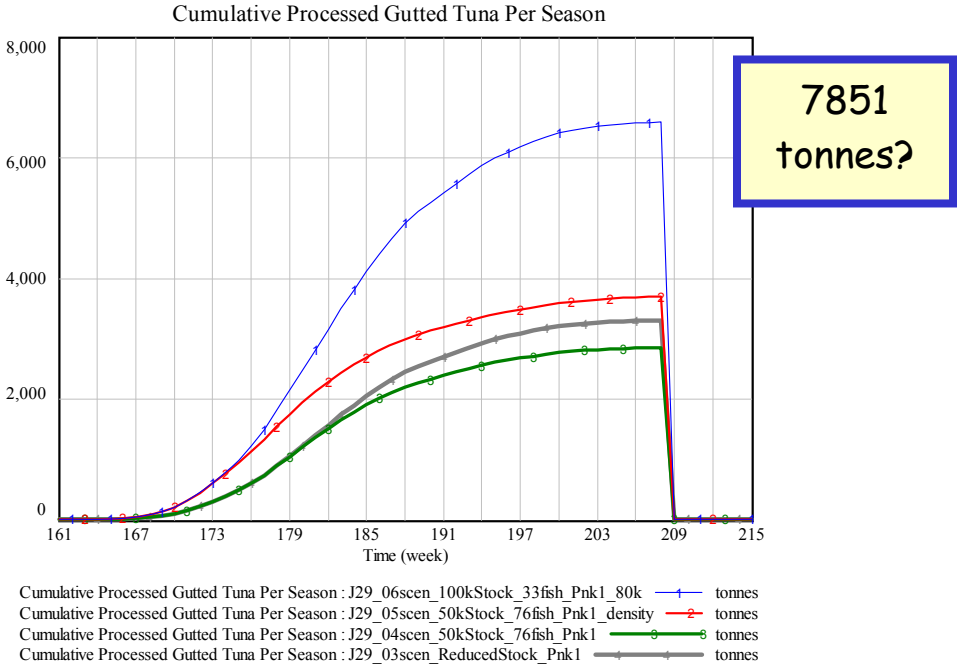

Figure 21 Scenario 4: Sustained Optimism: Tuna Stocks Stay High, and Ranches and Fishing Effort Can Expand

A Tasmanian firm, Aqua Assist, has already developed sophisticated decision support tools for individual tuna ranchers and other types of ranching operations and is reported to be used in both Australia, Mexico and the United States. Figure 24 indicates that the software author (Bronstein, 2007) incorporates many features of the broader, text book model as represented by Pillay and Kutty. The model presented here operates at an aggregate level, glossing over individual ranch differences. From an information system perspective, however Aqua Assist represents a major step forward, since it also includes specific modules related to tuna fishing quotas.

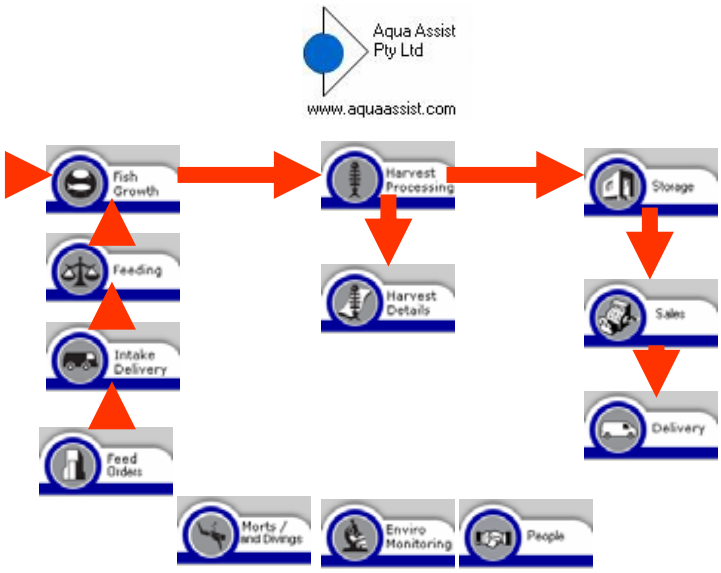

Figure 22 Decision making software for tuna ranchers by Aqua Assist (Bronstein, 2007, reproduced by permission.)

Conclusions and a look ahead

At the very least this work suggests that the present stance toward tuna ranching as a low visibility activity with few issues is unjustified when seen in its global context, most importantly in relationship to the market of Japan. Just as Japan has found numerous undesirable aspects of its prior trade relationship to Mexico, especially in relationship to the *maquiladora* arrangement, prompting a new trade agreement, Mexico might want to look again at whether the lowering of tariffs for seafood like Bluefin tuna is either enough or even the most important obstacle in the way of sustainability. Mexico might also want to have a seat at the table for the Western Pacific fisheries management initiative led by Japan. Perhaps tuna ranching, which on its face seems an independent and nearly self-sufficient activity, is indeed far more vulnerable to decisions made elsewhere that affect tuna supply, technology and standards, access to the market, and price.

Further extension of the modeling effort would not be aimed at analyzing individual firms within the industry, rather the hope is to generate better information to confirm or contradict output from model runs under reasonable sets of assumptions, in the spirit of the OECD proposals for future fisheries and aquaculture management in Mexico. In particular, this needs to include determining the full extent of the model boundary in order to see the extent of what should be

considered exogenous structure. This in turn will build confidence in using both the specific tool, and more broadly the frame of reference the systems thinking perspective can add to both determine and assure sustainability of Mexican tuna ranching in the face of a larger set of challenges based not on metaphors but on a deeper understanding of its structure and dynamics.

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