

Sustainable Fish Cage Aquaculture In Cirata Reservoir West Java, Indonesia: A System Dynamics Approach

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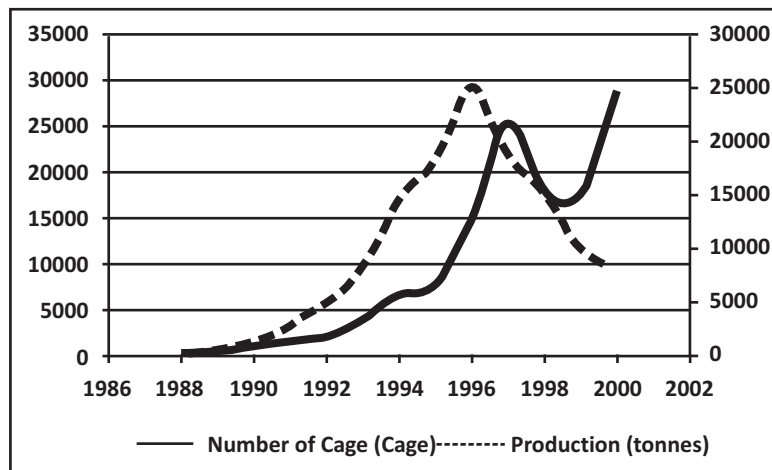
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INTRODUCTION

Cirata reservoir (widely 62.000.000 m²) is a big water body covering three regencies in West Java, that are - West Bandung Regency, Cianjur Regency and Purwakarta Regency, located at the basin with the height of 220 m above sea level (a.s.l.), and is used to produce electricity through hydroelectric power (PLTA). Since 1988, Cirata Reservoir has been used for Floating Net Cage Aquaculture (FNCA). At the beginning of the Cirata Reservoir establishment (1988), there were 74 units 4 x (7 x 7 x 2.5)m³ at FNCA, with the production at 32 tonnes per year and during 1996, the production went up to 15,289 units with the production of 25.114 tonnes per year. The FNCA units number was much higher than the limit recommended by **Balitkanwar**, that is 2,727 units (**Husen, 2000**). According to **Dhahiyat and Wikarta (2007)**, each year, the fish farmers at FNCA continued to increase (showed in Figure 1). This showed that their response to this aquaculture is high enough. However, the number of FNCA units had exceeded the limit recommended, resulting in decrease in the FNCA productivity (Figure 1).

Figure 1 : Number of FNCA (Cages) And Fish Production (Tonnes) In Cirata Reservoir



Nowadays, the FNCA used for aquaculture consists of two layers, that is the first layer with the dimension at 7 m x 7 m x 2.5 m, and the second layer with the dimension of 7 m x 7 m x 4 m. The first layer is used for rearing Carp (*Cyprinus carpio*) for 3 months and the second layer is used for *The Nile Tilapia* (*Oreochromis niloticus*) for 5 months. In a farming unit (one unit per four cages), the owner of FNCA in the Cirata Reservoir usually has more than 4 units, usually reaching 16 units per ownership. The increasing of the ownership number will stimulate new zones of FNCA area in the Cirata Reservoir.

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Empirical evidences as shown in Figure 2 and Figure 3 show the descending of productivity of FNCA and the descending of Dissolved Oxygen (DO).

Figure 2 : Fish Productivity of FNCA 1988-2000 in Cirata

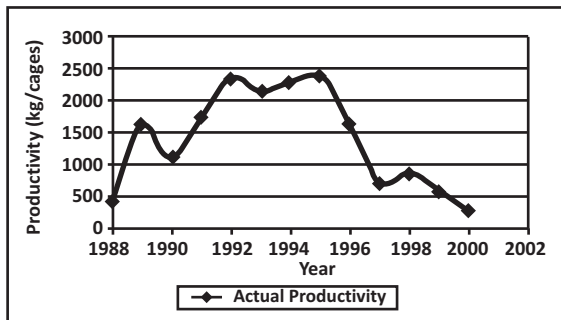
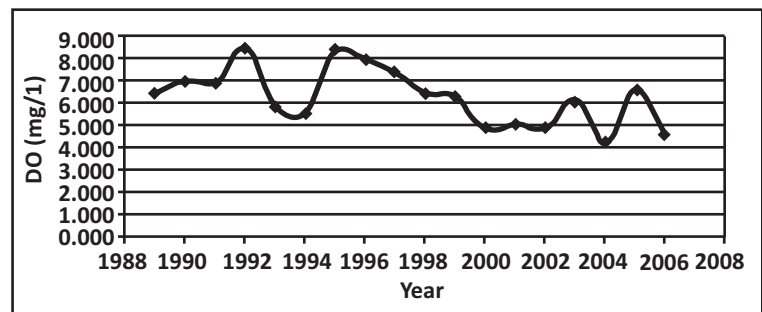


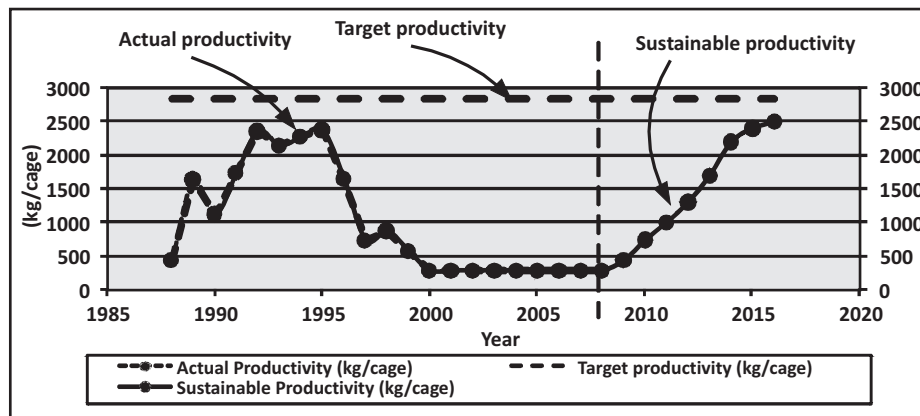
Figure 3 : Actual Dissolved Oxygen (DO) in Cirata



The FNCA sustainability in Cirata Reservoir must be known to prohibit the decrease in the productivity of fish because of the presence of eutrophication. The presence of eutrophication in case of the increasing of FNCA units and unused fish feed, could be considered as the reason for decrease in fish productivity in the reservoir. The unused fish feed adds to the concentration of the nutrient in the water. The increasing nutrient concentration is caused by decomposition of unused fish feed. The decomposition needs oxygen, that is also needed by the fish for their growth. The increase of decomposition will need much oxygen and cause lack of oxygen in the water. This condition (lack of oxygen) will descend the fish growth, and finally will reduce the productivity of the fish (kg/ units or kg/m³ water). Figure 4 shows that the main problem is the decrease of FNCA productivity in Cirata Reservoir and it needs to be increased up to the ideal target.

According to the previous explanation, some problems that are being dealt with are: (1) Processes that cause the increasing of the dynamics of FNCA productivity, (2) A Model that could be used as an analytical tool to explain no 1 condition, (3) Based on the model, which design of policy is needed to increase the FNCA productivity up to the ideal productivity (sustainable).

Figure 4 : Productivity In The Actual Condition, Target As Well As Sustainable Condition



(Source: The Authority Institution of Cirata Reservoir (BPWC), 2001 and Simulation Data)

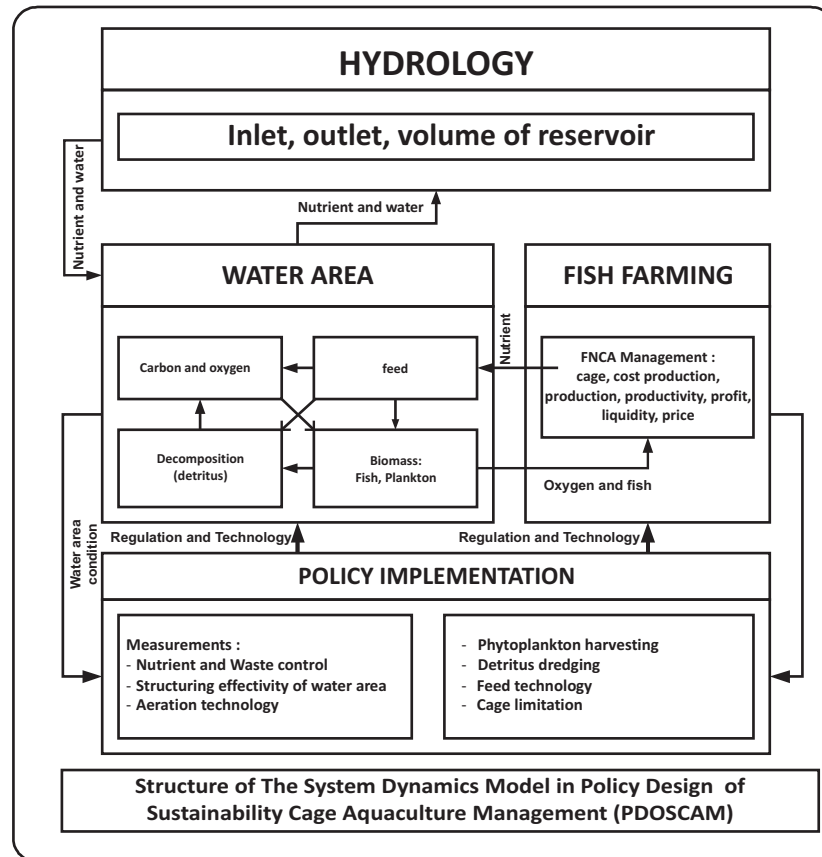
The system dynamics method was used in this research, because this method was process oriented and the principles of dynamic model making was fulfilled with this method. System dynamics is a part of the field that is wider than the simulation model. The result simulation model is causalistic. The model is made from the public's rules that depicts how each element in the system will change in responding to the combination of other elements to be understood. The model is used in the public understanding stage or policy planning in decision making (Tasrif, 2005).

Regarding the sustainable FNCA policy formulation, the policy is the intended direction that is determined by an actor

or several actors in overcoming the problem. **Winarno (2007)** defined the policy as a hypothesis that contained early conditions and predictable effects. The public policy has several implications that are goal oriented, and are not an unmanaged behavior. Sustainable FNCA policy is a fish farming strategy that is intended to change the behavior of fish production and productivity, without ignoring the availability of resources that are involved.

The functional activity in the Cirata Reservoir was to arrange maximum number of FNCA units that might operate. Figure 5 shows the global structure of the system dynamics model of sustainable FNCA policy based on parameters interacting as the framework of this research.

Figure 5 : Global Structure Model Of System Dynamics In Sustainable FNCA Policy



The research was the descriptive-analytical ex ante, that is analyzing a phenomenon or the incident before happening. The subject of the research was the process of eutrophication and the farming of FNCA in Cirata reservoir.

The test carried out in the model followed the rules of system dynamics approach, that is: the testing of the model structure; the test of the model behavior; and the testing of policy implications (**Sterman, 1984**). **Breierova and Choudhari (1996)** carried out the testing to measure how sensitive a model was with the sensitivity analysis by changing model parameters and the model structure to produce a useful model, that was valid as well as approaching the true condition (**Sterman, 1984; 2000**). The visual validation and statistics was also used by **Sterman (1981)**; according to **Sterman (2000)**, the Theil's unequility statistics test of the model separated the difference of a mistake into 3 components, that is the bias, unequal variation and unequal covariation.

RESULTS AND DISCUSSION

✿ **FNCA Trend** : Because the available serial data about FNCA was only in unit numbers, production and the productivity, oxygen, carbon, detritus, and the price of carp, the FNCA trend was indicated through seven variables as mentioned. The FNCA trend has been shown in the Table 1.

❖ **Fish Net Cage Aquaculture Model** : The FNCA model that was built represented the sub-model of the number of units (Figure 6), the production sub-model of *Carp* and *Nile Tilapia* (Figure 7 and 8), the oxygen sub-model (Figure 9), the liquidity sub-model (Figure 10), and the sub-model of the fish price (Figure 11) that was the main sub-model that could show the interaction of economics and the ecology aspects. Whereas, Figure 12 shows the behavior of several model parameters in various policies.

Table 1 : Main Variable That Depicted Progress Of FNCA In The Cirata Reservoir

Nu	Year	Cage number (cage/year)	carp prod. (kg)	carp productivity (kg/units/year)	Dissolved oxygen (mg/l)	BOD (mg/l)	Bicarbonate (mg/l)	Carp price (Rp/kg)
1	1988	74	32.000	432	7,36	1,235	62,5	1.550
2	1989	351	152.000	433	7,36	1,235	62,5	1.600
3	1990	899	997.000	1.109	6,98	1,008	62,5	1.725
4	1991	1.613	2.803.000	1.738	6,92	2,15	64,7	1.700
5	1992	2.056	4.850.000	2.359	8,48	2,3	64,7	1.850
6	1993	3.820	8.195.000	2.145	5,83	3,611	65,8	2.025
7	1994	6.473	14.798.000	2.286	5,57	10,026	66,6	2.075
8	1995	7.690	18.305.000	2.380	8,37	2,729	71,6	2.215
9	1996	22.550	25.114.000	1.114	7,92	13,042	71,61	2.360
10	1997	25.558	18.695.000	731	7,37	8,286	79,5	4.100
11	1998	17.477	15.265.000	873	6,46	9,409	76,17	4.900
12	1999	17.477	9.995.000	572	6,30	7,1	77,4	6.000
13	2000	28.738	8.100.000	282	4,84	10,405	83,2	6.575
14	2001	31.476	26.230.000	833	5,07	8,562	80,73	6.750
15	2002	36.952	33.592.000	909	4,93	16,675	107,09	7.000
16	2003	39.690	41.255.000	1.039	6,17	12,243	89,81	7.200
17	2004	40.945	43.381.000	1.059	4,23	11,425	80,19	7.450
18	2005	42.200	45.507.000	1.078	6,63	10,567	98,7	8.000

Source: Processed from various sources

❖ **Model Behavior: Number Of Cages** : The number of FNCA (Figure 6) depended on the number of previous cages, increase in yield due to addition of new cages and decrease in yield because of broken cages. Whereas, stock/ level of the cages in the production increased by making cages and decreased by finishing cages. The level of the finishing cages as the addition of the number of units was influenced by time to finish cages, whereas the broken units was influenced by the broken cages fraction. The production of the cages as the addition of the cages in the production as influenced by the production of the new cages that was wanted, the correction of the cages in the production, the effect of the maximum numbers of cages to the production of cages and the effect of liquidity. The effect of the maximum number of cages to the cage production will be how many numbers of cages will be produced. Because if the maximum number of cages were reached, then the production of new cages is no longer possible. The maximum number of cages were influenced by the allowed area of availability to be used for FNCA.

❖ **Model Behavior: Production And Productivity** : There were two kinds of fish that were often cultivated in Cirata Reservoir, that is *Carp* and *Nile Tilapia*. In the sub-model structure, the production of *Carp* was formed from one stock and three flow. Stock variable, that is, *Carp* population was influenced by the real fish stocking as the additional factor of stock and the fish harvest, as well as the fish mortality as decreasing stock. The productivity of the FNCA units as shown in Figure 7 and 8 were determined by the production (harvest) of the *Carp* and *Nile Tilapia* as well as the number of FNCA.

Figure 6 : Sub-Model - Numbers Of Cages

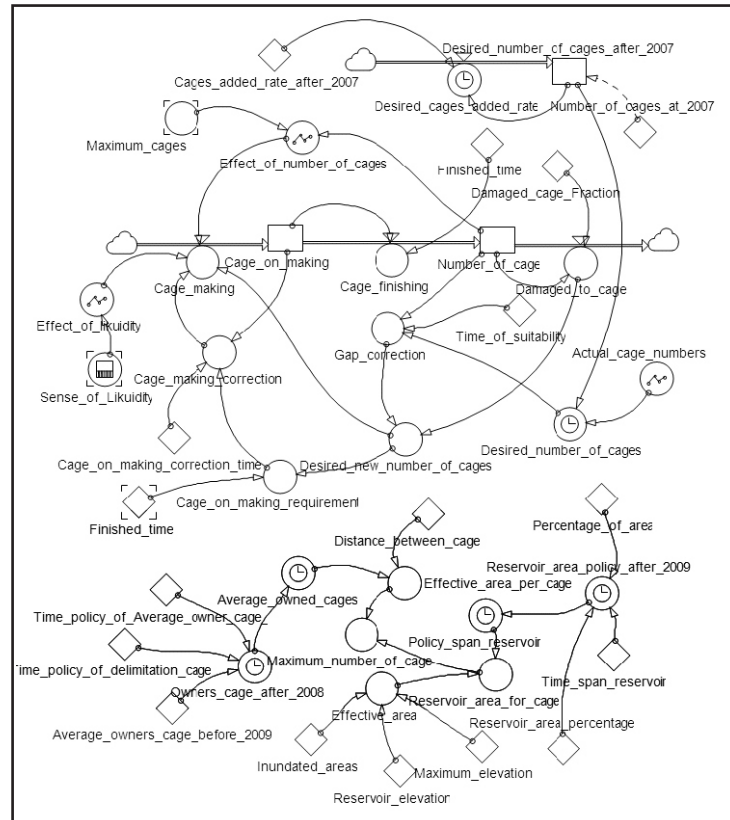
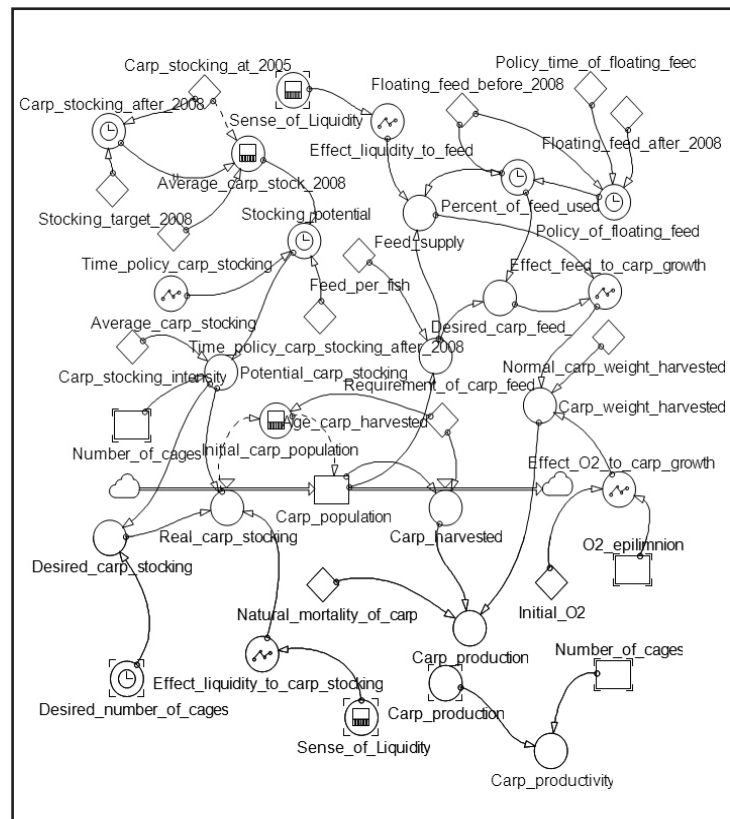


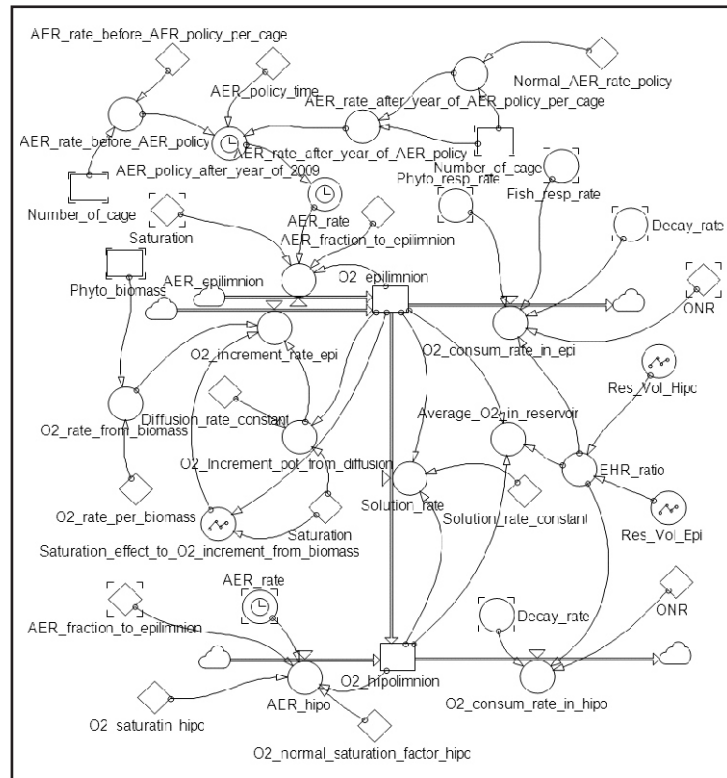
Figure 7 : Sub-model Of *Carp* Production



Nile Tilapia lived in the second layer, under the *Carp*. The unit area for *Nile Tilapia* was four times wider than that for *Carp*, and usually was acknowledged as the “*kolor*”. Food that was given for *Nile Tilapia* was not intended in the case of the *Carp*, because the *Nile Tilapia* usually eats unused food and faeces from the *Carp* layer. The other difference between the sub-model of the *Nile Tilapia* and the *Carp* was the ability of the *Nile Tilapia* to live in the condition of lower oxygen than that of the *Carp*.

The rate of oxygen increase in epilimnion was influenced by the rate of oxygen increasing from phytoplankton biomass, potential oxygen increment from atmospheric diffusion, and was also influenced by saturation effect due to the oxygen increment from phytoplankton biomass. Oxygen rate from biomass was influenced by the biomass

Figure 9 : Sub-model of Oxygen



magnitude and the oxygen production rate per biomass unit. Potential oxygen increment from atmospheric diffusion was influenced by oxygen saturation in the water and the diffusion rate constant. Oxygen from atmosphere would diffuse into the water, if oxygen saturation level was under 100 %. Whereas, if the oxygen saturation level reached 100%, then there was no longer diffusion from the atmosphere. If the saturation level exceeded over 100 %, then oxygen releasing from water to the atmosphere happened. Saturation level also influenced the saturation effect of oxygen increment from the phytoplankton biomass.

❖ **Model Behavior: Liquidity** : Liquidity sub-model structure as shown in Figure 10 consisted of one stock: cash and two flows : income and payment. The cash increased with the income and descended with the payment. Level of income was determined by level of fish sales revenue, both from *Carp* and *Nile Tilapia*. The fish selling value was determined by fish production and fish price. The other income came from the cash increment. This increment would exist if cash did not suffice to cover payments. The level of incremental cash was determined by the desired cash increment. Desired incremental cash was influenced by available cash, intended cash, average income, average payment and was determined by cash adjustment time. Desired cash was influenced by the required money for various transactions. Comparison between the available cash and desired cash was the liquidity from FNCA. If this liquidity value equaled to one, it showed that the desired cash was the same as the available cash and it was not necessary to get additional cash. The payment value as decrement of cash were determined by expenses that must be paid and were influenced by liquidity value, except for the labour cost, that have to be fulfilled.

❖ **Model Behavior : Fish Price** : Figure 11 shows that the desired price of the *Carp* was a stock that its value was influenced by price changes wanted by the farmer. Whereas, the actual price was determined by the desired price, profit value wanted as well as cost effect to the price. Cost effect to the price was influenced by desired price, the price sensitivity to the cost as well as the desired production cost. The desired production cost consisted of cost for food, cost for seed, and cost for labour. The cost value was determined by the potential production. Determination of *Nile Tilapia* price was inserted into the liquidity sub-model that was counted in average 70 % from the *Carp* price based on information from the FNCA farmer.

Figure 10 : Sub-model of Liquidity

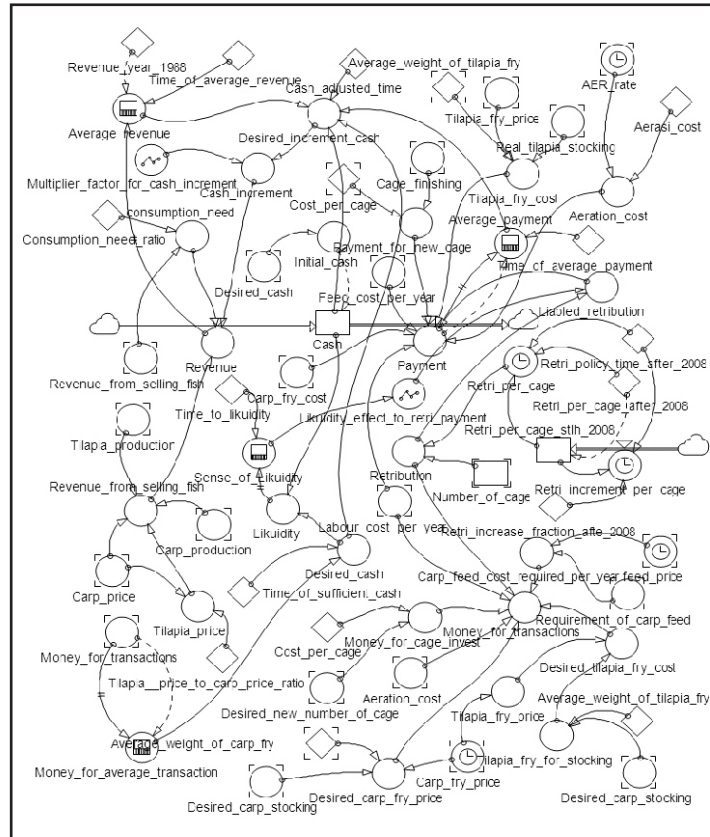
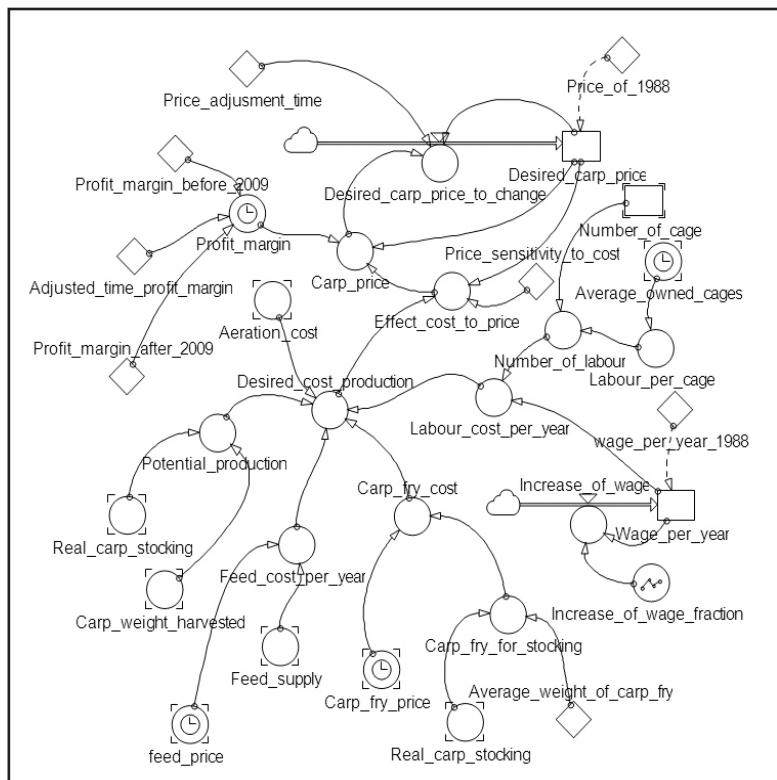


Figure 11 : Sub-model of Carp Price



TEST OF THE MODEL

Test results showed that the error source distribution on the model behavior was dominated by unequal covarians (UC). According to **Sterman (2000)**, the model built was good, because the average value and trend were almost the same as the historic data, or differed from the historic data point by point. Model behavior that had been tested by the sensitivity/validity testing as the FNCA historic pattern (year 1988-2007) run for 50 years. The historic model behavior run from 1988 to 2037 was acknowledged as the reference scenario. In this reference scenario, it could be stated that the model behavior had followed the historic behavior. The reference scenario was acknowledged as the reference policy that became the reference for the analysis of the policy, that is by comparing with the units restriction policy scenario, the eutrophication scenario and the acceleration scenario. Computer simulation result is shown in Table 2.

Table 2 : Main Variable Difference From Eutrophication And Acceleration Policy

No	Variable	Reference Behavior	Eutrophication policy scenario			Acceleration policy scenario		
			Eutrophication behavior	Change to reference on 2037 (%)	Dynamic tendention	Acceleration behavior	Change to reference on 2037 (%)	Dynamic tendention
1	Number of Cages	74 - 132000	65000	-50	D	65000	-50	D
2	Carp Productivity (kg/cage/year)	2500-1000	1500	+50	A	3000	+200	A
3	Oksigen (mg/l)	7,36 - 3,2	7,4	+131	A	7,4	+131	A
4	Carbon (mg/l)	62 - 390	170	-56	D	250	-36	D
5	Phytoplankton Biomass (mg/l)	0,183 -1,43	0,9	-37	D	1,05	-27	D
6	Detritus/BOD (mg/l)	1,235 - 209	6,51	-97	D	6,51	-97	D
7	Fish Price (Rp/kg)	1600- 50000	45000	-10	D	250000	+400	A
8	Liquidity (without unit)	1- 1		100 %	C	1	100 %	C
	Distinguish Factor	Fry and feed that influenced nutrient. Profit margin that influenced the price						

Expln. : A = Ascend, D = Descend, C = Constant

Figure 12 shows that the unit restriction, eutrophication and the acceleration policies produce the number of cages that lower than the reference policy. Eutrophication policy produced lower fish productivity as compared to acceleration policy. Meanwhile, both policies produced almost similar water quality (represented by dissolved oxygen).

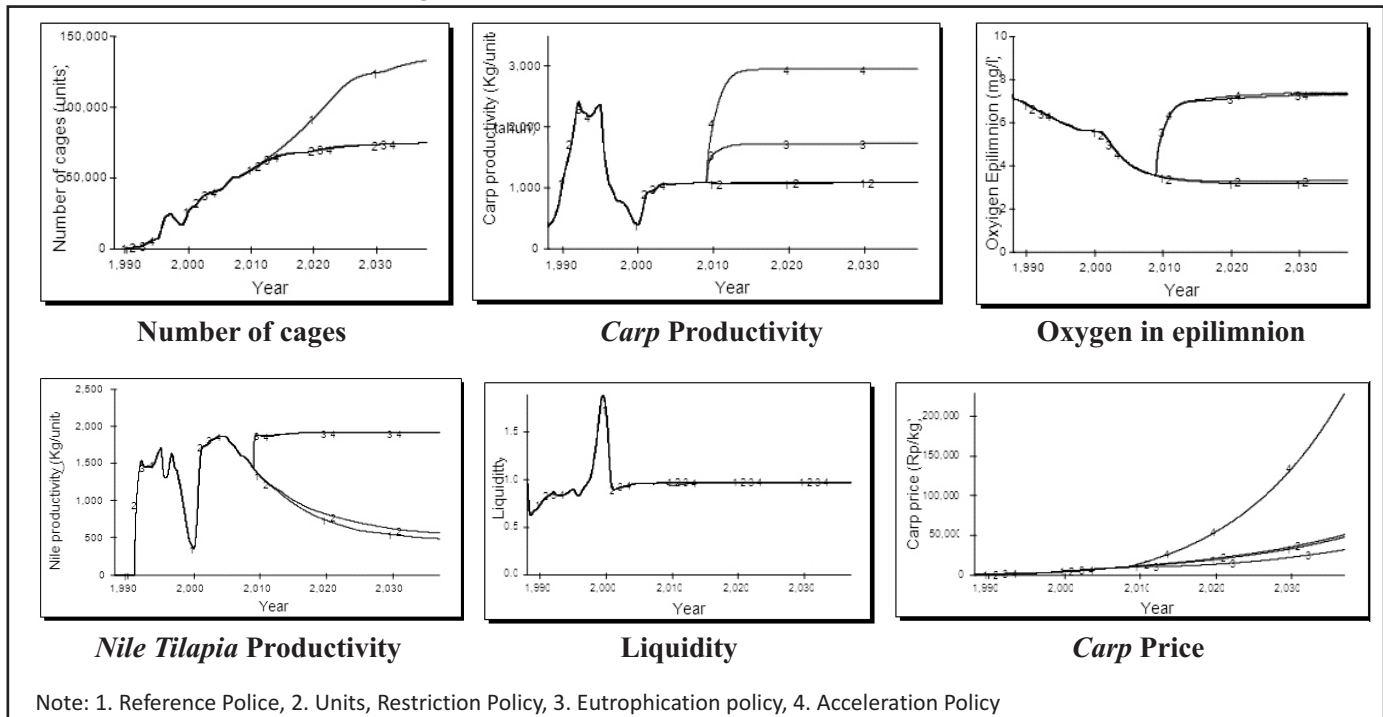
Based on Table 2, it was seen that the choosing of eutrophication policy was better than the acceleration policy in the case of the reduction in the nutrient carbon, but fish productivity was lower than the acceleration policy. The acceleration policy caused the high fish price, but the fish productivity was very high. The difference between them was on computer simulation results of the model built through the fish seed and the profit margin parameters. Both parameters could be a part of the sustainable FNCA policy instrument in Cirata Reservoir.

CONCLUSION

1. The phenomenon from the processes that happened in FNCA and Cirata Reservoir produced a system dynamics model. This model could explain the dynamics of processes of FNCA productivity fluctuation as a result of unbalance between fish production and FNCA units. Specifically, fish production was more determined by availability of food and oxygen. In this case, food had been given proportionally, so the fish growth was straightly determined by the availability of oxygen. The behavior of oxygen in the Cirata Reservoir tended to decrease.

2. In the long term, eutrophication policy produced the lower FNCA productivity, but the lower the fish price, the lower the carbon nutrient. Whereas, the acceleration policy produced high fish productivity, but the higher the fish price, the higher was the carbon nutrient.

Figure 12: Model Behavior On Different Policies



RECOMMENDATIONS

Based on the results of the research, the recommendations are:

✳️ Reservoir water as the public property (common property) must be a responsibility of government agency to manage it. In the future, the model could be used to estimate the behavior tendency in the FNCA activities and aquatic resources in Cirata Reservoir, as well as the test instrument on the reservoir management.

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