Modelling of A Wetland Through Sustainable Development

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This project deals with management policies toward sustainable development in a wetland. Wetlands are fragile ecosystems and constitute a great potential for economic, cultural, scientific, and recreational value to human life. Conservation and effective utilisation of natural resources can be achieved under sustainable development practices. Achievement of these goals requires well understanding of system under study so a holistic point of view is to be adopted. The geographical location of the region is in Temperate Climate Belt and consists of a shallow lake and its surrounding, an important nesting place for bird species. Fishing is a commercial activity. Ultimate goal of the project is to seek balance between ecosystem and human activities in order to secure a continuous improvement in well-being of the inhabitants while improving or at least maintaining the ecosystem. To this end, a system dynamics model of the wetland system will be constructed to analyse policy alternatives.

1. Introduction

Wetlands are extremely important because of their ecological functions and they form rich ecosystems. They also constitute a great potential for economic, cultural, scientific, and recreational value to human life. Similarly, shallow lakes form one of the most fragile ecosystem types on earth and generally they are the first to perish under development activities (Barbier *et al.*, 1997). Shallow lakes have only recently drawn attention of scientists; thus their ecology is still not well-known.

Recent studies on shallow lakes suggest that there may be two alternative equilibria over a range of nutrient concentrations: A clear state dominated by macrophytes and a turbid state dominated by high algal biomass. This has important implications on management of shallow lakes (Scheffer *et al.*, 1993).

It is wise to ask: “Do our so-called development activities constitute a true development while degrading our environment or are we digging our own graves?” Conservation and effective utilisation of natural resources can simultaneously be achieved under sustainable development practices. However, achievement of these goals requires careful analysis and well understanding of the system regarding the region under study. The elements such as wildlife, people, government etc. and relations amongst these elements are almost always constitute highly complex systems. So a holistic point of view is to be adopted and considerable amount of time must be devoted to field studies to analyse these systems and provide solutions.

Among a number of principles of Sustainable Development, the ones which are strongly associated with System Dynamics are the following:

There are three subsystems which are essential elements to be defined in a sustainable development practice. These are social, ecological and economic elements. The social subsystem deals with equity and disparity within the current human population and between present and future generations. The ecological subsystem considers the ecological conditions on which life depends. Finally, economic subsystem considers economic development and other non-market activities that contribute to social well-being. Moreover, the borders of the system under study must be carefully determined so as not to break any major links between elements (Hardi *et al.*, 1998).

A crucial characteristic of a sustainable development practice is participation from various disciplines and even from the society which is the subject of the study (Hardi *et al.*, 1998).

Systems thinking provides the proper philosophical perspective for Sustainable Development practices. In system dynamics literature, sustainable development studies has a distinct place. System Dynamics offers an important research potential and direction in sustainable development practices (Saeed *et al.* ,1998).

2. The Study Region

The geographical location of the region is in Temperate Climate Belt. The wetland under study is in the borders of Turkey, a developing country. The wetland consists of a shallow lake named Uluabat (or Apolyont), rivers flowing in and out of the lake, groundwater, and lands surrounding the lake. It is an important nesting place for bird species, some are under threat of extinction. In spite of this crucial role, the wetland plays and although it meets the Ramsar Criteria it was not under conservation status until recently. This resulted in “development” activities which damaged the ecosystem and, in turn, the habitat of endangered bird species. Crayfish population was an important element of the lake ecosystem until 1986; the year when the population was hit by a fungi (Yarar *et al.*, 1997). The lake under continuous load of organic wastes is faced with threat of becoming euthrophic (İnan *et al.*, 1997).

The inhabitants rely on fishing, agriculture and -until recently- crayfish harvest. On one hand, fishing and its industry is quickly replacing the crayfish harvest and industry; on the other hand, agriculture is the most pervasive way of subsistence among the inhabitants although some villages, such as Gölyazı, almost totally rely on fishing (İnan *et al.*, 1997). Tomato cultivation is significant. Tomato cultivated on lands surrounding the lake is processed by the plants near the lake to produce tomato paste. The production equals 80% of Turkey’s tomato paste production. The irrigation is done by water pumped from the lake. The intensive fertiliser and pesticide use may be potential sources for the pollution of lake’s waters which will in turn affect the agriculture in the wetland. However, no data is available yet (Demir *et al.*, 1998, İnan *et al.*, 1997).

Another problem about the wetland is intensive fishing. This is one of the major factors that has adverse effects on the fragile wetland ecosystem (Report on Inland Waters and Fish Farms of Turkey, 1994).

The industry in the wetland mainly consists of processing plants. The agricultural yield is processed in these plants. The -mostly organic- wastes of these plants also threatens the wetland ecosystem. On the other hand, installation of treatment facilities are the most important means to reduce the amount of wastes. Apart from these pollution sources, rivers, carrying the toxic and organic wastes of industrial plants and households, located in their catchment basins, further worsens the case in the lake (İnan *et al.*, 1997).

The inhabitants are aware of most of the problems of their region. However, they do not know the full extend of problems. Hence, it is important to educate the inhabitants and by this way raise awareness to desired levels with the endeavours of local organisations, and NGO's such as Society for the Protection of Nature (DHKD) and Development Foundation of Turkey (TKV).

The ultimate goal of the project is to seek a balance between ecosystem and human activities in order to secure a continuous improvement in well-being of the inhabitants while improving or at least maintaining the ecosystem. To this end, using system dynamics methodology, a model of the wetland system is being constructed by identifying the main elements and the interactions among them; after validation, various policies will be analysed to the model by altering some elements and/or relations.

3. Model Overview

The model has three subsystems as described above. These subsystems are Lake Ecology, Economic and Social Structure on the periphery of the lake. Each subsystem consists of several sectors.

Ecological elements of the lake and their interactions are modelled under Lake Ecology subsystem. In conceptualisation and construction of ecology subsystem, limited studies done on shallow lakes have been referred. It is not aimed to reveal a detailed model of the shallow lake ecosystem. The ecosystem is represented detailed enough as to serve to the purposes of the study. Economic Structure subsystem includes all activities of the inhabitants which have an intensive economic value such as industrial facilities, farming around the lake and fishing. Social Structure subsystem deals with the well-being of the inhabitants which is tightly related with the functioning of other two subsystems.

3.1. Lake Ecology Subsystem

The subsystem consists of five sectors: Hydrology sector, nutrients sector, water plants & zooplankton sector and fish & bird sector.

Hydrology sector is included in lake ecology subsystem. It is straight forward and calculates inflow, outflow, volume, surface area and depth of the lake, and irrigation.

Phosphorus (P) and nitrogen (N) are the two major nutrients, bound by plants during photosynthesis. In Lake Uluabat, the main sources for nitrogen are NO_2, NO_3, NH_3 whereas the main source for phosphorus is PO_4. Their concentration in the lake water and their ratio are important parameters. They dictate the trophic state of the lake. A portion of both phosphorus and nitrogen loads to a water body is stored in sediments. Moreover, phosphorus and nitrogen in sediments is released back to water at a certain rate. The sedimentation and release rates are determined by a number of factors. In general, sedimentation rate is higher and this results in nutrient excess in sediments and a nutrient supply to water body internally even if external loading no longer exists. The result is prolonged danger of eutrophication. This is also the case in Lake Uluabat where sedimentation rate is high. Therefore, stocks for phosphorus and nitrogen in sediment are added to the model. The concentration of phosphorus and nitrogen in the lake water and their ratio, P/N, are calculated in the nutrients sector.

Algal, macrophyte and zooplankton biomasses are calculated in the water plants & zooplankton sector. Algal biomass is represented by the chloro *a* content of the lake water which is found by a logarithmic relationship between algal biomass and P and N concentration of the lake (Jørgensen, 1994). However, algae is controlled by its predator, zooplankton. So, actual chloro *a* is the actual algal biomass that can be observed in lake although potential chloro *a* level dictated by P and N concentrations may be higher. Actual chloro *a* is flushed by the outlow of the lake.

Macrophyte biomass unit is PVI (Plant Volume Infested). It is a graphical function of P and N concentration of the lake and the P/N ratio. It is also affected by the chloro *a* content of the lake since algae is more efficient in getting nutrients from water than macrophyte. As the chloro *a* level gets higher, macrophyte is able to get less nutrients. Algal biomass has also an indirect effect on macrophyte biomass via lake water transparency. Transparency is dictated by actual chloro *a* level and it's unit is SE (Secchi disk transperancy). The relationship between SE and chloro *a* is a hyperbolic function as provided in Jorgensen, 1994. Macrophyte is able to colonise the lake water to a depth of three times the SE although the changes in lake transparency is not instantly reflected in the actual macrophyte biomass. It takes sometime for macrophyte to colonise newly available spaces and to perish from spaces with insufficient light conditions. This situation is reflected in the model by the use of a third order exponential smoothing function with a delay of twelve months. This is not the case for algae since it is much more flexible than macrophyte; that is it is able to respond to changes in its environment almost instantly.

Macrophyte provides refuge for zooplankton against its predators, carp and small pike, namely planktivorous fish, to a certain degree. Refuge effect increases with increasing macrophyte biomass; however, when planktivorous fish biomass is high, the refuge effect diminishes considerably no matter how high the macrophyte biomass (Schriver *et al.*, 1995).

Fish & Bird sector constitutes the top of the food chain and it is the sector of the ecology subsystem, directly linked to economy subsystem at the same time because of the fish industry. There are a number of fish species in the lake but two fish species are economically significant. These are carp and pike. Carp is a planktivorous fish; that is, it feeds mainly on zooplankton. It prefers turbid waters. On the other hand, pike preys on other fish including carp and it prefers clear waters. However, small pike is planktivorous. All these points are appropriately reflected in the model. Small pike and small carp has separate stocks than adults of their species. This allows both to differentiate the food sources and to set aside the small fish from reproduction. Reproduction of fish takes place during spring months. This serves as an opportunity for application potential policy alternative; that is to ban fishing during spring.

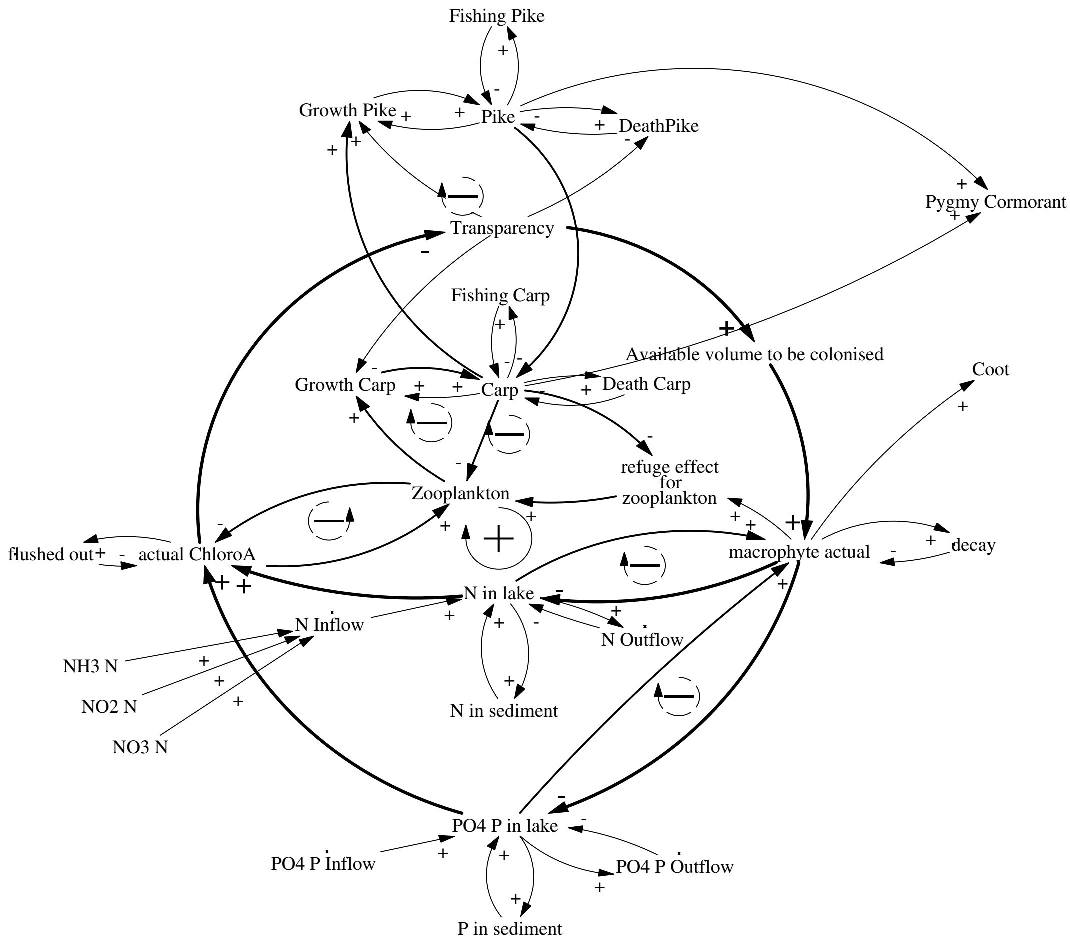

***Figure I**. Causal-loop Diagram of Lake Ecology Subsystem*

Growth of carp and pike are affected by the turbidity, or in other words transparency of water via two different graphical functions of transparency.

Information on population dynamics and feeding habits of birds is very limited. Therefore, it is decided to reflect their biomass as a linear function of their preys. Two bird species are selected as indicators of bird presence on the shores of the lake. These species are coot and pygmy cormorant. Coot feeds on macrophyte so its biomass is a linear function of macrophyte biomass; and pygmy cormorant feeds on fish so its biomass is a linear function of total fish biomass.

Information on habitat preference and population dynamics of crayfish is also vague. Also taking into consideration that crayfish has almost swept from the lake as the result of the fungi attack, it is not included in the model.

Most of the parameter values specific to the lake are missing, including carp and pike stocks in the lake. Hence, either their values were taken from literature or some estimates were done based on observations and available data. For example, fish stocks were estimated based on amount of fish sold per year in the local fish market. Causal-loop diagram of lake ecology subsystem is given in Figure I. Note that there are a number of balancing loops in the food chain and a large reinforcing loop. Hydrology sector is not included in the diagram.

3.2. Economy Subsystem

Three sectors constitute economy subsystem, being fishing, agriculture and industry sectors. The structure of these sectors are resembling each other.

Tomato cultivation sector is taken as an example. Marketprice of tomato is a fixed constant whereas Tomato cultivated per hectare is a function of irrigation. However, fishing from the lake is affected by the stock level of fish in the lake. Total income increases as total tomato cultivated increases. This increases welfare of inhabitants relying on tomato cultivation which in turn increases attractiveness of tomato cultivation for others. Nonetheless, this attractiveness is normalised with the attractiveness of other activities. The multiplication of normalised attractiveness of tomato cultivation, which is a number between 0 and 1, with total workforce determines the number of workforce in tomato cultivation. The land on which tomato is cultivated is a function of the workforce. Maximum value it can reach is the total arable land around the lake.

The main interactions between agriculture sector and the lake are irrigation and nutrient rich waters returning back to the lake from irrigated and fertilised lands.

Fishing has a similar structure. Since it is certain that the lake has not the capacity to sustain intensive fishing it is clear from Figure II that increased income draws more workforce to fishing so the pressure increases on fish which in turn inevitably reduce total fish caught as a result of diminished fish stocks. This is exactly what is observed in the lake now. This will either virtually exterminate fish from the lake or reduce workforce in fishing to a more 'sustainable' level. The outcome will be revealed as the model is completed and appropriate analyses are done.

In the fishing sector, the allocation of total fish caught between carp and pike is based on the ratio of both species' biomasses.

Industrial plants near the lake are for processing crop from agriculture and fish from the lake. An increase in either crop or fish is directly reflected as an increase on the production of industrial plants. Therefore, in the agricultural and aquacultural industry, the expansion of the industry depends on the amount of harvests and available workforce. So if there occurs a decline in harvests this will affect the industrial facilities.

The same balancing structure applies here also with slight modifications. The main interaction between industrial plants and the lake is the discharge of the plants. Being mostly organic, this discharges play a significant role in the probable eutrophication of the lake. Besides these plants, there are other industrial facilities outside the periphery of the lake discharges of which reach the lake. These discharges are considered as input from outside sources to the model.

Since other elements of the subsystem has a similar structure, only causal-loop diagram for Tomato Cultivation is provided in Figure II. The construction of economy subsystem has not totally completed yet.

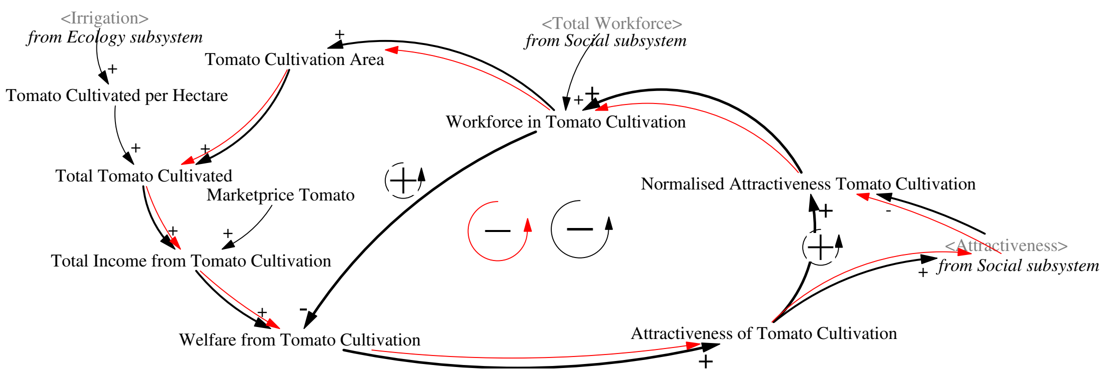

Figure II*. Causal-loop Diagram of Tomato Cultivation from Economy Subsystem*

3.3. Social Subsystem

Demographic indicators are in the social subsystem. Population, total workforce, welfare of the society are all included in this subsystem. It also provides parameters required to calculate allocation of workforce amongst economic activities. Indicators for policy options such as awareness, and adoption are located in this subsystem. As for the economy subsystem, its construction has not yet completed.

4. Implementation

The construction of the model is not totally complete. Various policy alternatives to prevent over-exploitation of the lake's resources were suggested on reports prepared by Society for Protection of Nature, Development Foundation of Turkey, related government organisations and universities. However, they depend on missing, even misleading data and more important they lack a holistic approach which is the main advantage of this study.

Being a part of a wider attempt to manage the resources of the region in a sustainable way, the alternatives proposed by the above institutions will be investigated and analyses will be carried out in collaboration with them after the model and its validation tests are completed. Especially, Development Foundation of Turkey is in preparation phase for a thorough sustainable development study of the region (TKV, 1998) and they commented that this model will be of great use for them. Furthermore, it is believed that the model will provide a basis for a common platform for the communication of experts and other responsible officials who work in the region. Lack of such a platform seems to be the biggest obstacle in present state and in the future in finding a solution for the better management of the region.

5. Conclusion

Sustainable development opens new horizons in front of human civilisation. It is widely recognised all around the world. This system dynamics modelling study on Lake Uluabat is part of a larger attempt to manage the resources of the region in a sustainable manner and is continuing with the co-operation of DHKD, TKV and other local institutions. The current state of the study which is an MSc thesis is documented in this paper. The study is continuing. Construction of lake ecology subsystem is completed; its verification has also been done. Its validation tests were carried out using information on shallow lake ecosystems in the literature and data from the lake although they are very limited and, in some cases, unreliable.

The completion of the rest of the model is expected not to take long. Data collection has already been completed and the remaining subsystems of the model is being constructed which will be followed by validation testing and investigation of a number of policy analyses. The study is expected to come to an end on August'99. After the completion of the study the results will be shared also with Ramsar Convention Bureau along with other organisations interested in the region.

Sustainable development has been a hot topic in recent years. Yet, maybe because it is so popular there is a lot of uncertainty on how to achieve it. There are studies done on Sustainable Development in System Dynamics literature, but extensive research potential still exists on this socio-economic concept and how to apply it.

References

Report on Inland Waters and Fish Farms of Turkey (in Turkish) (1994). V6, 91-110.

Barbier, E. B., Acreman, M. and Knowler, D. (1997). *Economic Valuation of Wetlands: A Guide for Policy Makers and Planners,* Ramsar Convention Bureau, Gland.

Demir, A. O., Aksoy, E., and Torunoğlu, T. (1998). *Environmental Problems in Lake Uluabat and Solution Suggestions (in Turkish)*, State Water Works-DSİ, Bursa.

Hardi, P. and Zdan, T. (1998). *Assessing Sustainable Development-Principles in Practice* International Institute for Sustainable Development, Quebec.

İnan, M., Bektaş, R., and Ergün, B. (1997). *Report on Lake Uluabat's Environmental Condition (in Turkish)*, Ministry of Environment, Bursa Provincial Principality of Environment, Bursa.

Jørgensen, S. E. (1994). *Fundamentals of Ecological Modelling,* Amsterdam; New York: Elsevier; New York.

Saeed, K. and Radzicki, M. (1998). Foreword. *System Dynamics Review* 14(2-3), 105-106.

Scheffer, M., Hosper, S.H., Meijen, M-L., Moss, B., and Jeppesen, E. (1993). Alternative equilibria in shallow lakes, *Trends in Ecology and Evolution* 8(8), 275-279.

Schriver, P., Bøgenstrand, J., Jeppesen, E., and Søndergaard, M. (1995). Impact of submerged macrophytes on fish-zooplankton-phytoplankto interactions: large-scale enclosure experiments in a shalow eutrophic lake. *Freshwater Biology* 33, 255-270.

TKV (1998). *Report on Economic, Social and Cultural State of Villages in the vicinity of Lake Uluabat (in Turkish)*, Development Foundation of Turkey-TKV, Ankara.

Yarar, M. and Magnin, G. (1997). *Important Bird Nesting Sites of Turkey (in Turkish)*, Society for Protection of Nature-DHKD, İstanbul.