Ref: 060 - "Ecological economic modelling for integrating environmental services in the welfare of commons: a case study in Tonameca catchment, Oaxaca, Mexico".

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Abstract:

Environmental services had been recognized as an important part of social welfare. In particular, the socio-economic and ecological relevance of coastal regions and impacts are presented as the general framework, for proposing in Tonameca catchment, an ecological economic model, for integrating environmental services in the welfare of commons. Tonameca watershed has 90% of common property land where agriculture and ecotourism are the main economic activities, as well as fisheries. Living conditions improvement depend on the maximization of profits from the previous activities without impairing the environment. An ecological economic model is proposed and described as a method for integrating environmental goods and services, in the production function of economic activities, in order to improve living conditions of the commons in Tonameca catchment. Ecological and economic diagnosis is followed by an optimization of socioeconomic profits.

Ecosystem diagnosis considers land use changes, water availability and quality as well as, an analysis of mangrove food web interactions using ECOPATH software. Fertilizer run-off and the effects on mangrove and phytoplankton biomass methods are presented. Results derived form the previous analysis provide the information for restricting the economic production function of ecotourism, agriculture and fisheries. An optimization of profits for each activity will be carried on in order to establish management recommendations.

Ecotourism is presented as an example of environmental services used by Ventanilla community. Sustainable indicators are presented highlighting the benefits of creating a cooperative as a form of common property rights. Environmental deterioration causes changes on demand and on the cooperative profits showing the value of ecosystem services and the importance of their conservation.

Keywords:

Environmental services, ecological economic modeling, community based management

1. Coastal importance and impacts

Population growth and economic development depends on natural resources and ecosystem services. Mangrove forests, coral reefs, and up-welling areas have been considered as very productive and diverse systems generating considerable ecological services. “The global value of goods and services provided by marine and coastal ecosystems is roughly double of value of those provided by terrestrial ecosystems, and is comparable with the level of global GDP” [1].

Coastal areas are crucial to support life in our planet, they comprise 20% of earth´s surface with 50% of human population located within 200km of the coast, with an average human population of 80 persons per square km and 70 % of world cities [2] [3]. Moreover, as mentioned before coastal systems are very productive since they provide 90% of global fisheries and produce about 25% of global biological productivity. In addition, coastal areas such as wetlands are responsible until a certain level for waste cleaning. Economic relevance of coastal areas remain to the importance of commerce, 90% of world tonnage is transported by ships [2]. Marine capture fisheries and marine aquaculture produces close to 100 million tons of fish providing direct and indirect livelihood to about 140 million people [4]. Finally tourism plays a very essential role in the economy of many coastal regions. The World Travel and Tourism Council (WTC) estimated that 10.9% of the world GDP would be generated by tourism [5].

Coastal regions have an enormous diversity and economic importance, but even though the majority of the world cities are located in the coast, in Latin America rural population in coastal regions is predominant. In Latin America 61 % of population is poor, and 60 million of person suffer from food insecurity, therefore, coastal regions suffer from poverty [6]. Moreover, coastal resources are well known for their common pool condition, making the regulation and management of natural resource more difficult. Coastal lagoons and wetlands for example, provide for many persons goods and services, however, property rights and land tenure definition are difficult to establish. Adger (2000) defines the common property as “ property whose individual users tend to have higher incentives to co-operate with each other than to pursue individualist strategies”. In addition, Adger (2000) mentions that common property is viable when “groups are small with shared needs and norms, clear boundaries for resource management; and relatively low costs of enforcement”.

The economic importance of coasts, is linked to the constant impacts to ecological services and uses from local and upland activities. Agriculture, fisheries, urbanisation and industrialization, are causing geomorphologic, physical, biological and social impacts. The alteration and destruction of habitats, effects of sewage on human health, eutrophication, decline of fish stock and hydrological changes represent the major impacts.

1.1 Agriculture impacts

Latin America count with 23 % of the world land with potential for agriculture, from which 12 % is cultivated land, and 46 % is tropical forest that could be transformed [6]. Agriculture impacts are strong, causing alteration in vegetation coverage, climate change and erosion due to deforestation, and damage on water quality by fertilizers runoff. The global use of fertilizers and pesticides is estimated to increase from 50 million nutrient tones from 1960 to more than 200 million tones for 2020 [1]. The Gulf of Fonseca in Honduras, has sever problems of pollution due to pesticides uses [6]. Moreover, it has been estimated that 20 000 death are due to fertilizer poison [6]. Agriculture productivity loss due to fertilizer, or pesticides uses as well as by monocultives are common. An example in the Amazon was demonstrated by Weinhold (1999) where land productivity drops in the first 5 years after clearing [7].

Overexploitation of water for agriculture is causing an increase in soil salinity, 10% of irrigated land is suffering severe problems of salinity. In Mexico, 50 000 ha has been abandoned due to salinity in soils [6].

Efforts have been oriented in establishing global and regional issues related to agriculture carrying capacity showing that soil fertility and water supply are problems for agriculture expansion [8].

1.2 Fisheries overexploitation

Fisheries represents for 120 million people a source of income and fish makes up about 19% of the total animal protein consumption in developing countries. However, 47% of fish stock is fully exploited and 28% is overexploited or depleted [4]. Jackson et al (2001) argue that overexploitation of marine resources increased ecosystem and food web vulnerability to environmental pressures such as, temperature augmentation and eutrophication, provoking a major depletion of populations and a disequilibria in the food web. Moreover they highlight the importance of historical data to have an overview of the evolution of fisheries and impacts upon them [9]. Fisheries are collapsing, due to the result of combined effects such as, sedimentation, pollution, over fishing and introduction of exotic species [1]. Over fishing is the primary reason for fisheries collapse, Toledo and Bozada (2002) show for Guerrero, since 1990 the capture decline. On the other hand , overexploitation and fisheries inefficiency are due to the low level of scholarity, the need of infrastructure for processing sea products, and a lack of adequate commercialisation, has been impediments for expanding the fishery [10]. National market for fishes is almost inexistent, the national consumption of fish is 10 to 12 kg a year per person, from which a high percent comes from the consumption of chicken that is nourished with fish flavour [11]. In that sense, industrial fishery is important in terms of national economy and exports but not necessarily in terms of local nutrition or welfare improvement. Moreover, fisheries analysis have been oriented to create complicated models of fish populations and captures (where artisanal fishery data are not included), but few studies have been oriented to know the fishermen. Alcalá (1999) mentions "it is equally important to know the volume of capture that the number of fishermen", it is central to understand the history of fishermen (from migration to the actual situation), the evolution of ports, and more precisely to understand what welfare means for fishermen [11].

Fishery arts have caused overexploitation, inefficiency and habitat destruction. Sheppard (2001) presents fishing methods like mining in coral reefs and aquaculture, as the main pressures for the Indian and Western Pacific [12]. In Mexico, in 1985 the shark fishery decreased enormously in Michoacan and Colima due to guill nets up to a point that fishermen decided to stop fishing with this art [11].

An indirect reason for fisheries depletion are geo-morphological impacts and lagoon dynamics changes due to the construction of ports or thermoelectric. Temperature increase, sedimentation of lagoon, or erosion of the coastal line are environmental impacts, but social impacts are also primordial. Fishermen have been removed from their lands, sometimes leaving the fishery for working in the construction of ports, resorts or in the thermoelectric. In Michoacan state, for example, fishermen were moved from their lands due to the construction of a thermoelectric; and indemnity has not caused an amelioration in welfare, because there are no good mechanisms of monitoring credits and even more indemnity became a political control and a form of corruption from local leaders [10]. A similar case exist in Manzanillo, were a thermoelectric was created, the community was moved but the water temperature increase provoking fish death was the major impact [11]. On the other hand, the Balsas river in Mexico, as many other rivers and lagoons has suffered from geo-morphological changes affecting negatively the lagoon dynamic and fisheries due to the construction of an industrial port. In the same region, destruction of mangrove habitat has reached 72% since the beginning of the century [10]. Another example of geomorphologic impact, is the construction of a jetty in Puerto Madero Port, in Chiapas causing severe impacts in the shrimp fishery [11].

1.3 Tourism growth and communities role

In the last two decades tourism industry has shown significant growth worldwide [13]. In 1998, tourism in developing countries rose 23%, showing the importance of those countries in the market supply [14]. The World Tourism Organization, has estimated that between 2000 and 2010 tourism growth rate in America will be 3.9% [5]. Moreover, in 2020 tourist will represent 1.6 billion with one billion tourists.

Environmental impacts due to tourism growth are several such as, pollution, sedimentation, and erosion. Therefore, Agenda 21, recognized the need of new forms of tourism as a potential tool for sustainable development for rural communities, particularly in fragile environments through conservation of nature generating social benefit [15]. Ecotourism have arisen as a need for "understanding and appreciating the natural environment including the respect for host cultures" and generating local benefits [16]. Ecotourism criteria are conservation of the environment, and minimization of impacts upon it, respect for local culture and welfare benefits for the communities involved.

Ecotourism is growing as an option for sustainability in local communities, especially in developing countries. The World Trade Organisation estimates that 7% of international expenses are related to ecotourism [17]. Ecotourism has shown a growth rate of 10-15% a year, where tourism is coming principally from developed countries such as Germany, the United States, the United Kingdom, Canada, France, Australia, Netherlands, Sweden, Austria, New Zealand, Norway and Denmark [18] [19]. Developing countries with high biodiversity represent the main source of supply [19]. Kenya earns $350 million annually in tourism receipts, which are almost entirely due to wildlife tourism [20]. However, the industry is facing challenges related to the determination of minimum impacts, contribution to local welfare, and integration within a regional integrated management process. In order to confront these problems, it has been recognised that community participation and local knowledge are nodule points to consider for building sustainable ecotourism projects.

The rationale that Renard (1991) proposes for developing Community Based Ecotourism Management (CBEM) is the fact that it provides an opportunity for equity and democracy, could be economically and technically efficient, it promotes a responsibility, stability and commitment to management and permits an adaptive management towards local, social and environmental conditions [21]. Therefore, CBEM ideally involves local benefits, local sovereignty, and facilitation of local conservation of natural resources .In that sense, valuation of ecosystem services where CBEM projects are based is an important tool for supporting CBEM, regional development, and policies for common property resources. Moreover, ecotourism planning needs to analyse tourists preferences, willingness to pay for ecosystem services and willingness to accept changes on the environment for conserving the demand [22-24].

1.4 Water scarcity

Water has been highlighted as a key resource for ecosystems health and economic development. Water quality in coastal lagoons, for example represents a key factor for fisheries success. Water overexploitation causes soil salinity affecting negatively cultivation of crops. Urbanisation depends directly on water supply. There is an intrinsic link between water and economic activities, showing the need for internalising the costs of its use and its conservation. Moreover, superficial water and groundwater is the link between different ecosystems and vegetations in a catchment. Rivers transport from upland to the coast, sediments, fertilizers but also biological organisms. However, water resource availability is a severe problem. The UNEP Vital water graphics document (2002) indicates that the total volume of water on Earth is around 1.4 billion km^3. The volume of freshwater resources is 2.5% of the total volume. Of these freshwater resources, 68.9% is in the form of ice and permanent snow cover , and 30.8% is stored underground in the form of groundwater. Freshwater lakes and rivers contain an estimated 105 000 km^3 or ~0.3% of the world's freshwater. The total usable freshwater supply for ecosystems and humans is ~200 000 km^3 of water, which is < 1% of all freshwater resources, and only 0.01% of all the water on Earth [25].

In Mexico, the National Commission of Water[1], estimate that in 2001, 74 000 million cubic meters were extracted, from which 63% was from superficial water and 37% from groundwater, and 80% was used for agriculture, 13% for public use and 7% for the industry [26]. Moreover,

[1] CNA part of the Ministry of Environment and Natural Resource, is in charge of the administration of national waters, as well as, of the hydrological systems management and regulation, and promotion to social development.

groundwater exploitation is 60% for agriculture and the number of aquifers exploited has been increasing. Agriculture is one of the major activities demanding water supply, and irrigation area increased from 750 000 ha in 1926 to 6.3 millions hectares nowadays. In Mexico, 88% of the population counts with potable water and 76% with sewage infrastructure. In rural areas, 70% of population has potable water and 37.9% sewage infrastructure, meaning that 80% of sewage water arrives to the rivers or the sea [26]. The inefficiency of irrigation infrastructure (46% of efficiency), lack of control of water extraction, low costs of water pump, no water treatment infrastructure and a lack of culture of water payment are the main problems [26].

Water strategies need to be addressed to irrigation efficiency, potable water extension, sanitation and sewage treatment, as well as to promote integrated management between watershed and coastal regions, adequate payments of water services, and environmental education

2. Integrated management and modelling

Marine and coastal pollution is due 80 % to upland based sources, causing many environmental impacts as described before. To confront the problem it is essential to promote from a political, social, scientific and economic perspective an integrated river basin and coastal management, to implement holistic and inter-sector management policies. Integrated coastal and river basin managements are a continuous and dynamic process by which decisions are made for the sustainable use, development and protection of the coastal zone. In order to build a management program it is necessary to have an ecological and socio-economic diagnosis, in terms of natural resource availability for economic growth and socio-cultural characteristics [27]. Thus, ecological economic models, where variables from each discipline are really linked, represent a holistic diagnosis to support management policies based on non-declining of the capital stock and equity to sustain welfare [28]. Sustainable agriculture, fisheries and tourism means maintaining the production in a long run minimizing impacts to the environment, equitable distribution and local welfare [29, 30]. In that sense, ecosystem services and goods, need to be understood, identified and quantified in order to show their importance for the economy, the society and ecosystems health. Moreover, it is crucial to investigate the links between economic, ecosystem and social systems, intrinsic to ecosystem services and goods exploitation.

3. Aim

Environmental impacts presented in paragraphs below, show the need for integrating coastal and river basin management as well as, an holistic approach for a watershed diagnosis, management programs and environmental policy. Therefore, an ecological model for a coastal rural catchment where common property land is dominant is presented in the next sections .

The ecological economic model aims linking coastal and river watershed management, as a way to confront the impacts generated locally and from upland activities, as well as, to contribute to ecosystem services valuation and to integrate economic, social and ecological disciplines using an ecological economic modelling**.**

The project aims to develop a sensible management policy for natural resources exploitation for the Tonameca watershed, Oaxaca, Mexico, specifically using an ecological economic modelling approach.

- In particular whether it is possible to link a production function approach to existing food web models such as, Ecopath in order to identify an optimal management strategy.

Water is used as an essential component of the system, and a mangrove forest as a sink of the pressures from upland. Agriculture, fisheries and ecotourism are the main economic activities and common property land dominant. Finally, Tonameca watershed model could be a replicable case study specially for the Pacific coast of Mexico and for Central American countries where 80% of the population live in the Pacific side rather than in the Caribbean coast.

4. Tonameca watershed

Tonameca watershed is located in the state of Oaxaca, South Pacific coast of Mexico. Tonameca watershed covers 49 800 hectares with a total population of 28 000 habitants, around 52 habitants per km^2 within six municipalities. Only Tonameca municipality has 15 546 habitants, where 96 % are zapotecs, and 5000 individuals speaking zapotec language [31]. Land regime is 99% communal and welfare conditions are critical showing for the catchment, 41% of household with electricity, and 31 % with water supply [32]. Health reports show that 45% of death are caused by malaria and 30% by stomach diseases. The percent of illiteracy in the Tonameca municipality is 35 % of adults and 20% of children [31].

Annual precipitation is around 1200 mm with a potential annual volume of 684 million cubic meters. Vegetation along the catchment is composed by pine forest, tropical forest where shadow coffee grows, deciduous tropical forest and mangrove forest. Different endangered species can be founded, such as, marine turtles (*Lepidochelys olivacea, Dermochelys coriacea*), the american crocodile (*Crocodylus acutus*), the white tailed deer (*Odocoileus virginianus*) and green iguanas (*Iguana iguana*).

Land use is dominated by shadow coffee exploitation, and agriculture for household consumption with around 16 000 ha in the catchment. Tonameca municipality land use is 77% for agriculture, 20% livestock, and 3% forestry. The crops cultivated are maize, chili, tomato and nuts. Maize crops in the Tonameca municipality covers around 8 500 has producing 1 ton/ha. Nuts crop is 1 360 ha producing 800 kg/ha [31]. Since 1995, ecotourism is starting to become a significant economic source of revenue for some communities, specifically for the Ventanilla community located in mangrove area.

Ventanilla community is organized in a cooperative since 1995, after the marine turtle exploitation band. The cooperative includes 90 % of the families where men take tourist to the lagoon for wildlife observation and women attend the cooperative restaurant. The community has showed social cohesion for a common sustainable project, as well as, a conservation commitment, prove of that is the mangrove reforestation and crocodile monitoring programs. Equity on benefit sharing, sovereignty of the cooperative and co-ordination with national, international and regional organizations and communities has been also demonstrated [33]

Environmental pressures from upland activities are the deforestation of the pine forest and the tropical forest due to the coffee market crisis. Coffee producers prefer to cut the forest for agriculture instead of protecting the forest for growing shadow coffee. Land use changes for agriculture is also an enormous pressure for the dry and mangrove forest covering just for one municipality 16 000 hectares [34] [35, 36].

Urbanization is also a central issue, there are 219 localities being Pochutla with 12 000 habitants one of the biggest. Tonameca river provides 1 442 000 liters per day of water to Pochutla. Land use for household construction, water extraction and waste water represent severe pressures for Tonameca river and mangrove forest [32].

Another considerable pressure is the tourism resort expansion coming from the coastal line to the Tonameca watershed coastal area. Tonameca is located between Puerto Escondido and Huatulco resorts. Huatulco is after Cancun the most important coastal resort receiving 170 000 tourists a year [37].

Finally, illegal wildlife trade exist in the region where marine turtles and iguana commerce are the most common species.

In sum, socio-economic driving forces are agriculture, urbanization and tourism causing sedimentation, water pollution, and hydrological changes. For facing environmental pressures it is necessary a regional planning in particular for agriculture, fisheries and ecotourism development.

5. Ecological economic model

The ecological economic model is proposed for a coastal catchment, where environmental goods and services, such as, mangrove forest and water, are used for ecotourism, agriculture and fisheries. The model is composed by an ecological diagnosis describing the land use changes, lagoon and river water quality, fertilizer run off, mangrove ecosystem food web and impacts of fertilizer in mangrove and phytoplankton biomasses as well as, the repercussion on the mangrove food web. Derived from the ecological diagnosis restrictions are included in the production function of agriculture, fisheries and ecotourism. Assuming that environmental quality is part of social welfare and 90 % of land is common property, profits of the 3 main activities are maximized in order to improve social welfare in the catchment. The model will provide management recommendations for Tonameca watershed. Figure 1.

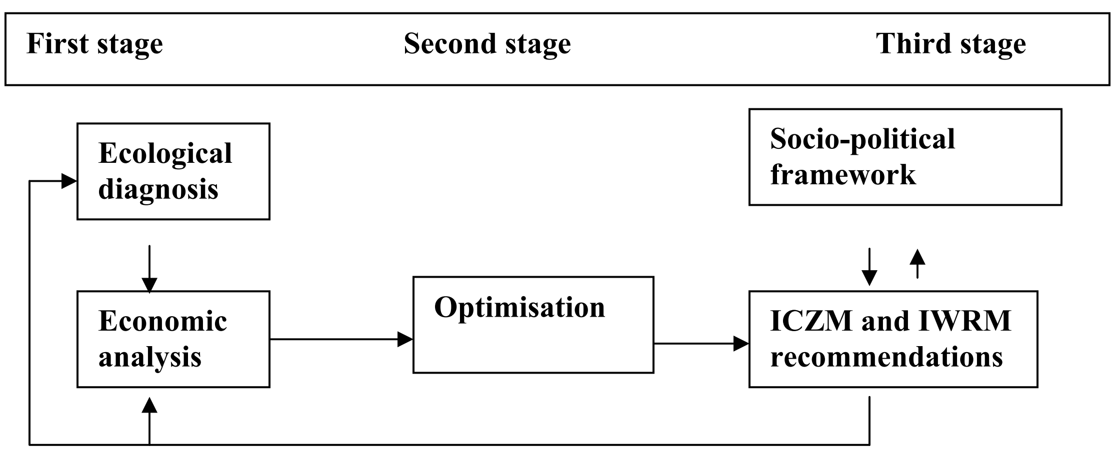

Fig 1. Model stages

The first stage is looking to establish the link between the economic and ecological variables. The relationships between agriculture, ecotourism and fisheries production with the nature goods and services are described in figure 2.

Agriculture production inputs are water, land and fertilizers that generates changes in water quality affecting the mangrove ecosystem and economic activities depending upon it, such as ecotourism and fisheries. Water quality is the link between upland activities and the coastal lagoon. Lagoon water quality has an effect on phytoplankton and fishes biomass, as well as on mangrove biomass habitat for many species. Fisheries is a direct measure of fishes biomass and effort. Ecotourism demand depends on the mangrove forest, crocodiles numbers and birds diversity. On the other hand, water extraction from agriculture, could causes in a long run hydrological changes and effects on mangrove seedling and crocodile nesting success. Hydrological changes, due to their long run scale, are only represented in this figure but not assessed. It is relevant to mention that it is assumed that sea water exchange is periodical (two or three months); thus, water quality and water levels measurements include the effects of sea water exchange. Ecological and economic models are described in detailed in the following parts.

5.1.-Ecological diagnosis

5.1.1- Land use change, water quality and fertilizer run-off

The ecological diagnosis is based on changes on vegetation land use that were assessed with a Geographic Information System with land use maps from 1973, 1995, and 2000.

Water quality was assessed along the river in 5 station corresponding to different types of vegetation and economic activities. In each station, two samples were taken and repeated around five days after. Samples were taken in 4 different periods of the year, at the end of the coffee harvest on February, during the dry season on April, beginning of the raining season in June and after fertilization during the raining season at the end of July. A total of 100 samples were taken for all the year; 21 on February, 25 on April, 26 on June, 28 on July and august. Temperature, and PH were measured in the field. Water quality samples were analyzed with a spectrophotometer HACH DR 2000. Nitrites, nitrates, ammonia, phosphate and salinity where the main parameters measured. The water quality assessment was summed to the runoff concentration, as a parameters to determine possible changes on phytoplankton and mangrove biomass.

Total nitrogen run off in Tonameca catchment was composed by urea run off and coffee pulp wash. Urea runoff in each municipality was the 20% of the recommended applied concentration per crop per hectare[38]. Nutrient input from coffee harvest, was estimated multiplying the amount of water used for the total production (20 liters of water per kg) in the catchment by 15 mg/l for nitrogen [39].

[Run off nutrients] = [urea added]*20% + TPW*15

where TPW is the total amount of water in litters

5.1.2 Mangrove food web

Ecopath is a mass balance model where production and consumption are balanced in a steady state system. Ecosim is a dynamic version of Ecopath II; it is a prediction of consumption flows representing predator prey encounters and physiological behaviour due to mass changes.

Ecopath equation is as follow:

$$B. (P/B)_i .EE_i - \Sigma B_j (Q/ B)_j DC_{ji} - EX_i - BA_i = 0$$

Where,

P = Production, B = biomass, EE_i = ecotrophic efficency, EX_i = export of group i

BA_i = biomass accumulation, $(P/B)_i$ = production /biomass ratio, equal to the coefficient of total mortality, $(Q/ B)_j$ = consumption/biomass ratio, DC_{ji} = fraction of i in the average diet of j

It is possible to apply the same equation for a system under fishery effort where the equation is then:

$$B. (P/B)_i .EE_i - \Sigma B_j (Q/ B)_j DC_{ji} - EX_i – BA_i - Y_i = 0$$

Where Y_i is the catch rate.

This program was created in order to have a world estimate on food web interaction for determining fisheries yields. It has been used in Mexico, for the Yucatan Peninsula by Christensen and Pauly (1998), Perez-España and Arreguin (1999), Vega Cendejas and Arreguin (2001) [40] [Arreguin-Sanchez, 1999 #25] [Vega-Cendejas M.E. And Arreguin-Sanchez F., 2001 #28].

The state variables selected for the food web were selected based on the following criteria:

- Biomass consumption and production between organism corresponding to different trophic levels.
- Typical and abundant species

- Species with economic and social importance.
- Species studied in the region.

Phytoplankton, detritus, mangal, zooplankton, macro benthos, insects, demersal and pelagic fishes, shrimp, piscivorous birds, insectivorous birds, herbivorous birds and the American alligator (*Crocodylus acutus*) are the main state variables. Fishes species (*Centropomus nigrescens, Mugil curema, Lutjanus colorado* and *Gerres cinereus*) were selected mainly because of their fishery importance . Birds species where selected also in terms of their abundance, occurrence, type of prey, human use, residence and information available. The criteria have the same importance and species with high number of points were selected. For example, from piscivorous birds the specie selected is *Bubulcus ibis*. Phytoplankton and mangal biomass depend on the water quality. Ecopath will be linked to the rest of the model by changing the biomass due to changes on nutrient concentration.

5.1.3 Impacts of fertilizer run off in mangrove and phytoplankton biomass

Monod equation was used to estimate the influence of water nutrients (N) concentration on phytoplankton biomass changes in order to relate the water quality and the Ecopath biomass input .

$$\mu = \mu_{max} (S/ K_s + S)$$

where $\mu_{max} = 1$, $K_s = 10$ µg/l for N and $K_s = 1$ µg/l for P

and since $\mu = 1/B \; dB/dt$

$$dB/dt = \mu B$$

Onuf et al (1977) estimated the production biomass in a low ammonium concentration more than 1 g/m^2 a day arguing that the concentration is more than concentrations in other studies such as Valiela et al (1975)[41] [42]. The total production biomass of all parts of the plant show a significant difference of 100 g dry weight per 1 cm of branch in the high concentration compared to 71.6 in the low concentration. The difference between the two sites is 30 %. Thus, if the initial biomass is 26 t/km^2 then an increase of 30 % would give us 33.8 t/km^2 .

The increase of biomass for mangrove and phytoplankton are changed in the Ecopath to see the impacts on the biomass of other components. The parameters and new values of biomasses will be linked to the production function of agriculture, fisheries and ecotourism.

5.2 Agriculture production function

The general equations for the agriculture production and profits functions would be:

$$Q_a = f\,(\text{land, water, fertilizer, labour})$$

Profits:

$$Л_a = P_a\, Q_a - C_a$$

Where:

Pa = price per crop in one year

Ca = Fixed costs = labour + technology + fertilizer

Water quality and quantity is an input that normally is not include, and introducing this parameter in the equation would permit to internalise the costs of water use, as well as to optimise the profits of this activity restricted to the water availability.

5.3 Fisheries production function

The production function of fisheries is equivalent to catches. Based on the logistic growth model by Schaefer (1954) catch is related to biomass and catchability constant.

$$h = q\, E\, B_{(x)}$$

q= catchability, E= effort, $B_{(x)}$=biomass

Ecopath equation is:

$$B.\,(P/B)_i\,.EE_i - \Sigma\, B_j\,(Q/\,B)_j\, DC_{ji} - EX_i - BA_i = 0$$

Thus harvest will be given by :

$$h = q\, E\, B_{(x)} - \text{mortality by crocodiles and birds}$$

$$h = q\, E\, B_{(x)} - \Sigma\, B_j\,(Q/\,B)_j\, DC_{ji}$$

where mortality depends on crocodiles biomass

Thus, catch is calculated in relation to the amount of predators given by the Ecopath, that is, crocodiles and piscivorous birds.

Costs and profits can be calculated with the Gordon´s model

$$TC = cost * E$$

$$TR = price * C$$

Profits

$$Л_f = P_i\, Y_i - C_i$$

Fisheries profits is restricted to the amount of fishes that depend on the effort, biomass of fishes, and mortality. In that sense, fishes biomass depend on water quality and more directly from phytoplankton increase. Fluctuation of phytoplankton due to fertilizer runoff were estimated, it is then possible to see the effect on fishes biomass in the profits of fishermen.

5.4 Ecotourism production function

The model proposes that ecotourism demand depends on ecological attributes of the place, price and socio-economic variables. Ecological attributes of different destinations has been considered for tourism demand; however, in this model demand for Ventanilla varies in relation on changes of ecological attributes. In this particular case, ecotourism is in a mangrove ecosystem.

The production function or demand of ecotourism depends on mangrove, crocodiles and birds.

$$Q = f\,(M, C\,(fish), B\,(fish), X)$$

M = mangrove C= crocodiles B= birds and X= socio-economic variables.

Tourism arrivals depend on the quality of mangrove, number of crocodiles and birds; where crocodiles and birds depend on fishes biomass related to the phytoplankton biomass and indirectly to fertilizer run-off.

The tourism preferences is modelled based on the revealed preferences, that is from tourism visiting the place. This is a different approach from travel cost or contingent valuation methods where tourists are asked about their preferences when they do not know the destination. The demand is conditioned to the probability that a tourist repeat a visit depending on the ecological conditions. The probability of repeating a visit will give us an estimate of the demand. The model is a binary response model for repeating a visit or not based on changes on ecological attributes (x_e), income (x_i), price (x_p) congestion (x_c) and travel expenses (x_{te}).

$$P\,(y = 1/x) = P\,(y = 1/\,x_1, x_2, ...x_n)$$

$$P(y = 1/x) = P\,(\,y = 1/\,x_e, x_i, x_{p,}\, x_c, x_{te})$$

The binary response model would give use the relationship from repeating a visit and on ecological attributes changes. Ecopath model would provide ranges on biomass changes on mangrove, crocodiles and birds following an increase on fertilizer runoff and tourism returns can be assessed under those ranges. The model is restricted for one cooperative running ecotourism within the catchment.

Ecotourism costs will be calculated using ecotourism cooperative costs.

Cv = average fixed costs + variable costs
Fixed costs = information centre expenses + food for animals + workers + petrol
Variable costs= trips + material + accountant + light + others

Cooperative profits will be calculated using tourism arrivals (Q_V) per ecotourism price (P_V) minus costs C_V.

$$Л_V = P_V Q_V – C_V$$

5.5 Joint profit maximisation

The joint profit maximisation aims to show the externalities from one activity to the other. In this case, for example, the externality from agriculture to ecotourism . Agriculture is maximised in relation to the cost of fertilizer, that is if there is a major use of fertilizer, there is major productivity but less production in ecotourism. On the other hand, ecotourism look to maximise the investment on conservation of natural resources . The following part present only a theoretical example.

If we have goods X y Y produced by two companies and K input for producing X and L for producing Y. Z is pollution produced by Y that affects X .

$$X= X(K, Z); \quad Y= Y(L); \quad Z= Z(L)$$

Profits of producing X

$$Л_X= P_xX- P_kK = P_xX (K, Z)- P_kK$$

Profits of producing X

$$Л_y= P_y Y- P_LL= P_yY (L)- P_LL$$

Joint profit maximisation

$$Л_{X+y}= P_xX (K, Z) + P_yY (L)- C_k- C_L$$

$$Л_y= P_y Y- P_LL= P_yY (L)- C_L¶Л_{X+y}/ ¶ K= P_xX_k – P_k=0$$

$$¶Л_{y+x}/ ¶ L= P_{x.} ¶ X/ ¶Z. ¶ Z/ ¶L+ P_yY_L- C_L =0$$

$$P_{x.} ¶ X/ ¶Z. ¶ Z/ ¶L + P_yY_L = C_L$$

That is,

Price *Marginal negative change * Marginal production/ marginal value of the damage produced by L in the production of X + costs

6. Conclusions

Ecological economic modelling for Tonameca catchment gives the externalities from one activity to the other, in order to establish management recommendation and economic instruments. In the production function of agriculture, fisheries and ecotourism inputs that normally are not included, were integrated based on results from the ecosystem analysis. Ecopath software is a useful tool for establishing certain levels of deterioration and the repercussions in the food web. A major contribution was to link the software to agriculture run off and the effects on mangrove and phytoplankton biomasses. Maximisation of profits, derived from production functions with environmental restrictions permit to maximise the catchment welfare, since 90% of land is common and activities are carried on by communities.

In particular, ecotourism is shown as a way of ecosystem services use for community welfare, where the conservation of ecosystem attributes are the main input for obtaining profits, since the demand preferences are oriented to nature. Ventanilla is a cooperative that has shown social cohesion for a common sustainable project, as well as, a conservation commitment, equity on benefit sharing, sovereignty of the cooperative and co-ordination with national, international and regional organizations and communities [33] . Cooperative has been a successful form of social organization and conservation of natural resources. Therefore, cooperative formation for ecotourism can be a legal structure for ecotourism supply and a form of social organization, giving rise to natural resources conservation and an increase on welfare conditions.

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