An inter-sectoral economic model for optimal sustainable mangrove use in the small island economy of Tonga.

Paper Presented at the New Zealand Agricultural and Resource Economics Society Conference 25-27 August 2006

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Summary

The dependency of small island economies on natural resources coupled with the pubic nature of these resources means that sustainability is a topical issue especially when development projects offer opportunities for 'better living' for communities. For a mangrove dependent community of Pangaimotu in Vava'u in Tonga tourism development offers better income from employment opportunities. Yet reclaiming mangrove areas for tourism development is likely to impact on fisheries resources that have traditionally been the main form of livelihood for the community. It is argued that for small island communities, whenever development activities ignore the critical role of mangroves on fisheries resources, the wider implications to the community are also overlooked. In this paper an inter-sectoral economic model is used to demonstrate the impact it would have on fisheries resources in Pangaimotu if tourism is developed beyond a certain capacity. The sustainability of mangroves and its symbiotic relationship to fisheries is an issue easily overlooked by development planners when the central focus is placed on employment and money generating activities. The issues of exploitation and sustainable use of natural resources for economic development in small island communities remains as pertinent as ever.

Keywords: economic model, optimal, sustainable, small island economy, Tonga

Introduction

The dependency of small island households on natural resources, coupled with the public nature of environmental goods such as mangroves, has meant that sustainable management of such common pool resources is an important and topical issue. Furthermore, in small island communities, the ever-increasing populations and aspirations for better living have exerted tremendous pressures on the natural resource base, leading to its rapid degradation and depletion. Therefore, the concept of sustainable development encompassing a harmonious blend of resource exploitation, investment, technological progress and institutional change to sustain a growing level of well being has assumed the utmost priority in development planning. One particular natural resource pertinent to small island economies especially for domestic fisheries is mangroves.

Mangroves are under threat primarily through deforestation for wood products, including fuel-wood for cooking, primary material for the construction of boats, houses, furniture and fence posts, charcoal, tannins, pulpwood, chip-wood and timber (Polunin, 1983), to accommodate aquaculture or established harbour facilities, or infilling for land-based developments (Hatcher, Johannes & Robertson, 1989). There is a critical need then to understand the function of mangroves in small islands due to the rate at which these natural resources areas are being converted to alternative land uses. Mangrove areas have been reduced by between 20% to 75% in many developing tropical countries in Asia and the Caribbean. In the Asia Pacific region 1% decline per year has been recorded (Ong, 1995). In Tonga, the demand for the use of the bark of the mangroves as dye for tapa making[1] is also significant. Mangroves areas are also reclaimed for agriculture, residential and tourism development. In contrast to forestry, which attempts to maintain some sustainable yield in mangrove ecosystems, reclamation activities often result in the loss of this resource in the coastal zone areas.

This paper therefore sets out the point of view that economic development activities such as tourism usually ignore the capacity of the mangroves to support other important economic activities such as forestry and fishing. In this paper the focus will be on the impact of reclaimed mangrove areas for tourism development on the fishing activities of an island community. An inter-sectoral model is developed and used to study the link and inter-relationship between these activities. A mangrove dependent community of Pangaimotu in the outer island of Vava'u in Tonga in the South Pacific is used to validate results obtained from the model. The focus will be on the optimal use of the mangrove ecosystem at a sustainable level. A description of the ecosystem as well as its relationships with fisheries production is covered next. After that there is a description of the model and discussion of the results.

Development of mangrove ecosystem

The development of mangrove ecosystem is the result of topography, substrate and freshwater hydrology, as well as tidal action. These factors help determine the resilience and capacity of support of the ecosystem. Mangroves are a taxonomically diverse assemblage of tropical salt-tolerant trees that inhabit the low-energy tidal range of sheltered shores. They colonise newly formed tidal flats in the wind and wave shadows of promontories and islands, and behind wave-absorbing sand bars and sea-grass beds (Carter, 1988). It has been estimated that as much as 75% of low-lying tropical coastlines with freshwater drainage support mangrove ecosystems (WRI

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[1] Tapa making requires the removal of the bark of the mangroves as dye.

and IUCN, 1986). Mangroves also provide the basis for complex and extensive ecosystems at the interface of terrestrial, freshwater and marine ecosystems (Mann, 1982; Robertson and Alongi, 1992). Information that describe the function of mangroves more clearly is needed for a better understanding of the importance of these systems to the fisheries of small island communities such as in Tonga.

Mangrove Functions

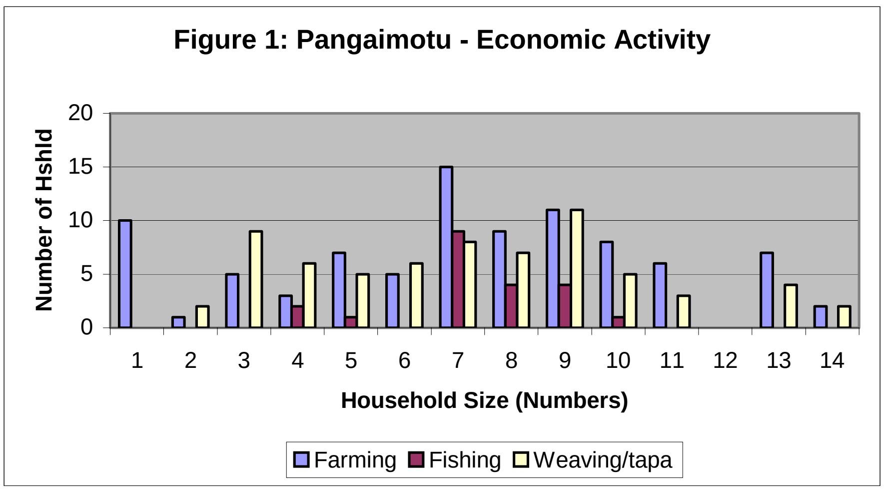
There are a number of perceived benefits of maintaining intact mangrove ecosystems. This include their utility as fish/fishery nurseries, the out welling of primary and secondary productivity and nutrients to surrounding near shore areas, flood reduction, a cleansing system for sediments and nutrients in estuaries, shoreline stabilisers and as sources of forest products (Sengel et al., 1983; Hatcher et al., 1989; Robertson & Phillips, 1995; Lee, 1995; Tam & Wong, 1995). With regards to fisheries more specifically, mangroves directly provide nursery grounds and critical habitats, a direct food source, and surface for epizoic organisms used by fished organisms (Thorhaug, 1990). Mangroves' intricate aerial root system, mostly developed within the lower inter-tidal zone, provide a substrate for colonization by algae, woodborers and fouling organisms such as barnacles, oysters, molluscs and sponges. Arthropods, crustaceans and molluscs are also abundant and have a significant role in mangrove ecosystems. Crabs and snails are also important components of the detritus food chain. Shrimp also find food and shelter in mangrove areas. From a commercial point of view, important bivalves such as oysters, mussels and clams are also commonly found in and around mangrove roots (Odum and Heald, 1972; Lat et al., 1984 Robertson, 1988). Fundamentally, mangroves are recognized as the essential nursery habitat for a diverse community of fish that find protection and abundant food in this environment especially during juvenile stages.

Mangroves in Tonga

In Tonga the total area of mangroves is estimated at 10 sq km. This represents 1.33 percent of Tonga's total land area of 750 sq km. The information collected from a baseline survey of mangrove species using 45 mangroves transects at 20 mangrove locations shows that there are 8 mangrove species altogether. The most common species are the *Rhizophora mangle, Rhizophora stylosa (Tongolei/Tongo), Bruguiera gymnorrhiza (Tongo ta'ane), Excoecaria agallocha (Feta'anu) and Lumnitzera littorea (Hangale) (*ESCAP, 1999). Basically, tannins from *Rhizophoraceae* are used for protection of nets and fish traps owing to their fungicidal properties. The prop roots of *Rhizophora* are used for the construction of fish traps, fuel-wood or light construction. The timber of the *Lumnitzera littorea* is a good building material, being hard and durable, and resistant to marine borers. The bark of the *Bruguiera gymnorrhiza* is used in Tonga to make decorative dye for tapa (Prescott, 1992).

The major threats for the mangrove ecosystem in Tonga are clearance and reclamation. This situation can be observed in the context of the law that declares that all territorial land and sea (where mangroves are found) belong to the Crown. Essentially, this open-access system is anti-conservation in nature. It is a general reflection of the thinking amongst Tongans that "*it is best to harvest as much as possible as fast as possible*." Since mangroves are under constant development pressure the basic question therefore is: "under what conditions should the mangrove ecosystems be maintained and managed for fisheries activities and other environment services?" The economic model developed and discussed further below, attempts to provide answers and a solution.

Area of Empirical Study: Pangaimotu Community - Vava'u.
Pangaimotu is a raised coral island located on the main island of Vava'u in Tonga in the South Pacific. It has an approximate land area of 9.2sq km with 23.7km of shoreline. The population of Pangaimotu is 689 people (comprising 94 households), living primarily on subsistence fishery and agricultural activities with an increasing share of the local economy coming from tourism. It is estimated that 84% of households are engaged in fishing and farming. Fishermen are mostly artisanal fishermen. Women constitute 48% of the total population of Pangaimotu. The household size shows that more than 71% of households have a household size of more than five, Figure 1 refer.



Source: Statistics Department - Census Report

The total mangrove area for Pangaimotu is 28.13 hectares. Pangaimotu has geographical features and natural resources that provide opportunities for economic activity unique to the country. This region is considered to be reasonably well preserved and the mangrove ecosystem plays an important role in the subsistence of the people. There were three economic activities undertaken by the community on its mangrove ecosystem. These are fisheries, forestry - which is the use of the bark of the mangrove as dye for tapa making, and tourism. The key question to be answered is derived from the fact that these three activities all compete for the use of mangroves.

Fishing is an important activity for the people of Pangaimotu village. More than 75% of the households fish for subsistence. A few families occasionally sell their catch especially *hulali* and the few homes that own a boat also fish and sell their catch in the capital centre of Vava'u, Neiafu. The sea forms part of the daily lives of the community and so shellfish and fish are vital for the food security of the community.

The barks of the mangroves are also important in making dye for tapa making. Tapa making is the commonly used name for a variety of traditional textiles produced in the Polynesian and Melanesian island groups and usually made from the inner bark of the Paper Mulberry. The strips of fiber are dried, soaked and pounded until they become wide and very flexible. A number of strips are then felted together to form a fine white cloth ready to be decorated with home made dyes. The brown shade is made from the bark of mangrove trees and black from the soot of burnt candlenuts and the red color from clay. Tapa cloth plays an important part in religious rites and ceremonial gift giving in the Pacific Islands.

Hinakauea Beach resort is the only tourism development at Pangaimotu. The resort comprises of two *fales* and a cultural house on 0.61 hectares of reclaimed land. This area constitutes 5% of the total mangrove area of Panagimotu.

I now turn to the economic model of inter-sectoral interactions that highlights the salient issues associated with the interaction between fisheries and tourism since 1994 when 0.61 hectares of mangroves were reclaimed for tourism development in Pangaimotu.

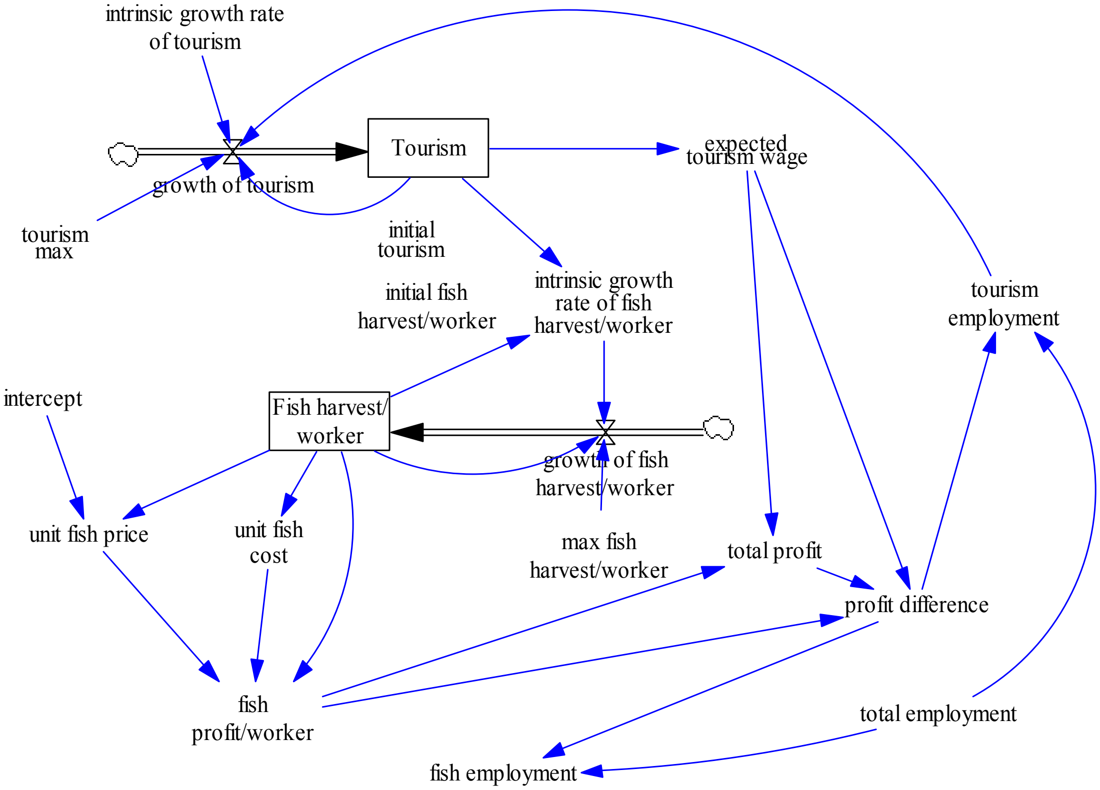
The Inter-sectoral model

In this model the focus will be on two broad issues: (i) the impact of the tourism sector on the growth of fisheries and (ii) the changes in labour allocation between the two sectors. The model built here will look at the interaction of tourism and fisheries in the community to optimise the allocation of workers between these activities. The workers have the opportunity of choosing their activity each month. So, if it is assumed that the net benefit from fisheries is bigger than from tourism, the majority of the workers will decide on fishing. This kind of behaviour may lead to over-exploitation and possible extinction of the resource. However, due to the connection between the different economic activities that an ecosystem can support, it will be more rational for the workers to exploit the resource at a sustainable level. Since there is no property right assigned to the mangroves, the best allocation of workers between activities is based on the per capita benefit of each one. The model should provide tools for decisions about the optimal situation of the economic activity as well as about the maintenance of the ecosystem (Grasso, 1998).

Description of the model sectors

It is assumed that although fisheries and tourism development can operate alongside each other, the mangroves should be reclaimed for tourism development in such a way that ensures that sustainability of the mangroves is still paramount so that fisheries will not be adversely affected. As explained earlier, the mangroves play a significant role as the breeding ground for coastal fisheries. This is an important remainder since reclamation of mangrove areas for development activity such as tourism implies the loss of available mangrove areas that in turn would impact directly on fisheries activity. For this purpose, empirical data from the small fishing community of Pangaimotu is included in later discussions. Figure 2 presents the main sectors of the model and how they connect with each other.

Figure 2: Model Structure



Description of the model variables

The variables of the model and the basic assumptions used for its construction were based on the work of Grasso (1998). Refer to Appendix 1 for details

In this model it is assumed that a social planner is trying to make a decision about the possible optimum mangrove exploitation of the area that could result in none or very small loss for the local artisanal fishermen. The externalities of the tourism sector would directly affect fisheries that depend on the mangroves area. The majority of the fish harvested in a mangroves embayment depend on this area for growth, development and/ or reproduction.

Tourism.

Let the growth rate of the tourism sector, defined here as the number of hotels and hotel-related activities, be a function of the stock of hotels and hotel-related activities, *T(t)*. That is:

$$\dot{T} = G(T(t)),\ \partial G/\partial T < 0. \qquad (1)$$

The number of workers employed in tourism depends on the size of the tourism sector:

$$N_T(t) = N_T(T(t)),\quad \partial N_T/\partial T > 0. \qquad (2)$$

Lastly, the (monthly) wage earned in the tourism sector, W_T, is a function of employment in the sector:

$$W_T = W_T(N_T(t)), \quad \partial W_T / \partial N_T > 0. \tag{3}$$

Fishery

Let the fish stock, *F(t)*, grow logistically prior to harvesting (Conrad 1995), with an intrinsic growth rate, *r*. Note that $r = r(T)$; i.e., tourism impacts on the intrinsic growth rate of the fish stock by destroying mangroves ($\partial r/\partial T < 0$). *X(F,T)* is the growth rate function describing net biological recruitment to the fish stock prior to harvesting:

$$X(F(t),T(t)) = r(T(t))\left(1 - \frac{F(t)}{\overline{F}}\right)F(t), \tag{4}$$

where $\overline{F}$ is the carrying capacity of the fish stock. The term $r\left(1 - F/\overline{F}\right)$ denotes the per unit growth rate of the stock. With harvesting the growth rate of the fish stock falls:

$$\dot{F} = X(F(t),T(t)) - h(t), \tag{5}$$

where *h(t)* is the harvest rate. Fish are sold at price $P_F(t)$, which is a function of *h(t)*; $\partial P_F / \partial h < 0$. The total cost of catching fish, $C_F(t)$, depends on the fish stock. We assume that $P_F h - C_F \geq 0$.

Net (monthly) incomes from production activities, *Y*, are given by:

$$\begin{aligned} Y_T(t) &= W_T(N_T(T(t))) \\ Y_F(t) &= P_F(h(t))h(t) - C_F(F(t)) \end{aligned} \tag{6}$$

where *h(t)* has been scaled to reflect monthly harvests.
We assume that $Y_F \geq 0$, $Y_T \geq 0$ and $Y = Y_F + Y_T > 0$.

The total number of workers, *N*, is fixed, where $N = N_F(t) + N_T(t)$. (7)

Define *d(t)*:

$$d(t) = \frac{Y_T(t) - Y_F(t)}{Y(t)}, \quad -1 \leq d \leq 1. \tag{8}$$

Workers allocate their effort between the two sectors depending on the size of *d* (Grasso 1998):

$$\begin{aligned} N_T(t) &= \frac{N}{2}[1 + d(t)] \\ N_F(t) &= \frac{N}{2}[1 - d(t)]. \end{aligned} \tag{9}$$

It is assumed that if $d = 0$, labour is split evenly across tourism and fishing.

The management objective function

Following Grasso (1998) the workers are free to interchange between these fisheries and tourism activities and they do not have gear capacity to fish outside the mangrove areas. The social planner seeks to allocate workers according to per capita net incomes across sectors. The objective functional for the two state variables, *F(t)* and *T(t)* becomes:

$$\max \int e^{-\delta t} \left[\frac{Y_T}{N_T} + \frac{Y_F}{N_F} \right] dt \tag{10}$$

$$\Rightarrow \max \int e^{-\delta t} \frac{2}{N} \left[\frac{Y_T}{1+d} + \frac{Y_F}{1-d} \right] dt$$

s.t. $\dot{T} = G(T(t))$ (11)

$\dot{F} = X(F(t), T(t)) - h(t)$. (12)

Define the current value Hamiltonian, H, as:

$$H = \frac{2}{N} \left[\frac{Y_T(T)}{1 + d(T, F, h)} + \frac{Y_F(F, T, h)}{1 - d(T, F, h)} \right] + \lambda_T G(T) + \lambda_F (X(F, T) - h),$$

where λ_T and λ_F are the current value multipliers. (13)

Among the optimality conditions, we require (T, F) to satisfy:

$$\frac{\partial H}{\partial T} = \frac{2}{N} \left[\frac{\partial Y_T / \partial T}{1+d} - \frac{Y_T (\partial d / \partial T)}{(1+d)^2} - \frac{Y_F (\partial d / \partial T)}{(1-d)^2} \right] + \lambda_T \frac{\partial G}{\partial T} + \lambda_F \frac{\partial X}{\partial T} = -\dot{\lambda}_T + \delta \lambda_T \tag{14}$$

$$\frac{\partial H}{\partial F} = \frac{2}{N} \left[\frac{\partial Y_F / \partial F}{1-d} - \frac{Y_T (\partial d / \partial F)}{(1+d)^2} - \frac{Y_F (\partial d / \partial F)}{(1-d)^2} \right] + \lambda_F \frac{\partial X}{\partial F} = -\dot{\lambda}_F + \delta \lambda_F \ . \tag{15}$$

The impact of tourism on fisheries output

From an increase in tourism, we now seek to determine the impact on fisheries output; i.e., the sign of $\frac{\partial F}{\partial H} \frac{\partial H}{\partial T}$.

Lemma. Define $H = f(F)$. Let there be an inverse function, $F = f^{-1}(H)$. Then $\frac{\partial F}{\partial H} \frac{\partial H}{\partial T} = \frac{\partial H / \partial T}{\partial H / \partial F}$.

Proof. Since:

$$f o f^{-1} = id$$

$$\Rightarrow \frac{\partial f}{\partial F} \times \frac{\partial f^{-1}}{\partial H} = 1$$

$$\Rightarrow \frac{\partial F}{\partial H} = \frac{\partial f^{-1}}{\partial H} = \frac{1}{\partial f / \partial F} = \left(\frac{\partial f}{\partial F} \right)^{-1}$$

$$\therefore \frac{\partial F}{\partial H} \frac{\partial H}{\partial T} = \left(\frac{\partial f}{\partial F} \right)^{-1} \times \frac{\partial H}{\partial T} = \frac{\partial H / \partial T}{\partial f / \partial F} = \frac{\partial H / \partial T}{\partial H / \partial F} \ .$$

Proposition. An increase in the stock of tourism has an indeterminate impact on the stock of fish.

Proof. From the Lemma,

$$\frac{\partial F}{\partial H}\frac{\partial H}{\partial T}=\frac{\left[\frac{\partial Y_T/\partial T}{1+d}-\frac{Y_T(\partial d/\partial T)}{(1+d)^2}+\frac{Y_F(\partial d/\partial T)}{(1-d)^2}\right]+\lambda_T\frac{\partial G}{\partial T}+\lambda_F\frac{\partial X}{\partial T}}{\left[\frac{\partial Y_F/\partial F}{1-d}-\frac{Y_T(\partial d/\partial F)}{(1+d)^2}-\frac{Y_F(\partial d/\partial F)}{(1-d)^2}\right]+\lambda_F\frac{\partial X}{\partial F}}.$$

The proof follows from an inspection of the terms on the RHS of the equation. Consider $\partial d/\partial T$:

$$\frac{\partial d}{\partial T}=\frac{\partial W_T}{\partial N_T}\frac{\partial N_T}{\partial T}\left[\left(W_T+P_F h-C_F\right)^{-1}+\left(W_T+P_F-C_F\right)^{-2}\left(P_F h-W_T-C_F\right)\right],$$

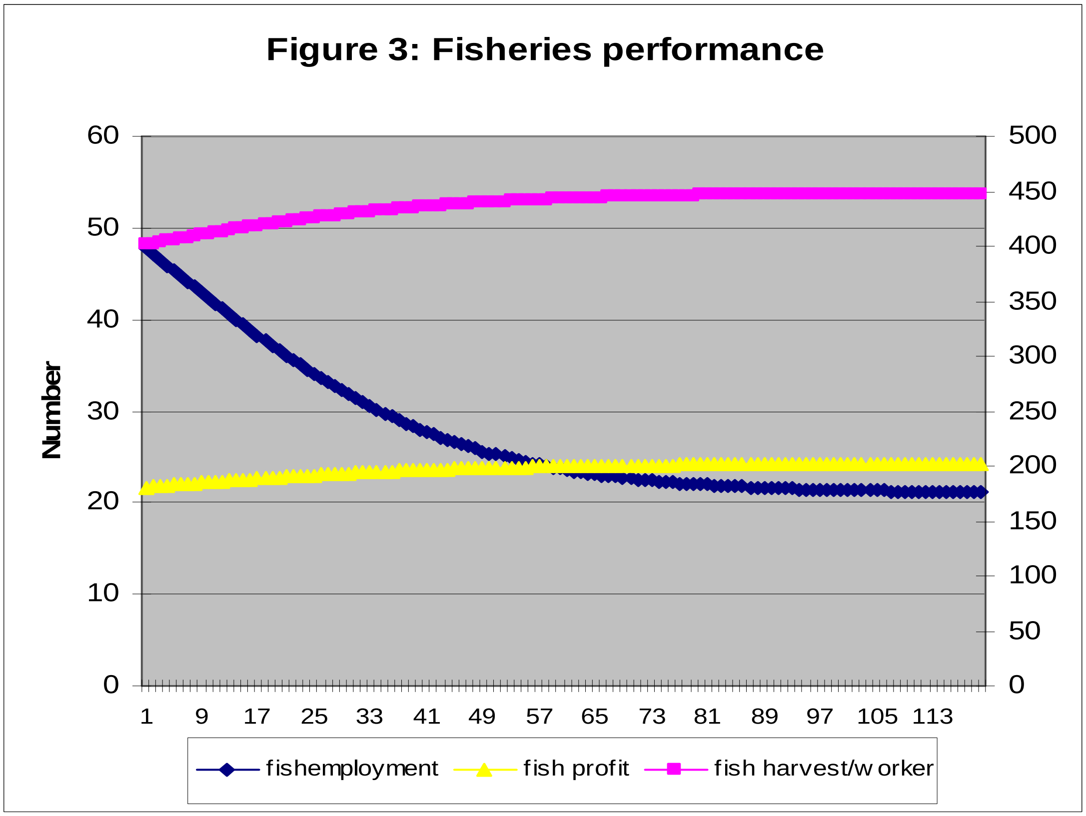
with $\partial W_T/\partial N_T>0$, $\partial N_T/\partial T>0$ and $P_F h-C_F\geq 0$. The sign of $\partial d/\partial T$ therefore corresponds to the sign of $P_F h-W_T-C_F$, which is indeterminate.

The Lemma suggests that care be taken in analysing the economic impacts of tourism. For even from our simple model the impact on inter-sectoral labour allocation and that of tourism on the fisheries sector growth is by no means clear. It cannot be assumed that tourism will harm fisheries as much as the initial destruction of mangroves suggests. The relative importance of the above partial derivatives require further research especially if policy makers wish to influence food supplies and the structural transformation of the economy.

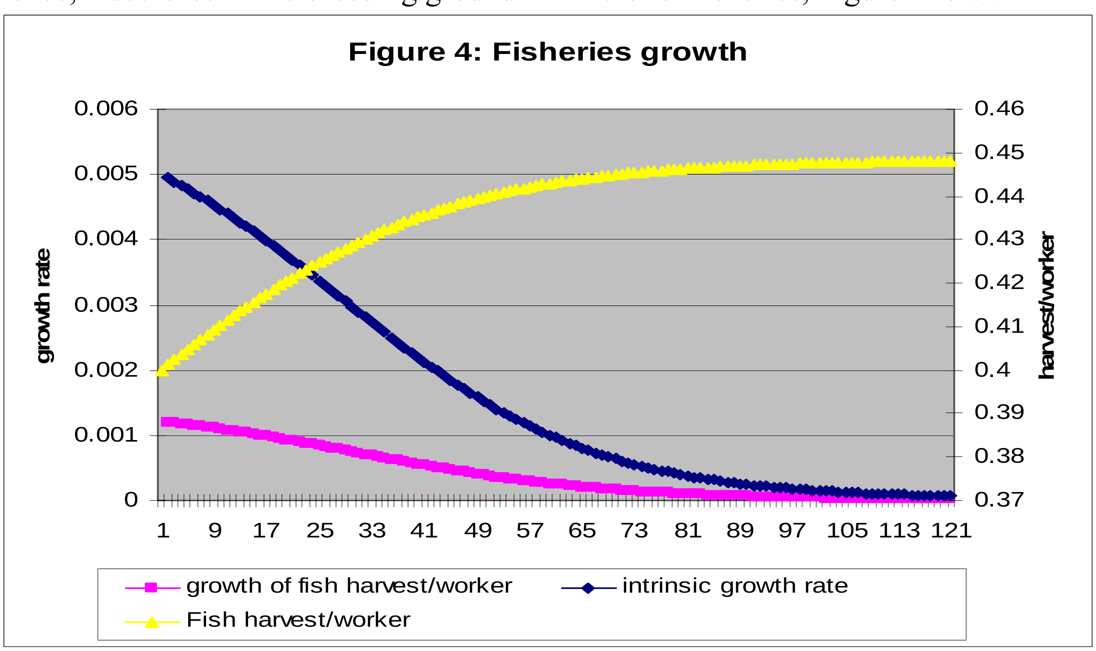
Discussion of results

The model was compiled in the software VENSIM for windows. Appendix 2 provides a list of model equations and parameters value. The simulation model will provide a laboratory in which one can experiment to understand how different elements of structure determine behaviour. The main goal of this model is to observe whether the economic and the ecological optima could both be achieved at the same time. The optimum of the allocation is found when the natural capital stock is kept constant, meaning that its use has been carried out on a sustainable level. It is important to note that this equilibrium will only be achieved due to the fact that the workers can interchange between activity (fisheries and tourism) and assuming that there is no cost to them to change economic activity.

The simulation resulted in an initial allocation of 30 percent workers to tourism and 70 percent to fisheries. Fish employment falls with general increase in fish harvest per worker from 400kg to level at 450kg after the first 4 years, Figure 3 refer. Fish profit on the other hand generally increased at a much slower pace from just over \$180/worker/month to a level at almost \$200/worker/month after the first 4 years.

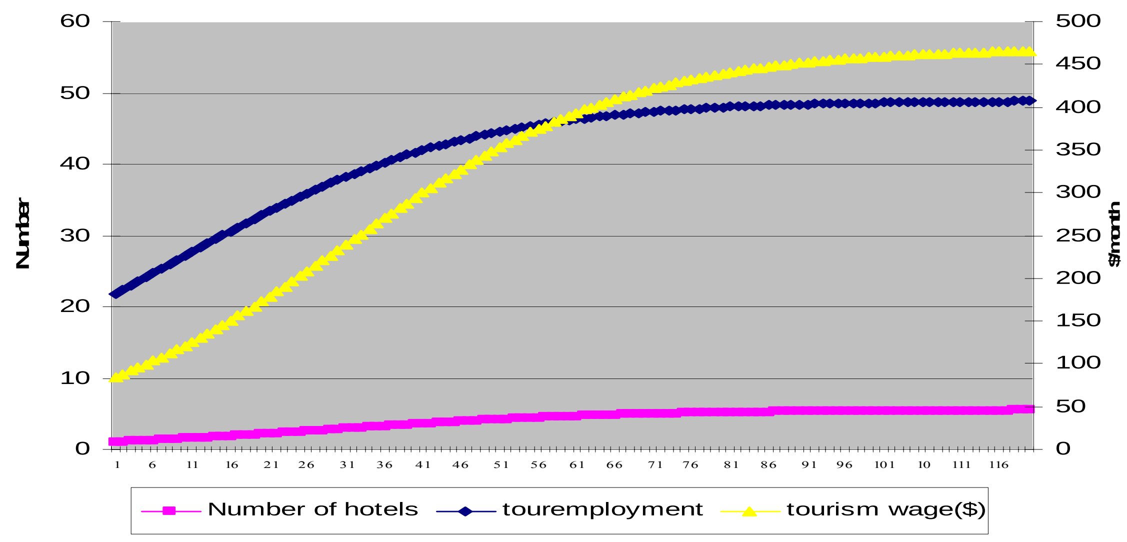


Whilst there is a general increase in fish harvest per worker, intrinsic growth and fish growth were greatly affected, indicating a fast crash of the system, Figure 4 refer. This is further affected by the growth in the tourism sector that led to an increase in the reclaimed mangrove areas, hence, a decrease in the breeding ground available for fisheries, Figure 4 refer.



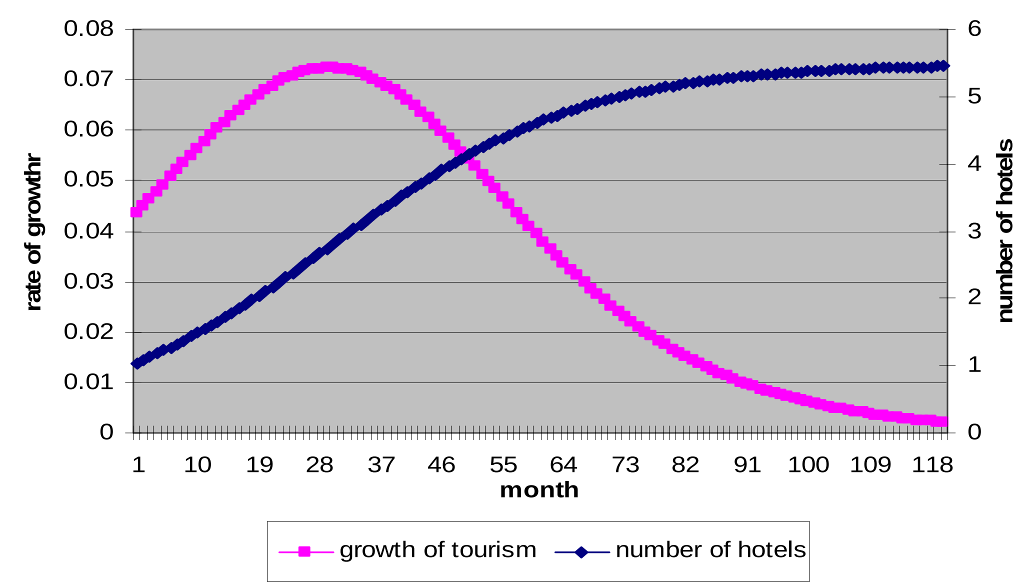
The tourism development performance shows a general increase in the number of hotels, hence the number of workers too. With more workers moving across to the tourism sector, there will be a fast crash of the fishery activity due to the lack of protection for the juvenile fish, Figure 5 refer. The Fisheries sector was greatly affected since mangroves were cleared to meet the growth of the tourism industry.

Figure 5:Tourism Performance



As the number of hotels starts to increase so too is the number of tourism employment. Tourism earnings also increase as the number of tourism employment increases, Figure 5 refer.

Figure 6: Growth of Tourism



The number of hotels grew exponentially in the first 2 1/2 years and reached the maximum. After that it slows down. The rate of hotel growth peaked at 30 months with an average of 0.725 units per month. The rate of tourism growth declined after that to as low as 0.008 after 9 years of operation, Figure 6 refer.

The total mangroves area of Pangaimotu can support a maximum of 5 hotels and hence full capacity will be achieved after 6 years with the given rate of growth.

Conclusions

The model is sensitive to the initial number of workers in each activity. The best management option is to have more workers in the fishery activity. Hence, policies of taxation and law enforcement against clear cutting the mangroves should be implemented – for small island communities some participative management technique should be used to demonstrate to local people the advantages of rationally using the resources from the mangroves ecosystem

The model presented here is based on the simple interactions between tourism development and fisheries activities, and the benefit that could be gained when planners have an overview of how the ecosystem works. Knowledge of the interactions of a physical system gives a wide range of options for using policy tools for the preservation of the area and consequently for the economic benefit of local workers. With increasing ecological and socio-economic knowledge the conversion of mangroves into development activities whose social costs far outweigh their benefits should be reduced.

The development of models will often lead to many new questions and to answer these, one must return to the field, laboratory or library to gather more information and restructure the models. Often this results in more questions, and so the cycle continues (Swartzman and Van Dyne, 1972).

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Appendix 1

The variables used in the construction of this model are as follows

T_t	Number of hotels and hotel related activities at time t
F_t	Fisheries stock at time t
C_F	Unit cost of fish harvest
W_T	Wage earn from tourism
P_F	Average unit price of fish
N_t	Number of tourism workers
N_f	Number of fisheries workers
Y_T	Tourism production activities
Y_F	Fisheries production activities
λ	Shadow value of the growth in respective capital stock
δ	Social discount rate
t	Time

Control variable:

h_t	Fish harvest per unit boat (net-men effort) at time t

Appendix 2

Model Equations and parameters value

The following equations and parameters have been built into the VENSIM model to determine the allocation of workers between tourism and fishery activity.

(1) expected tourism wage= (400+5*Tourism)*Tourism* 0.2

(2) FINAL TIME = 120 months

(3) fish employment= Active Initial(total employment/2)*(1+profit difference),55)

(4) Fish harvest/worker= INTEG (growth of fish harvest/worker, initial fish harvest/worker)

(5) fish profit/worker=(unit fish price-unit fish cost)* Fish harvest/worker

(6) growth of fish harvest/worker=intrinsic growth rate of fish harvest/worker*(Fish harvest/worker)*(1-Fish harvest/worker/max fish harvest/worker)

(7) growth of tourism=(intrinsic growth rate of tourism-intrinsic growth rate of tourism*Tourism/tourism max+0.0001*tourism employment)*Tourism

(8) initial fish harvest/worker=0.4 ton/month

(9) initial tourism=1 hotel

(10) intrinsic growth rate of fish harvest/worker= 0.01-0.001*Tourism-0.01*Fish harvest/worker

(11) intrinsic growth rate of tourism=0.05

(12) max fish harvest/worker=1: ton/month

(13) profit difference=(fish profit/worker-expected tourism wage)/total profit

(14) total employment= 70 workers

(15) total profit=fish profit/worker + expected tourism wage

(16) Tourism= INTEG (+growth of tourism, initial tourism)

(17) tourism employment=(total employment/2)*(1-profit difference)

(18) tourism max= 5 hotels

(19) unit fish cost= 150-1*Fish harvest/worker

(20) unit fish price=600-0.05*Fish harvest/worker