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Different Property Rights Regimes in the Lake Victoria Multiple Species Fishery

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Abstract

Greater ecosystem complexity is recognized by studying a two species predator-prey model under two property rights regimes: free entry and a system such as individual quotas which execute an economically optimal solution. A bottom-up management experiment is discussed in the context of Lake Victoria fisheries.

JEL Codes: Q22 Fishery and Wildlife

Q28 Government Policy

Introduction¹

In the real world it is more likely and therefore more empirically relevant that there is species interaction than to assume a single species (lumped parameter) model which dramatically dominates the fishery economics literature. The focal point then for the research presented herein is a predator-prey fishery whose fate is determined either by free entry or by a property rights structure such as individual quotas designed to facilitate an optimal economic solution.

Natural scientists have given some attention to the study of multiple interacting species [Larkin, 1966, May, 1974, Pielou 1969, Maynard-Smith 1974] but there has been less study of multiple species in an optimization framework, particularly from a bioeconomic perspective. Multiple species models are not generous in the results produced. Clark [1990] concludes that while optimal steady state values often can be determined, exact solutions for the optimal path to the steady state are not known and may not exist for some problems. The simpler the model, the more likely clean results will emerge. Solow's analysis of a Volterra model is insightful but the model has no intraspecific competition; i.e. natural resource capital has no diminishing returns. Still, he concludes that even in the two species models, there are no easily obtained qualitative results resembling those gleaned from single species model.

Wilén and Brown (1986) make some progress in characterizing the solution to a predator-prey optimization problem. Modest success comes at the cost of assuming a unidirectional coupled system. The lower organism enhances the growth of the upper-

level organism but the predator has no effect on the prey. This assumption seems to be rather strong and is not empirically credible for the perch-dagaa population dynamics studied below. Ragozin and Brown (1985) established the existence of a steady state and described the unique approach to it for a predator-prey system in which only the predator species is harvested. Hannesson (1983) studies the same bioeconomic model analytically as we do, but does not compare the bioeconomic model with a free entry model and has limited analytical comparative statics analysis. Flaaten (1989) follows May et al. (1979) in the population dynamics of the predator-prey model which differs from ours, compares the optimal solution to the open access solution and derives comparative statics results for price and interest rate changes on stocks. We compare these results with ours below.

In the model below we assume that the prey enhances the predator's growth in proportion to both the stock of predator and prey. The alternative is to assume that the predator's carrying capacity is proportional to the size of the prey population. In such a model, the predator has specialized on a single species for its food supply. Gut samples indicate that the predator (perch) feeds on a variety of species and fisheries biologists in the Lake Victoria region (Kulindwa, 2001) accepted the model as specified. The choice of model is not inconsequential as the subsequent discussion of comparative statics indicates.

The Model

Perch (predator) population dynamics is given by²

¹ The authors thank the very helpful comments of two anonymous reviewers.

² For an excellent treatment of competing species where $\alpha < 0$, see Flaaten (1991) and Schulz (1997).

$$(1.1) \quad \frac{dR}{dt} = \dot{R} = f(R) - h_1 + \alpha RD,$$

where R = the stock of perch at time t ; time subscripts are suppressed, $f(R)$ is logistic (see below),

h_1 = harvest of perch,

D = the stock of dagaa, and

msy = maximum sustained yield (single stock definition).

The dagaa enter the perch population dynamics linearly. α is the effect of a unit change in dagaa on the percent growth rate of perch.

In particular, assume the underlying population dynamics for the perch is logistic,

$$(1.2) \quad \dot{R} = r_1 R \left[1 - \frac{R}{\bar{R}} \right] - h_1 + \alpha RD,$$

where

r_1 = the intrinsic rate of growth for the perch,

$\bar{R}$ = the carrying capacity for the perch.

The logistic is introduced for illustrative purposes, but both biological and economic reasoning require any candidate growth function to exhibit diminishing returns.

Dagaa (prey) population dynamics is specified as

$$(2.1) \quad \frac{dD}{dt} = \dot{D} = g(D) - h_2 - \beta DR,$$

where $g(D)$ is logistic (see below),

h_2 = harvest of dagaa.

Adopting the logistic form again,

$$(2.2) \quad \dot{D} = r_2 D \left[1 - \frac{D}{D} \right] - h_2 - \beta DR.$$

In this primitive model, it is assumed that the marginal cost of harvest is constant (perhaps 0), independent of the population size. The goal in the introductory model is to maximize the present value of profit (Π)

$$\Pi = \int_0^{\infty} e^{-\rho t} [P_1 h_1 + P_2 h_2] dt,$$

where ρ = the discount rate,

P_i = the unit profit of harvested fish, $i = 1$ (perch), 2 (dagaa).

It is understood that harvest cannot exceed a certain maximum

$$\begin{aligned} 0 &\leq h_1 \leq h_{1\max} \\ 0 &\leq h_2 \leq h_{2\max}, \end{aligned}$$

at any moment, an assumption made for mathematical convenience.

Forming the current value Hamiltonian for the simple maximization problem,

$$(3) \quad H = P_1 h_1 + P_2 h_2 + \lambda_1 [f(R) - h_1 + \alpha RD] + \lambda_2 [g(D) - h_2 - \beta DR],$$

with λ_1 and λ_2 the adjoint variables for (1.1) and (2.1).

For a maximum of H , either we use the following bang bang controls,

$$(3.1) \quad h_1 = 0 \text{ if } \lambda_1 > P_1,$$

$$h_1 = h_{1\max} \text{ if } \lambda_1 < P_1,$$

or singular controls when

$$(3.2) \quad \lambda_i = P_i,$$

The adjoint equations are

$$(4.1) \quad \dot{\lambda}_1 - \rho \lambda_1 = -\lambda_1 [f'(R) + \alpha D] + \lambda_2 \beta D$$

$$(4.2) \quad \dot{\lambda}_2 - \rho\lambda_2 = -\lambda_2[g'(D) - \beta R] - \lambda_1\alpha R$$

In a steady state interior equilibrium, from (4.1) (4.2) and (3.2).

$$(5.1) \quad \rho = f'(R) + \alpha D - \frac{P_2}{P_1} \beta D,$$

$$(5.2) \quad \rho = g'(D) - \beta R + \frac{P_1}{P_2} \alpha R.$$

In equilibrium, according to the right-hand side of (5.1) and (5.2), the real marginal rate of return on each species has to earn the market rate of return (ρ).

Elsewhere we have worked out the comparative statics results for the optimal control solutions [Brown et al. 2002]. The derivations are here summarized in the Appendix. Not surprisingly, general results are limited but there are important special cases which are presented below. The species interaction terms create a biological technical externality that creates a term in the steady state conditions for the optimal population of both stocks (see (5.1) and (5.2), $\alpha P_1 - \beta P_2$). Assume this term is positive as it fortunately is in the case of Lake Victoria. We expect it to be positive because αP_1 is basically the value of marginal product in converting dagaa to perch which should not be less than the marginal cost or opportunity cost (βP_2) of forgone dagaa harvest. Moreover, the empirical evidence supports the necessary conditions to sign the response of harvest to price changes.

$$R^* < \frac{1}{2} \bar{R},$$

$$D^* > \frac{1}{2} \bar{D}.$$

Under these conditions, when the price of perch rises, the equilibrium stock of both fish rises as does perch harvest. Dagaa harvest decreases. When the price of dagaa rises, both populations decrease as does perch harvest but dagaa harvest increases. See Table 1.

Free Entry

The obvious alternative property rights case is the observed free entry. Under free entry, harvesters enter each fishery until total revenue equals total cost. Adopting a Schaefer production function for each species for illustration,

$$(6.1) \quad h_1 = E_1 R,$$

$$(6.2) \quad h_2 = E_2 D,$$

where E_i is the level of effort devoted to each fishery. Effort is obtained at a constant

unit cost of w . The total cost of harvesting perch, using (6.1) is $\frac{wh_1}{R}$. The equilibrium

conditions of total revenue and total cost equality results in

$$(7.1) \quad R = \frac{w}{P_1},$$

$$(7.2) \quad D = \frac{w}{P_2},$$

and from (7.1), (7.2), (1.1) and 2.1), in equilibrium,

$$(7.3) \quad h_1 = r_1 \frac{w}{P_1} \left(1 - \frac{w}{RP_1}\right) + \frac{\alpha w^2}{P_1 P_2}$$

$$(7.4) \quad h_2 = r_2 \frac{w}{P_2} \left(1 - \frac{w}{DP_2}\right) - \frac{\beta w^2}{P_1 P_2}.$$

The comparative statics for the free entry property right option is easily computed from equations (7.1) – (7.4) and are illustrated in Table 1. When the price of perch (dagaa) rises, its equilibrium population falls as we would expect. Dagaa harvest increases because harvest substitutes for decreased predation. Perch harvest responds to own price change in an ambiguous way because the original equilibrium population could be to the right of maximum sustained yield (msy) and when stock falls, due to price change, harvest increases. The sign is reversed if $R < R_{msy}$. The same explanation underlies the ambiguous sign in the case of dagaa. The interesting result is that exogenous price changes affect harvest and stocks differently under the two property right options in four of the eight possible comparisons and for a further two more cases when the cost price ratio results in low equilibrium populations. Thus, for example, introducing or increasing a landing tax is equivalent to a price reduction for that fishery. It increases perch (dagaa) harvest under free entry when stocks are relatively low but decreases perch (dagaa) harvest under optimal management or on individual quota system. Thus a national tax policy would have opposite consequences if some fisheries are operated under a free entry property rights regime and others are subject to individual quotas. Mixed property rights systems are common in many countries today and call for non-uniform management policies.

A Politically Feasible Implementation of the Optimal Solution

There are two parts to this paper. The analytical first part tells us where to go. The second part is a design of how to get there in the real world.

Using an optimal control formulation to determine the optimal harvest rates of both the predator and prey directly produces a rental rate or user cost for each species. It

is a small step made by most economists to immediately recommend a policy of charging the rental rate for harvesting each species. However, the dual to the charge is the standard or a specified harvest level per period. A standard is not very operational in this world because in the real world there are harvesters which are missing in the model. So, more structure is required when we move toward stylized policy making.

In most parts of the world, for most fisheries and for a very long time, it has not been politically feasible to charge a landing tax or its equivalent per unit of fish harvested; that is, a tax reflecting the social opportunity cost of fishing. Given its low probability of viability, we pass from a charge policy to individual tradable quotas (ITQs) to be discussed below.

The sad history of fisheries management throughout the world is familiar to most so we won't dwell on details. Only 25 percent of the fisheries throughout the world are under exploited; many of the exploited fisheries have been harvested to the point of extinction. [United Nations, 2002] Individual policies to control open access such as trip limits, season closures, total harvest quotas for fisheries and a variety of restrictions on gear very rarely have prevented the social waste of natural and human resources, as well as wasted manufactured capital that accompanies over fishing - fishing too fast at the wrong times in the wrong places. Limiting total catch per season has had wondrously bad consequences in North America. A halibut season in the Pacific Northwest of more than 200 days was reduced to a couple of days. [Wilens, 1994] The sable fish season in the same region was reduced to three weeks in order to prevent gross over fishing (S.S. Hanna 1995). It is unlikely that fishery wide input and output control policies effectively can manage Lake Victoria Fisheries, although one or two such as area and seasonal

closures to protect nurseries or particularly vulnerable periods can play an important partial role. The economic analogues, such as a landing fee that varies with location of catch has high monitoring and enforcement costs.

The success of management policies depends vitally on how they are developed and implemented. Success requires the co-evolution of the management tools and the process by which they are created, implemented and sustained. At one extreme, top down management refers to a situation in which the central government dictates policy and executes it in some decentralized bureaucratic fashion. This is a loser from the start. It surely has not worked previously in Lake Victoria and the mere enunciation of new policy tools is unlikely to be a panacea.

The promising place to begin is at the other end of the spectrum with bottom up management. In this case, the local community determines who fishes, how and when they fish, together with the other modalities of fishery management including total catch and catch per harvester. Bottom up management works well when the human and physical environment is homogeneous, a condition strikingly not satisfied in the Lake Victoria fishery under study. Over the relevant range, the more fish for the perch harvesters, the less for the dagaa harvester. This allocation decision has critical ramifications for the perch processing, largely export industry, which does not have deep, shared cultural roots with the harvesters. Moreover, the three nations contiguous to Lake Victoria have an interest in pursuing national objectives such as foreign exchange earnings which are antithetical to the interests of the dagaa harvesters. [Kulindwa *et al*, 2001]

For some time to come, the scientific analysis supporting the population dynamics, hence in part, the determination of annual allowable catch within an ITQ framework will be done, at least at the level of one or more regional agencies, in all likelihood. Finally, there may be technical externalities between other resources; for example, the threatened cichlids, [Kitchell *et al.*, 1997] over which national governments have jurisdiction and the perch. National responsibility for these other parts of the ecosystem require some form of intervention by legal entities higher than the local community in the political hierarchy.

It is not surprising that some sort of co-management structure has the best chance to be successful. Under co-management, authority is shared between local communities, perhaps public regional organizations and the national governments. Actual day-to-day management will be largely in the domain of the users and their local beach associations or fishermen cooperatives.

Illustratively, regardless of the particular policies chosen, some cost effective means of monitoring and enforcing must be devised by the co-management structure. Here user participation is essential for reducing cost and for success they must be involved in establishing policy in order to legitimate the regulations. In all likelihood it will be necessary to monitor and enforce individual harvest levels. In addition, perhaps mesh size or some policy will be necessary to manage discards and prevent fishing in specific areas at specific times.

Stiglitz (1990) has written about the importance of peer monitoring in the context of credit markets where self-formed groups made up of a small number of farmers are mutually responsible for ensuring that the loans each member has borrowed are repaid. In

this case, the incentive for one's peers to enforce the contracts is quite direct. A similar arrangement has promise at the beach association – fisherman's cooperative level. Elinor Ostrom (1990) and others have studied self-government of common property. In successful cases, the costs of monitoring and enforcement are reasonable because the existing social and cultural fabric of the community is essentially a free resource relied upon to induce conformance to the rules of the game. Top down management does not have access to this free resource. If the local harvesters go to the same church, shop in the same markets, their children go to the same schools and play sports together, a harvester may feel less inclined to cheat because it betrays the community's trust in him. He may be less inclined to cheat if he knows that it will hurt his friendly neighbors. If caught he faces both formal punishment and social opprobrium.

Our proposal embraces the idea of individual tradable quotas (ITQs). The economic advantages of ITQs have been discussed elsewhere. [Arnason, 1999] Some have argued that co-management and private property rights systems such as individual tradable quotas “are based on very different theoretical perspectives.” [B.J. McCay, 1995] We see no reason for fundamental incompatibility between the two concepts. Co-management is the institutional framework in which ITQs are the instrument for allocating catch among harvesters. Deciding who should be endowed with the ITQs is a time consuming and terribly controversial process. It can and has been accomplished in a bottom-up fashion, by the harvesters in the fishery. [Arnason, 1996, 1997] Some are concerned that the lifestyles of fishing communities will be changed if ITQs are introduced. Communities own commons, museums, and other natural and man-made treasures thought to be in the community's interest. Fishing rights can be another

community asset and distributed by the community as it sees fit. The Community Development Program (CDQ) in Alaska is a living expression of this idea. Since 1992, fifty native villages have been allocated 7.5 percent of the Bering Sea Pollock annual allowable harvest, a quota estimated to be worth more than 20 million dollars annually. [National Research Council, 1999]. More than sixteen other species are covered under the CDQ. Concentration, another concern about ITQs, is readily addressed by limiting ownership. We lay out an experiment below for rationalizing the fishery. For concreteness, it is specified in terms of ITQs.

Demonstration Project

We propose an experiment on a small scale that should serve as a demonstration not only to fishermen but also to policy makers. The demonstration effect, if successful, should lead to widespread support for a broader intervention and the formulation of the more complex policies to encompass all of Lake Victoria by the policy makers. The ability of a demonstration project to remove suspicion and convert ideas and concepts into reality should not be underestimated. For example, the British Columbia (Canada) Ministry of Fisheries adopted its individual quota program for halibut in 1991. It was immediately successful with landing prices more than 50 percent higher than their nearby neighbors in the U.S. received because smoothed harvest over time favored fresh over processed fish. U.S. halibut fishermen immediately saw the gains from privatization and just one year later, the North Pacific Management council (U.S.) approved an individual quota system, an idea fruitlessly debated to no avail for more than a decade previously.³

³ Personal communication, Gregory Williams, International Pacific Halibut Commission 1/13/04.

The feasibility of an ITQ system would be demonstrated at a landing beach, fishing bay, or a small inland fishery from each of the three East African countries. Several considerations should constitute the criteria for the site or fishery selection. The fishery should resemble the species in Lake Victoria, or close to it. It should be currently over-fished, it should not have very many fishermen; the fisher community should be as cohesive as possible; and the fish should not migrate beyond the beach, bay or inland water body. Illustratively, Lake Kanyaboli in Kenya and Lake Nabugabo in Uganda are good candidates. The governments of the three countries would be persuaded to allocate property rights of the selected fisheries to the fishing communities. The Lake Victoria Fisheries Organization (LVFO) has indicated that it could lobby for political support of this rights allocation. [Kulindwa, 2001] A non-government organization or other financing body such as World Bank would pay fishermen to exit the fisheries.

Before the fishermen are paid to leave or forgo fishing for a period of time, they should be involved in the monitoring of their catch. The purpose of this is to ensure that fishermen will believe that select catch is declining. Consequently, they will be able to compare/observe these data with the change of sample harvest productivity over time and attribute improved performance to the intervention. The preliminary data collected with the help of the fishermen could, additionally, be used to update the estimation of optimal yield and harvest rate.

The stock rebuilding process plus restriction on harvest levels to the optimal level result in the catch per unit of effort increasing substantially. Since the fishermen will continue being involved in the recording of their catch data over the life of the experiment, they will be able to directly observe the benefits associated with the restricted

access regime. Other fishermen in Lake Victoria, on observing the benefits, could be expected to lend support to a similar intervention designed for the entire lake. Discussions with fishery resource scientists indicate that this experiment could succeed. [Kulindwa *et al.*, 2001]

To be a bit more specific, the first step regarding ITQs is to have a record for several years of individual harvest, since ITQs historically have been allocated, for the most part, on the basis of catch history. For political feasibility, a determination must be made about how much to pay existing harvesters per year who will be forced to leave the fishery. Excluding harvesters involuntarily will be interpreted as confiscating prescriptive property rights, rights actually or perceived to have been acquired by active engagement in the fishery for a number of years. The payment is likely to be a high fraction of current income since alternative opportunities are limited and because of political necessity. The funding agency will make clear how much of the payments must be paid back when the fishery returns to good health and the terms of repayment. These charges can be regarded as a partial future payment for capital acquired through the ITQ property rights institution. At the cost of a delayed recovery, large numbers of marginal fishermen might be paid to leave at low cost and the remainder left to harvest some specified quantity annually.

Conclusion

This paper is one of a small class of papers that takes a small step into the realm of ecological complexity through bioeconomic analysis of two interdependent predator-prey species instead of the usual single species model. We have analytically described the present open access equilibrium using a population dynamics model suitable for the two

key income generation species in Lake Victoria. The population dynamics model satisfies the biological stylized facts for that ecological system and in this sense it is unique in the literature. At least one other form of population dynamics describing a predator-prey relationship has been analyzed by economists than the one portrayed here. The comparative static analysis sometimes differs between these two characterizations. Not surprisingly, the results from comparative statics analysis also differ between a property rights system of free entry compared to one in which a fishery is managed as if there was an owner of that fishery.

Since population and harvest levels for predator-prey species respond differently to policies which directly or indirectly impinge on ex-vessel prices and the cost of effort, depending on the property rights structure and the biology, the welfare effects of such policies will differ. This is one more case where a uniform policy is unlikely to be appropriate in a heterogeneous setting. It also means that policy makers must be informed of the institutional, biological and economic facts if they are to make good policy, conditions often not met even in developed economies.

Monitoring and enforcement are essential features of a successful fishery and have been notably lacking in the Lake Victoria fishery. The many possible landing sites and scarce money for management are two reasons for adopting bottoms up management. Transferring harvest rights to the fishermen gives the individuals an incentive to protect what is now their fishery resource. They can rely on the existing social and cultural fabric to provide social pressure to not cheat and thereby reduce the monitoring and enforcement costs.

Shifting property rights structures is not easy. It creates uncertainty and suspicions about what the unknown is like. Demonstration projects are a way to ameliorate these natural reservations, in moving away from free entry toward ITQs for Lake Victoria. In smaller lakes nearby, the location of demonstration projects, an investment project would pay existing harvesters to leave the fishery. Future harvest would begin following the optimal bioeconomic path. Resources would be devoted to organizing a workable institutional structure for managing a restricted entry fishery and allocating rights. Successful demonstration projects make a change in the property right structure for the more complex Lake Victoria fisheries more feasible.

Table 1

Comparative Statics

Direction of Change

	Free Entry	Optimal
$\frac{dR}{dP_1}$	-	+
$\frac{dR}{dP_2}$	0	-
$\frac{dD}{dP_1}$	0	+
$\frac{dD}{dP_2}$	-	-
$\frac{dh_2}{dP_2}$	-	+
$\frac{dh_2}{dP_1}$	+	-
$\frac{dh_1}{dP_1}$	-	+
$\frac{dh_1}{dP_2}$	- +	-
$\frac{dh_1}{dP_1}$	- +	+
$\frac{dh_1}{dP_2}$	-	-

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Appendix

Derivation of Comparative Statics Results

How do the optimal stocks and harvest of perch and dagaa respond to changes in the price of each species? From (4.1), (4.2), 1.1) and (1.2), in equilibrium one obtains

$$(A.1) \quad R = \frac{\bar{R}}{2} \left(1 - \frac{\rho}{r_1} \right) + \frac{\bar{R}D}{2r_1} \left(\frac{\alpha P_1 - \beta P_2}{P_1} \right),$$

$$(A.2) \quad D = \frac{\bar{D}}{2} \left(1 - \frac{\rho}{r_2} \right) + \frac{\bar{D}R}{2r_2} \left(\frac{\alpha P_1 - \beta P_2}{P_2} \right).$$

Differentiate (A.1) and (A.2) with respect to P_1 , simplify to one equation and rearrange,

$$(A.3) \quad \frac{\partial D}{\partial P_1} = \frac{\frac{\bar{R}\bar{D}D\beta P_2(\alpha P_1 - \beta P_2)}{4r_1r_2P_1^2P_2} + \frac{\bar{D}R\alpha}{2r_2P_2}}{\left(1 - \frac{\bar{R}\bar{D}(\alpha P_1 - \beta P_2)^2}{4r_1r_2P_1P_2} \right)}$$

Assume $(\alpha P_1 - \beta P_2) \geq 0$ which makes the numerator > 0 . Optimum R^* and D^* solved from (A.1) and (A.2) requires $\left(4r_1r_2P_1 - \bar{D}\bar{R}(\alpha P_1 - \beta P_2)^2 P_2^{-1} \right) > 0$ for $R^* > 0$.

Therefore the denominator of (A.3) is positive. Thus

$$\frac{\partial D}{\partial P_1} > 0. \text{ A similar proof establishes } \frac{\partial R}{\partial P_1} > 0.$$

From (1.1), in equilibrium,

$$(A.4) \quad h_1 = r_1 R - \frac{r_1}{R} R^2 + \alpha R D.$$

Differentiating (A.4) with respect to P_1 and rearranging terms,

$$\frac{\partial h_1}{\partial P_1} = \left(r_1 \left(1 - 2 \frac{R}{R} \right) + \alpha D \right) \frac{\partial R}{\partial P_1} + \alpha R \frac{\partial D}{\partial P_1} > 0$$

if $\frac{R}{R} < \frac{1}{2}$, and undetermined otherwise. A similar proof using (1.2) establishes that

$$\frac{\partial h_2}{\partial P_1} = \left(r_2 \left(1 - 2 \frac{D}{\bar{D}} \right) - \beta R \right) \frac{\partial D}{\partial P_1} - \beta D \frac{\partial R}{\partial P_1} < 0$$

if $\frac{D}{\bar{D}} > \frac{1}{2}$, and undetermined otherwise.

The signs of $\frac{\partial R}{\partial P_2}$, $\frac{\partial D}{\partial P_2}$, $\frac{\partial h_1}{\partial P_2}$, and $\frac{\partial h_2}{\partial P_2}$ are obtained by following the same strategy employed above.