

The Management of Fishery in the Lagoon of Venice

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Abstract. Recently, Mediterranean lagoon environment, mainly in the North Adriatic area, has been threatened by the overexploitation of fishery. Fishing has been rapidly growing since clam (*Tapes phippinarum*) fishery has spread over several lagoons. Fishing growth has been accomplished by capital-intensive fishery equipments increasing harvesting beyond the sustainable biological growth. This pattern is driven by myopic behavior and common property fisheries with free entry or open access. Institutional arrangements on fish resources may encourage a fishing farming matching the biological capacity. In this study a bioeconomic dynamic model is used to describe the optimal resource allocation in case of sole owner of fishery resource. This model has been applied to a specific fish, namely Great green goby (*Zosterisessor ophiocephalus*), living in the lagoon of Venice. Results confirm biological overfishing and stock depletion has occurred. Mainly factors affecting bioeconomic equilibrium such as prices, interest rate and fishing effort are fixed by market. New institutional arrangements and policy tools such as confining clam fishery, limited-licensing entry and catch quotas may ensure stock rehabilitation, highly productive fisheries as well as environmental protection only if they are supported by adequate market policies.

Keywords: clam, overfishing, fishery management, myopic behavior, dynamic programming, limited access, cooperatives.

1. INTRODUCTION

The Lagoon of Venice covering more than 55,000 hectares is the widest lagoon area of the Mediterranean basin. Lagoon fisheries play an important role on the socio-economical and environmental equilibrium of all Lagoon area. The lagoon fishery business accounts to over 80 million \$ including secondary effects coming from related economic sectors (Boatto and Defrancesco, 1994). About 2,500 people are employed (full or part-time) in the lagoon fishery sector but this number increases to 3,500 if related economic activities are taken into account.

Almost 1/3 of Mediterranean fishery production comes from North Adriatic sea where the Lagoon of Venice plays a critical biological role. Not only are lagoons and fishing valleys an important source of fish but they are also nursery areas of many commercial fishes or feeding grounds for others. Therefore, lagoon environment allows many species to complete their biological cycle. The lagoon fish production comes, however, from few species because most of them are migratory and caught on the sea.

The lagoon fishery economy may downsize its importance in the next future. Several issues have arisen recently:

- progressive subtraction of lagoon covered water areas because of sediment deposition;
- competitive and conflicting uses of lagoon area: navigation, public facilities, tourism, industrial and residential settlements;
- heavy pollution and environmental degradation coming from industrial and agricultural activities;

- the increasing fishing effort beyond the sustainability level;
- the adoption of sophisticated fishing capital-intensive technologies with a consequent decrease in manpower level and increase in efficiency.

The lagoon fishery production comes to several activities: traditional fishing on lagoon canals and water areas; valley fishing; farm fishing (aquaculture); mussel farming and clam fishing. Valley fishing is quite similar to the traditional one but it occurs on fenced lagoon valleys and it is managed following rules issued in XI century. In particular, the breeding is accomplished by shifting fish from an area to another and regulating water salinity but without feeding it. The fish quality coming from this breeding is higher than aquaculture one and the corresponding market price is 4-5 times higher than fish farming one. The valley fishing ensures high revenue while employing low environmental breeding techniques.

Lately, the lagoon environment has been threatened by the spreading clam fisheries. In the last decade, clam fishery has dramatically increased fisherman's revenue, many traditional operators have specialized in this activity, and new operators enter to this production while the number of vessel has risen up. Even if clam fishery does not compete with the traditional one, it has triggered a rapid and cruel fishery. In particular, open access and high revenues have encouraged a more efficient and, often, illegal fishery without considering any environmental damages. In 1995-96, unauthorized or illegal clam fishery trough extreme fishing equipments such as suction dredger, vibrating, scrapers, and legal clam fishery

amounted to the record production of 55.000 ton, corresponding to 40 million \$ and 200-300 people employed. Since clams live under water bottom, their extraction implies sediment movements with unavoidable environmental impacts not only on morphology, sediment and biology of the specific site but also on entire lagoon ecosystem. Sediments, carried out by tidal or upstream current, muddy water and deposit elsewhere often occluding canals of Venice. Environmental damages coming only from bottom modifications and sediment losses have been estimated in roughly a dozen million dollars (Orel, 1997; Di Silvio, et al., 1997) even though more detailed analyses suggest environmental costs beyond 50 million \$.

Actually, the important clam fishery issue lies on the regulation of harvesting by:

- a control over clam fishery activity (harvesting rate, total harvesting, timing, etc.);
- the adoption of clam fishing techniques not environmental wasteful.

The local administration has proposed a management resource plan aiming to mitigate environmental fishery impacts on Venetian lagoon. This plan encompasses all lagoon fisheries focusing attention not only on clams but also on traditional fishing. This project envisages a regulation of clam fishing restricting it to 1/10 of the total lagoon area (4,000 hectares). These new arrangements include also traditional fishery which management is a complex task involving multiple species and multiple uses. In particular, the management of migratory species (mulletts, basses, sea-brems, cuttlefish, eels, etc.) living in the Lagoon for a limited time, requires international agreement on fishery among North Adriatic countries (Italy, Slovenia, Croatia), while the management of sedentary species is under national, regional or local administrative control.

This paper examines socio-economic and environmental conditions underlying an optimal control management of sedentary lagoon species. The dynamic approach underlying the bioeconomic model suggests directions for intertemporal tradeoff between socio-economic and environmental demand. The outline of the paper is as follows: the second section illustrates the current lagoon fishery economy; in the third section fishery resource management of Lagoon of Venice is discussed. In the fourth paragraph the bioeconomic model is formally outlined and, in next paragraph it is extended to myopic behavior and open access resource. The sixth section, parameters required for model calibration are set and, subsequently, simulation results are discussed. The final part discusses conclusions.

2. THE LAGOON FISHERY

The production of Lagoon of Venice includes several species: mollusk (mussels, clams, cuttlefish), crustaceans (shrimps, grabs), marine and inland fishes (eels, mulletts, gilthead, basses, etc.) as they are reported in table 1.

Mollusks	Crustaceans
Mussels	Grabs:
Clams	- <i>Carcinus mediterraneus</i>
- <i>Tapes decussatus</i>	Shrimps:
- <i>Tapes philippinarum</i>	- <i>Crangon crangon</i>
Cuttlefish	- <i>Palaemon spp.</i>
	Fish
Great green goby	Mulletts:
- <i>Zosterisessor ophiocephalus</i>	- <i>Mugil cephalus</i>
Boyer's sand smelt	- <i>Chelon labrosus</i>
- <i>Atherina spp.</i>	- <i>Liza ramada</i>
Flounder	- <i>Liza aurata</i>
- <i>Platichthys flesus</i>	- <i>Liza sapiens</i>
Bass	Eels:
- <i>Dicentrarchus labrax</i>	- <i>Anguilla anguilla</i>
Sea-bream	
- <i>Sparus aurata</i>	

Table 1 – Fish species of Lagoon of Venice

Data on lagoon production (excluding clams and mussels) are reported on Figure 1. The mean yearly production over 1972-94, supplied by ASAP (ASAP, 1994), is compared with the 1997-98 mean production, estimated by CVN¹ (CVN, 1998). This analysis suggests a decreasing production of almost traditional lagoon species over time.

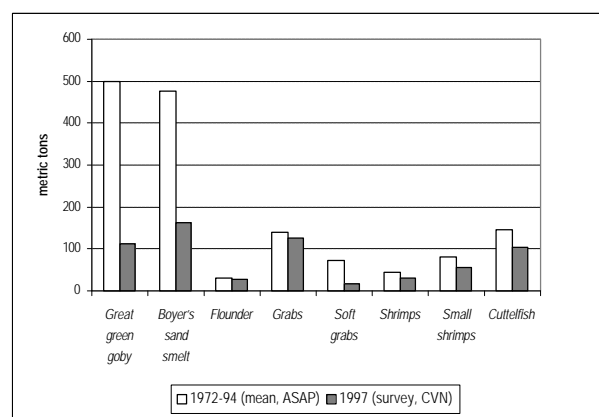


Figure 1 – Production of main fish lagoon species
Source: ASAP, 1995; CNV, 1998

The value of this production is reported on table 2. Assuming average prices recorded in 1997, the yearly

¹ ASAP, local association promoting aquaculture and fishery; CVN, Consortium Venezia Nuova.

value of lagoon traditional production is roughly around 3 million \$ (excluding recreational and illegal fishing).

	Mean price \$/Kg	Revenue \$
Fishes:		
Great green goby	1.9	213,000
Boyer's sand smelt	6.3	1,012,500
Flounder	4.5	108,000
Eels	13.5	81,000
Crustaceans:		
Grabs	2.0	254,000
Soft grabs	17.5	297,500
Shrimps	5.0	160,000
Small shrimps	5.0	280,000
Mollusks:		
Cuttlefish	5.0	521,000

Table 2 – Prices and revenue of main fish lagoon species

Source: CNV, 1998

The total revenue, coming from valley fishing and hunting lagoon activities, is estimated in 7.5 million \$: 50 percent comes from selling fish, 18 percent from hunting and the residual from other activities (agriculture, minor fish productions, etc.). The average revenue is around 1,750 \$/ha but it changes dramatically from valley to valley depending on their productivity. Variable costs are about 325 \$/ha while fixed costs are around 350 \$/ha. Therefore, the average net revenue is 225 \$/ha.

Now, we turn attention to clam fishery production. In the Lagoon of Venice there are two clam species: the autochthonous one, *Tapes decussatus*, and the allochthonous one, *Tapes philippinarum*. This latter was introduced into Venetian lagoon in the eighties. This species, coming from Indo-China, has developed rapidly because its biology (high growth rate, easy artificial reproduction and tolerance to temperature excursions, to salinity or quality substrate) is particularly suited to Venetian lagoon environment. This imported clam does not significantly modify ecosystem equilibrium (resource availability, competition, etc.) because it found a free ecological niche. A hectare of clam may generate a revenue of about 4,500-5000 \$ that is 15-20 times greater than traditional fishery. This high revenue has led to socio-economic and environmental problems outlined in first paragraph.

The economic analysis of lagoon fisheries shows strong price instability because of production seasonality. The fish price may vary according to specific fish and harvesting time. This instability is stressed by illegal fishery, especially on clams, selling fish at lower prices because of lower production costs.

Fishing firms operating in the Lagoon of Venice are mostly managed by a single operator and their production comes especially from clams and mussels while traditional fisheries (shrimps, grabs, mullets, etc.) accounts to only 30 percent of the total. Most of the firms are member of co-operatives especially because of bureaucratic and fiscal reasons but neglecting market strategies.

3. THE MANAGEMENT OF FISH RESOURCE

Since XI century, the management of fish resources on Lagoon of Venice has had to match impacts of productive activities (agriculture, fishery, navigation, etc.) and the conservation of lagoon ecosystem. During Serenissima Republic, fishermen were joint in confraternities. Each confraternity had its own fishing area and was governed by rules and customs called "*Mariegole*". In other words, fish resources were allocated among confraternities and managed by a set of rules concerning the environment (certain fishing tools were forbidden), the fish biology (fine-mesh net were forbidden), the management (each fisherman could fish only some species) and the market (price differentiation according to specie and size). After the fall of Serenissima and the advent of Habsburg Empire, fishery rules were issued on Adriatic sea while regulations on the Lagoon of Venice were neglected. Recent rules on fishing lagoon management aim to conservation of environment and fish stocks through a strict classification of fishing tools and their employment (how and when) while penalties are not significant. These regulations suffer a fundamental error: the management of fishery resources on Lagoon occurs in a open access regime whose consequences, explained by the "Tragedy of Common" (Hardin, 1968), are the overexploitation and degradation of fish resources.

In the last decades, the management of fishery has received an ever-increasing interest all over the world. The exploitation of fish resources has led to diminishing stocks and, in some cases, to stock depletion, i.e., the extinction of species. The problem of the overexploitation is particularly serious when fishery is managed as common property resource (Clark, 1985). In this case, a significant difference between the current harvesting rate and the biological compatible one is found. A great contribution to optimal management fishery has been supplied from H.S. Gordon (Gordon, 1954) establishing, during fifties, fundamental aspects of common property resource theory. According to this author, the overexploitation is associated with incorrect definition of the property rights on fish resource. Being fishing effort (or extraction cost) lower than fish market price, the current harvesting level is higher than the optimal biological one. Roughly speaking, each fisherman can fish wherever and whenever he likes without worrying about

others: everyone takes into account only his cost ignoring the fact that the increase in their catch affects the returns to fishing effort for other fishermen as well as the health of future fish stocks. In this way, the fishing effort of any fisherman is equal to average revenue rather than marginal one while open access provides for free entry until all the economic rent is dissipated.

The Gordon static model has been integrated by M.B. Schaefer (Schaefer, 1954) introducing the concept of bioeconomic equilibrium. The bioeconomic model has been successively extended dynamic analysis (Scott, 1955). These models give intertemporal solutions including harvesting and stock evolution compatible with fish growth and simulate economic and biological changes. Bioeconomic dynamic fishery models have had several applications and developments (Burt and Cummings, 1977; Clark, 1985; Kolberg, 1993; Larkin and Sylvia, 1999).

4. MODEL

The bioeconomic model employed in this study was firstly outlined by H.S. Gordon, Schaefer and Scott (Scott, 1988). The dynamic model applied refers to fishery stocks managed by a sole owner². Such simplified assumption emphasizes any single economic and biological effect focusing attention on critical decisions about fishery management. Next, the analysis has been extended to the case of the fishery management as common-property resource or open-access resource.

In this model, fish is a renewable resource. In fact, when fish resource is correctly managed, it offers product for an unlimited time. The stock may vary by increasing or decreasing harvesting over time, i.e., by investing or not investing in fish resource. The investment on fish resources is based on the following equation:

net growth rate = natural growth rate – harvesting rate
The net growth rate is the production function while the natural growth rate is the biological component. According to the Schaefer model (1954, 1957) the natural growth rate pattern is fitted by a logistic function whose rate is given by:

$$\frac{dS_t}{dt} = g(S_t) = kS_t \left(1 - \frac{S_t}{K}\right) \quad (1)$$

where S_t is the stock (biomass), $g(S_t)$ is the growth rate while k and K are the intrinsic growth rate and the environmental carrying capacity, respectively. The intrinsic growth rate is maximum growth rate of the population, i.e., k @ $g(S_t)$ when $(S_t) \ll K$. Analogously, K is the stock at steady state equilibrium and the current stock level $(S_t) @ K$ when $t @ \infty$.

² This is not a monopolist because the sole owner has not market price control.

The logistic curve shows a decreasing rate assuming positive values from the Minimum Sustainable Yield (MSY_{min}) to that Maximum Sustainable Yield (MSY) and negatives values from MSY to the environmental carrying capacity (K) (Figure 2).

The stock may change from MSY_{min} , close to zero, to the highest value of K , ie, the maximum stock supported by the aquatic ecosystem.

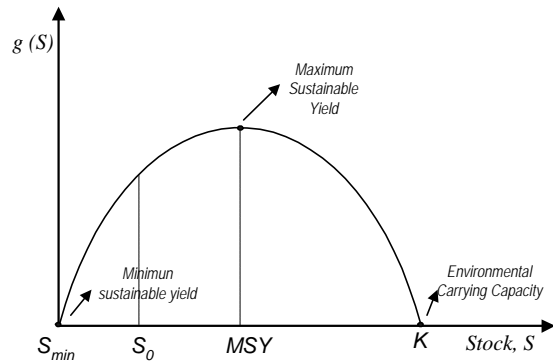


Figure 2 - Logistic growth curve
Source: Clark, 1986

From a biological point of view, when stock is less than its carrying capacity, the fish population grows (without considering any harvest) until the growth rate becomes zero. If the harvesting rate is equal to rate growth rate, the population is stable. Therefore, all combinations on the logistic curve are potential equilibrium points (or steady state) of the population. The growth rate is maximum (and, therefore, the potential harvesting) where stock is equal to the MSY . The logistic curve has been modified by Schaefer introducing the harvesting rate, Q_t ,

$$\frac{dS_t}{dt} = g(S_t) = kS_t \left(1 - \frac{S_t}{K}\right) - Q_t \quad (2)$$

where the harvesting rate is expressed as a function of fishing effort:

$$Q_t = qE_t S_t \quad (3)$$

where E_t is the fishing effort, i.e., the amount of input such as fixed capital, equipment, labor, fuels, etc. employed, while q is catchability coefficient. Dividing by S_t , the rewritten equation shows the mortality coefficient, F_t , which is directly proportional to the fishing effort and the catchability coefficient:

$$F_t = qE_t \quad (4)$$

Rearranging equation (2), and solving for Q_t on the steady state MSY , the fishing effort and harvesting rate will be:

$$E_{MSY} = \frac{k}{2q} ; Q_{MSY} = \frac{kK}{4} \quad (5)$$

These values show useful information about harvesting and fishing effort pattern depending on growth rate. Eventually, these parameters test the exploitation level of fishery. The economic component of Gordon model is

formalized by a profit function resulting from subtracting fishing effort to sale revenues:

$$\max \mathbf{p}_t = pQ_t - cE_t \quad (6)$$

where p is the selling fish price while c is the input cost per fishing effort unit.

The equilibrium depends on the shape of growth curve, on the level of input employment (fishing effort) and on the fishing coefficient. These parameters are included in a production function expressing the harvesting as a function of fishing effort and stock (Clark, 1986):

$$b_t = b(E_t, S_t) \quad (7)$$

where b_t is the harvesting level depending on fishing effort and stock.

Dynamic modeling on natural resources is based on intertemporal optimization framework. These models derive optimality conditions on biological and economic components and show the resource allocation path maximizing the welfare of present and future generations. The key elements of a dynamic model are:

- 1) interest rate used to discount future profits;
- 2) the production function;
- 3) prices and costs;
- 4) the equation of motion. In fishing, this equation includes the logistic growth curve:

$$S_{t+1} = S_t + g(S_t) - Q_t \quad (8)$$

where $g(S_t)$, is the growth function; Q_t , the harvesting, and S_t the stock level at time t . This expression is the dynamic component taking into account changes in stock and harvesting over time. The renewable resource is sustainable when stock does not change over time, resists to short-run shocks and generates a stable long-run output. In a dynamic model the steady state is a long-run equilibrium, which is hardly reached in the short-run because environmental and economic variables change over time continuously. Actually, the existence of a long-run steady state ensures the sustainability of the resource. Formally, the intertemporal optimization model can be defined as follows. We assume a variable stock, S_t , and a variable for harvesting, Q_t at time t , while parameters are the unit cost, c , and the growth, $g(S_t)$. The optimization process is carried out through a maximization of net benefits, i.e., total benefits less costs discounted at interest rate, r , and subject to the stock regenerating function. The main assumption is decreasing marginal benefits over time approaching zero when the time tends to infinity:

$$\text{Max}_{Q_t, S_t, I_t} L = \int_0^{\infty} e^{-rt} [B(Q_t) - Q_t c(S_t)] dt \quad (9)$$

$$\text{subject to: } \Delta S = g(S_t) - Q_t; \quad Q_t = qE_t S_t \quad (10)$$

where $B(Q_t)$ is the revenue function and $c(S_t)$ the unit cost of fishing effort. This problem of intertemporal optimization was firstly proposed by Hamilton and solved using the Principle of the Maximum (Pontryagin, 1964):

$$H(t) = B(Q_t) - Q_t c(S_t) + I_t [g(S_t) - Q_t] \quad (11)$$

where λ is the shadow price or opportunity cost, i.e., the cost of the foregone alternative of not using the resource. The shadow price estimates the resource scarcity. The optimization problem is solved by differentiating (11) with respect to the three variables, Q , S and I (Howitt et al. 1993):

$$\frac{\partial H}{\partial Q} = H_Q = B_Q - c(S_t) - I_t = 0 \quad (12)$$

$$\frac{\partial H}{\partial S} = H_S = -Q_t c_S(S_t) + I_t g_S(S_t) = -\Delta I_t + r I_t \quad (13)$$

$$\frac{\partial H}{\partial I} = \Delta S = g(S_t) - Q_t = 0 \quad (14)$$

In the first equation marginal revenue is equal to marginal cost. The latter is the sum of the unit cost of fishing effort and the shadow price. If fishery is managed by a single firm operating in a competitive market, the marginal revenue is equal to market price. The second equation shows that the shadow price change is influenced both positively by the interest rate and the cost of fishing effort and negatively by the growth rate. The equation (13) can be rewritten as:

$$\frac{\Delta I_t}{I_t} = r + \frac{c_S(S_t)}{I_t} Q_t - g_S(S_t) \quad (15)$$

The equation (15) suggests the following: when stock is relatively low the shadow price could diminish because the effect of the interest rate added to the cost of fishing effort may be counterbalanced by a positive increase of the stock. On the contrary, when stock is high the growth rate effect is positive and, therefore, the shadow price can only increase. The relation (14) expresses the production function taking into account the regeneration of the stock.

The Hotelling rule (Hotelling, 1931), suggests an optimal dynamic equilibrium when the fish price grows as the interest rate. Actually, fishermen have two alternatives: 1) fishing and selling the product on the market and, thus, investing money (getting interests); 2) do not fish and wait till fish price increases. According to Hotelling rule, when values coming from these two options are equal, harvesting is optimally allocated between the present and the future (Figure 3).

The interest rate influences both consumption and price patterns over time. In particular, a high interest rate increases actual consumption while future one goes down quickly. On the opposite, a low interest rate shifts consumption to the future (Figure 3).

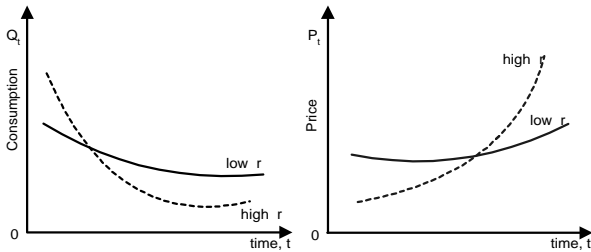


Figure 3 – Effect of interest rate on consumption and price pattern over time

The equilibrium between the actual and future consumption and the price is influenced not only by the interest rate but also from the level of the initial stock and the demand trend. For example, a high initial stock increases both current and future consumption and reduces price level over time. Analogously, an increasing demand pushes current prices up and lowers consumption over time. If the dynamic model establishes equilibrium where prices change as the interest rate, then the price trend can be forecasted but the equilibrium can be reached only when fishing is managed by a sole-owner. Under these conditions and assuming that cost of fishing effort increases as stock diminishes, the harvesting level lowers, over time, *ceteris paribus*.

The model has been simplified assuming a fishing cost equal to zero, $c=0$, to better understand the fisherman's behavior when the net discounted revenue is maximized and optimal conditions are met. Hence, shadow price changes depend only on the difference between the growth rate and the interest rate:

$$\frac{\Delta I}{I_t} = \frac{(r - g_{S_t})}{(1 + g_{S_t})} \quad (16)$$

The equilibrium is, therefore, reached when the change in price shadow price is zero while the growth rate is equivalent to the interest rate:

$$g(S_t) = r \quad (17)$$

The equation (16) strengthens the fact that the foregone marginal revenue for not fishing depends on two components: one is economic (interest rate) and the other is biologic (the growth rate). When stock is equal to MSY , the growth rate is zero ($g_S=0$). Since $r>0$, the optimal solution is reached when stock is less than MSY . Thus if

the current stock is higher than MSY , fishing should be encouraged to reach the optimal stock level as soon as possible. If $r=0$, the optimal stock is just equal to MSY , ie, this is the biological optimal solutions, The biological and economic equilibrium point is established where $r-g_S=0$ (point S_0 in Figure 2), ie, the difference between price and marginal cost is stable and the growth rate is exactly equal to the interest rate. If $S>S_0$, fishing should be increased diminishing the stock and increasing the growth rate. On the opposite, If $S<S_0$, fishing should be reduced increasing the stock and favoring resource appreciation over time.

Optimal dynamic conditions can be better highlighted in Figure 4, showing revenue and cost patterns as a function of stock. From an economic perspective, the optimal solution lies where stock is equal to Maximum Economic Yield, MEY . This solution does not meet biological, technological and economic constraints which push harvesting up and lower the optimal stock S^* . Thus, the optimal stock is located in any position between MEY and S_0 where the profit is zero. The optimal stock is equal to MEY only when $r=0$. Usually, a positive and increasing interest rate implies a lower conservation of fish resource and thus optimal stock shifts to the left. At the same time, profits go down till zero (S_0) because of diminishing revenues. The extreme case happens when the interest rate is always greater than rate of growth, ie, $r>g(S)$. The solution may be a stock level not sustainable or close to the extinction.

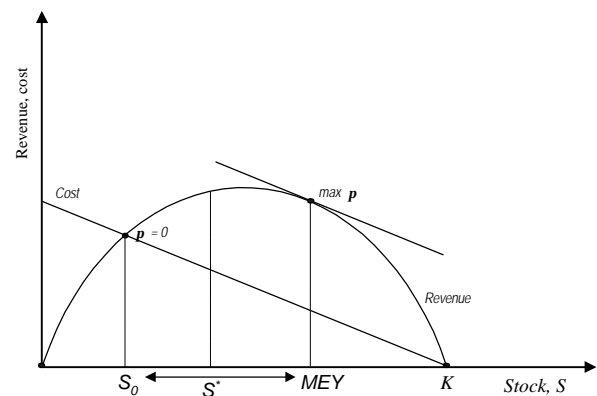


Figure 4 - Dynamic equilibrium
Source: Clark 1986.

However, the cost of fishing effort is always positive and makes the extinction a solution not significant. More realistically, fishing costs increase as stock diminishes, i.e., $DC(S)/DS=C_S<0$. Theoretically, increasing costs support conservation of fish resources. Formally, costs modify the equilibrium solution as follows:

$$\frac{\Delta I_t}{I_t} = \frac{(r - g_{S_t})}{(1 + g_{S_t})} + \frac{C_{S_t}}{I(1 + g_{S_t})} \quad (18)$$

This equation suggests that shadow price changes depend not only on the difference between the interest and growth rate but also on fishing cost changes. The equilibrium conditions, therefore, are reached when:

$$r = g_{S_t} - \frac{C_{S_t}}{I_t} \quad (19)$$

Since $-C_{S_t}$ is positive, the optimal equilibrium (if r is constant) is established where g_{S_t} is greater than a solution without fishing costs. Consequently, the optimal stock will be higher than S^* (Figure 4).

5. MYOPIC DECISION RULES AND COMMON-PROPERTY RESOURCE

So far, resource management has been analyzed assuming a sole-owner of fishery resource stock. In this paragraph effects of common-property resource or open access have been outlined.

First of all, we assume that fishing is accomplished by a large number of fishermen and each of them has the right to fish. This assumption reflects what is now happening in the Lagoon of Venice. In this situation, each fisherman maximizes his discounted revenue without taking into account the behavior of the others or effects on future generations. When all fishermen behave myopically, ie, ignoring that his catch affects return to fishing of other fishermen, the harvesting level increases and stock decreases until all rent will be dissipated.

From an environmental point of view, the myopic behavior and open access lead to the overexploitation of resources held in common as “tragedy of commons” predicts. Actually, the “tragedy of commons” approach, does not take into account socio-economic factors, either conflicting or cooperating, characterizing fishermen operating in the Lagoon of Venice. The way and scale of overexploitation depend on biology of single-species captured, on market prices, on fishing effort and, thus, on technology employed (Feeny et al., 1996). Notwithstanding, the number of fishermen still plays a relevant role, ie, the fishing effort increases with the fleet size, *ceteris paribus*. Graphically, a greater fleet size shifts the bioeconomic optimal equilibrium to the left till to the point S_0 where the profit is zero (Figure 4).

However, the exploitation of fishery should be evaluated in a long time horizon because the evolution of fish prices may increase fisherman’s revenue and fishing efficiency while worsening the conservation of fish resource. For

example, latest technological innovations have exacerbated the fishing capacity, reducing costs and encouraging overexploitation of fishery beyond the critical level of extinction (e.g. capturing non-market size fish).

In order to avoid overfishing, many countries have adopted policies limiting fishing effort (fleet size and fishing power) such as Total Allowable Quotas (TAC) and Individual Transferable Quotas (ITQ)³. The TAC sets a low fishing level to permit stock rehabilitation and once TAC has been taken, the fishery is closed until the following year. The TAC operates in specific time (or months) during year. The ITQ provides a mechanism to eliminate redundant capital and labor accumulated under pre-ITQ regime and encourages a cost-efficient production. These policies have increase fisherman’s revenue while a reduction of fishing time has raised fixed cost incidence⁴. Roughly speaking, these rules change the overfishing into under capacity utilization, decreasing, *ceteris paribus*, the fisherman’s revenue. Therefore, these policies limiting fishery are successful only if they are accomplished with an adequate market or trade policy aiming to increase fish prices.

6. SIMULATION RESULTS

The model has been carried out on a single fish species namely Great green goby (*Zosterisessor ophiocephalus*), included on *Gobiidae* family, because its biological cycle is done inside the Lagoon. Results could also be extended to migratory species living on Lagoon for limited time (using lagoon as nursery area or feeding grounds). Data supplied by biologists (Orel, 1995) and supported by a fisherman’ survey (Province of Venice, 2000) suggest that:

- the environmental carrying capacity is equal to 800 Kg/ha;
- the intrinsic growth rate is 0,5⁵;
- the market price is around 2 \$/Kg;

Costs are endogenous. They are performed by a non-linear cost function whose parameters have been calibrated on data coming from the sample survey analysis.

In particular, when average harvest is equal to 50 Kg/ha the total cost is 2.9 \$/Kg: 1.65 \$ is variable and 1.25 \$ is fixed. The functional form of total cost function is quadratic as the following:

$$C = aQ + bQ^2 \quad (20)$$

³ These policies have been adopted by European Union (CE reg. 3760/92).

⁴ When fishing is suspended, boats stand by on harbor not having alternative uses.

⁵ The fish population doubles each year.

where $\alpha=10$ $\beta=15$. A 0.5 \$ starting shadow price and 5 percent interest rate have been assumed.

Data have been processed in a multi-period non-linear mathematical programming model. Non-linearities derive from the quadratic cost function aiming to perform an increasing fishing effort. State variables such as harvesting and resource dynamics are treated endogenously while market fish price, biological and cost parameters and transversality conditions are fixed. The model has been firstly calibrated over time and state variables such as stock, harvesting become stable after 15-20 years. Hence, a 20-year time horizon has been considered. The model has been run to test the current fishery and to simulate effects of policies aiming to increase fishery profitability.

Results show that the current harvesting rate is neither optimal nor stable and higher the optimal one. Assuming a interest rate of 5 percent and a shadow price of 0.75 \$/Kg, in the first decade the level of harvesting decreases from 129 to approximately 107 Kg and reaches 90 Kg in the next decade (Figure 5). The stock goes down rapidly until the 6th – 7th year, then remains stable at around 510 Kg. Therefore, the current harvesting (130-150 Kg) is 40 percent higher than the optimal one (Figure 5).

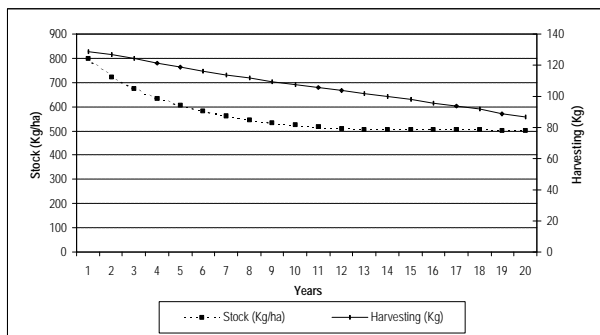


Figure 5 - Stock and harvesting patterns

These results suggest a prudent fishery control aimed to reduce harvesting of about 50 percent through the adoption of limiting harvesting policies such as TAC, limited-entry licensing, market policies (e.g. prices).

Then, the following effects have been simulated:

- decrease of shadow price;
- reduction of fish market price;
- increase of shadow price;
- changes of interest rate;
- effects on fisherman's revenue.

Shadow price is a measure of resource scarcity: high shadow price denotes positive social expectations for fish conservation or environmental protection while a low shadow price indicates a greater current consumption and market-oriented policy.

Assuming a reduction in fishery shadow price from 0.75 \$/Kg to 0.25 \$/Kg, ie, assuming a decreasing stock value, the simulation shows a declining equilibrium stock (approximately 360 Kg) while harvesting is about 114 Kg, *ceteris paribus*. In fact, a lower stock value means increasing fishery exploitation beyond the natural growth rate and, consequently, a progressive decline of fish population.

The optimal harvesting can be reached by decreasing market fish price or increasing the shadow price of fish resource. For example, if market fish price decreases of 25 percent the harvesting lowers of almost 30 percent; if shadow price doubles the harvesting decreases of almost 30 percent. Results are strongly influenced by the interest rate fixed by financial market. Low interest rate expectations may shift the consumption to the future, reducing the current harvests and, thus, favoring the conservation of fish resource. For example, if the current interest rate decreases from 5 to 2 percent, the stock increases sensitively (2-3 percent) while, in the first decade, harvests go down (-2 percent). On the opposite, a perspective of increasing interest rates does not definitively support fish conservation while, paradoxically, mitigating the difference between the current and optimal harvesting.

Next, income effects on fishermen have been analyzed. The model simulates revenue effects of market price and interest rate changes. Assuming a reduction of market fish price from 2 \$/Kg to 1.5 \$/Kg the corresponding fisherman's revenue change is negative only in the short run, then approaches to zero. After the eight year, the revenue becomes positive because the value of increasing stock offsets the direct economic loss suffered by fishermen. A decreasing interest rate from 5 to 2 percent increases revenue significantly while preserving fish resource. On the opposite, an increasing interest, from 5 to 8 percent, discourages fish resource conservation while fisherman's revenue goes down. Therefore, revenue effects of a policy aiming to change market fish price may be offset by an increase in the interest rate or exacerbated by decreasing interest rates.

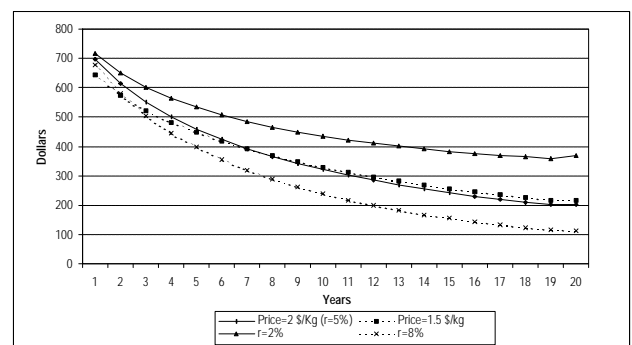


Figure 6 – Revenue patterns

Finally, effects of environmental protection and future fish resource preservation on fisherman's revenue have been analyzed. A shadow price reduction, from 0.75 \$/Kg to 0.25 \$/Kg, shifts fisherman's revenue to the left (see fig. 7) since the increase in harvesting does not offset a lower fishery resource value.

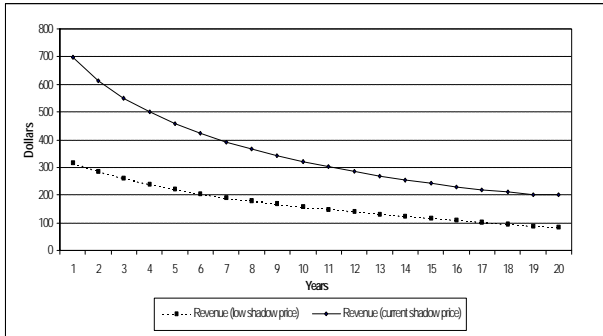


Figure 7 – Revenue path and decreasing shadow price

7. CONCLUSIONS

Results indicate that the current harvesting level is greater than the optimal one. Moreover, this latter may further diminish because of the interest rate reduction worsening the fish stock size. The fish stock could also decrease because of increasing fish price and technological changes. In fact, innovations both increasing fishing efficiency and reducing fishing effort may encourage harvests and diminish stock till reaching the S_{min} where fish population is close to extinction. Indeed, a limiting harvesting seems to be the only effective policy. Only can the optimal stock ensure permanent and stable revenue representing also the maximum amount coming from a long run fishery management. This management is economic, biological and environmental sustainable.

However, any limiting harvesting regulation should be accomplished by a market policy avoiding revenue fisherman's losses. The fishery co-operatives could be a key tool in solving management fishery issues. In particular, a fishing co-operative may accomplished the following tasks:

- to guarantee a better control over supply (quality and quantity);
- to implement marketing policies;
- to enjoy preferential selling conditions;
- to enjoy financing and fiscal facilities;
- to ensure a control over fishermen by self-regulation or regulation imposed by the public agency management;
- to reduce transaction costs of regulation policy with respect to public control.

A rational and logical application of these tools increases fisherman market power ensuring better and stable revenues. At the same time, co-operatives regulate fisheries limiting harvesting and encouraging traditional harvesting tools not environmentally wasteful. Eventually, a co-operative may apply for certificating and labeling its product. Since average Veneto income is high and consumers are willing to pay for a better quality food, this marketing policy may be a successful strategy in getting high revenue while preserving fish stocks.

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