RE3-06-002

Economic and
Sector Study
Series

FISHERIES MANAGEMENT IN THE GALAPAGOS MARINE RESERVE: A BIOECONOMIC PERSPECTIVE

Jon Conrad
Henrik Franklin
Linda Nøstbakken
Steven Stone
César Viteri

May 2006

REGION 3

Inter-American Development Bank

Fisheries Management in the Galapagos Marine Reserve
A Bioeconomic Perspective

Steven Stone[Ψ]
Cesar Viteri[φ]
Jon Conrad, Cornell[δ]
Linda Nøstbakken[ω]
Henrik Franklin[ε]

[Ψ] Steven Stone, IDB - Natural Resource Specialist. (stevens@iadb.org)
[φ] César Viteri, IDB - Consultant. (cviteri@fnatura.org.ec)
[δ] Jon Conrad, Cornell University- Associate Professor. (jmc16@cornell.edu)
[ω] Linda Nøstbakken, Cornell University - Ph.D candidate on (lgm2@cornell.edu)
[ε] Henrik Franklin, IDB - Natural Resource Specialist. (Henrikf@iadb.org)

Foreword

The Galapagos Islands represent one of the most complex, diverse and unique ecosystems in the world, considered as a natural laboratory for the study and understanding of evolutionary processes. Since early colonization, the resource base of Galapagos has provided for the subsistence of a small local population as well as a source of raw materials for whalers and pirates in the 18th century.

However, since the establishment of the Galapagos Marine Reserve in 1996, industrial fishing has been excluded from a forty-mile perimeter surrounding the archipelago and limited to small-scale artisan fishing by local residents. Today, fishing generates approximately US$4-6 m annually and sustains a population of about 1000 fishermen and their families in Galapagos. This fishing activity has generated great international interest, primarily for its potential impact on the biodiversity of the marine reserve.

This study analyzes the management of fisheries in the Galapagos Marine Reserve using a stochastic discrete-time model developed by Reed (1979) and incorporating biological and economic variables. The findings indicate that the fisheries are being managed sub-optimally, and that potential gains may be derived from using improved management tools, including applied economic analysis.

The authors wish to thank Sergio Ardila (RE2/EN2); Leonardo Corral (RE3/EN3); Michelle Lemay (RE2/EN2); and Raul Tuazon (RE1/RE1) for reviewing an earlier draft of the study and Fidel Jaramillo (REA/RE3) for providing comments and suggestions for the final one. A special thank to Gisella Barreda (RE3/EN3) for help in preparing the document and Jesus Bengoechea (RE3) who was in charge of this publication.

Alicia S. Ritchie
Manager, Regional Operations Department 3
Inter-American Development Bank

TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

ANNEXES

I. INTRODUCTION AND OVERVIEW

The Galapagos Islands represent one of the most complex, diverse and unique ecosystems in the world, considered as a natural laboratory for the study and understanding of evolutionary processes. Each year, the Galapagos Islands attract more than 60,000 international visitors and generate tourism revenues exceeding US$200 million annually.

Since early colonization, the resource base of Galapagos has provided for the subsistence of a small local population as well as a source of raw materials for whalers and pirates in the 18th century. However, since the establishment of the Galapagos Marine Reserve in 1996, industrial fishing has been excluded from a forty-mile perimeter surrounding the archipelago and limited to small-scale artisanal fishing by local residents (see Figure 1). Today, fishing generates approximately US$4-6 m annually and sustains a population of about 1000 fishermen and their families in Galapagos. This fishing activity has generated great international interest, primarily for its potential impact on the biodiversity of the marine reserve.

However, despite numerous efforts and a large investment by the Ecuadorian Government and the international community, fishery management in Galapagos remains highly conflictive and essentially ineffective. Biological monitoring by the Charles Darwin Station and subsequent reports on stock levels and acceptable catch are distrusted by the fishing community and rejected as biased, making consensus decisions on resource use in the Marine Reserve difficult. Levels of mistrust and lack of communication have eroded the governance mechanisms in place to resolve conflicts over competing uses in the Reserve.

In an effort to provide new information and analytical content into the policy debate regarding fisheries management in the marine reserve, the authors developed this research utilizing an economic approach to regulating use of the primary commercial fisheries in Galapagos. In particular, the objective of this study is to determine the optimal harvest, escapement, and fishing effort for the small-scale fishing fleet of the Galapagos Marine Reserve (GMR). In this study, we focus our attention on the two most important fisheries: the sea cucumber (pepino de mar, or "pepino") and the spiny red lobster. We base our analysis on a stochastic discrete time bioeconomic model developed by Reed (1979). This model considers a basic escapement function for the bioeconomic resource models for each fishery.
The paper is organized into five sections. In the next section we describe the sea cucumber and the spiny lobster fisheries and the participatory management system that governs small-scale fisheries in the GMR. The third section provides a brief review of the literature on fisheries management. In the fourth section we describe the stochastic, discrete-time fishery model on which our analysis is based, as well as the functional forms used in the model and the solution of the fishery management problem via dynamic programming.

The second part of Section 4 contains a discussion of the data and the econometric methods used to estimate the parameters of the growth function and the catchability coefficient, and presents these estimates for the sea cucumber and spiny lobster fisheries. These parameter estimates are then used to solve for the optimal escapement and harvest levels for the GMR. Sensitivity analysis is also conducted on the main parameters to determine the stability of the results.

Finally, in the fifth section, we summarize the results of our analysis and offer some suggestions and directions for further research that could improve the management of fisheries in the GMR.

II. FISHERIES MANAGEMENT IN GALAPAGOS

In this section we describe the management system for small-scale fisheries in the GMR. In addition, this section describes how and where the sea cucumber and spiny lobster are harvested.

A. The Management System

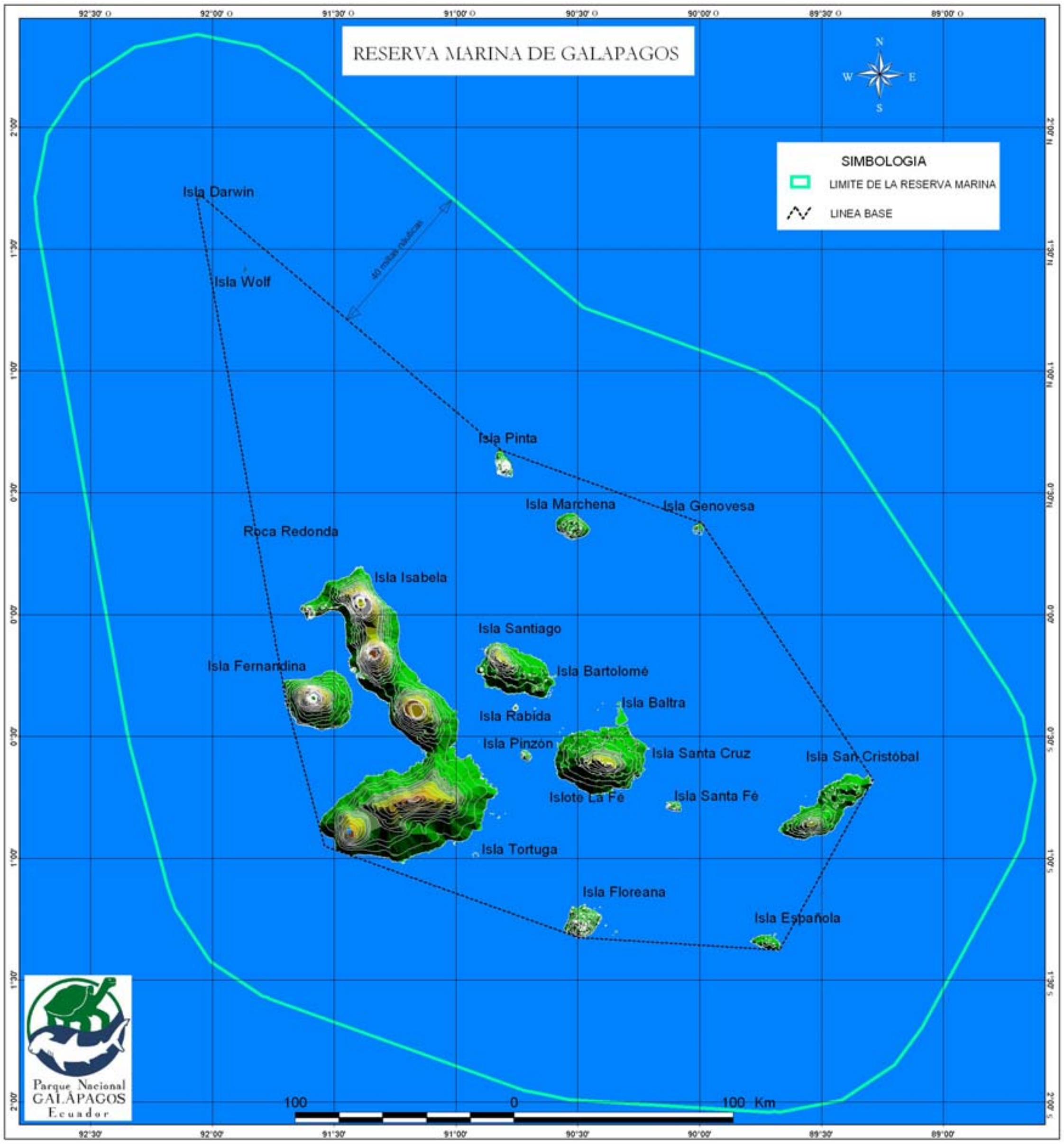
Fishery management within the GMR was established as part of the "Special Law for the Conservation and Sustainable Development of the Province of Galapagos" in 1998. This law was enacted to resolve conflicts over natural resource use among competing groups in the marine reserve, and included a strategy of involving local users in decision making as a "buy in" strategy[1]. Specifically, the law contains a series of provisions that delegate decision-making for resource management to a local coordination body known as the Participatory Management Board (PMB), comprised of representatives of the tourism sector, the small-scale fishery sector and the conservation sector. In addition, the Law grants to the Galapagos National Park (GNP) the authority and the instruments to promote and implement the regulations and decisions agreed to by the PMB.

With regard to small-scale fishery, the law contains two key elements for regulating the use of fishery resources in the marine reserve. First, the law establishes a local management regime for common property resources, with an identified and limited group of users. In this sense, the law restricts fishery activities in the area of the GMR to small-scale fisheries, as defined in the Management Plan, and it establishes entrance barriers to the small-scale fisheries through the imposition of a series of requirements affecting both fishermen and boat size and technology options.

Second, as noted above, the law establishes a scheme for decision-making to control small-scale fishery activities. This consists of involving local fishermen in the decision-making process through the PMB, where aspects related to the use of the fishery activity are analyzed and subsequently proposed to the Inter-institutional Management Authority (IMA). Decisions taken by the IMA are summarized in the "fishery calendar," which determines the species may be harvested, the fishing season, and the total allowable catch. Once approved by the IMA, the fishery calendar sets the "rules of the game" which the small-scale fishermen must obey.

1 These aims are reflected in the mission statement of the new management regime as elaborated by the *Grupo Núcleo* (a group made up of representatives of the fishery and tourism sectors in the Galapagos, the Charles Darwin Foundation, the GNP and the Fisheries Bureau) in June 1997. The statement endorses the effective participation of the local sector in decision-making as a key element to promote a commitment to comply with the regulations (Heylings, *et al.* 1998).

Figure 1: Map of Archipelago and Galapagos Marine Reserve



Source: Galápagos National Park Service

With regard to fisheries quotas or total allowable catch, the decision making process begins with an assessment of the fish stock (or population) by the Participatory Monitoring and Research Program. Members of the Charles Darwin Research Station (CDRS), the Galapagos National Park and the Small Scale Fishermen Cooperatives of Galapagos contribute to the stock assessment, and the information they provide about species abundance is analyzed inside the PMB (financed by IDB since 2002 – 2005). If a decision is achieved by consensus, then it is approved by the IMA; otherwise the decision is made by IMA through voting[2].

[2] This decision making system for the GMR, by consensus at the PMB level and by voting at IMA level, applies to the regulation of other activities within the GMR such as tourism and zoning.

According some experts, the political nature of the PBM complicates sounds policy making, where in most of the cases scientific information is absent or ignored. For example to define the 2003 global quota, the PBM was not able to reach a consensus position among users and the decision went to the IMA. The IMA in turn based its decision not on available scientific data but rather on "socio-economic" considerations, reflecting the pressure of local fishermen to get a quota similar or lager than the last season. In this regard, although the decisions are apparently based on economic decisions, the resulting management policy may not benefit from full information or a complete analysis of trade-offs in present harvests and benefit streams over time.

B. The Sea Cucumber and Spiny Lobster Fisheries

Policy makers participating in the PMB have focused their attention on what are currently the two most commercially important fisheries in Galapagos, the sea cucumber and spiny lobster.

1. Sea Cucumber (Isostichopus fuscus)

The sea cucumber is a coastal species usually found at a depth of 4 to 12m, and fished commercially to about 20 - 25 m, even though there are records that indicate a range as deep as 61m. [Ben-Yami (2001)]. The sea cucumber belongs to the Holothuriodea class and performs a key role within the sea floor (benthic) community, making it indispensable to the productivity of the coastal marine environment [Murillo J.C. et. al., (2002a)].

The sea cucumber fishery commenced in the Galapagos in 1991, after its numbers were depleted in the waters off the Ecuadorian mainland. In 1992, the Ecuadorian Government banned the harvest of sea cucumber in Galapagos. In 1994, after a two-month experimental harvest, the Government declared a moratorium for five years lasting until 1999 when the fishery re-opened [Murillo J.C. et. al., (2002a)]. The sea cucumber fishery is an export oriented product for Asian markets and currently is the most important source of income for the small-scale fishermen of the Galapagos. According to data provided by the CDRS, in 2002 this fishery generated a gross income close to 1.7 million USD (larger than the income generated by the spiny lobster or whitefish fisheries), with a total catch of 8.3 million of individuals. A presentation of the disaggregated catch data for the period 1999-2003 is presented in Annex 2A, and summarized in Table 1 below.

Table 1: Sea cucumber catch

Year	*Number of Individuals*
1999	4.401.657
2000	4.946.947
2001	2.672.345
2002	8.301.449
2003	5.005.574

Source: Murillo J.C, Chasiluisa C., Bautil Bet al., 2003. "Monitoreo de la pesquería del Pepino de mar (Stichopus fuscus) en las islas Galápagos, 2003. Informe Técnico Interino, ECCD –SPNG", Santa Cruz, Galápagos: Ecuador.

The sea cucumber is harvested to a depth of approximately 20 m. in 8 specific macro-zones of five different islands. The fishermen cook, salt and dry the harvested sea cucumbers. The

minimum dry commercial size is approximately 10 cm. Since 1999, the most important management measures taken for this fishery includes (1) no-take zones, (2) restricted fishing seasons (two months April - May), (3) size restrictions, and (4) a catch quota. The quotas are determined by a combination of two methodologies for stock assessment. One is based on catch and effort data, and the other on direct observations made at specific locations within the GMR [Ben-Yami (2001)]. During 2000, the population was estimated to be between 30 and 40 million individuals, and the allowable catch was set at the 10% of 35 million, or 3.5 million individuals [Toral (2000) in Ben-Yami (2001)]. However, total estimated population in 2004 was less than 20 million.

2. Spiny Lobster (Panulirus penicillatus and P. gracilis)

Galapagos small-scale fishermen catch three species of lobster: spiny red (Panulirus penicillatus) and green lobsters (Panulirus gracilis); and the slippery lobster (Scyllarides astori). This study focuses on the spiny red lobster. The red lobster is more abundant and is present across most of the archipelago's coastal waters, with exception of the southern and eastern sections of Isabela where the green lobster is dominant. Lobsters tend to live in turbid areas, preferring rocky substrates where they hide in crevices and caves; normally they are fished at 10 m. depth [Ben-Yami (2001)].

According to Bustamante R.H. et. al., 2000 [quoted in Ben-Yami (2001)], the export oriented lobster fishery began in the 1960s. Harvest was year-round, and until 1984 was conducted by divers working from mainland-based vessels. Since 1984, lobsters have been harvested primarily by local divers. Currently, the lobster fishery is the second largest in terms of economic importance. During 2002, the fishery yielded revenues of 1.2 million USD with a catch of 51.4 mt. [Murillo (2002)]. In the next table, we present a summary of spiny lobster catch in the last years.

Table 2: Spiny Lobster catch(1)

Year	*Lobster Tails (Kg)*
1997	65.300
1998	31.000
1999	54.400
2000	85.000
2001	66.000
2002	51.400
2003	45.780

(1): Includes red and green lobster.

Source: Hearn A, Castrejón M, Reyes H, et al. 2004. "Fundación Charles Darwin: Evaluación de la pesqueria de langosta espinosa (Panulirus penicillatus y P. gracilis) en la Reserva Marina Galapagos 2004", Santa Cruz, Galápagos: Ecuador.

Divers harvest lobsters by hand, although lance- and pistol-type harpoons, both of which are illegal, are widely used. Only the tail of the lobster is marketed. Most lobster tails are frozen and exported. In theory, a permit system allows officials to trace the chain of product ownership from the fishing vessel to the export market [Wilen et al. (2000)], although in practice this has been difficult to enforce.

The spiny lobster fishery is part of the five-year fishing calendar of the GMR, implemented since 2002. According to Toral (2002), this fishery has the most complete management plan with a fishing season from September to December, a minimum legal size of 15 cm tail length, and a ban on the harvest of egg-bearing females.

III. A Brief Review of Fisheries Management: Theory and Applications

In this section, we present the basic economic theory used to address fisheries management. Next, we mention some studies that attempt to explain the growth of Galapagos fishery stocks and recommend optimal catch policies based on the concept of maximum sustainable yield. Finally, we analyze the limitations of the standard biological model to obtain maximum sustainable yield policies, and explain briefly the the bioeconomic model we will use in this study.

In the economic literature, renewable resources are defined as those whose stocks are not fixed and can decrease or increase. The growth of the stock has a limit and cannot go beyond the carrying capacity of the ecosystem that sustains the resource (Pearce W.D. et. al. 1990). The most common renewable resources addressed by economic theory are forests, water (surface or aquifer) and fisheries. In the case of fisheries, the focus is upon the nature of the fishery production function and how fishing effort in the form of labor and capital interacts with the fish stock.

Usually the models of fishery exploitation must include a representation of the underlying biological growth process. The most widely used form to represent the growth of the resource is the logistic function [F(X)-rX(1-X/K)], where: "X" is the size of the population or stock, "r" is the intrinsic growth rate and "K" is the carrying capacity of the ecosystem (Hanley N. et. al. , 1997). This functional form allows high growth rates of the resource at low levels of population; indicating for example, that at low level of population, fish have more food and can reproduce more rapidly. As the population grows, there is more competition for food and the growth rate begins to slow. The fish population will continue to increase until the size of resource equals the maximum carrying capacity (K), at which the net rate of growth is zero.

Behind this process, we can identify the concept of maximum sustainable yield (MSY), when the rate of growth of the resource reaches its maximum. This concept is appealing because if we have an amount of growth equal to the MSY, the stock of the resource will remain constant and will be able to reproduce the same amount of resource for the next period (Pearce et. al. 1990). So, levels of production or harvest equal to MSY allow users to take the maximum amount of resources from the stock without decreasing its capacity of reproduction over time. However, as we will point out below, this analysis does not consider interest rates or the "time cost" of money.

Usually, the fishery production function combines fish stocks and fishing effort. Fishing effort measures the capital, energy and labor devoted to fishing during a particular period of time. The yield or the number of fish caught is in general "stock dependent"; this reflects the fact that the more fish there are, the easier they are to catch. The most popular model in fishery economics is the Schaefer model, which assumes that the harvest is proportional to the stock level [Y/E=qX].

That is, the catch per unit of effort (Y/E) is a constant proportion (q) of the stock (X). Using the growth function and the production function, we can identify a biological equilibrium where the catch equals the growth of the resource. This gives a unique equilibrium catch at each level of effort (Hanley N. et. al. 1997).

The approach just described is followed by Murillo et. al. (2003) to calculate the MSY in the red lobster fishery of Galapagos. In this study Murillo, based on Schaefer model; performs a linear regression between the catch per effort unit of red lobster (as the dependent variable) and the corresponding effort levels (expressed as number of one-day fishing trips)[3]. The parameters estimated (the intercept and slope) are used to calculate the MSY (26.8 mt. of lobster tails) and the corresponding effort level (5.769 one-day fishing trips). These results suggest that the current fishing levels of red lobster fishery in Galapagos exceed what is biologically optimal.

As Murillo et. al. (2003a) recognize in their study, this approach requires that the fishery under study is at a steady state during the interval of analysis, an unlikely assumption in the case of Galapagos fisheries. Additionally, Schaefer model has been criticized for simplifying complex biological processes (Clark C. 1990).

Hearn A. (2004) develops a study that considers the biological complexity of red lobster growth by incorporating population characteristics in the analysis. In this study, Hearn estimates the biomass of red lobster in the Galapagos Marine Reserve based in cohort analysis developed by Jones (1981). In this analysis, the catch information is subdivided in cohorts of lobsters of different sizes, and results in estimations of the lobster biomass arranged by sizes. The author also applies these results to the Thompson and Bell (1934) fishery model to estimate the MSY of the red lobster fishery. The figure derived is 83mt. of entire red lobster per year. This figure is consistent with the MSY calculated by Murillo et. al. (2003a), which is 26,8 mt. of lobster tails.

Nonetheless these policies have been criticized on a number of grounds, according to Conrad & Clark (1987), because MSY:

a. Is unstable; the slightest overestimate of MSY can lead to depletion or extinction of the resource stock.
b. Is not actually sustainable over the long run, because of natural fluctuations in the resource stock.
c. Ignores social and economic considerations of renewable resource management.
d.

The bioeconomic model used in this study is a stochastic, discrete–time fishery model that was first developed by Reed (1979). This model selected to analyze the Galapagos Marine Reserve fisheries attempts to deal with some of the concerns addressed by the limitations of MSY analysis. This model:

a. Maximizes the current and future net revenues; it considers a benefit function that includes the price of resources, the costs of exploitation and the time-cost of money (discount rate).
b. Incorporates a stochastic element that delivers an optimal adaptive harvest policy.

[3] The data used in this regression are annual observations. The total number of observation is 7.

c. Reflects economic conditions and incentives facing resource users.

To sum up, the model proposed for this paper builds on earlier biological models and research but goes further by incorporating economic variables such as prices, costs and interest rates. As a result, the analysis presented comes closer to reflecting the economic concerns and realities of the principal resource users in the Marine Reserve, and as such represent an advance over previous efforts to analyze and provide policy recommendations in the fisheries management in Galapagos.

IV. The Bioeconomic Model: Application and Results

In this section we present the bioeconomic model used in this study and preliminary results. First, we explain the functional forms adapted to the growth and catch functions of the fisheries. The model assumes that the sea cucumber and red lobster fishery conform to the same functional forms, based on the logic outlined above. Next, we construct a revenue function incorporating costs and market prices of the fisheries. Then, we construct a model to maximize revenues along a finite number of periods, employing stochastic dynamic programming. The solution defines an optimal escapement policy and, by consequence, optimal harvest and effort levels. This section concludes with the econometric specification to estimate the parameters for each fishery function, a brief explanation of the econometric models applied to perform the regressions, a presentation of results.

A. Theoretical Model

Considering the information needs of decision makers of the Galapagos Marine Reserve to determine the catch quotas of main commercial fisheries (sea cucumber and spiny lobster) and the random ecosystem conditions that determine the stock growth of fisheries, we decided to adopt a stochastic discrete-time fishery model as the most suitable tool to analyze the sustainable management of sea cucumber and spiny red lobster fisheries. The model was developed by Reed (1979) and is more succinctly summarized in Conrad (2002). With unchanging parameters, the optimal escapement level is stationary, but the optimal harvest is adaptive, depending on stochastic year-to-year recruitment. We adopt the same model to analyze the sea cucumber and the red lobster fisheries.

First, we define the difference between the stock size (X_t) and harvest (Y_t) as escapement (S_t):

$$S_t = X_t - Y_t$$

The dynamics of resource is given by the stochastic difference equation:

$$X_{t+1} = z_{t+1} G(S_t)$$

Where, zt+1 are i.i.d. random variables and E{zt+1}=1

Conrad (2002) suggests the following function form of production fishery:

$$Y_t = X_t(1 - e^{-qE_t})$$

where, E_t is fishing effort in period "t" and $q>0$ is a catchability coefficient. Note that if $E_t=0$, $Y_t=0$; and as $E_t \rightarrow \infty$, $Y_t \rightarrow X_t$. After some algebra, it is possible to show that:

$$E_t = (1/q)\ln[X_t/(X_t - Y_t)] = (1/q)\ln[X_t - Y_t] = (1/q)[\ln X_t - \ln S_t]$$

Considering a cost function as: $C_t = cE_t$, where $c>0$ is a cost coefficient, we can write:

$$C_t = (c/q)[\ln X_t - \ln St]$$

Net revenue in period "t" is given by:

$$\pi_t = pY_t - (c/q)[\ln X_t - \ln S_t] \text{ or } \pi_t = pX_t - (c/q)\ln X_t - [pS_t - (c/q)\ln S_t]$$

Where p is the price (as observed in local markets). We assume that fishers are price takers (that is, their catch levels do not influence prices) and that they have certainty about prices.

If we define N(m)=pm-(c/q)ln(m), we can write net revenue as a separable function of *Xt* and *St*.

$$\pi_t = N(X_t) - N(S_t)$$

The problem of maximizing expected discounted net revenue subject to stochastic recruitment may be stated as:

$$\text{Maximize} \qquad E_o\left\{\sum_{t=0}^{T}\rho^t\left[N(X_t)-N(S_t)\right]\right\}$$

Subject to $\qquad X_{t+1} = z_{t+1}G(S_t)$

X_0 given and z_{t+1} i.i.d. with $E\{z_{t+1}\}=1$

To solve this maximizing problem, we have to employ stochastic dynamic programming. After some algebra, presented in Annex 1, the solution can be stated as:

$$W(S) = \rho E_z\{N(zG(S))\} - N(S)$$

$$G'(S)\left[\frac{E_z\{N'(zG(S))\}}{N'(S)}\right] = (1+\delta)$$

where S^* satisfies the last equation. Once we get the optimal (stationary) level of escapement, the optimal (adaptive) harvest policy takes the form:

$$Y_t^* = (X_t - S^*) \qquad \text{if } X_t > S^*.$$

$$Y_t^* = 0 \qquad \text{if } X_t \leq S^*$$

In other words, if optimal escapement is less than stock in year t, then there is an optimal catch. If not, the optimal harvest in year t is zero.

To apply this model to the Galapagos fisheries, we must define the parameters and the functional forms in the above solution. We have already defined the functional form for fishery production:

$$Y_t = X_t(1 - e^{-qE_t})$$

In the case of resource dynamics, we adopt a function that explains the growth of the resource based on the escapement function. Stock will depend on the number of individuals that are not harvested and survive for reproduction. The functional form is:

$$X_{t+1} = G(S_t) = S_t e^{r(1-S_t/K)}$$

where: K is the ecosystem carrying capacity and r is a growth coefficient of the resource.

Based on the available data for the two fisheries, we estimate the parameters of both equations, as outlined below.

B. Econometric Model Specification and Results

As data availability for each fishery is distinct, we had to derive different estimating equations. Next, we present a description of the available data for each fishery, and the econometric model employed to perform the regressions.

1. Sea Cucumber[4]

Data on the sea cucumber fishery is available since 1999, and it comprises information from eight macro-zones located in the archipelago[5]. The available data includes:

a. **Catch:** This information represents the total catch of sea cucumber in one year for each macro-zone. The available data is expressed both in metric tons and in number of individuals. In both cases the data includes legal and illegal sea cucumber size (legal size is over 20 cm of length).

b. **Abundance:** This data expresses the number of individuals[6] on an area of 100 m^2.

---

4 Murillo J.C, Chasiluisa C., Bautil Bet al., 2003. "Monitoreo de la pesquería del Pepino de mar (Stichopus fuscus) en las islas Galápagos, 2003. Informe Técnico Interino, ECCD –SPNG", Santa Cruz, Galápagos: Ecuador.

5 A macro-zone represents a monitoring or extractive site or group of sites that have certain characteristics. For sea cucumber, there are eight macro-zones: Española, Fernandina, Floreana, Isabela Norte y Este, Isabela Oeste, Isabela Sur, San Cristóbal, Santa Cruz.

6 The abundance data is available since 1999 for both seasons: pre and post sea cucumber fishery. For this study we have just considered the pre-fishery data. Additionally, the abundance data was available just for seven macro-zones, the abundance data for Isabela Oeste and

c. **Catch per unit of effort**: This figure express the number of kilograms of sea cucumber caught divided by the hours of diving. The weight data comprises legal and illegal sea cucumber size[7].

The availability of stock information (abundance) makes it possible to perform separate regressions for the two functional forms to estimate:

a. The dynamics of the resource function.

b. The fishery production function.

To derive the estimating equation for the dynamics of the resource, we make the original equation linear and we get:

$$\ln\left(\frac{X_{t+1}}{S_t}\right) = r\left(1 - \frac{S_t}{K}\right)$$

The econometric model chosen to perform the regression was the Ordinary Least Squares model[8]. The parameter to estimate is *r.* The econometric specification is as follows:

$$yit = \beta' \mathbf{x}it + \varepsilon it$$

Where:

ε represents the error and εit~(0,σ)

i represents the groups in our case i= 1…8 (one for each macro-zone).

t represents observation on time "t". In our case t= 1999, …2003.

Isabela Sur are presented merged. In order to avoid losing information, we decided to split out the data in two, weighing the original figure by an index built dividing larger catch per unit of effort by the smaller catch per unit of effort observed between these two macro-zones.

7 The catch data available for macro-zones do not discriminate between legal or illegal sized individuals.

8 In the process to define which econometric model fits the best, we tried several models:

- Panel data Random effects model
- Panel data Fixed effects model
- Ordinary Least Square model with intercept
- Ordinary Least Squares First Order Autocorrelation.

To choose among these different econometric models, we decide to select the model that deliver the high quality econometric results (we used tests such as Lagrange Multiplier, Hausman and t-student).

y = dependent variable, in our case: $\ln\left(\frac{X_{t+1}}{S_t}\right)$

x = independent variables, in our case: $\left(1-\frac{S_t}{K}\right)$

The carrying capacity (*K*) and the stock of the resource (X_{t+1}) were estimated based on abundance data of sea cucumber and physiographic and bathymetric information of sea cucumber habitat[9]. In both cases, the data are expressed on number of individuals. In the case of the escapement data (*St*), it was calculated by subtracting the catch information (expressed on number of individuals) from the stock of the resource.

To derive the estimating equation for the function of production fishery, we make linear the original equation and we get:

$$E_t = \frac{1}{q}\ln\left[\frac{X_t}{S_t}\right]$$

The econometric model chosen to perform the regression was the Panel Data Random Effects Model (REM)[10]. The parameter to estimate is: *1/q*. The econometric specification of this model is (Green W.H., 1995):

---

9 According to Hickman (1998) (in Hearn *et. al.* 2003), sea cucumber inhabit in rocky areas until 40 meters of depth, but some individuals have been observed at 60 meters of depth (Martínez P, obs per ROV 1996 in *Hearn et. al. 2003*). So, based on batimetric and physiographic information provided by the Galapagos National Park [retrieved from the study of Briones *et al.* (2002) by the Zoning Unit of the National Park]; we estimated the sea cucumber total habitat area for the eight macro-zones considered in this study. The total ecosystem area estimated is estimated to be 10.327 has. This area was estimated by adding 10% to the rocky and rocky with peaks sea floor area in the range 0-20 meters approximating the area in the range 0-25 m. This methodology is the same used by Hearn *et. al.* (2003), and it is consistent with: 1) the physiographic information is available just to 20 meters of depth; 2) the sampling of sea cucumber densities to 15 or 20 meters of depth; and 3) the record of diving in Galapagos is 30 meters of depth [Ben-Yami (2001)].

To calculate the stock size of the resource for each year by macro-zone, we multiplied the ecosystem areas of each macro-zone by their abundance data. To calculate the carrying capacity of each macro-zone, we select the maximum abundance data recorded in each macro-zone during the time of study (1999-2003), and multiply this figure by the ecosystem area of each macro-zone, thus defining an upper bound to the population estimates.

10 In this case we also tried several econometric models:

- Panel data Random Effects Model with intercept
- Panel data Fixed Effects Model (FEM)
- Ordinary Least Square model with/without intercept
- Ordinary Least Squares First Order Autocorrelation.

To choose among these different econometric models, we decide to select the model that deliver the high quality econometric results (we used tests such as Lagrange Multiplier, Hausman and t-student).

$$yit = \alpha + \beta' \mathbf{x}it + \varepsilon it + ui$$

Where:

i represents the groups in our case i= 1…8 (one for each macro-zone)

"t" represents observation on time "t". In our case t= 1999, …2003

y = dependent variable, in our case: E_t

x = independent variables, in our case: $\ln\left[\frac{X_t}{S_t}\right]$

εit + ui represent a composite error term, where E[ui] = 0, Var[ui] = σ, Cov[εit,ui] = 0. But, for a given i, the disturbances in different periods are correlated because of their common component, ui. Thus: Corr[εit + ui,εis + ui] = ρ = σ / σ².

The effort data (*Et*) was obtained from the catch per unit of effort information and is expressed on hours of diving[11]. To perform the econometric regressions this data is expressed in number of hours of diving dedicated to the sea cucumber fishery in each macro-zone by year.

a) Results – Sea Cucumber

As we stated in the last section, we perform two separate regressions to estimate the parameters of the resource dynamics and production fishery functions of sea cucumber.

In Table 3, we exhibit the results of the estimation for resource dynamics using the Ordinary Least Squares model[12]. Even though we had a time series with a cross sectional data (macro-zones) the Lagrange Multiplier Test result [chi-sqd. (d.f.=1): 2,37] favors the use of an ordinary least squares model over the panel data. The information presented includes the estimated value for r, which is significant at 1% level. The table also presents R2 and Durbin Watson (DW), and the maximum likelihood test (ML)[we report the chi-square statistic]. The R2 (0,49) and ML

[11] It was calculated dividing the catch on kilograms by the catch per unit of effort.

[12] The regression uses a pool of 21 observations after discarding the missing observations and one outlier (catch of Isabela Oeste 2002).

indicate that the model is significant [critical value chi-squared (d.f=1, 1%): 6,63]. The value of the DW suggests the model has a degree of autocorrelation[13].

Table 3: Ordinary Least Squares Estimation for Resource Dynamics of Sea Cucumber [(1)]

R	1,3496891	*
R2	0,489647	
R2 (Adj)	0,48965	
Durbin Watson	0,71523	Autocorrelation
Rho	0,64238	
Observations	21	
Parameters	1	
Degrees of Freedom	20	
-2 (Ln Lr - Ln Lu)	14,1258	

(*): Significant at the 1%.

(1): Estimating equation: $\ln\left(\frac{X_{t+1}}{S_t}\right) = r\left(1 - \frac{S_t}{K}\right)$

Source: Elaborated by the authors based on the econometric regressions.

In Table 4, we display the results of the Random Effects Model for production fishery of sea cucumber. This technique was selected because we had a time series of data with cross sectional groups (macro-zones) After discarding the missing observations and one outlier[14] we had a pool of 26 observations. The estimation of "*q*" is significant at 1% level and the result obtained in the Lagrange Multiplier Test[15] favors [chi-sqd (d.f.=1): 11,25] the use of a REM or FEM over the classical ordinary least squares[16].

13 This result motivated us to try an ordinary least squares first order autocorrelation. The outcome of this regression was satisfactory in terms of the statistics (i.e. the model eliminated the autocorrelation, the parameter is significant at 1% level, the ML indicates the significance of the model), but the parameter estimated is r= 2,66. This value almost doubled the figure estimated with the least squares model, so we decided to follow a conservative approach and choose the smaller value.

14 The catch data of Isabela Oeste 2002 was discarded.

15 High values of LM favor FEM/REM over ordinary least squares model (Green W.H., 1997).

16 We report in Table 2 also the result of the Hausman Test [chi-sqd (d.f.=1): 0,72]. This result favors the use of the REM (Green W.H.,1997).

Table 4: Panel Data with Random Effects Model
Estimation Production Fishery of Sea Cucumber [1]

q	0,00024832	*
Observations	26	
Parameters	1	
Degrees of Freedom	26	
Lagrange Multiplier Test (OLS vs. FEM/REM)	11,25	LM favor FEM/REM at 1%
Hausman Test (FEM vs. REM)	0,72	Hausman favor REM

(*): Significant at the 1%.
(1): Estimating equation: $E_t = \frac{1}{q}\ln\left[\frac{X_t}{S_t}\right]$
Source: Elaborated by the authors based on the econometric regressions.

b) Optimal Escapement and Harvest policies

The solution derived from the discrete time fishery model is:

$$W(S) = \rho E_z\{N(zG(S))\} - N(S)$$

Where: N(m)=pm-(c/q)ln(m)

So, using the results from above to calculate the S* that satisfies this equation, we define the following parameters:

r = 1,349	Intrinsic growth of the fishery
K = 48.339.467,9	Maximum carrying capacity (aggregated for all macro-zones)
P = 0,99	Price
Q = 0,00024832	Catchability coefficient.
C= 29,18	Cost per unit of effort
δ= 20%	Rate of discount

The parameters r and q were estimated from our regressions. K was calculated from the sea cucumber abundance data and physiographic and bathymetric information. The price (p) corresponds to the average price (USD/unit) recorded in the 2003 season (Murillo J.C. et. al. 2003b). The cost (c) was calculated as percentage of the gross income obtained in a one hour of

diving[17]. The rate of discount (δ) considered was 20%[18]. We assume the expected value of the stochastic term of the dynamics resource function is one (E{zt+1}=1)[19].

Next in Table 5, we show the results obtained. The first column of the table indicates the macro-zones. The second column presents the carrying capacity of each macro-zone. The third column displays the maximizing value with the optimal escapement policy (S*) (fourth column); the maximizing value is in US$ and indicates the present value of the benefit that can be obtained in each macro-zone. The fifth column shows the stock population estimated based on pre-fishery abundance data of sea cucumber for 2003, this data is useful to calculate the optimal harvest policy (Yt) (sixth column). In macro-zones were Xt<St, the optimal harvest policy is 0. The last column presents the optimal catch in each macro-zone.

Table 5: Optimal escapement and catch policies estimated for Sea cucumber Fishery 2003

Macro-zones	*(# of ind)*	*Objective Function USD*	*St* (# of ind.)*	*X2003 (# of ind.) (Pre-fishery 2003)*	*Yt=Xt-St (# of ind.)*	*Y_{2003} (# of ind.)*
Española	349.678,7	287.575,2	177.867,2	144.957,0	0,0	NA
Fernandina	6.916.014,1	2.620.181,1	2.564.821,2	1.792.496,1	0,0	736.000,0
Floreana	369.410,3	294.826,1	184.772,8	145.173,1	0,0	NA
Isabela Norte y Este	15.503.457,6	5.625.481,1	5.691.039,6	5.068.717,0	0,0	267.879,0
Isabela Oeste	10.498.177,3	3.875.320,6	3.868.878,5	4.606.749,2	737.870,8	3.054.595,0
Isabela Sur	10.335.915,3	3.818.528,3	3.809.807,7	3.895.014,7	85.207,0	484.814,0
San Cristóbal	590.633,5	376.505,3	263.715,8	464.577,8	200.862,0	121.845,0
Santa Cruz	3.776.181,1	1.515.676,9	1.421.853,9	1.747.723,4	325.869,5	340.435,0
Total	**48.339.467,9**	**18.414.094,4**	**17.982.756,7**	**17.865.408,3**	**1.349.809,2**	**5.005.568,0**

Source: Elaborated by the authors based on Solver calculations.

In other words, the present value of the sea cucumber fishery is maximized by harvesting 1.35 m individuals in 2003, resulting in a total fisheries value of US$ 18.4 m in NPV terms. Nonetheless, actual observed harvest was almost four times that amount in 2003.

17 We considered that the cost represents the 35,9% of the gross income obtained in a one hour of diving (Murillo J.C., 2002). This figure corresponds to the sea cucumber season in 2000, but we assumed that this relation between costs and gross income does not change. So, we proceed to calculate the income per hour of diving (based on the average catch per unit of effort and the average prices observed in 2003) and this figure was multiplied by 0,359.

18 This figure is the official ceiling for loan-interest rates in Ecuador (March, 2004). Lending above this rate is considered a criminal offense, although informally rates of up to 20% per month have been observed. Using this rate is consistent with the fact that Galapagos fishermen do not have access to the formal financial market.

19 The z_{t+1} are i.i.d. as given by:

$Pr(z_{t+1}=z_1=0,5) =$ 0,25

$Pr(z_{t+1}=z_2=1,0) =$ 0,5

$Pr(z_{t+1}=z_3=1,5) =$ 0,25

As with the biological studies, these results indicate that present catch levels are on a depletion path. Interestingly, however, although the observed catch is significantly highly than the optimal catch, using a discount rate of 20% the corresponding net present value of the observed catch of 2003 is US$ 16.2 m, only 12% less than the NPV of what is economically optimal.

c) Sensitivity Analysis

Due to the particular economic conditions in Galapagos, especially its limited financial markets, we decided to test the results delivered by the model for changes in the discount rate. Considering the random conditions of the sea cucumber population, we also tried different variations for the probability function of the stochastic term of the resource dynamics function[20], but the model does not show sensitivity to the changes of variance of the stochastic term. So, we tested two values of discount rate: 30% and 10%.

In Table 6, we present the main results obtained. In the second column we present the optimal catch aggregated for the zones where sea cucumber fishery could be open. The third column shows the macro-zones that must be closed to sea cucumber fishery.

Table 6: Response of the Optimal Catch Policy to changes on the expected value and discount rate

Variables	*Yt=Xt-St (# of ind.)*	*Number of Macro-zones Closed*
δ=10%	962.417,2	5 (Española, Fernandina, Floreana, Isabela Norte y Este, and Isabela Sur).
δ=30%	1.841.700,5	4 (Española, Fernandina, Floreana, and Isabela Norte y Este).

Source: Elaborated by the authors based on information presented in Annex 2.

It is interesting to note from this sensitivity analysis that using a lower rate of discount such as 10%, which might include social considerations, lowers optimal catch to less than 20% of observed catch. Using a discount rate of 30% increases optimal catch to 1.8 million individuals, but this figure is still less than 50% of the observed catch. Indeed, the rate of discount implied by the observed behavior is approximately 70%, indicating that the resource base is highly insecure and that fishermen are heavily discounting future benefits from managing the fishery. In other words, with regard to the pepino fishery, they are literally behaving as if there is no tomorrow.

2. Lobster

Data on spiny lobster (red and green lobster) has been recorded since 1975, with a gap in the information during the period 1980-1995. Information of catch per effort unit by macro-zone is available since just 1997 with a lot of missing observations for the macro-zones identified in this

[20] We tried with different variances, but the expected value remained equal to 1.

period 1997-2003[21]. In the case of catch, since in some years the observations were incomplete, we had to work with only 16 macro-zones[22].

The information gathered includes:

a. Catch[23]: The annual catch per macro-zone of red and green lobster tails expressed in kilograms. The recorded data includes legal and illegal red lobster tail size (legal size is over 15 cm of length).

b. Catch per Unit of effort[24]: Catch of red and green spiny lobsters measured in kilograms taken in a one-day trip.

c. Abundance: Total population of spiny red lobsters are estimated for 2003 by Hearn *et. al.* (2004). These estimations are done just for spiny red lobster and present the abundance of individual by size ranges[25].

The lack of time-series abundance data for spiny lobster necessitated using other econometric techniques to estimate the parameters of the:

a. Function for resource dynamics

b. Production function for the fishery.

Thus, following a methodology suggested by Coppola G. & S. Pascoe (2003), we start from our original functional forms: $Y_t = X_t(1-e^{-qE_t})$ and $X_{t+1} = S_t e^{r(1-S_t/K)}$, assuming $E(z_{t+1})=1$. We introduce the production equation on the stock function and we get the next estimating function[26]:

$$\frac{Y_{t+1}}{Y_t} = \left[\frac{1-e^{-qE_{t+1}}}{1-e^{qE_t}}\right] e^{r\left[1-\frac{Y_t}{K}*\left(\frac{e^{-qE_t}}{1-e^{-qE_t}}\right)\right]-qE_t}$$

---

21 From the data presented for spiny lobster in ECCD publications, it is possible to identify 21 macro-zones. Nonetheless, there are cases where a macro-zone appears in one year and disappear in the subsequent year. Data can be seen in Annex 2.

22 The macro-zones identified are: Española, Floreana, Genovesa, Isabela Norte y Este, Isabela Oeste, Isabela Sur, Marchena, Pinta, Pinzón, Rábida, San Cristóbal Norte y Oeste, San Cristóbal Sur y Este, Santa Cruz, Santa Fe, Santiago y Wolf.

23 Information was retrieved from Bautil B. *et. al.* (2003).

24 Information was retrieved from Toral MV., *et. al*. (2002).

25 It is possible to find records of the spiny red and green lobster abundance expressed as the number of individuals catch or seen in one hour of diving. These data are available just for the 2000 to 2002 period and presents a lot of missing observations. According to ECCD officials this information can be use as an indirect indicative of the abundance, and they cannot be used to estimate the size of the stock of spiny lobster. So, we decided to use instead the stock estimations based in a cohort analysis done by Hearn *et. al.* (2004), for spiny red lobster.

26 Note that: $X_t = Y_t/(1-e^{-qE_t})$ *and,* $X_{t+1} = Y_{t+1}/(1-e^{-qE_{t+1}})$, since: $S_t = X_t - Y_t$.

Because of the non-linear nature of the estimating equation, we employ a non-linear least squares estimation model. In this equation the parameters to estimate are: *q* (catchability coefficient), *r* (growth coefficient of the resource) and *K* (ecosystem carrying capacity). To have enough flexibility, we assume that *K* is the same for the 16 macro-zones considered in this study, an assumption that probably introduces some noise into the model.

The econometric regression performed for this fishery only includes the spiny red lobster data, since the population data was available only for this type of lobster[27]. The effort data (E_t) was calculated dividing total catch of spiny red lobster by catch per unit of effort, and the results are expressed in the number of one-day fishing trips.

The parameters estimated for spiny red lobster fisheries were applied in our theoretical solution of the model to get the optimal escapement policy (S^*).

a) Results – Lobster

To estimate the parameters of the resource dynamic and production fishery function we employed the non-linear least square model. The significance levels of the parameter *r, K, q* are satisfactory (all are significant at 1% level), the R2 is 0,98 and the F-test result suggests that all the model is significant. We tried other econometric specification but this model delivered the best results and was applicable to the solution derived from our theoretical model [28].

Table 7: Non-Linear Least Squares Estimation for Red Spiny Lobster fishery (1)

r	0,80216402	*
K	15289,504	*
Q	0,00063884	*
Observations	25	
Parameters	3	
F (3,22)	334,31	
R2	0,9785	
R2-adj.	0,9756	

(*): Significant at 1%.

(1): Estimating equation: $\frac{Y_{t+1}}{Y_t} = \left[\frac{1 - e^{-qE_{t+1}}}{1 - e^{qE_t}}\right] e^{r\left[1 - \frac{Y_t}{K} * \left(\frac{e^{-qE_t}}{1 - e^{-qE_t}}\right)\right] - qE_t}$

Source: Elaborated by the authors based on the econometric regressions.

---

27 This fact does not affect significantly to results, because green lobster represents a small percentage of the total spiny lobster catch (i.e.: in 2003 green spiny lobster represented approximately 20% of the total catch).

28 We tried the following estimating equation based a logistic functional form for the stock growth: $\frac{Y_{t+1}}{Y_t} = \left[\frac{(1-\beta^{E_{t+1}})}{(1-\beta^{E_t})}\right]\left[r - \frac{rY_t}{[K(1-\beta^{E_t})]} + \beta^{E_t}\right]$ and also tried a Gompertz function for the stock growth. The results obtained were also satisfactory in econometric terms, but the original specification had more robust results.

b) Optimal escapement and Harvest policies

We proceed as in the case of sea cucumber; the estimated parameters were applied to the solution derived from the discrete time fishery model. To find *S** we used Excel Solver. Next, the values of the parameters used are:

r = 0,80216402	Intrinsic growth of the fishery
K = 244.632,06	Maximum carrying capacity (aggregate for all macro-zones on kilograms)
p = 23,40	Price
q = 0,00063884	Catchability coefficient.
c= 26,74	Cost per unit of effort
δ= 20%	Rate of discount

The parameters *r*, *q* and *K* were estimated from our regressions. To have an aggregate of *K* for the entire archipielago, the estimated value was multiplied by 16 (# of macro-zones considered). The price (*p*) corresponds to the average price (USD/unit) recorded in the 2003 season (Murillo J.C. *et. al.* 2003a). The cost (*c*) was calculated as percentage of the gross income obtained in a one-day fishing trip[29]. As in the case of pepino, the rate of discount (δ) considered was 20%. We assume the expected value of the stochastic term of the dynamics resource function is one ($E\{z_{t+1}\}=1$)[30]. The optimal escapement and harvest policies were calculated for the whole archipelago. As in the case of sea cucumbers, we assume the same *K* (carrying capacity) for each macro-zone, enabling us to aggregate the resource stock data available.

29 We considered that the cost represents the 14,9% of the gross income obtained in a one-day fishing trip (Murillo, 2002). This figure corresponds to the lobster season in 2000, but we assumed that this relation between costs and gross income does not change. So, we proceeded to calculate the income per one-day fishing trip (based in the average catch per unit of effort and the average prices observed in 2003) and this figure was multiplied by 0,149.

30 The z_{t+1} are i.i.d. as given by:

$Pr(z_{t+1}=z_1=0,5)$ = 0,25

$Pr(z_{t+1}=z_2=1,0)$ = 0,5

$Pr(z_{t+1}=z_3=1,5)$ = 0,25

Table 8: Optimal escapement and catch policies estimated for Spiny red lobster Fishery 2003

Carrying Capacity (Kg. of lobster Tails)	244.632,06
Objective Function (USD)	872.792,90
St (Kg. of lobster Tails)*	87.890,93
X2003 (Kg. of lobster Tails) (1)	117.227,72
Yt=Xt-St (Kg. of lobster Tails)	29.336,80
Y_{2003}	40.716,00

(1) The stock of the resource was estimated with information presented in Hearn A. et. al. (2004). Hearn estimates a total population of spiny red lobster of 900.000 (individual > 16 cm), this figure was multiplied by 0,130 Kg. (the approximated average weight of a tail for a >16 cm. Individual). We use the estimations for >16 cm. individuals, because catch information includes legal and illegal size lobsters.

Source: Elaborated by the authors based on Solver calculations.

These results indicate that actual harvests exceed what is economically optimal, in this case by 37%. While indicative of overfishing or sub-optimal management of the resource, the difference between actual catch and optimal catch is not as extreme as in the case of the pepino fishery.

c) Sensitivity Analysis

We tested the results delivered by the model to changes of the discount rate. As we did for sea cucumber, we tested two values of discount rate: 30% and 10%. In regard to the expected value of the stochastic term, we tried a sensitivity analysis varying the probability function of the stochastic term, but as in the case of sea cucumber the results of model remain constant in the face of variance changes[31].

Table 9 presents the results. Each column contains the results obtained with different expected values and discount rates.

Table 9: Response of the Optimal Catch Policy to changes on the expected value and discount rate

	δ=10%	*δ=30%*
Objective Function (USD)	1.106.835,01	693.082,75
St (Kg. of lobster Tails)*	98.599,37	77.804,66
X2003 (Kg. of lobster Tails) (1)	117.227,72	117.227,72
Yt=Xt-St (Kg. of lobster Tails)	18.628,35	39.423,07
Y_{2003}	40.716	40.716

Source: Elaborated by the authors based on Solver calculations.

[31] The expected value of the stochastic term was kept constant, equal to one.

It is interesting to observe that optimal catch calculated for 30% interest rate level is close to the 2003 season actual catch, providing a notion of the implied or derived interest rates that fishermen are facing.

V. CONCLUSIONS

In this section we discuss the results obtained in regard to the parameter estimations and the optimal escapement and harvest policies. We also present some conclusions and implications for policy options to improve the management of the sea cucumber and spiny red lobster fisheries in Galapagos.

In general, we have to acknowledge the data limitations in developing our model and in the results that it generates; in both the sea cucumber and spiny lobster fisheries we are hampered by limited time-series data. This results in parameter estimates that will likely change as more data becomes available.

The other main weakness in our results could lay in the functional forms adopted for the dynamics of resource and the production of the fishery. The choice of functional form could be debated, but based on the literature available and the underlying biological processes we feel it represents that best available specification at present. It may however not include all elements including some aspects of risk aversion on behalf of fishermen, and in this regard optimal results may be different from observed due to limitations in model specification.[32] Nonetheless, the exercise indicates the potential gains that are possible by including economic variables in determining optimal catch levels.

A. Sea Cucumber

The results suggest that optimal outcomes would be generated by closing the sea cucumber fishery in four macro-zones and decreasing of the whole harvest quota by more than 70% in relation to the catch quota of 2003.

Both estimations for resource dynamics and production fishery were significant as models and their individual parameters also presented good levels of significance. The ordinary least squares estimation for the resource dynamics function indicated the presence of autocorrelation, and when we tried to correct this autocorrelation we got a parameter estimated of r that doubled the first estimation[33]. We decided on a conservative approach and choose the first estimate.

The sensitivity analysis suggests, that under any scenario, the closing of the macro-zones Española, Fernandina, Floreana and Isabela Norte y Este is compulsory.

[32] As one reviewer pointed out, given that the model does not capture all stochastic elements (including risks posed by the management scheme itself) we might expect that observed catch that will be higher than the estimated by the model and derived optimal escapement decision rule.

[33] To correct autocorrelation we employed the default estimator of LIMDEP (AR1) which is the iterative Prais and insten algorithm (a two-step estimator). With this correction we got a "r" of 2,66. Employing that figure, we got an optimal catch 3.3 M of individuals (sea cucumbers). It is almost three times the optimal catch we estimated using r =1,349.

Another valid strategy to deal with autocorrelation could have been employing the same specification used for lobster – non-linear model that merges both equations. We tried the econometric estimations with this specification, but we got unreasonable results (i.e. K estimated for sea cucumber was 3.360 individuals, which is extremely low).

Considering the informal financial market of the islands and the high indebtedness of fishermen to local middlemen, we decided to test different discount rates. The results of the sensitivity analysis indicate how optimal escapement depends on the discount rate, with an increase of the discount rate producing a rise in the optimal catch quota. This fact is relevant in the Galapagos Islands considering that the local population, especially fishermen, do not have access to formal financial markets, and are dependent on moneylenders, contributing to their high rates of time discount.

B. Lobster

Although the results for the lobster fishery are not as striking as for pepinos, the results suggest that optimal outcomes would be generated by decreasing actual harvests by more than 28% in relation to the catch quota permitted in 2003. The econometric results obtained from the non-linear regression are satisfactory, the model explains in 98% (R2=0,98) of the variations in the resource dynamic relationship, and that the parameters are significant at 1% level.

The results indicate that the optimal catch in 2003 was 29,34 mt. of red lobster tails, consistent with the historical catch in the archipelago and but interestingly higher than those calculated by using MSY methods. For example Murillo J.C. *et. al.* (2003a) estimates the maximum sustainable yield of red lobster tails through the Schaefer model and got a figure of 26,8 mt.. Hearn, (2004), based in his cohort analysis estimates a maximum sustainable yield of around 28 mt. The differences among our results and those from the biologists can be explained because of the economic variables the model, as opposed to the biologists' models that consider physical variables.

The lack of resource stock information by macro-zone, as well as the assumption of a homogenous carrying capacity for all the macro-zones made it difficult to develop a spatially disaggregated analysis as we do for sea cucumber. Nonetheless, if in the near future it is possible to have the stock data available by macro-zones, the parameters estimated can be used to develop a fallow policy for red lobster, by fishing zones.

The sensitivity analysis of the escapement and harvest in response to changes in the discount rate are important. Optimal harvest decreases by 10 mt. if the discount rate falls to 10%, and the harvest grows by almost 11 mt., if discount rates increase to 30%. Again, the results highlight the fact the importance of interest rates in determining natural resource use decisions.

VI. Summary

This paper has endeavored to show, on an empirical level, that substantial gains can be made through implementing a more rational approach to fisheries management in Galapagos that includes economic parameters. In this regard, the adaptive and stochastic nature of the theoretical model employed can be a useful tool for resource management, particularly for decision-makers facing difficult trade-offs between short-term economic and social considerations and the long-term sustainability of the resource base. This adaptive methodology is especially relevant

considering the fluctuating conditions of sea cucumber and red lobster population, which can be affected by random events such as the *El Niño* phenomenon.

For example, based on the stock information for each macro-zone, the IMA can develop a no- or limited-take policy allowing ecosystem restoration of closed macro-zones responding to fishing sector demands. This opening and closing strategy gives the flexibility to respond to different demands of local marine reserve users (i.e. conservation and fishery sector) and preserve the reproductive capacity of the resource base.

In terms of constraints to more sustainable fishing levels, the study found that limited access to loans in the formal sector pushes local fishermen to increase the exploitation of the Marine Reserve. In the context of our analysis where the individual tries to maximize the present value of revenues from natural resource exploitation, it can be considered "rational economic behavior" to the detriment of conservation to extract the highest level possible of resources from the fisheries in the short run. Policy-makers must consider this perverse incentive created by the informal financial market of the islands and consider facilitating access to lower interest-rate loans as part of an overall strategy to regulate and reduce fishing effort in the Galapagos.

In addition, aside from expressing the time-cost of money, the rate of discount used by fishermen also indicates how secure the ownership of the resource and its future revenues are. High discount rates reflect a low level of security over the ownership of the resource. Security is reduced when there are high levels of illegal fishery; when management regimes obligate fishermen to be part of a race to catch the most of the resource (i.e. : a global quota); and, when an increasing number of fishermen are entering the fishery. These aspects are relevant to Galapagos considering the high levels of illegal fishery, the ruling of a global quota, and the existence of loopholes in the regulations to stop growth of the fishery sector.

These considerations suggest that the authorities should be cautious in implementing and handling of any fishery management schemes. The IMA must consider the effects of any management measure on the certainty of future access to the resource (and by default the impacts on the fishermen's discount rate). For example, a proposed moratorium (in a framework where illegal fishery reigns) may also contribute to an increase in the implicit discount rate and consequent over-exploitation of the fishery.

Finally, an efficient long-term management of the fisheries in Galapagos requires fishermen to have secure property rights over the resources. In that sense, the development of a system of transferable individual quotas could contribute to achieve an efficient fishery management. If such a system is established, the fishing effort of each individual could be spread out more evenly in time, reducing the volatility of fisher income and alleviating the insecurity inherent in the race to attain the global quota.

On a deeper level, however, it is clear that the governance mechanisms established in Galapagos to regulate fishery use are imperfect and require some amount of rethinking. For example, even though the results of biological models have indicated that a reduction in harvest levels is called for, the decision-making bodies in place have opted for significantly higher quotas, primarily in response to the social pressures being exerted by fishermen in Galapagos. While it is possible that introducing economic parameters into the analysis will go further to allay the fears of the

fishing sector that their interests are being taking into account, it remains an open question whether the reduced harvest levels that would lead to optimality conditions would be socially acceptable to them. In this regard, further research should focus on the trade-offs and willingness-to-accept conditions that might enable a reduction in fishing effort to sustainable levels.

As such, over the long run, possible solutions to the challenges presented by over-fishing in Galapagos will require a concerted effort focusing not only on the technical parameters of improved management, but also a focus on the governance aspects regulating access to and use of the fisheries. In addition, consideration will need to be given to the compatibility of small-scale fishing with other non-extractive uses of the marine reserves such as eco-tourism. Given the high opportunity costs of over-fishing in the reserve, it may well represent a pareto-optimal shift to encourage some movement to other, non-extractive uses of the reserve more compatible with the unique environmental endowments of the Galapagos and their future income earning potential.

BIBLIOGRAPHY

Ben-Yami M. 2001. *Managing Artisanal Fisheries of Galápagos*. Galápagos, Ecuador: Consultancy Report for WWF,

Briones, E.E., J. Sonnenholzner, *et al.,* 2002. *Mapificación preliminar de los humedales marino costeros de las islas Galápagos*. Galápagos, Ecuador: Sistema de Información Geográfico de EcoCiencia. EcoCiencia/Parque Nacional Galápagos/Ministerio del Ambiente/GEF Banco Mundial/RAMSAR

Bustamante R.H. *et. al*., 2000. "The Galapagos spiny lobster fishery", In Philips, B.F. and J. Kittaka, editors. *Spiny Lobsters: Fisheries and Culture*, Chapter 12. United Sates of America: Fishing News Books.

Clark C. 1990. *Mathematical Bioeconomics: The optimal Management of Renewable Resources Second Edition*, United States of America: A Wiley Interscience Publication.

Conrad, J. M. 2002. "Renewable resource management." To appear in the Encyclopedia of Life Support Systems, Paris: United Nations- UNESCO.

Conrad J. & C. Clark 1987. *Natural Resources Economics: Notes and Problems*. United States of America: Cambridge University Press.

Coppola G. & S. Pascoe, 1998. "A Surplus Production Model with a Nonlinear Catch-Effort Relationship", in *Marine Resource Economics.*

Fundación Natura & el Fondo Mundial para la Naturaleza WWF, 2002. *Informe Galápagos 2001 –2002.* Quito, Ecuador.

Greene W. H. 1997. *Econometric Analysis Third Edition*. United States of America: Prentice Hall PTR.

Greene W.H. 1995. *LIMDEP Version 7.0: User's Manual*. New York, United States of America: Econometric Software Inc.

Hanley N., J.F. Shogren, & B. White 1997. *Environmental Economics in Theory and Practice*. United States of America: Oxford University Press.

Hearn A., P. Martínez, J.C. Murillo, M.V. Toral & J. Polovina 2003. "Effects of fisheries and El Niño (1997-8) on the population and recruitment of the sea cucumber *Isotichopus fuscus* in the western Galapagos Islands, Ecuador. Galapagos, Ecuador. Unpublished paper

Hearn A. 2004. *Evaluación de las Poblaciones de Langosta en la Reserva Marina Galápagos Informe Final 2002-2004*. Galápagos, Ecuador: ECCD-SPNG.

Heylings, P. & M. Bravo 2002. "El Sistema de Manejo Participativo de la Reserva Marina de Galápagos- Principales Actividades en el año 2001", in *Informe Galápagos 2001-2002*. Quito, Ecuador: Fundación Natura/ WWF.

Heylings, P., F. Cruz, R. Bustamante, Cruz D., M. Escarabay , A. Granja, W. Martínez , J. Hernández, C. Jaramillo, P. Martínez , M. Piu, P. Proaño ,F. Valverde , C. Zapata, 1998. "El Grupo Núcleo de la Reserva Marina de Galápagos", in *Informe Galápagos 1997-8*. Quito, Ecuador: Fundación Natura/ WWF.

Hickman, C.P. 1998. *Guia de campo sobre estrellas de mar y otros equinodermos de Galápagos*. Virginia, United States of America: Sugar Spring Press.

Murillo J.C. 2002. "Indicadores Socio-económicos de la pesca", in: Danulat E & GJ Edgar ediotors. *Reserva Marina de Galápagos, Línea Base de la Biodiversidad*. Galápagos, Ecuador: ECCD-SPNG.

Murillo J. C., P. Martínez, V. Toral & A. Hearn 2002 "Pepino de Mar", in Danulat E & GJ Edgar editors. *Reserva Marina de Galápagos, Línea Base de la Biodiversidad*. Galápagos, Ecuador: ECCD-SPNG.

Murillo J.C., F. Nicolaides F., H. Reyes, J. Moreno, L. Molina, C. Chasiluisa, M. Villalta & L. García 2003. *Investigación y Monitoreo de la Pesquería de Langosta en Galápagos, 2003 Informe Técnico Sep. – Dic. 2003*. Galápagos, Ecuador: ECCD – SPNG.

Murillo J. C., R. Andrade, J. Vizcaíno, B. Bautil, A. Hearn, C. Chasiluisa, F. Nicolaides, L. Molina, J. Moreno & E. Espinoza 2003, "Pesquería de pepino de mar en Galápagos durante el 2002: Análisis comparativo con las pesquerías 1999, 2000 y 2001", in: *Evaluación de las pesquerías en la Reserva Marina de Galápagos, Informe Compendio 2002*. Galápagos – Ecuador: ECCD – SPNG.

Murillo J.C, C. Chasiluisa, B. Bautil, J. Vizcaíno, F. Nicolaides, J. Moreno & L. Molina 2003. *Monitoreo de la pesquería del Pepino de mar (Stichopus fuscus) en las islas Galápagos, 2003*, *Informe Técnico Interino*. Galápagos, Ecuador: ECCD –SPNG.

Nicolaides F., J.C. Murillo, M.V. Toral & G. Reck 2002. "Bacalao", In Danulat E & GJ Edgar editors. *Reserva Marina de Galápagos, Línea Base de la Biodiversidad*. Galápagos, Ecuador: ECCD-SPNG.

Pearce W.P. & R.K. Turner 1990. *Economics of Natural Resources and the Environment.* Madrid, España: Celeste Ediciones.

Reed, W. J. 1979 "Optimal Escapement Levels in Stochastic and Deterministic Harvesting Models". Journal of Environmental Economics and Management, 6:350-363.

Toral M.V. 2000. "¿Cómo se estableció la cuota de pepinos para la temporada 2000?". Galápagos, Ecuador. ECCD. Unpublished paper.

Toral M.V., E. Espinoza, A. Hearn & C. Martínez 2002. "Langostas Espinozas", In Danulat E & GJ Edgar, editors. *Reserva Marina de Galápagos, Línea de Base de la Biodiversidad*". Galápagos: Ecuador.

Wilen J. E., M. Stewart, & D. F. Layton 2000. *Economic Analysis of the Galápagos Marine Reserve Resources Management Plan, Final Report to IDB*. Quito, Ecuador.

ANNEX I

The problem of maximizing expected discounted net revenue subject to stochastic recruitment may be stated as:

Maximize $E_o\left\{\sum_{t=0}^{T}\rho^t\left[N(X_t)-N(S_t)\right]\right\}$ **I. [1]**

Subject to $X_{t+1}=z_{t+1}G(S_t)$

X_0 given and z_{t+1} i.i.d. with $E\{z_{t+1}\}=1$

To solve this maximizing problem we have to employ stochastic dynamic programming.

Momentarily we will let T $\rightarrow \infty$, but for now we assume T is finite. Then we start in period t=T, where the value function can be written:

$$V_T = Max\left[N(X_T)-N(S_T)\right]$$ **II. [2]**

Recall that the value functions presumes optimal behavior and in [2] we are assuming that the bracketed expression is being maximized by the choice of S_t. It is assumed that X_t is known and thus $N(X_T)$ is a constant. The first order condition simply requires that $-\partial N(S_T)/\partial S_T = 0$. Given our definition of $N(\bullet)$ the first order conditions implies that $-p + c/(qS_T)=0$ or $S_T = c/(pq)$. S_T is sometimes called the open access escapement level because it corresponds to zero net revenue or rent dissipation in the terminal period. The value function becomes $V_T = N(X_T) - N(c/(cq))$.

Then in period t=T-1, the value function is:

$$\begin{aligned} V_{T-1} &= Max\left[N(X_{T-1}) - N(S_{T-1}) + \rho E_{T-1}\{V_T\}\right] \\ &= Max\left[\rho E_{T-1}\{N(z_T G(S_{T-1}))\} - N(S_{T-1}) + N(X_{T-1}) - \rho N(c/(pq))\right] \end{aligned}$$ **III. [3]**

In going from the first line to the second line in equation [3] we substitute $V_T = N(z_T G(S_{T-1})) - N(c/(cq))$. The last two terms on the second line of [3] are constants and

the value of S_{T-1} , which maximizes the bracketed expression, also maximizes $W(S_{T-1}) = \rho E_{T-1}\{N(z_T G(S_{T-1}))\} - N(S_{T-1})$.

If $W(S_{T-1})$ is quasi-concave, the first-order condition is both necessary and sufficient:

$$W'(S_{T-1}) = \rho E_{T-1}\{N'(z_T G(S_{T-1}))z_T G'(S_{T-1})\} - N'(S_{T-1}) = 0 \qquad \textbf{IV. [4]}$$

With $G'(S_{T-1})$ independent of z_T equation [4] implies.

$$G'(S_{T-1})\left[\frac{E_{T-1}\{z_T N'(z_T G(S_{T-1}))\}}{N'(S_{T-1})}\right] = (1+\delta) \qquad \textbf{V. [5]}$$

Assuming that the expectation operation is well defined, equation [5] is one equation with one unknown and may be solved for S^*_{T-1}. We may then write V_{T-1} as:

$$V_{T-1} = N(X_{T-1}) - N(S^*_{T-1}) + \rho E_{T-1}\{N(z_T G(S^*_{T-1}))\} - \rho N(c/(pq)) \qquad \textbf{VI. [6]}$$

In t=T-2 the value function is initially written as:

$$\begin{aligned} V_{T-2} &= Max\left[N(X_{T-2}) - N(S_{T-2}) + \rho E_{T-2}\{V_{T-1}\}\right] \\ &= Max\left[\begin{aligned}&\rho E_{T-2}\{N(z_{T-1}G(S_{T-2}))\} - N(S_{T-2}) + N(X_{T-2}) - \rho E_{T-2}\{N(S^*_{T-1}\} \\ &+ \rho^2 E_{T-2}\{N(z_T G(S^*_{T-1}))\} - \rho^2 N(c/(pq))\end{aligned}\right] \end{aligned} \qquad \textbf{VII.}$$

In period t=T-2, X_{T-2}, S^*_{T-1}, and $S^*_T = c/(pq)$ are given, and with the z_{T+1} being i.i.d, the last four terms in [7] are constants. The optimal level of escapement, S^*_{T-2}, that maximizes [7] also maximizes:

$$W'(S_{T-2}) = \rho E_{T-2}\{N(z_{T-1}G(S_{T-2}))\} - N(S_{T-2}) \qquad \textbf{VIII.}$$

While the period index is one period earlier in equation [8], equations [8] and [4] have the same form and if we continued to work our way back in time, the same form would emerge for $W(S_{T-3})$, $W(S_{T-4})$, and so on, back to $W(S_0)$.

Now let T $\rightarrow \infty$. In any period the optimal escapement policy, S*, must maximize

$$W(S) = \rho E_z \{N(zG(S))\} - N(S) \qquad \textbf{IX. [9]}$$

Taking the derivative, and noting again that $G'(S)$ is independent of *z, S** must also satisfy:

$$G'(S)\left[\frac{E_z\{N'(zG(S))\}}{N'(S)}\right] = (1+\delta) \qquad \textbf{X. [10]}$$

ANNEX II

I. Table 1: Sea Cucumber Data

Year	Macro-zones	Catch (units)	Abundance (# of ind. / 100 m2)	Effort (Hours of diving)	Sea cucumber habitat area (1) Hectares
1999	Española	489.669,0	13,7	3.717,4	255,2
1999	Fernandina	169.877,0	15,0	947,4	428,8
1999	Floreana	78.980,0	8,0	1.000,0	398,6
1999	Isabela Norte y Este	282.883,0	6,7	NA	2.175,4
1999	Isabela Oeste	1.641.360,0	7,7	18.151,5	1.582,0
1999	Isabela Sur	98.724,0	7,5	1.062,5	2.045,8
1999	San Cristóbal	1.163.104,0	4,2	15.192,3	1.229,8
1999	Santa Cruz	477.060,0	2,1	5.655,2	2.212,3
2000	Española	256.980,0	10,8	4.190,5	255,2
2000	Fernandina	NA	100,2	NA	428,8
2000	Floreana	239.843,0	5,7	4.100,0	398,6
2000	Isabela Norte y Este	378.418,0	19,1	3.500,0	2.175,4
2000	Isabela Oeste	2.615.495,0	32,2	25.468,8	1.582,0
2000	Isabela Sur	117.206,0	21,1	1.619,0	2.045,8
2000	San Cristóbal	621.405,0	4,8	10.105,3	1.229,8
2000	Santa Cruz	717.600,0	10,2	9.541,7	2.212,3
2001	Española	NA	7,4	NA	255,2
2001	Fernandina	624.105,0	161,3	4.909,1	428,8
2001	Floreana	47.324,0	6,9	531,3	398,6
2001	Isabela Norte y Este	52.689,0	71,3	1.000,0	2.175,4
2001	Isabela Oeste	1.735.181,0	66,4	15.657,9	1.582,0
2001	Isabela Sur	73.419,0	38,4	1.136,4	2.045,8
2001	San Cristóbal	52.697,0	3,9	1.133,3	1.229,8
2001	Santa Cruz	86.931,0	17,1	1.571,4	2.212,3
2002	Española	79.775,0	12,9	896,6	255,2
2002	Fernandina	758.775,0	100,4	3.717,9	428,8
2002	Floreana	235.652,0	9,3	4.687,5	398,6
2002	Isabela Norte y Este	1.551.529,0	34,9	10.206,9	2.175,4
2002	Isabela Oeste	NA	57,5	NA	1.582,0
2002	Isabela Sur	279.913,0	50,5	2.527,8	2.045,8
2002	San Cristóbal	NA	3,5	NA	1.229,8
2002	Santa Cruz	NA	6,6	NA	2.212,3
2003	Española	NA	5,7	NA	255,2
2003	Fernandina	736.000,0	41,8	6.384,6	428,8

I. Table 1: Sea Cucumber Data

Year	Macro-zones	Catch (units)	Abundance (# of ind. / 100 m2)	Effort (Hours of diving)	Sea cucumber habitat area (1) Hectares
2003	Floreana	NA	3,6	NA	398,6
2003	Isabela Norte y Este	267.879,0	23,3	4.000,0	2.175,4
2003	Isabela Oeste	3.054.595,0	29,1	26.384,6	1.582,0
2003	Isabela Sur	484.814,0	19,0	7.705,9	2.045,8
2003	San Cristóbal	121.845,0	3,8	2.533,3	1.229,8
2003	Santa Cruz	340.435,0	7,9	4.074,1	2.212,3
	μ	604.004,9	26,3	6.353,4	1.291,0
	σ	739.013,4	33,5	6.878,0	792,7

(1): The habitat area comprises rocky and peak-rocky areas in the range of 2-20 m of depth plus 10%.
Source: Murillo JC et. al. (2003b) and Murillo JC et. al. (2003c).

II. Table 2: Red Lobster Data

Year	Macro zones	Ct (Tail Kg) [D] Red	Et (Number of one-day fishing trips)
2001	Darwin	3083,0	NA
2001	Española	2345,0	162,6
2001	Fernandina	171,0	NA
2001	Floreana	3454,0	372,9
2001	Genovesa	1959,0	200,1
2001	Isabela Norte y Este	1609,0	210,1
2001	Isabela Oeste	3633,0	596,5
2001	Isabela Sur	6463,0	1311,0
2001	Marchena	2443,0	190,3
2001	Pinta	112,0	11,0
2001	Pinzón	113,0	NA
2001	Rábida	113,0	NA
2001	San Cristóbal Norte y Oeste	1766,0	177,3
2001	San Cristóbal Sur y Este	12947,0	1143,1
2001	Santa Cruz	8914,0	1160,5
2001	Santa Fe	970,0	91,0
2001	Santiago	2487,0	421,0
2001	Wolf	2248,0	133,8
2002	Darwin, Wolf	1972,0	NA
2002	Española	1394,0	87,2
2002	Floreana	2636,0	308,9
2002	Genovesa	516,0	35,2

II. Table 2: Red Lobster Data

Year	Macro zones	Ct (Tail Kg) [D] Red	Et (Number of one-day fishing trips)
2002	Isabela Norte y Este	1185,0	233,0
2002	Isabela Oeste	4519,0	735,4
2002	Isabela Sur	5137,0	1379,0
2002	Marchena	371,0	135,9
2002	Pinta	1264,0	128,4
2002	Pinzón	41,0	5,8
2002	Plazas	36,0	NA
2002	San Cristóbal Norte y Oeste	1948,0	324,7
2002	San Cristóbal Sur y Este	6731,0	950,6
2002	Santa Cruz	10307,0	1590,1
2002	Santa Fe	550,0	53,2
2002	Santiago	2836,0	350,1
2003	Darwin, Wolf	213,0	NA
2003	Española	1872,0	275,0
2003	Floreana	3738,0	520,2
2003	Genovesa	125,0	13,4
2003	Isabela Norte y Este	650,0	179,1
2003	Isabela Oeste	483,0	185,8
2003	Isabela Sur	4186,0	2249,3
2003	Pinta	407,0	46,7
2003	Rábida	337,0	89,6
2003	San Cristóbal Norte y Oeste	786,0	129,5
2003	San Cristóbal Sur y Este	8014,0	1263,1
2003	Santa Cruz	6510,0	1353,6
2003	Santa Fe	409,0	112,4
2003	Santiago	1396,0	282,1
	μ	2.612,5	468,3
	σ	2.921,5	538,0

Source: Bautil B. et. al. (2003) and Toral MV., et. al. (2002).

ANNEX III

III. Table 1: Optimal escapement and catch policies estimated for Sea cucumber Fishery 2003 (Discount Rate 10%)

Macro-zones	Objective Function USD	Carrying Capacity (# of ind)	St* (# of ind)	X_{2003} (# of ind) (Pre-fishery 2003)	Yt=Xt-St (# of ind)	Y_{2003} (# of ind)
Española	200.640,5	349.678,7	181.161,6	144.957,0	0,0	NA
Fernandina	2.937.632,0	6.916.014,1	2.707.137,8	1.792.496,1	0,0	736.000,0
Floreana	208.774,9	369.410,3	188.447,3	145.173,1	0,0	NA
Isabela Norte y Este	6.497.149,2	15.503.457,6	6.016.400,0	5.068.717,0	0,0	267.879,0
Isabela Oeste	4.423.251,8	10.498.177,3	4.087.542,0	4.606.749,2	519.207,3	3.054.595,0
Isabela Sur	4.355.990,2	10.335.915,3	4.025.012,5	3.895.014,7	0,0	484.814,0
San Cristóbal	301.324,4	590.633,5	271.803,2	464.577,8	192.774,6	121.845,0
Santa Cruz	1.633.180,2	3.776.181,1	1.497.288,1	1.747.723,4	250.435,3	340.435,0
Total	**20.557.943,2**	**48.339.467,9**	**18.974.792,4**	**17.865.408,3**	**962.417,2**	**5.005.568,0**

Source: Elaborated by the authors based on Solver calculations.

IV. Table 2: Optimal escapement and catch policies estimated for Sea cucumber Fishery 2003 (Discount Rate 30%)

Macro-zones	Objective Function USD	Carrying Capacity (# of ind)	St* (# of ind)	X_{2003} (# of ind) (Pre-fishery 2003)	Yt=Xt-St (# of ind)	Y_{2003} (# of ind)
Española	361.215,0	349.678,7	174.866,0	144.957,0	0,0	NA
Fernandina	2.361.645,7	6.916.014,1	2.429.544,5	1.792.496,1	0,0	736.000,0
Floreana	367.734,2	369.410,3	181.420,6	145.173,1	0,0	NA
Isabela Norte y Este	4.911.592,3	15.503.457,6	5.381.102,7	5.068.717,0	0,0	267.879,0

IV. Table 2: Optimal escapement and catch policies estimated for Sea cucumber Fishery 2003 (Discount Rate 30%)

Macro-zones	Objective Function USD	Carrying Capacity (# of ind)	St* (# of ind)	X_{2003} (# of ind) (Pre-fishery 2003)	Yt=Xt-St (# of ind)	Y_{2003} (# of ind)
Isabela Oeste	3.427.432,7	10.498.177,3	3.660.756,0	4.606.749,2	945.993,2	3.054.595,0
Isabela Sur	3.379.241,9	10.335.915,3	3.604.985,5	3.895.014,7	290.029,1	484.814,0
San Cristóbal	440.445,4	590.633,5	256.250,6	464.577,8	208.327,2	121.845,0
Santa Cruz	1.421.376,3	3.776.181,1	1.350.372,5	1.747.723,4	397.350,9	340.435,0
Total	**16.670.683,4**	**48.339.467,9**	**17.039.298,4**	**17.865.408,3**	**1.841.700,5**	**5.005.568,0**

Source: Elaborated by the authors based on Solver calculations.

0