Asset Pricing and Option Trading
for Harvesting Rights to Renewable Resources

Eyjólfur Guðmundsson, Lecturer, Faculty of Fisheries Studies,
University at Akureyri, Iceland

and

James L. Anderson, Professor, Department of Environmental and Natural Resource Economics,
University of Rhode Island, Kingston, RI USA

Abstract: This paper discusses the use of options as a tool to retrieve valuable information on the value and level of risk associated with owning a share in a stock of renewable resource. The objective is to show how theory on options trading can be used to obtain information on the perceived risk of the resource, and to discuss how this market information can be used to enhance the economic performance of the management framework in place.

Keywords: Renewable resources, fisheries management, options, options trading, harvesting rights, ITQs.

1.   Introduction

The commons of the world include renewable resources, such as water, forests, fisheries, land, etc. The tragedy of open access to the commons is all too well known, where the common future of the resource tends to decimate the resource in question (Hardin, 1968).

The general trend in history has been one of privatization of common resources after the resource has been over-harvested as common property (Stevenson, 1991). In the last two decades, the trend has been the same for fisheries resources, where more and more fisheries are controlled through individual quota and other rights-based systems (see Wilen, 1985; Hannesson, 1991; Arnason, 1995; Squires, *et al*., 1995; and Grafton, *et al*., 1996).

Privatization of fisheries resources has, in most cases, led to enhanced economic performance of the fishery. Fisheries of New Zealand, Iceland, and the halibut fishery in the US are all examples on how privatization has improved economic efficiency of those fisheries (see Hannesson, 1996, Runolfsson, 1996, Runolfsson, 1999, Homans and Wilen, 1997).

With the privatization of common resources, markets for ownership, or harvesting rights, emerge. Those markets should generate valuable information for the resource manager.

Financial and commodity markets have developed rapidly over the past century, despite the fact that markets are far from perfect. These markets use futures contracts extensively, and recently various forms of options. These markets provide valuable information to participants in the spot markets for the underlying assets.

The most important role of markets for options is not to be a price discovery mechanism but rather: "…Provide valuable information about the volatility and hence the risk of the underlying spot asset" (Chance, 1998).

The objective of this paper is to show how options trading can be used to obtain information on the perceived risk of a renewable resource, such as a fish stock. We also discuss how this market information can be used to enhance the economic performance of the management framework.

We start by reviewing theoretical work on prices of harvesting rights of renewable resources, and give an overview of classic finance theory on the asset pricing models. We then go on to describe how options markets could be used as a price formation market for harvesting rights of renewable resources.   We then discuss how these tools could be used to include additional information for the management process in order to enhance existing management framework.

2.   Background

The wasteful means of unlimited harvesting of fish stocks has probably been known for a long time. Over-harvesting of some sort has occurred, and indeed was a reason for exploration of new fishing grounds in the Middle Ages. In Japan, coastal ocean resources were allocated to specific user groups as early as the 17th

century (Yamamoto, 1995). The economic problem of open access fisheries was first formalized by Warming in 1911 and Andersen (1983). More famous is the work of Gordon (1954) and Scott (1955). Initially, the economic discipline suggested that limited entry be used in order to reduce the effort in the fishery (Copes, 1986).

The idea of allocating ownership of a share in the total allowable catch from an fish stock, to individuals, were set forth by Christy (1973), and formalized by Moloney and Pearse (1979) and Clark (1980). This early work focused on showing that individual transferable quotas (ITQs) are a sustainable and efficient form of managing fisheries resources. As ITQ systems have been implemented in fisheries around the world, the research focus is shifting towards efficiency, equity, effectiveness, and price formation for ownership rights in ITQ fisheries.

Arnason (1990) showed that under individual transferable share quota system (ITSQ) minimum information was needed obtain socially optimum management in fisheries, all the resource manager had to was to maximize the spot value of the quota shares. Arnason named this approach the Minimum Information Management System, or MIMS, for short.

The MIMS system assumes that the resource manager wants to find a time path of fishing effort that maximizes present value of industry profits, subject to biological and technological constraints, under a system of Individual Transferable Share Quotas (ITSQ). The objective function is:

$$\underset{\text{for all }\{\alpha_i\},\{Q\}}{Maximize}\sum_i\int_0^\infty (p\cdot\alpha_i\cdot Q - C(E(\alpha_i\cdot Q,x)))\cdot e^{-rt}dt$$

(1)

subject to:

$$\frac{\partial x}{\partial t}=\dot{x}=F(x)-Q$$

$$\sum_i\alpha_i=1$$

$$\alpha_i\ge 0 \text{ for all } i$$

$$Q\ge 0$$

where $\{\alpha_i\}$ stands for path of individual firms quota shares for firm i, $\{Q\}$ is the optimal path of the total allowable catch (the allocated quota), $F(x)$ is the growth function for the stock, p is price (assumed constant), r is discount rate, and i is number of firms. Price and discount rates are assumed to represent true social shadow prices. The individual firm is assumed to maximize its profits according to:

$$\underset{\{z\}}{Maximize}\int_0^\infty (p\cdot\alpha\cdot Q - C(E(\alpha\cdot Q,x)-s\cdot z)e^{-rt}dt$$

(2)

subject to:

$$\dot{\alpha}=z$$

$$1\ge\alpha\ge 0$$

where all variables are the same as in equation (1) except this time the changes (z) in quota held by each firm is multiplied by the price each firms sells or buys quota shares, and quota holdings becomes the control variable.

Using Hamiltonian formulation for dynamic optimization and applying Pontragyn's maximum principles, Arnason proves that under the given assumptions, maximizing the price for quota, s, is the same as if the firm maximized their individual net profits, or:

(3)

$$\underset{\{Q\}}{Maximize}\ s(0)\Leftrightarrow\ldots$$

$$\underset{\{Q\}}{Maximize}\ \sum_i\int_0^\infty [(p-C_E(E(q_i^*,X(x(0),\{Q\}))))\cdot q_i^*]e^{-rt}dt$$

Hence, the quota authority only needs to monitor quota prices and adjust allocated quotas, Q, such that the market price for quotas is maximized.

This result is based on several critical assumptions. Among these are that the expectations of the fishing firms are the best available predictor of future conditions in the fishery, and that the resource rent and profits are equivalent, or:

(4)

$$(p-C_E\cdot E_q(q^*,x))\cdot q_i^* = p\cdot q_i^* - C(E(q^*,x))$$

and equation (4) must hold for all i and t. Another critical assumption is that social and private discount rates are the same. Generally speaking, social and private discount rates are not assumed to be the same, and some economists have argued that social discount rate should be close to zero (Solow, 1992).

These assumptions are restrictive and make practical use of the MIMS system difficult. Squires and Kirkley (1996), Matthiasson (1997), and Lindner (1992) have shown that in the face of transition, or under non-equilibrium conditions, quota prices may not reflect the true shadow value of the resource.

As an example, we can imagine that discount rates are high. This means that future revenues account for an increasingly smaller part of the asset's net discounted value. Let's say that under those circumstances, the resource manager has been observing the quota market for a while, and decides to increase the allowable harvest in order to increase the overall value of the share in the resource. The resource manager is unsure of the effect the increase in harvest will have on the future sustainability of the resource. The market value

2

of the asset might increase, signaling to the resource manager that his decision was good. However, this increase in value may come with increased uncertainty about the future state of the resource. The value of this uncertainty is included in the price of the asset, and, therefore, it is not possible for the resource manager to actually observe the increase in uncertainty. He might be headed down the wrong path without warning. This is where the resource manager will make use of observing the options market for harvesting rights to the renewable resource.

3. Finance theory

We define net income as the difference between price, *P*, and economic costs, *c*:

$$(5) \quad NI = P - c$$

The value of each share is the discounted future net income from holding that asset. In standard financial theory the value of an asset in a deterministic world is:

$$(6) \quad P_0 = \sum_{t=1}^{T} \frac{NI}{(1+r)^t}$$

Extensive variations to this formula have been used in the financial literature, but the basic notion is always the same. Nothing is worth more than it will pay back to the owner.[1]

It is important to note that different discount rates will value the same asset in different ways. Hence, if the private discount rate is higher than the social optimum discount rate, the private sector will value the asset less than is socially optimal.

One might argue that stocks in a corporation traded on the stock market bear many similarities to a share in a renewable resource stocks. First of all, one holds a share in the company, which value might increase or decrease due to actions of the management team, just as resource manager can increase the stock of a resource through good management practices. Second, this share is expected to yield some dividend and/or growth over a period of time. In the same manner, the share in the resource is expected to yield some net income and/or growth.

Major factors that affect the price of an asset are risk and uncertainty. Generally speaking, investors are risk averse and are willing to trade an asset with high risk for an asset bearing lower risk, if both assets pay the same dividend.

---

[1] This, of course, excludes all non-monetary attributes of the specific resource in question.

By holding shares in many stocks, the overall risk of the collection of stocks (portfolio) can be reduced. This is the basic notion behind the Capital Asset Pricing Model (CAPM) developed in the 1960s and 1970s (for overview on CAPM see Copeland, 1992). The basic formula of the CAPM model is:

$$(7) \quad P_0 = \frac{E(\tilde{P}_e) - \lambda \cdot \mathrm{cov}(\tilde{P}_e, \tilde{r}_m)}{1 + r_f} \quad where \quad \lambda = \frac{E(r_m) - r_f}{\mathrm{var}(r_m)}$$

where P_0 is the spot price for the asset, $\tilde{P}_e$ is the expected value of the asset, r_m is the expected rate of return, and r_f is the risk free rate of return (discount rate). The CAPM model takes into account the relative risk of the asset compared to the overall portfolio of investment.

An overview of the basic asset price theory shows that the asset price has two basic components; the discounted value of the net income stream and the value of the risk associated with the asset. In order to extract the pure value of the risk, one must turn to theory on financial derivatives.

3.1 Options

Options have been used for a long time as a way to alleviate risk among trading partners. Options are a contract that gives the holder the right to buy, or sell, a specific asset at a given price and time in the future.

In 1973, formal trading exchange in option contracts was established by The Chicago Board of Trade. This was an independent exchange, named The Chicago Board Options Exchange. This market became highly successful from the beginning, and is currently the largest options exchange market in the world.

So, what is the value of an option? How much is someone willing to pay for the *right* to do something? This question is complex. The are many factors that enter the decision process, and some of them, such as perceived risk or different investors expectations make it difficult to form a unique price for each option.

Black and Scholes (1973) developed a method to value options. The model is complex, and the derivation. is beyond the scope of this paper, but we will present the basic steps in the derivation of the Black and Scholes option pricing model. This overview is based on Hull (1989).

Assume that the price movement of a share in a resource stock can be described, using discrete form, as:

$$(8) \quad \frac{\Delta S}{S} = \mu \Delta t + \sigma \Delta z$$

where S represents the share price, μ represents expected rate of return and σ is the share price

volatility, and Δz is a *Wiener* process. This equation is known as a *geometric Brownian motion*[2] and is a stochastic process around a mean with a time trend. Ito´s lemma proofs that a function *f*, which depends on S and t, follows a particular process, known as Ito process; shown below in discrete form:

$$(9) \quad \Delta f = \left(\frac{\partial f}{\partial S} \mu S + \frac{\partial f}{\partial t} + \frac{1}{2} \frac{\partial^2 f}{\partial S^2} \sigma^2 S^2 \right) \Delta t + \frac{\partial f}{\partial S} \sigma S \Delta z$$

where *f* is the price function for a given derivative on shares with price *S*. Investors can reduce risk by buying both stocks and options on a specific stock. By taking opposite stands on the stock and options market, the investor can eliminate the uncertainty described by the Wiener process, *Δz*. The value of a portfolio with a short derivative and a long share position is:

$$(10) \quad \Pi = -f + \frac{\partial f}{\partial S} S$$

and the change in value is then:

$$(11) \quad \Delta \Pi = -\Delta f + \frac{\partial f}{\partial S} \Delta S$$

Since this would be a risk-free portfolio, it must earn the same rate of return as other risk-free investment opportunities in a world with no transaction costs. Hence, the change in the value of the portfolio over a small time interval is:

$$(12) \quad \Delta \Pi = r \Pi \Delta t$$

and substituting equations (10) and (11) into equation (12) gives us the Black-Scholes-Merton differential equation.

$$(13) \quad \frac{\partial f}{\partial t} + rS \frac{\partial f}{\partial t} + \frac{1}{2} \sigma^2 S^2 \frac{\partial^2 f}{\partial S^2} = r \cdot f$$

This equation is a general formula with many different solution depending on the boundary conditions on the differential equation. The most famous solution is the Black-Scholes option pricing model for valuation of European call options. The solution for a European Call option has the boundary condition as:

$$(14) \quad f = \max(S - X, 0) \text{ when } t = T$$

where S is the stock price, X is the strike price, and t stands for time. Using the above boundary condition to solve equation (13) gives the Black-Scholes model, generally represented with three equations:

---

[2] See Hull, 1989 p. 226

$$V = S_0 N(d_1) - Xe^{-rT} N(d_2)$$

$$(15) \quad where$$

$$d_1 = \frac{\ln(S_0/X) + (r + \sigma^2/2)T}{\sigma \sqrt{T}}$$

$$d_2 = d_1 - \sigma \sqrt{T}$$

Hence, the value of an option depends upon five factors, the stock price, S, the strike or exercise price, X, the risk free interest rate, r, the time to maturity, T, and the stock price volatility, σ. Of these, the risk-free interest rate, stock price, and the stock volatility can be regarded as exogenous to the value of the option. The other factors are chosen by the investor who writes the option. However, what does not enter the value of the option is the investor's expected rate of return. Hence the option price for a given strike price gives valuable information about the overall market expectations on the value of the uncertainty of the underlying asset.

The boundary condition (14) is really the intrinsic value of the option, i.e., the value of the option. The total value of an option is then its intrinsic value plus its time value. A simple graph below explains how changes in one of the parameters affect the total option value.
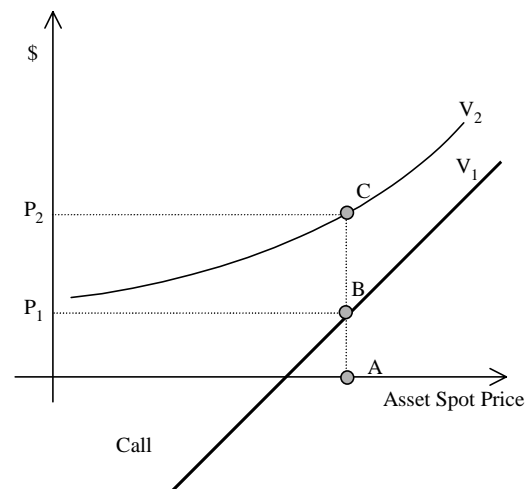

Figure 1: Option value and different time periods

Figure 1 shows the value of a European Call option at a given strike price, compared to the value of the underlying asset. The 45° degree line represents the difference between the spot price(s) and the strike price(s). The distance between points A and B represents the intrinsic value of the option, or the difference between the spot price and the strike price. This would be the value of the option if it were exercised immediately, since the exercise price is higher than the current spot price. If the option expires some months later, its value would be P_2. The total value of the option is then the intrinsic value (B – A) plus the

time value (C – B), which represents the risk premium. It is the time value that contains the most important information, since it depends on the volatility of the price of the asset. Changes in time value will, therefore, give the holder of the asset valuable information on the changes in perceived risk of the asset.
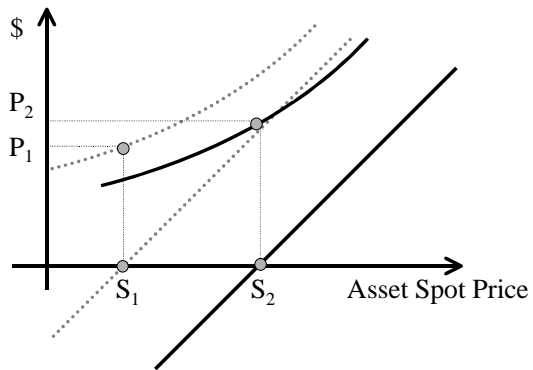

Figure 2: Option value and changes in asset price

Figure 2 shows how the option value changes when the underlying asset increases in price. We begin with an asset price S_1, and option value P_1, for a strike price equal to the current spot price (also called at-the-money). Now assume that an exogenous event causes the asset price to instantaneously increase. The asset is now more valuable, but the question remains, what happens to the value of the option? In this example, the price of the at-the-money option (P_2) has increased. Since time to maturity has not changed, the comparison of the at-the-money option immediately before and after the exogenous event reveals information about perceived risk. In this example, perceived risk increased after the exogenous event.

4. Using market information to evaluate management practices

First, let's look at the signals that the resource manager receives from the spot market. There are several reasons why a share in the resource might increase in value. There might be increased demand for the product from the resource, leading to higher prices, and hence, making the current value of holding a share in the resource higher. This might happen *despite* the fact future sustainability of the resource may be threatened.

Second, the increase might be due to better management practices leading to a more valuable asset, such as conservation methods that lead to larger fish stocks in the future. Third, the buyer might have

expectations of increased price in the future, and fourth the buyer might have some knowledge about future status of the resource, or products derived from it, which the resource manager is unaware of.

It is clear that simply observing the spot price of the stock sends mixed signals to the resource manager. The manager cannot make strong conclusions about the effectiveness of the management plan in place and, therefore, needs more information.

If there is an active market for options in the shares of the renewable resource, the market will reveal the expectations about the risk of the resource from those who participate in the trading. Those most likely to participate are the current owners, processors that use the resource, and speculators.

LEAPS could give the resource manager the most valuable insight into the expected state of the resource in the future since they have an expiration period of several years.[3]

For a given r and T, if the optimal premium increases, the traders must be expecting a decreases in price volatility of the share and/or the share spot price, and vice versa for a price decrease of the option.

As previously illustrated, if we look in combination at the spot price and the options price, the resource manager can deduce some valuable information about current expectations regarding the future state of the renewable resource in question.

First, let's assume we have a fishery with an ITSQs management system. The fisheries management announces the TAC for the next five years, given no environmental or ecological changes. Hence, there is uncertainty about the actual TAC for any given year in the future. There is a public, well developed spot market for share quotas and options, where participants can buy or sell without restrictions. Prices for quota shares depend on the expected price for the final fish products, TAC, and quantity of available shares for sale. The objective of the fisheries manager is to maximize the total resource value over time.

Let's examine what happens if the price of quota shares on the spot market increases without any announced changes in the TAC. This could happen for two reasons; either the expected price for fish products increased, or the perceived volatility of the value of the asset has declined, all else constant. If the spot price for shares increases due to an increase in expected fish prices, the time value of the option will not change. If the spot price for shares increases because of decreased volatility, time value of the option will decline.

---

[3]Currently, LEAPS with three-year maturity are being traded on the CBOE.

Another example would be if the fisheries manager chooses to set the TAC. This will likely change the perceived volatility of share value. Since the TAC is higher, the prices of shares in the harvesting rights of the resource are likely to increase, especially if the discount rate is high. However, to determine if, in fact, the change in TAC increases the perceived volatility of the share, the manager should look at the option value. If volatility (likelihood of stock collapse) is perceived to increase, the options value will increase.

What becomes important for fisheries managers of an ITSQ fishery with active option trading for the underlying share in the fishery is to monitor the interaction between the spot price and the option price. By so doing, the fisheries manager can better make the tradeoff between maximizing the value of the resource, and reducing perceived risk of the resource. Hence, active options trading can be used as a valuable tool for fisheries managers in understanding the volatility (sustainability) of the resource.

5. Discussion and conclusion

Shares in the TAC for a given fish stock are like share in a publicly traded company. The tools and trades of modern stock trading can, therefore, be applied to trading in shares of the catch from a fish stock.

In this paper, we have reviewed classical financial theory and shown how the tools of the financial markets can be used to extract useful information for those participating in the fishery, as well as fisheries management.

We also discussed Minimum Information Management Systems for fisheries and pointed out that some of the model limitations become less severe if option trading is taken into account.

If trading with quota shares does develop to the same extent as modern stock trading, various information on the fish stock and the expectations of those who trade products from the fish stock could be extracted. This could be done by simply monitoring the trade of shares and by monitoring the trade in options for quota shares.

It is our belief that private property rights will develop in most of the world's fisheries over the next few decades. The need for asset and derivative pricing for quota trading is likely to rise significantly over the next few years.

There is much to be done within this field of fisheries economics. Bioeconomic analysis is known to be complicated theoretically and difficult to test empirically. Options pricing is also difficult, requiring knowledge of stochastic calculus and dynamic optimization.

The next step would be to formalize the ideas set forth in this paper to include information from options trading within a dynamic bioeconomic model. This is needed in order to show how option prices could be used directly to enhance the information available for fisheries management, and by so doing, increase the overall efficiency of the fishery in question.

References

Andersen, P. ""On rent of fishing grounds": A translation of Jens Warming's 1911 article, with an introduction." *History of Political Economy* 15, no. 3(1983): 391-396.

Arnason, R. *The Icelandic Fisheries: evolution and management of a fishing industry*. Oxford, London, Edinburgh, Cambridge, Carlton: Fishing News Books, 1995.

Arnason, R. "Minimum Information Management in fisheries." *Canadian Journal of Economics* 33, no. 3(1990): 630-653.

Baldursson, F. M., and G. Magnusson. "Portfolio fishing." *Scandinavian Journal of Economics* 99, no. 3(1997): 389-403.

Black, F. and M. Scholes. "The Pricing of Options and Corporate Liabilities." *Journal of Political Economy* 81(May-June 1973): 141-183.

Chance, D. M. *An Introduction to derivatives*. 4 ed. Orlando: The Dryden Press, 1998.

Christy, F. J. "Fisherman Quotas: A tentative suggestion for domestic management." Occasional Paper. The Law of the Sea Institute, November, 1973.

Clark, C. W. "Towards a Predictive Model for the Economic Regulation of Commercial Fisheries." *Canadian Journal of Fisheries and Aquatic Sciences* 37, no. 7(1980): 1111-1129.

Copeland, T. E. W., J.F. *Financial theory and corporate policy*. New York: Addison-Wesley publishing company, 1992.

Copes, P. "A critical review of the individual quota as a device in fisheries management." *Land Economics* 62, no. 3(1986): 278-291.

Gordon, H. S. "The economic theory of a common property resource: the fishery." *Journal of Political Economy* 62(1954): 124-142.

Grafton, R. Q., D. Squires, and J. Kirkley. "Private Property Rights and Crises in World Fisheries: Turning the Tide?" *Contemporary Economic Policy* 14, no. October(1996): 90-99.

Hannesson, R. *Fisheries Mismanagement*. Oxford: Fishing News Book, 1996.

Hannesson, R. "From common fish to rights based fishing. Fisheries management and the evolution of exclusive rights to fish." *European Economic Review* 35(1991): 397-407.

Hardin, G. "The Tragedy of The Commons." *Science* 162, no. 1968(1968): 1243-1248.

Homans, F. R., and J. E. Wilen. "A model of Regulated Open Access Resource Use." *Journal of Environmental Economics and Management* 32(1997): 1-21.

Hull, J. C. *Options, Futures & Other derivatives*. Toronto: Prentice-Hall International, Inc., 1989.

Lindner, R. K. C., H.F.; Bevin, G.F. "Rent generation during the transition to a managed fishery: The case of the New Zealand ITQ system." *Marine Resource Economics* 7, no. 4(1992): 229-48.

Matthiasson, T. "Consequences of local government involvement in the Icelandic ITQ market." *Marine Resource Economics* 12, no. 2(1997): 107-26.

Moloney, D. G., and P. H. Pearse. "Quantitative Rights as an Instrument for Regulating Commercial Fisheries." *Journal of Fisheries Research Board of Canada* 36(1979): 859-866.

Runolfsson, B. (1999) The Icelandic System of ITQs: Its nature and performance, ed. R. Arnason, and H. H. Gissurarson. Reykjavík, The University of Iceland Press.

Runolfsson, B. T. A., Ragnar (1996). "Evaluation and Performance of the Icelandic ITQ system." Icelandic Economic Papers. Economic Institute, University of Iceland.

Scott, A. "The Fishery: the objectives of sole ownership." *Journal of Political Economy* 63(1955): 116-124.

Solow, R. "An almost practical step toward sustainability." *Resource for the future, An invited lecture on the occasion of the 40th anniversary*, no. October(1992): 5-22.

Squires, D., and J. Kirkley. "Individual Transferable quotas in a multiproduct common property industry." *Canadian Journal of Economics* 24, no. 2(1996): 318-342.

Squires, D., J. Kirkley, and C. A. Tisdell. "Individual Transferable Quotas as a Fisheries Management Tool." *Reviews in Fisheries Science* 3, no. 2(1995): 141-169.

Stevenson, G. G. *Common property economics: A general theory and land use applications*. 1 ed. New York: Cambridge University Press, 1991.

Wilen, J. E. "Towards a theory of the regulated fishery." *Marine Resource Economics* 1, no. 4(1985): 369-388.

Yamamoto, T. Y. "Development of a Community-Based Fishery Management System in Japan." *Marine Resource Economics* 10(1995): 21-34.