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The Cost of Delaying Cooperative Management of a Transboundary Fish Stock Vulnerable to Climate Variability: The Case of Pacific Sardine

Gakushi Ishimura, Sam Herrick and U. Rashid Sumaila

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email: gakugaku@sgp.hokudai.ac.jp

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Corresponding Author: Mr. gakushi ishimura, MMA

Corresponding Author's Institution: Hokkaido University

First Author: gakushi ishimura, MMA

Order of Authors: gakushi ishimura, MMA; sam herrick, Ph.D; Ussif Rashid Sumaila, Ph.D

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THE COST OF DELAYING COOPERATIVE MANAGEMENT OF A TRANSBOUNDARY FISH STOCK VULNERABLE TO CLIMATE VARIABILITY: THE CASE OF PACIFIC SARDINE

Gakushi Ishimura[1,*] Sam Herrick[2] , Ussif Rashid Sumaila[3]

* Corresponding author

1, Center for Sustainability Science, Hokkaido University, Kita-Ku Kita 9 Nishi 8,
Sapporo, Hokkaido 060-0809 Japan; Tel: +81-11-706-4530; Fax: +81-11-706-4534;
E-mail: gakugaku@sgp.hokudai.ac.jp

2, NOAA Fisheries Services, Southwest Fisheries Science Center, 3333 North Torrey
Pines Court
La Jolla, CA 92037-1022 USA; Tel: +1-858-546-7111; Fax: +1-858-546-7003;
E-mail: sam.herrick@noaa.gov

3, Fisheries Centre, University of British Columbia, AERL, 2202 Main Mall, Vancouver,
B.C., Canada, V6T 1Z4; Tel: :+1-604-822-0224; Fax: :+1-604-822-8934;
E-mail: r.sumaila@fisheries.ubc.ca

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Challenges in the management of a transboundary fish stock, with time variant and asymmetric distribution of biomass caused by ocean climate variability, lie in delaying the implementation of cooperative management and the incurring of cost due to such delays. This is particularly true for Pacific sardine (*Sardinops sagax)*, which has exhibited extreme decadal variability corresponding to warm and cold regime shifts of the California Current Ecosystem (CCE). Pacific sardine is exclusively fished by Canada, the U.S. and Mexico without any cooperative agreements in place. Our study applied a three-agent bioeconomic framework that incorporated environmental effects on sardine abundance and biomass distribution to estimate the cost of delaying cooperative management of this fishery. Our results showed that the cost of delaying cooperative management is significant for a country having a dominant share, while countries that have minor shares gain economic benefits from delaying cooperative management.

1.Introduction

Ocean climate variability, on both inter-annual and decadal scales, alters the marine environment over time (Brander 2007). Impacts that can result through such changes in the marine environment include food availability and the habitats for marine organisms. Fish stocks often respond to these changes by 1) increasing or reducing their abundance; and 2) migrating to habitats conducive for growth and reproduction. These two responses are not mutually exclusive, and jointly result in changes in the local fish availability, thus inevitably threatening the spatial stability of available fish stocks for fisheries exploitation.

This issue of spatial instability is a critical challenge particularly with a transboundary fish stock which is exclusively shared by more than one country. Without cooperative agreements, competing fishing activities, upon which the impacts of ocean climate variability could have compounding effects, threaten transboundary fish stocks. Two critical elements to fisheries management need to be agreed on for there to be cooperation in the use of a transboundary fish stock (Munro *et al.*, 2004). First, the size of the fish stock left unfished, called the escapement biomass, must be agreed upon to ensure the resource's sustainability. The escapement biomass thus defines the total allowable catch (TAC) permitted to participating fishing countries. Second, the allocated share of the total catch permitted to each country needs to be addressed. Fixed shares of catch have often been allotted by considering the catch history of the countries involved, fixed physical distribution of stocks, or the migration patterns of a transboundary fish stock. With spatial instability of a fish stock caused by ocean climate variability, fixed allocations may no longer be effective, and therefore, it is anticipated that challenges to establishing cooperative transboundary management will arise.

Potential uncertainties in fisheries production and spatial distribution arising from ocean climate variability have received increasing attention in transboundary fishery management over the years. A body of scientific studies on the impacts of ocean climate variability on a fishery has quickly developed, but it is mostly limited to geographical considerations or methodological approaches rather than by anticipating effects on a fish stock or fisheries (Brander 2009). In terms of practical case studies on transboundary fish stocks under climate variability, Laukkanen (2003) devised a multinational fishing game for Northern Baltic salmon with environmental variability in recruitment, and concluded that there were significant effects from environmental variability on maintaining cooperative management. Miller and Munro (2004) undertook a case study of Canada - US Pacific salmon fishery management in which abundance and distribution changes related to ocean climate variability are taken into account, and concluded that predictions of the impacts of environmental variability on a fish stock are a key to successful cooperative managements. Miller (2007) argued that the stability of regional fishery management organizations for highly migratory fish stocks[1] (e.g., tropical tuna) is heavily dependent on how effectively countries' incentives for cooperative management are maintained under the anticipated changes to fish stocks by ocean climate variability. Despite these three studies successfully demonstrating the need for cooperative management of transboundary fish stocks under ocean climate variability, studies that estimate the risk of overexploitation and the loss of potential economic benefits, from a transboundary fish stock under ocean climate variability and non-cooperative management, are largely absent from the academic literature.

A large challenge in the management of a transboundary fish stock, where its availability is affected by ocean climate variability, lies in delaying implementation of cooperative management and consequently incurring the cost of such delays. First, it

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[1] A highly migratory fish stock is one type of shared fish stocks that migrate through both exclusive economic zones and the high seas. While a transboundary fish stock can be exclusively fished by participating countries, in principal, highly migratory fish stocks can be fished freely on the high seas by any country.

takes a long time to recognize and confirm changes in a fish stock caused by ocean climate variability, to which must be added the time needed to predict anticipated changes. Second, negotiations to establish cooperative management take additional time because of likely conflicts in economic interests compounded by political obstructions. Such negotiations also include agreements on anticipated changes to a fish stock and decisions on sharing future benefits among the participating stakeholders on both the domestic and international levels. These difficulties all serve to delay the adoption of cooperative management of a transboundary fish stock.

As in Miller (2007), one key to the stability of cooperative management of a transboundary fish stock is to maintain the participating countries' incentives to continue to cooperate, despite changes in fish abundance and distribution. Therefore, revealing the cost of delaying such cooperative management, which includes both the potential loss of economic benefits and the risk of stock depletion, would help give countries sufficient incentives to engage in cooperative exploitation to avoid potential negative outcomes. Although the number of global studies on the cost of adapting to climate changes is rapidly increasing (e.g., World Bank 2009), as far as we know, studies on the cost of delaying cooperative management on a transboundary fish stock under ocean climate variability have been largely absent until now.

Transboundary fishery management of Pacific sardine (*Sardinops sagax)* in the California Current Ecosystem (CCE) is now faced with the aforementioned challenges, under ocean climate variability. Inter-annual and decadal scale climate variability, with drivers such as the El Niño/Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO), has shaped the ocean climate of the CCE, which extends up to southern Vancouver Island from Baja California (Field and Francis 2002). Since the early twentieth century, three ocean climate regime shifts have been recognized; a warm regime from 1925 to 1947, a cold regime between the 1940s and late 1970s, and a warm regime from 1977 to the present (Figure 1) (McFarlane *et al.*, 2000).

[Figure 1 HERE]

While projecting trajectories of ocean climate variability in the CCE and the subsequent dynamics of Pacific sardine is in the early stages, the need to establish a robust cooperative management by Mexico, the U.S. and Canada seems pressing. However, currently, no cooperative management exists. Accepting cooperative exploitation will require strong economic incentives and the threat of a collapse of the fish resource.

Therefore, creating incentives for the three countries to engage in cooperative management of Pacific sardine is an urgent need if we are to minimize the risk of the degradation of economic benefits and depletion of the Pacific sardine stock.

To this end, this study aims to reveal the cost of delaying cooperative exploitation of the Pacific sardine fish stock under ocean climate variability. Ishimura *et al.* (2010) developed a three-country transboundary fishery bioeconomic model for Pacific sardine incorporating distribution and abundance uncertainties under CCE ocean climate variability. They showed the potential effects on economic and biological outcomes from cooperative and non-cooperative management of the Pacific sardine stock by the three countries rather than precise estimations of biomass and economic outcomes. This study further extends their model to estimate the cost and the risk of depletion to a fish stock, in this case Pacific sardine, from delays in cooperative exploitations. In the study, we conduct 35-year simulations, and define the ‘cost of delay’ as the difference in net economic benefits between a) cooperative management by the three countries for all 35 years, and b) cooperative management after *i* years of non-cooperative management. We summarize and discuss the results from the simulations.

2. Material and methods

2.1. Pacific sardine in the California Current Ecosystem

The abundance and distribution of the northern stock[2] of Pacific sardine, which is the largest substock in the CCE that is exclusively fished by Canada, the U.S. and Mexico, has exhibited extreme variations as result of three regime shifts in the CCE (Norton *et al.*, 2005; Herrick *et al.*, 2007). In this study, hereafter, the term Pacific sardine implies this northern stock. Until the early 1940s under a warm regime, the biomass of Pacific sardine varied between 1.2 million and 2.8 million tonnes, and sardine fisheries were widespread in Canada, the U.S. and Mexico. Between the late 1940s and 1970s a cold regime shift in the CCE, combined with overfishing, resulted in the collapse of the Pacific sardine stock, with biomass failing below 5,000 tonnes. As abundance decreased, the spatial availability for commercial fisheries shifted from a wide range to the limited southern region of southern California and Mexico. Finally, directed fisheries for Pacific sardine in the U.S. were closed in 1974 (Wolf 1992). In the 1980s, a warm regime shift occurred in the California Current, and coupled with conservation efforts, the abundance of Pacific sardine rebounded to 1940s levels, and reappeared in the waters of

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[2] Three substocks of Pacific sardine in the CCE (Felix-Uraga *et al.* 2005) are widely recognized. These are the 1) northern substock, which is found from northern Baja California to south-eastern Alaska; 2) southern substock whose distribution ranges from Baja California to southern California; and 3) Gulf of California substock ,which spends its life within the Gulf of California.

the Northwest U.S. (Oregon and Washington) and Canada. In 1986, directed fisheries for Pacific sardine officially reopened in the U.S. Canada removed Pacific sardine from its endangered species list and reopened its sardine fisheries in 2003. In 2006, the estimated biomass of Pacific sardine reached 1.2 million tonnes. In 2008, the estimated biomass decreased to 0.58 million tonnes (Hill *et al.*, 2009). Latest improvements to the stock assessment model have resulted in a retrospective reduction in biomass estimates for recent years (see Hill *et al.*, 2007, 2008, 2009). Currently, although unconfirmed, we are likely facing a cold regime shift in the CCE. In summary, warm regimes enhance the abundance of Pacific sardine and expand its distribution. Cold regimes lessen abundance and restrict distribution.

2.2. Model overview

Our integrated model mimics ocean climate variability in the CCE and the abundance and distribution of Pacific sardine stocks corresponding to ocean climate variability. Previous studies have demonstrated significant correlations between sea surface temperature (SST), abundance, and distribution of Pacific sardine[3] (e.g. Herrick *et al.*, 2007; Jacobson and MacCall 1995; Jacobson *et al.*, 2005). This study therefore assumes

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[3] SST at the Scripps Institute of Oceanography pier, in La Jolla, California (SIO SST), is often used as an indicator of the decadal cold-warm shifts in the CCE.

that SST is a major driver of biomass abundance and the geograpchical distribution of Pacific sardine, and adapts the model developed by Ishimura *et al.* (2010). Our alternative stochastic model consists of four components: *a*) a population dynamics model driven by SST; *b*) a biomass distribution model spread over three countries; *c*) an SST development model; and *d*) an information model of fish stock distribution. We integrate these four components to model the expected population dynamics and distribution of Pacific sardine.

2.3. Population dynamics model driven by SST

We adapt a surplus production model with environmentally dependent components developed by Jacobson *et al.* (2005), and assume that the fish stock migrates from a spawning area to each country's fishing grounds and then returns to their spawning ground for reproduction. Fishing is assumed to occur after reproduction, and occurs simultaneously in each country's fishery. From the Gompertz-Fox model (Fox 1970), Jacobson *et al.* (2005) calculated environmentally dependent surplus production as:

$$B_{y+1} = S_y - e\eta S_y \ln\left(\gamma \frac{S_y}{I_y}\right) \tag{1}$$

$$S_y = B_y - h_y^{Canada} - h_y^{U.S.} - h_y^{Mexico} \tag{2}$$

where B_y and S_y are the biomass and escapement biomass at year y, respectively. The constant e is Euler's number (2.718), I_y is SST at year y, which affects the stock's carrying capacity. η and γ are constants. For the Gompertz-Fox model, η is the ratio of the maximum productivity and the carrying capacity (Quinn and Deriso 1999). The constant γ is a scaling factor for SST to the carrying capacity. Ishimura *et al.* (2010) estimated η (0.04) and γ (2.55) by using updated stock assessment data from Hill *et al.* (2007). This study incorporates these estimations.

2.4. Objective function under cooperative management

Here, we assume that the three countries fish cooperatively thereby acting as the sole owner of the fish stock and seek to maximize joint benefits by adjusting the optimal escapement biomass, S_y^*. The objective function that maximizes the present value of the economic benefit at year y ($f_{solo,y}$) is assumed to be:

$$\max \quad f_{solo,y}(S_y^*) = p \cdot (B_y - S_y^*) + \frac{d \cdot p \cdot \left\{ -e\eta S_y^* \ln\left(\gamma \frac{S_y^*}{I_y} \right) \right\}}{1-d} \qquad (3)$$

$$\text{where} \quad d = \frac{1}{1+r}$$

where d is the discount factor and r is the discount rate. We assume a constant net economic price per unit catch (p= 0.03 USD per pound). The first term expresses the economic benefits from the current catch and the second term expresses the future economic benefit (Hannesson 2005). In this study uses a discount rate, 5% to project economic and biological outcomes. With rates of 3%, 10% and 15% applied to assess the sensitivity of the model to different discounting rates. For the maximization of the objective function under sole ownership (cooperative management), the optimal escapement biomass (S_y^*) is calculated using the first order condition of Equation (3):

$$S_{solo,y}^* = \frac{I_y}{\gamma} e^{-\left(1+\frac{1-d}{de\eta}\right)} \qquad (4)$$

2.5. Objective function under non-cooperative management

Hannesson (2005, 2006) studied a transboundary fish stock that migrates between two countries with time-variant distribution changes under climate change. Two complementary assumptions related to the maximization problem are assumed in his study. First, the minor country, with less than a half share (distribution) of a fish stock, has an incentive to fish the biomass level down to zero ($S^{Minor}*=0$). Second, the major country with more than half the share (distribution) of a fish stock has an incentive to leave the stock in the ocean until it reaches the level that maximizes net present value of the benefits. This paper adopts this variant major/minor framework and develops an optimal escapement biomass for non-cooperative management based on the updated Jacobson's population dynamics model by Ishimura *et al.* (2010). The escapement biomass that maximize the present value for invariant shares of a fish stock are:

$$\begin{cases} S_{w,y}^{Majar*} = \dfrac{I_y}{\gamma}\, e^{-\left(\frac{1-d}{de\eta\hat{D}_{w,y}}+1\right)} \quad \text{if } \hat{D}_{w,y} > 0.5 \\ \qquad S_{w,y}^{Minor*} = 0 \quad \text{Otherwise} \end{cases} \tag{5}$$

where $\hat{D}$ is the expected distribution of a fish stock. Hanneson's analysis was for a two-agent model, where a fish stock's distribution clearly defined which country is major and minor except when the two countries' distributions were the same ($\widehat{D}=0.5$) and the two countries jointly acted as the sole owner. In our three-agent model with Canada, the U.S. and Mexico, however, it is possible for the biomass distributions of all countries to be less than 0.5, in which case all countries act as minor players. This could lead to the drastic depletion of Pacific sardine.

2.6. Sea surface temperature development model

The nature of the climate regime of the CCE is based on decadal scale interchanges of warm and cold regime shifts (two or three regime shifts during the twentieth century). This study adopts a 35-year time trajectory where one regime shift from warm to cold and vice versa, would be appropriate. We use an increasing and a decreasing trend of SST (τ), calculated as:

$$\tau_{y+1}=\tau_y+\mu+\sigma\Delta z_y \tag{6}$$

$$\Delta z_y \sim N(0,1)$$

where y is year. Equation (6) generates a stochastic SST trend as the sum of two components: 1) a static driven part, μ; and 2) a stochastic error term, Δz_y. In this study, the value for μ and σ are 0.044 and 0.602, respectively, obtained from the average annual SIO SST from 1970 to 2002, which is considered a warm regime period in the CCE (from Ishimura *et al.*, 2010) . The current situation in the CCE might be the initial stage of a cold regime shift, but this is yet to be confirmed since it takes several years to confirm warm and cold climate regimes. Therefore, the period from 1970 to 2002, which has been confirmed as a warm climate regime is the period which we use as a basis to estimate ocean climate variability. This study evaluates two scenarios for SST trends, 1) an increasing (time-increment) SST trend (μ = 0.044); and 2) a decreasing (time-decrement) SST trend (μ = - 0.044). The estimated SST (τ_y) from Equation (6) now replaces *I* in Equations (4) and (5).

2.7. Biomass distribution model driven by SST

The biomass distribution model of Pacific sardine is a discrete three-box model. With changes in SST, the sardine biomass is redistributed between Mexico (*MX*), the U.S. (*US*) and Canada (*CA*) in a discrete manner. The general pattern of the distribution of Pacific sardine within country *w* (D_w) relative to the others is assumed to be linear when the SST (τ) drops below the low threshold level (τ_{low}), and then approaches zero ($D_w = 0$) as the high threshold level of SST (τ_{high}) is reached.

$$\begin{cases} D_{MX,y} = \min\left[1, (\tau_{high_{MX}} - \tau_y) / (\tau_{high_{MX}} - \tau_{low_{MX}})\right] \\ D_{US,y} = (1 - D_{MX,y}) \cdot \min\left[1, (\tau_{high_{US}} - \tau_y) / (\tau_{high_{US}} - \tau_{low_{US}})\right] \\ D_{CA,y} = 1 - D_{MX,y} - D_{US,y} \end{cases} \quad (7)$$

$$\text{s.t.} \quad 0 \le D_{w,y} \le 1$$

$$D_{MX,y} + D_{US,y} + D_{CA,y} = 1$$

This study models biomass distribution by estimating a direct relationship between SST and discrete biomass distributions over the Exclusive Economic Zones (EEZs) of Mexico, the U.S. and Canada based on three descriptive facts. First, the current U.S. harvest policy for Pacific sardine assumes a fixed distribution with 87 % of the northern stock in U.S. waters (California, Oregon and Washington) and 13 % in Mexican waters (Pacific Fishery Management Council 1998), and does not include a percentage for Canada (Hill *et al.*, 2008). Second, Canadian management assumes a fixed biomass distribution where 10% of the northern stock is assumed to enter Canadian waters. This assumption is based on an analysis of historical catch and trawl survey data (DFO 2004). Third, around 1990, Pacific sardine reappeared in Canadian waters. Based on the above observations and analyses, this study makes two assumptions about the relationship between SST and the biomass distribution of Pacific sardine. First, at an SST of 17.9 ^{o}C, which was the five-year average SIO SST in 1999, the proportions of the biomass of Pacific sardine in Mexico, the U.S. and Canada are set at 13%, 78% and 9%, respectively. Second, at a SST of 17.5 ^{o}C, which was the five-year average in 1992, the proportions of the biomass of Pacific sardine in Mexico, the U.S. and Canada are 20%, 77% and 3%, respectively. We set different high and low threshold levels for Mexico ($\tau_{high_{MX}}$ =18.3 and $\tau_{low_{MX}}$ =15) and the U.S. ($\tau_{high_{US}}$ =21.5 and $\tau_{low_{US}}$ =17.5), with Canada having the residuals.

Since our intention in this study is not the precise estimation of biomass or economic outcomes, but rather to examine the effects of delaying cooperative management, we use five-year averages from 1997 and 2001, a confirmed warm regime of the CCE, as the initial SST, 17.9^{o} C, and initial biomass, 1.2 million tones, in the simulations (Hill *et al.*, 2007). The initial biomass distributions for Mexico, the U.S. and Canada are set at 13%, 78%, and 9%, respectively. As SST reaches 19.4 ^{o}C, more than half the biomass is distributed in Canadian waters[4]. More than half the biomass is distributed in

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[4] The historical maximum and minimum SIO between 1918 and 2002 was 19.1^{o}C in 1997 and 15.5 in 1975, respectively.

Mexican waters when the SST drops below 16.7 ^{o}C (Figure 2).

[Figure 2 HERE]

2.8. Information model for biomass distribution

We incorporate an auto-correlation function into the estimation of expected fish share for each country based on the assumption that changes in the biomass distribution of Pacific sardine is based on existing and past time series of biomass distributions. Therefore, a time dependent auto-correlated error function is appropriate. This is expressed as:

$$\hat{D}_{w,y} = \rho \cdot D_{w,y} + (1-\rho)\hat{D}_{w,y-1} \tag{8}$$

$$\text{s.t.} \;\; 0 \le \hat{D}_{w,y} \le 1$$

$$\hat{D}_{w,0} = D_{w,0}$$

where $\hat{D}_{w,y}$ is an expected distribution at time y in country w, and ρ is the auto-correlation weighting factor. The value of the weighting factor (ρ) captures the information delay regarding a fish stock's distribution. The magnitude of the weighting factor affects the amount of the stock, expects to have availability to update their fishing strategy. In the simulations, we assume symmetric information for the three countries and arbitrarily set the weighting factor at $\rho = 0.5$. Sensitivity analysis was carried out in Ishimura *et al.* (2010).

2.9. Catch

Due to the time-variant fish stock distribution and information delays, the target catch might be more than the amount of fish available in each country's waters. The catch in a given year for each country is expressed as:

$$h_{w,y} = \min\left\{D_{w,y} \cdot B_y, \widehat{h}_{w,y}\right\} \tag{9}$$

$$\widehat{h}_{w,y} = \widehat{D}_{w,y} \cdot B_y - S^*_{w,y}$$

where the target catch ($\widehat{h}$) is induced by the expected distribution ($\widehat{D}$), biomass (*B*) and the optimal escapement biomass (*S*) at year *y*.

2.10. Cost of delaying cooperative management

The present value (*PV*) of the net economic benefits from fishing by the three countries over the 35-year time horizon of the 10,000 simulations is taken as the measure of economic performance. The average of the present value of benefits received by each country is calculated as:

$$\overline{PV}_w = \frac{1}{10,000}\sum_{k=1}^{10,000} PV_w^k \tag{10}$$

where PV_w^k is the net present value for country, *w*, in the k^{th} simulation:

$$PV_w^k = \sum_{y=1}^{35} d^{y-1} \cdot \pi_{w,y}^k \tag{11}$$

We define the i^{th} year delay of cooperative management in the 35-year projection as:

1) From the first to i^{th} year, all countries engage in non-cooperative management,

2) From $i^{\text{th}}+1$ year to 35th year, all countries engage in cooperative management.

The cost of delaying cooperative management for a country, *w*, ($C_{w,i}$) is assumed to be the difference between the present value of benefits under cooperative management over the entire 35-year period and the $i^{\text{th-}}$year delay in non-cooperative management.

$$C_{w,i} = \overline{PV}_{w,35} - \overline{PV}_{w,i} \tag{12}$$

The 35-year time horizon is assumed as the management time horizon in this study. The total cost to the three countries is defined as the sum of the individual cost to the three countries:

$$C_{Total,i} = C_{Canada,i} + C_{U.S.,i} + C_{Mexico,i} \tag{13}$$

This is a generalization of many earlier results of game theoretic models of fishing, where the difference in net benefits under cooperative and non-cooperative management (i.e., the loss due to non-cooperation throughout the time horizon of the analysis) are expected to motivate cooperation (e.g., Sumaila, 1997).

2.11. Biological indicators - the conservation risk

We assume that the conservation risk, or the probability that the biomass falls below 10 % of the initial biomass (1.2 million tonnes), happens at least once over the 35-year time horizon. Ten percent was chosen because of the biological resilience of Pacific sardine is high as shown by its history (less than 5,000 tonnes of a Pacific sardine during 1970s).

$$P(B_y^k < 0.1B_0) = \frac{1}{10,000} \sum_{\mathrm{k=1}}^{10,000} I(B_y^k < 0.1B_0) \tag{14}$$

where $I(B_y^k < \varphi B_0)$ is an indicator that equals 1 if the biomass during year y in simulation k is less than φ (0.1) of the initial biomass.

3. Results

The results of costs of delaying cooperative management with a discount rate of 0.05 are presented in Tables 1 and 2, respectively. Since a zero-year delay in cooperative management implies cooperative exploitation for all years, the cost for the zero-year delay is zero. The 35th-year delay implies that all countries are engaged in non-cooperative management through all years. The maximum total cost of 88.1 million USD occurred at the 25th-year of delay (Table 1) for the time-increment SST scenario, and 80.6 million USD for the time-decrement SST scenario (Table 2); the costs of delaying cooperative management then decreased beyond the 25th-year of delay.

The total cost for the time-increment and decrement SST scenario showed a ‘concave’ trend. This implies that cooperative management should not be attempted if the expected delay in implementing cooperative management were to exceed 25 years. This is because the total cost of delay is the sum of all the three countries’ costs, the significantly high cost for the U.S. offsets the economic benefits of engaging in non-cooperative behavior for Canada and Mexico. With more delay in cooperative management, 1) there is less benefit from fewer years of cooperative management; and 2) the cost to rebuild to the optimal escapement biomass from a depleted stock level would result in high conservation risks in later years (see Table 3 and 4). With combinations of these elements, a ‘concave’ type trend appeared. It is, however, certain that the delay in cooperative exploitation increases the conservation risk proportional to the years of delay, for all discount rates and both ocean climate scenarios (Table 3 and 4).

[Table 1 HERE]

[Table 2 HERE]

[Table 3 HERE]

[Table 4 HERE]

In both ocean climate scenarios, the most distinguishing feature is the significant costs for the U.S (Table 1 and 2). As the major country, under non-cooperative management, the U.S. has an incentive to maintain the optimal escapement biomass for future benefits by setting low or even zero catch, while the other two countries benefit from such U.S. conservation efforts. After any delay, once the three countries are engaged in cooperative management, the U.S. engages in rebuilding the biomass up to the optimal escapement biomass, for future benefits. As it turns out then costs to the U.S. to rebuild or maintain the optimal escapement biomass are incurred regardless of how many years of delay there are in cooperative management. On top of the cost of rebuilding the biomass for all years, there is also economic loss due to an inability to achieve optimal escapement biomass, an added cost for the U.S.

While the cost to the U.S. is significant, the costs to Canada and Mexico appear to be negative except for Canada, for more than a 20th -year of delay in the time-increment SST scenario (Table 1). The negative cost implies that Canada and Mexico benefit by delaying cooperative management. For SSTs up to 19.5 °C in the time-increment SST scenario and down to 16.7 °C in the time-decrement SST scenario, Canada and Mexico are always minor countries, i.e., they always have less than half of the biomass distribution within their waters (Figure 2). As minor countries, Canada and Mexico benefit from engaging in non-cooperative rather than cooperative behavior. Under non-cooperative management, the conservation efforts by the U.S. to maintain the optimal escapement biomass bring benefits to Canada and Mexico.

In the time-increment scenario with r =0.03 and 0.05 (Figures 3), the delay of cooperation beyond the 10th and 20th years respectively left Canada with the cost of rebuilding up to the optimal escapement biomass. This is because the stochastic time-increment SST scenario shifted biomass towards Canada and made Canada the major country, hence the cost of rebuilding a biomass to the optimal escapement biomass appears as costs for Canada (e.g., 3.7 million USD for a 25th-year of delay in Table 1). The results of the time-decrement scenario with r=0.03 showed a similer result for Mexico because the stochastic time-decrement SST scenario shifted the biomass distribution into Mexican waters (Figure 4).

[Figure 3 HERE]

[Figure 4 HERE]

Sensitivity analysis using different discount rates (r=0.03, 0.05, 0.1 and 0.15) showed identical trends for the time-increment and time-decrement scenarios except for the costs to Canada when r=0.03 and r=0.05 in the time increment SST scenario, and Mexico when r=0.03 in the time decrement SST scenarios (Figures 3 and 4). Due to the discounting of the future net benefits, one would expect less net benefit and less cost for delaying cooperation for higher discount rates (e.g., r = 0.15). This is explicitly confirmed in the modeled total costs and the costs for the U.S. for both time-increment and time-decrement SST scenarios. Both ocean climate scenarios showed the same trends for the total cost, the costs to the U.S and Mexico as well as for the conservation risk (Tables 3 and 4). At the end of the 35-year simulations, under both the time-increment and time-decrement scenarios SSTs are expected to be 19.5 ^{o}C and 16.4 ^{o}C, respectively, without stochastic disturbance (see Equation (6)). In this case, the U.S. emerges as the major country with more than half of the biomass distribution (Figure 2).

In both climate scenarios, the cost of delaying cooperation with r = 0.15 yielded less negative results than when r = 0.1 for Canada and Mexico (Figures 3 and 4). In addition to the net economic benefits of a higher discount rate, higher discounting drives the optimal escapement biomass level lower. The lower escapement biomass set by the U.S. leads to less spillover benefits for Canada and Mexico, which then results in less negative costs for Canada and Mexico. The conservation risks shown in Tables 3 and 4 confirmed a lower biomass under $r = 0.15$ relative to other discount rates in both ocean climate scenarios.

4. Discussion

The purpose of this study was to compute the cost of delaying cooperative management of Pacific sardine in the CCE under the influence of ocean climate variability.

Two significant costs of delaying cooperative management are, 1) loss of the economic benefit that can be gained by maintaining the optimal biomass for future benefits; and 2) the costs incurred to rebuild stocks to the optimal escapement biomass once they are depleted by an extended period of non-cooperative management. As the years of delaying cooperative management increased, more drastic conservation efforts were required to replenish the fish stock to the optimal escapement biomass. The U.S. bears the cost of restoration because of its status as the major resource holder under both ocean climate scenarios.

The study clearly suggested that Canada and Mexico have less incentive to engage in cooperative management on the grounds that these countries actually benefits from non-cooperation. On the other hand, this study demonstrated that the U.S. has significant incentive to engage in cooperative management immediately.

As Miller and Munro (2004) noted, the predictions of the impacts on a fish stock and the economic benefits to participants in shared fish stock fisheries are keys for cooperative behavior. Our results demonstrated the potential cost incurred from delaying cooperative management given ocean climate variability. Although it is not the precisely defined cost, our estimated cost of delaying cooperative management and the conservation risk would be information useful toward engaging the three countries in cooperative management. Miller (2007) suggests that a key in cooperative management of a transboundary fish stock is to maintain each country’s incentives to cooperate, despite changes in fish availability. The significant costs incurred by the major country for resource share (the U.S.) provides a strong incentive for cooperative management; conversely, the negative costs for minor countries for resource share

(Canada and Mexico) explicitly suggest that there is less incentive for them to cooperate. Our results suggested that a key for achieving cooperative management of a transboundary fish stock under ocean climate variability, establishing the means by which a major country for resource share can motivate minor countries for resource share to engage in cooperative fishing behavior.

5. Conclusion

In this study, simulations of a three-country transboundary fishery for Pacific sardine, which incorporate ocean climate variability in the CCE, revealed the potential cost of delaying cooperative management by participants in the fishery.

Our choices for fishery resource management with ocean climate variability are always a combination of reducing fishing pressure and increasing the capacity of fishing participants to cope with the impacts of changes to a fish stock. While a sole resource user of a fish stock is expected to have much more control over the conservation and management response to such circumstances, this situation presents much more of a challenge when conservation and management of the stock involves multiple competing countries with diverse economic incentives. Our study revealed that most of the cost of delaying cooperative management is incurred by the country that has the dominant share of a transboundary fish stock. Hence, that is the country that should take the initiative to bring about cooperative management.

Looking to the past, in the late 1940s, Pacific sardine landings started to decline dramatically and the sardine stock shifted southward. The subsequent collapse of Pacific sardine fishery has been attributed to a combination of overfishing and the occurrence of a cold regime in the CCE. During the 1970s, all Pacific sardine fisheries were closed in the U.S. As the CCE may be in the initial stages of a new cold regime, this study concludes that vigorous action towards cooperative management is needed now, before the cost of delaying cooperative management of the Pacific sardine resource reflect what was experienced from the 1940s through the 1960s.

It is noted that the far-reaching process of building cooperative fishery management among multiple countries will be extremely challenging due to political considerations and diverse economic motivations. It is suggested that future studies of cooperative exploitation need to further address the costs and the risks that result from ocean climate variability.

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Figures Captions

Figure 1: Biomass changes of Pacific sardine over time (biomass data from Hill *et al.*, 2009) and the climate regime in the California current ecosystem.

Figure 2: Development of the modeled biomass distribution and carrying capacity in accordance with the SST.

Figure 3: Sensitivities of the cost of delaying cooperative management in the time-increment SST scenario with four discount rates (r=0.03, 0.05, 0.1 and 0.15).

Figure4: Sensitivities of the cost of delaying cooperative management in the time-decrement SST scenario with four discount rates (r=0.03, 0.05, 0.1 and 0.15).

Dear Editor Ecological Economics,

Please find accompanying this letter our paper entitled "The cost of delaying cooperative management of a transboundary fish stock vulnerable to climate variability: the case of Pacific sardine," for possible publication as a scientific article in the *Ecological Economics*.

This paper undertakes the cost of delaying cooperative management of a transboundary fish stock with time variant/asymmetric distribution caused by ocean climate variability. As a case study, we studied Pacific sardine (*Sardinops sagax),* which exhibit extreme decadal variability in abundance and geographic distribution corresponding to climate regime shifts within the California Current Ecosystem. An interest twist here is that Pacific sardine is a transboundary resource that is exclusively caught by Mexican, U.S. and Canadian fisheries. Our study applied a three-agent bioeconomic framework that incorporates environmental effects on Pacific sardine abundance and biomass distribution. Simulations were conducted to evaluate the cost of delaying cooperative managements of Pacific sardine fisheries. Our results showed that the cost of delaying cooperative management is significant for a country having a dominant share, while countries that have minor shares gain economic benefits from delaying cooperative management.

Moreover, we believe that the implications of the results from this paper have potential impacts on current multi-national transboundary fish stock managements under climate variability (or climate change).

The telephone and fax numbers, email and mailing addresses of all authors are shown in the last page. All co-authors contributed substantially to this study and approved the final submission of the manuscript, which is not being submitted elsewhere. This research is funded partly by NOAA Southwest Fisheries Science Center and the Sustainability Governance Project, Center for Sustainability Science, Hokkaido University.
I look forward to receiving your response.

Sincerely yours,
Gakushi Ishimura

Gakushi Ishimura
Center for Sustainability Science, Hokkaido University, Kita-Ku Kita 9 Nishi 8, Sapporo, Hokkaido 060-0809 Japan; Tel: +81-11-706-4530; Fax: +81-11-706-4534;
E-mail: gakugaku@sgp.hokudai.ac.jp

Sam Herrick
NOAA Fisheries Services, Southwest Fisheries Science Center, 3333 North Torrey Pines Court
La Jolla, CA 92037-1022 USA; Tel: +1-858-546-7111; Fax: +1-858-546-7003;
E-mail: sam.herrick@noaa.gov

Ussif Rashid Sumaila
Fisheries Centre, University of British Columbia, AERL, 2202 Main Mall, Vancouver, B.C., Canada, V6T 1Z4; Tel: :+1-604-822-0224; Fax: :+1-604-822-8934;
E-mail: r.sumaila@fisheries.ubc.ca

Figure

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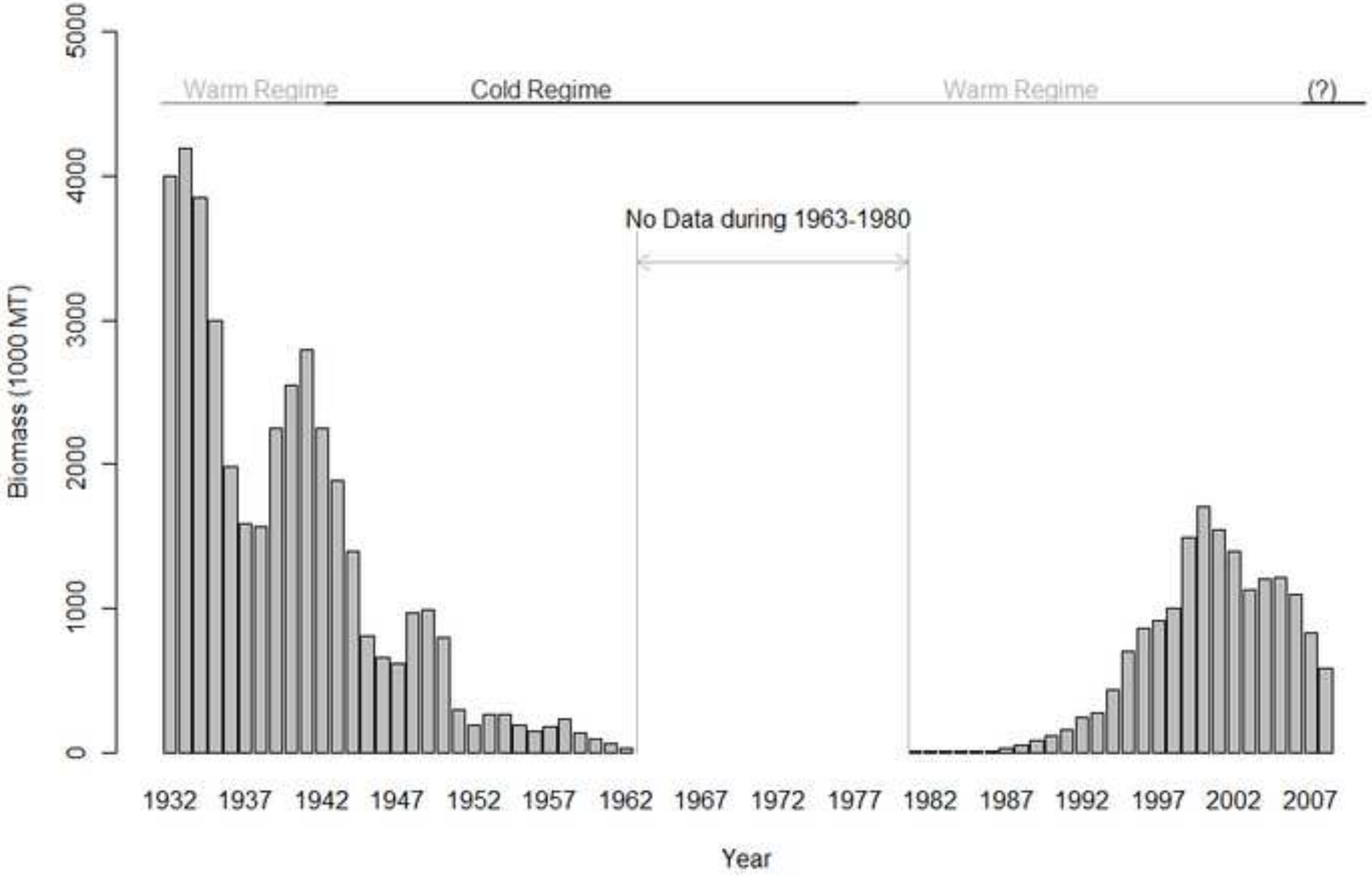

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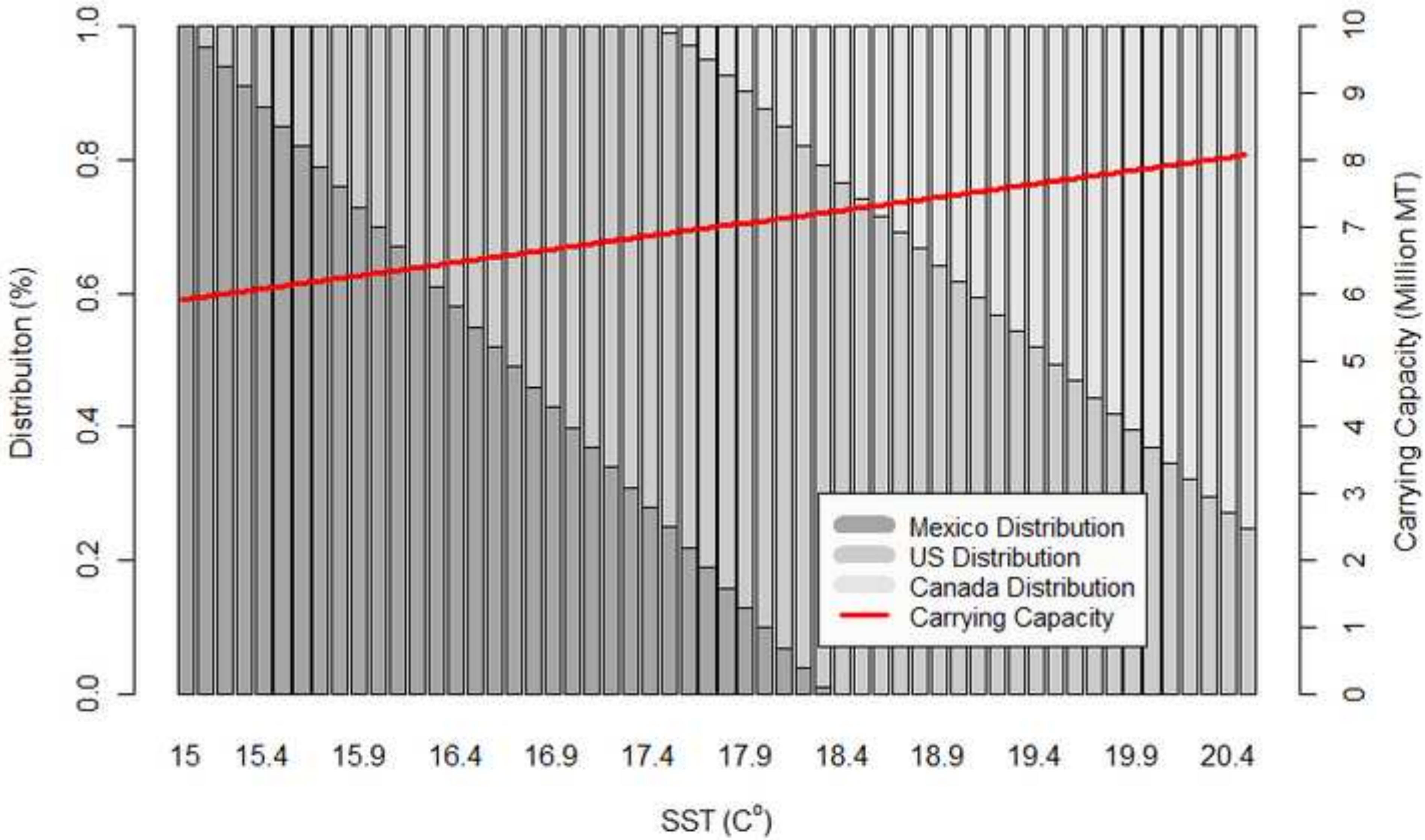

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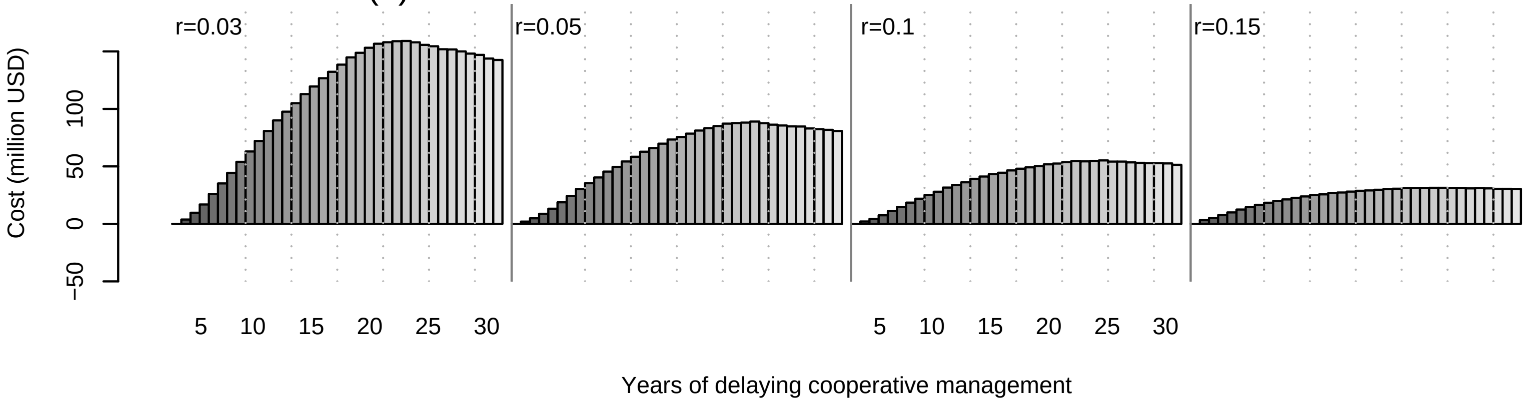

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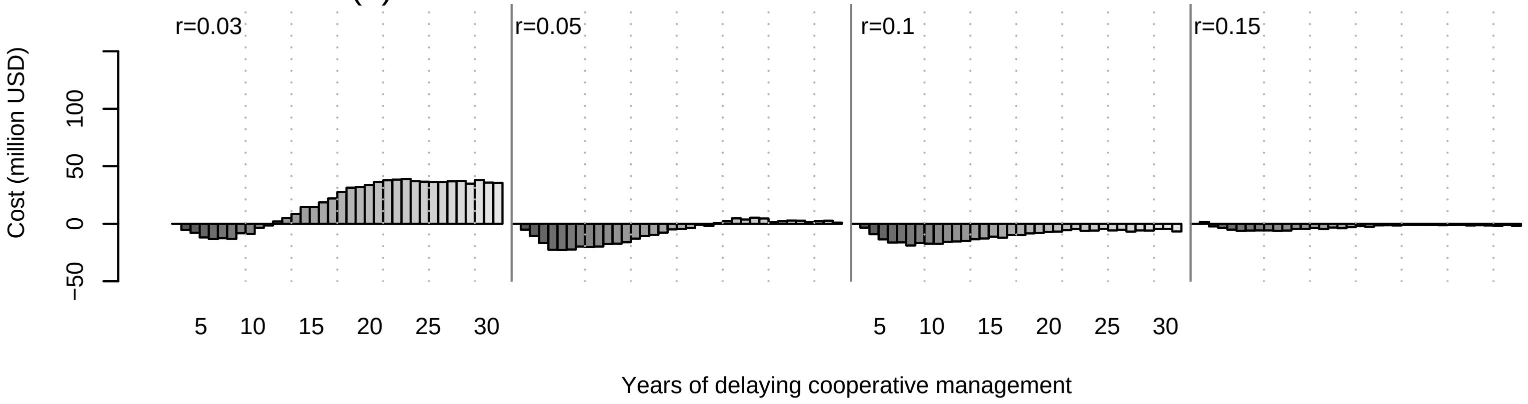

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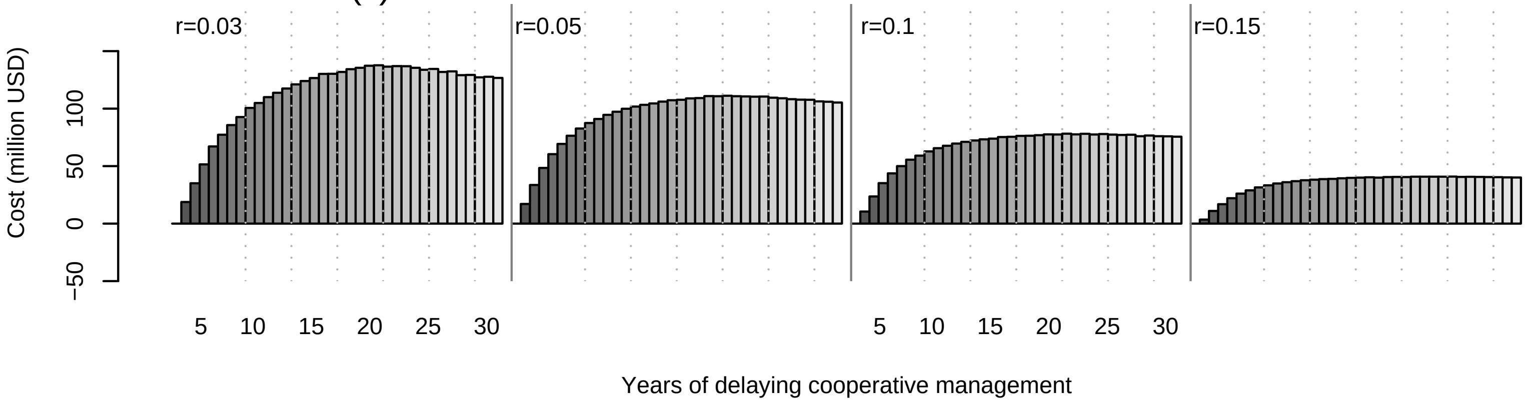

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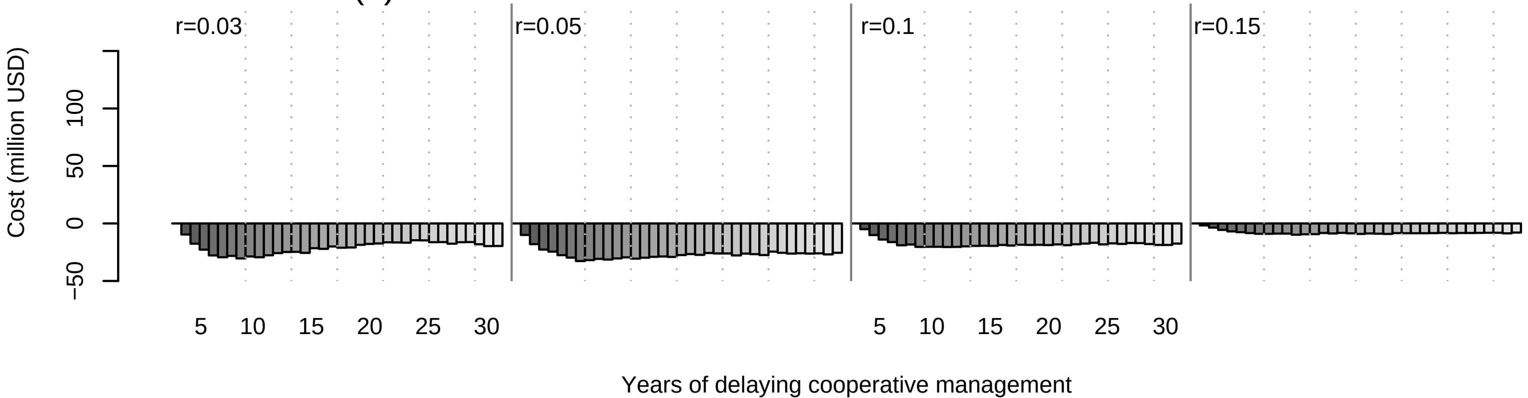

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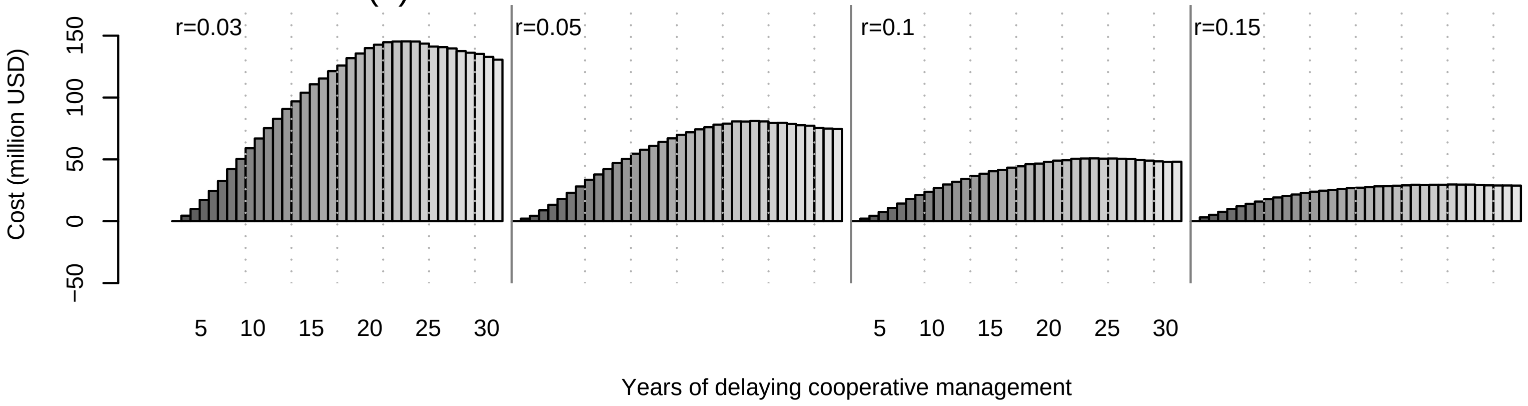

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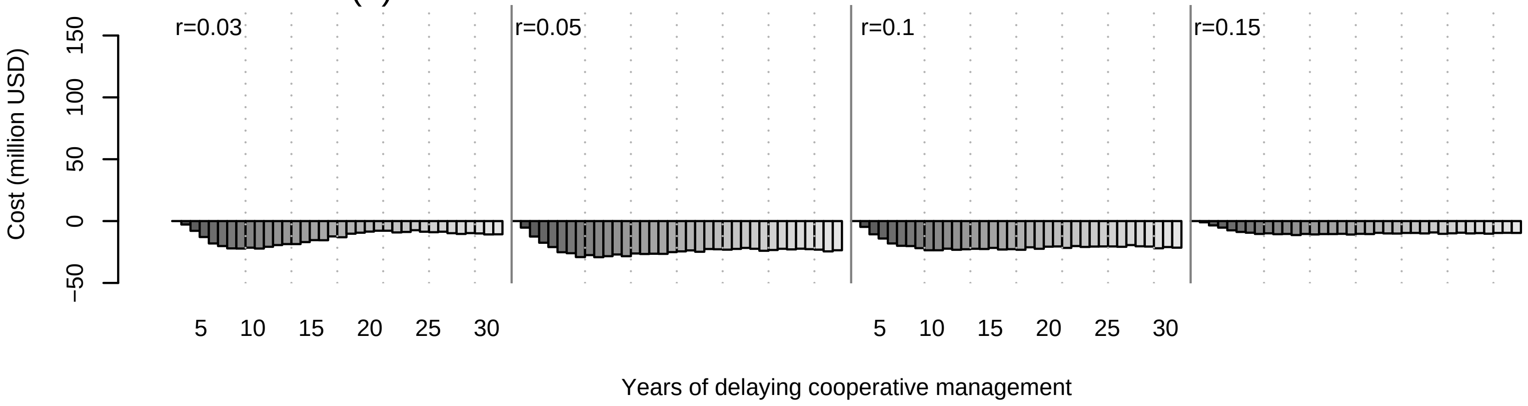

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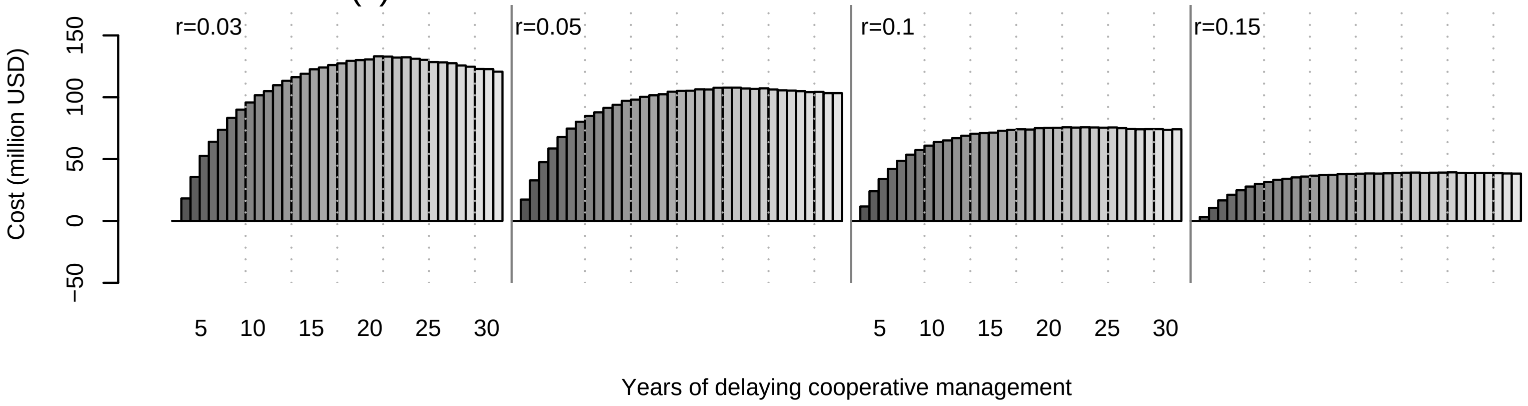

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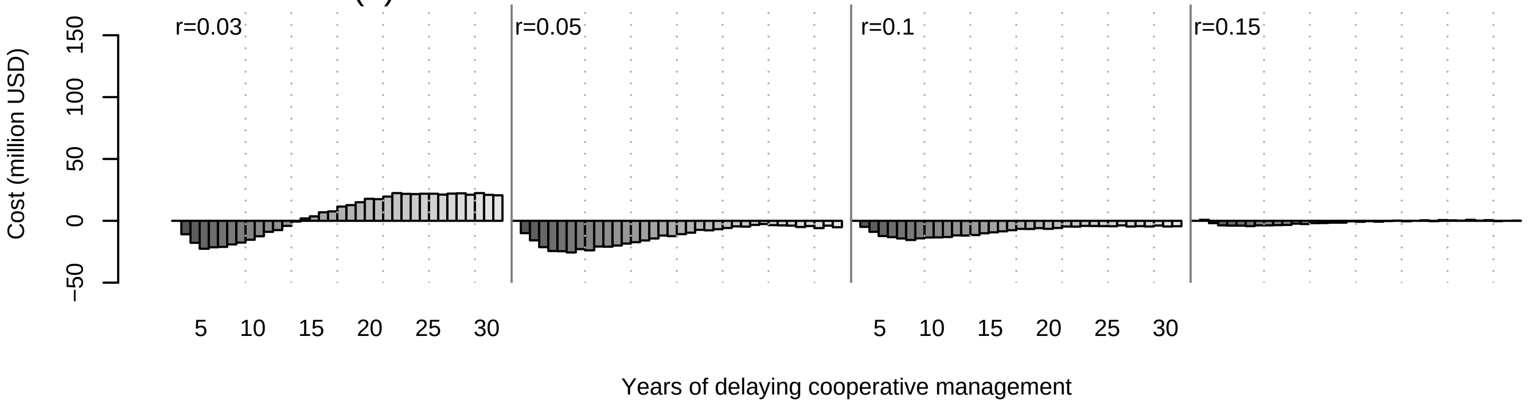

Tables

Table 1: The cost (million USD) of delaying cooperative management to each country separately and collectively in the time-increment SST scenario with discount rates, r=0.05. Note that the total payoffs slightly may differ from the sum of the three countries' costs due to rounding.

	Cost of i^{th} -year delay of cooperative management in the 35-year projection (million USD)							
	1	***5***	***10***	***15***	***20***	***25***	***30***	***35***
Total	2.0	18.8	45.5	66.0	81.2	88.1	84.8	81.8
CAN	-5.1	-22.9	-17.6	-9.6	-0.8	3.7	2.8	2.7
US	17.1	69.3	94.6	104.5	109.2	110.5	108.2	106.0
MX	-10.0	-27.6	-31.4	-29.0	-27.3	-26.2	-26.2	-26.9

Table 2: The cost (million USD) of delaying cooperative management for total and each country in the time-decrement SST scenario with discount rates, r=0.05. Note that the average total payoffs slightly may differ from the sum of the three countries' costs due to rounding.

	Cost of i^{th} -year delay of cooperative management in the 35-year projection (million USD)							
	1	***5***	***10***	***15***	***20***	***25***	***30***	***35***
Total	2.1	18.0	42.1	60.9	74.3	80.6	78.5	74.5
CAN	-5.3	-25.2	-28.4	-26.4	-24.8	-21.7	-22.9	-23.6
US	17.3	67.8	91.4	101.6	106.4	107.1	85.9	103.3
MX	-10.0	-24.6	-20.9	-14.3	-7.3	-4.7	-3.9	-5.2

Table 3: The conservation risk (%) for the time-increment SST scenario - probability that the biomass falls below 10 % of the initial biomass (1.2 million tonnes) at least once over the 35-year simulation.

Discount rate	*Conservation index of delaying i^{th} –year in cooperative management (%)*							
	1	***5***	***10***	***15***	***20***	***25***	***30***	***35***
0.03	0.0	1.6	5.1	13.8	23.7	32.3	39.2	44.0
0.05	0.0	1.6	5.3	13.4	24.3	33.0	38.7	43.8
0.1	0.0	2.2	8.1	18.2	27.9	36.8	43.0	48.3
0.15	0.0	4.3	16.3	30.7	41.3	48.5	53.9	58.3

Table 4: The conservation risk (%) for the time-decrement SST scenario - probability that the biomass falls below 10 % of the initial biomass (1.2 million tonnes) at least once over the 35-year simulation.

Discount rate	***Conservation index of delaying i^{th} –year in cooperative management (%)***							
	1	***5***	***10***	***15***	***20***	***25***	***30***	***35***
0.03	0.0	1.4	5.2	13.9	22.5	31.1	37.5	41.6
0.05	0.0	1.6	5.6	14.2	23.4	31.6	38.2	42.4
0.1	0.0	2.2	8.0	18.7	27.9	36.6	41.7	46.6
0.15	0.0	4.2	16.4	31.0	41.4	47.4	54.6	56.7