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Abstract

Management of trans-boundary fisheries is a complicated problem with biological, legal, economic and political implications. We propose a simple stochastic differential-equation model to describe a biopolitical consensus view of fish stock dynamics. Estimates of the drift and diffusion terms of 3 stochastic differential equations are obtained using data from the southern bluefin tuna (SBT) fishery with a method based on the Kolmogorov-Smirnov statistic. We refer to these estimated equations as alternative biopolitical consensus views of SBT stock dynamics. Each of these is used to generate a time series of optimal harvest that achieves the objective of maximising the present value of expected fishery returns. These time series of optimal harvests are then compared to actual harvests for the period 1981-1997.

Acknowledgements

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1. Introduction

In 1995, guidelines for the management of transboundary fisheries were provided at the United Nations' conference on highly-migratory and straddling stocks (United Nations, 1995). Multilateral negotiations for management of transboundary fisheries remain problematic, however. Differing national positions about productivity and population dynamics give rise to substantially different opinions on the state of fish stocks.

Much has been written in the legal and economics literature about negotiations for managing transboundary fisheries. Recent legal literature has tended to examine the institutions that nation states use to negotiate articles under the Law of the Sea Convention (cf. Hayashi, 1993, 2000; Tayhindro, 1997; de Lone, 1998; De La Fayette, 1998; Boyle, 1999; Barston, 1999; Churchill, 1999; Maric, 2001; Agorau, 2000a, 2000b; Molenaar, 2000; Valencia, 2000; and Ellis, 2001). The economics literature has explored the behaviour of nation states from a game-theory perspective (Clark 1980, Kaitala 1986, Kaitala and Pohjola 1998, McKelvey 1997, Bjorndal *et al.* 1998, Datta and Mirman 1999, Lindroos and Kaitala 2000, and McKelvey *et al.* 2002), and issues ranging from incomplete markets, externalities, non-market values and property rights (Kennedy and Pasternak 1991, Thebaud 1997, Aston 1999, Gazelius 1999, Polacheck *et al.* 1999, Stokke 2000, Campbell *et al.* 2000 and Grafton *et al.* 2000). These provide the foundations for explaining complicated multinational negotiations that have been established to reach agreement on management of transboundary fish stocks.

In the present paper, the focus is the consensus that emerges from the different national positions on the status of a highly migratory stock. We describe this consensus with a stochastic dynamic model of stock dynamics and refer to this as a biopolitical consensus.

2. A Model for Inferring a Biopolitical Consensus View of Stochastic Dynamics

Our point of departure from the transboundary fishery-management literature is to propose a simple stochastic differential equation (SDE) to model what nations perceive to be the population dynamics of a highly-migratory pelagic fish stock. Enumeration of this model comes from fitting fishery catch data, and stock assessments corresponding to each negotiating nations' position, and estimating model parameters using the method of McDonald and Sandal (1999). The results yield what we interpret to be a biopolitical consensus view of the stochastic dynamics of the fish stock. This estimated model gives explicit recognition of both the evolutionary nature of, and the uncertainty involved in, establishing international agreement about the spatial and temporal dynamics of fish species that migrate across national boundaries.

The purpose of this paper is to suggest a possible mechanism for determining harvest rates when considering different opinions about the population dynamics. We do not suggest detailed models of population dynamics or international negotiation processes, either separately or jointly. The data available to us do not support specification of models that have numerous parameters or which can be subjected to strict interpretation. What we acknowledge openly, however, is the importance of dealing simultaneously with systematic and stochastic aspects of forming a view of fish stock dynamics.

The general form of our SDE model is given by

$$dx_t = f(x_t, t)dt + g(x_t, t)dw_t \qquad (1)$$

where x_t is the perceived biomass of the fish stocks at time t, $f(x_t,t)$ is the drift or rate of change in the fish stock over the instant dt, $g(x_t,t)$ is the diffusion or scale of random variation in the perceived fish stock over the instant dt, and dw_t represents the instantaneous change in the standard Wiener process w_t.[1] This equation therefore traces the change in perceived biomass, dx_t, which is made up of a deterministic drift component, $f(x_t,t)dt$, and a stochastic diffusion, $g(x_t,t)dw_t$ component. In the context of multinational management negotiations, the drift reflects beliefs about biomass growth, net of natural and fishing mortality. The diffusion represents uncertainty in beliefs, or doubts, that arise from deficiencies in knowledge about the fish species and the ecosystem in which it lives, as well as an incomplete understanding of the various national negotiating positions.

The estimated solution of equation 1 provides what we interpret to be a consensus view of stock size in biomass, either an absolute measure (in kg) or relative to a benchmark like unexploited biomass. It is important to note that this consensus view relies on the fact that that there is agreement among negotiating nations on the form of the drift and diffusion terms, but disagreement in the relative importance of each. The solution to equation 1 is, in general, a nonlinear function of the parameters of the drift and diffusion terms. The evolution of perceived biomass will therefore be dependent not only on the mean but also on the variance of the stochastic process. Hence the mathematical expectation of the state at any time cannot be obtained simply by

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[1] A standard Wiener process is continuous and Gaussian with independent increments such that $w(0) = 0$, $E[w] = 0$ and $var\ [w_t - w_s] = t\text{-}s$ *for* $0 \leq s \leq t$. Here $E\ [\bullet]$ is the mathematical expectation operator and var $[\bullet]$ is the variance.

omitting the diffusion and working with the resulting ordinary differential equation (see McDonald and Sandal, 1999, for further discussion of this topic).

An important practical issue in evaluating SDEs is the relative importance of the drift and diffusion terms of equation (1). Applied to our biopolitical consensus view of fish stock dynamics, the drift and diffusion terms determine how much perception of the stock dynamics are dominated by known features of the biopolitical system and how much is dominated by uncertainty. In order to address this issue, we examine three of many plausible alternative forms of equation 1 for ease of both interpretation and comparison. Each of the forms examined has a logistic drift term but they differ in the diffusion term. The logistic drift term is analogous to the Schaefer (1954) surplus production model, which considers the population to be an undifferentiated biomass. This type of model relates the biomass gained from recruitment and individual growth to that lost from natural mortality. The first alternative takes the form

$$dx_t = [\alpha x_t(1-\frac{x_t}{k}) - h_t]dt + \beta x_t(1-\frac{x_t}{k})dw_t \qquad (2)$$

where α is the intrinsic growth rate, k is environmental carrying capacity, h_t is harvest rate and β is a diffusion scaling constant. This form can be rearranged to

$$dx_t = x_t(1-\frac{x_t}{k})(\alpha dt + \beta dw_t) - h_t dt \qquad (3)$$

which describes logistic growth with stochastic intrinsic growth rate. This rearrangement not only demonstrates how an apparently complicated error process can be re-interpreted more simply but also allows two interesting biological interpretations of the SDE. The first (equation 2), is that the diffusion, which is the weighted error process, behaves like the drift; that is, variation around the drift is scaled to the drift. This, in essence, is a simple extension from logistic growth in the mean perceived biomass to logistic growth in higher moments (including variance) of perceived biomass. Not only will perceived “average” biomass growth be least at low and high biomass levels, and greatest at mid-range biomass levels, but so too will be the random variation around the perceived trend in growth. Compared to this interpretation, equation 3, however, indicates that the variation around the drift is interpreted to be the result of random variation in the intrinsic growth rate.

The second SDE specification that we examine is of the form

$$dx_t = [\alpha x_t(1-\frac{x_t}{k}) - h_t]dt + \beta x_t{}^2 dw_t \tag{4}$$

where all parameters and variables are defined above.

Equation 4 clearly implies that the drift and diffusion terms evolve differently, the former logistic and the latter quadratic in perceived biomass level. Rearrangement of this equation (equation 5) does not lead to the clear interpretation of stochastic intrinsic growth rate, although it is clear that the random component, which is quadratic in perceived biomass level, depends on the ratio of intrinsic growth rate to carrying capacity.

$$dx_t = (\alpha x_t - h_t)dt - (\frac{\alpha}{k}dt - \beta dw_t)x_t{}^2 \tag{5}$$

The third SDE we consider has linear diffusion in perceived biomass level:

$$dx_t = [\alpha x_t (1 - \frac{x_t}{k}) - h_t]dt + \beta x_t dw_t \tag{6}$$

As for equation 4, rearrangement of equation 6 (equation 7) does not reveal a straightforward interpretation, except that the intrinsic growth rate has a random component that depends on perceived biomass level and carrying capacity.

$$dx_t = -h_t dt + (\alpha(1 - \frac{x_t}{k})dt + \beta dw_t)x_t \tag{7}$$

These equations form the basis for inferring alternative biopolitical consensus views of the stock dynamics of the highly-migratory Southern Bluefin Tuna (SBT).

3. Inferring a Biopolitical Consensus View of Stochastic Dynamics for Southern Bluefin Tuna

The SBT fishery spans the southern oceans between 30°S and 50°S, with most fishing activity relatively close to Australia. The species follows a long migration route, around Australia through large areas of the Indian, Southern and (Western) Pacific Oceans to its major spawning ground in the Timor Sea. Historically most of the fishing for SBT has been carried out by Japanese, Australian and New Zealand vessels, although, more recently, significant fishing effort has been exerted by Korean, Taiwanese and Indonesian vessels. [2]

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[2] More detailed information about this fishery is available in Polacheck *et al.* (1999) and Cox *et al.* (1999)

Management of the SBT fishery is undertaken by the Commission for the Conservation of SBT (CCSBT), whose member countries are presently Japan, Australia and New Zealand. The CCSBT is charged with setting and allocating catch quotas. This has been a difficult task because there is considerable disagreement among member countries about the state of the SBT stock. Indeed, given the negotiating positions of member nations, the CCSBT has failed to reach a binding agreement on quotas since 1997.

One way of resolving disagreements of this type is to provide negotiators with alternative scientific perspectives, not only on the stochastic dynamics of the fish population itself, but also on the perceptions inherent in members' negotiating positions. The model outlined above, along with the estimation methods used to enumerate it, provides a basis for inferring a biopolitical consensus view of the stochastic dynamics of SBT biomass. This, naturally, relies on availability of data that reflect the negotiating positions of member nations.

We focus on the various stock assessments put forward by members of the CCSBT in their deliberations on setting and allocating catch quotas. These stock assessments have been reproduced using Virtual Population Analysis (VPA) by Polacheck *et al.* (1999), under the assumptions and maintained hypotheses of the participating nations. These data constitute 50 alternative age-structured realisations of SBT stock dynamics over the period 1981-1997. They span the range of possibilities suggested by the negotiating positions of the member nations of the CCSBT. We have used age-weight relationships to convert each of these age-structured realisations into biomass time series, which form the basis for our empirical analysis.

In the present paper, we infer a biopolitical consensus view of the stochastic dynamics of SBT involves, first, by using the multiple biomass time series to estimate the parameters of the SDE model represented alternatively by equations 2, 4 and 6. Second, in order to determine whether these estimated SDEs are broadly consistent with the outcomes of CCSBT negotiations, we determine the catch quotas that arise from a possible management response to each of these alternatives. The calculated catch quotas will then be compared and contrasted with actual historical catches.

3.1 SDE Parameter Estimation

A summary of the VPA data from which the model parameter estimates were made is given in Figure 1, and the associated trajectories are plotted in Figure 2. These data appear to span a range of negotiating views on the stock. In particular, data points in the upper left part of Figure 1 represent views of low initial stock size and high productivity, whereas views of high initial biomass and low productivity are indicated in the lower right part of the figure. The three different consensus views defined by the parameter estimates of equations 2, 4 and 6, were made using the method of McDonald and Sandal (1999). This method, based on the Kolmogorov-Smirnov statistic, implicitly weights all national negotiating positions equally and, uses historical catches to quantify the harvest rate, h_t. Estimation involves searching for the set of SDE parameters that yields multiple realisations which most-closely match the available multiple time series.

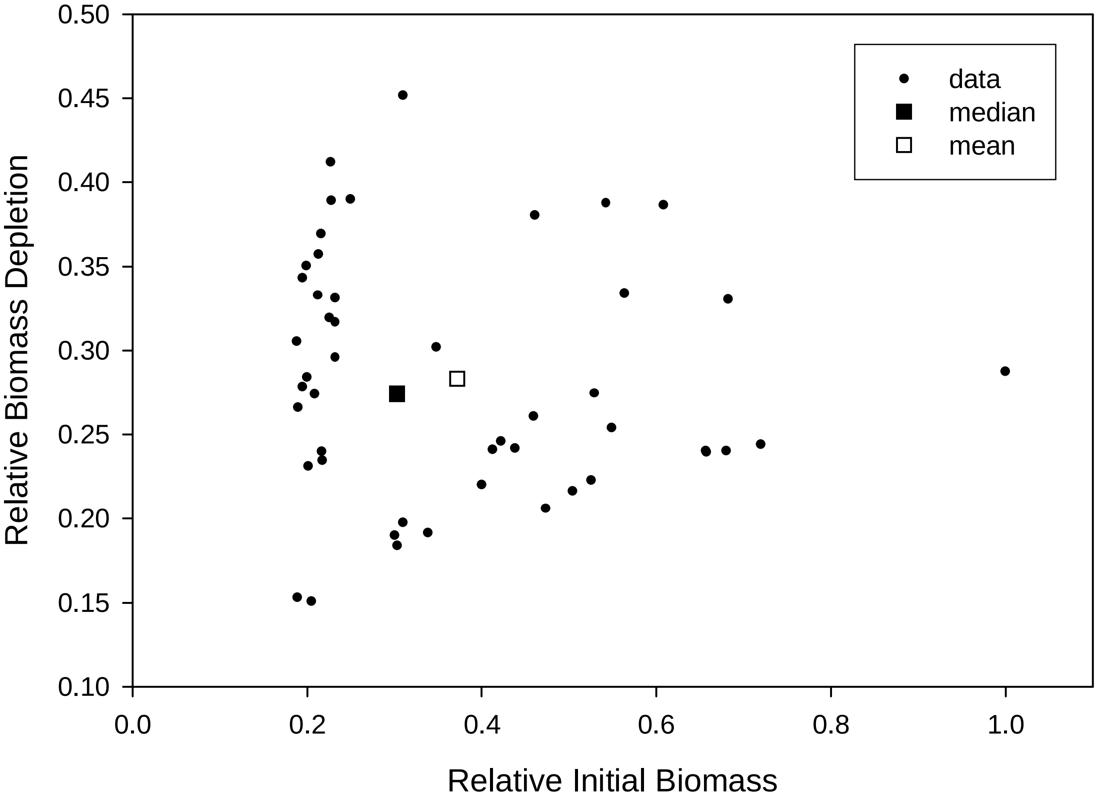

Figure 1. Summary plot for each of the 50 data trajectories. The horizontal axis represents the 1980 biomass of each trajectory as a fraction of the highest conjectured 1980 biomass. This is referred to as the relative initial biomass.The vertical axis represents amount of biomass depleted as the ratio of the 1997 biomass to the 1980 biomass.

For each year in the time series, the empirical distribution function for the order statistics is determined from the VPA stock estimates (Polacheck *et al.*,1999) and is defined as

$$S_m(x) = \begin{cases} 0 & \text{if } x < x_{(1)}, \\ \frac{k}{m} & \text{if } x_{(k)} \leq x < x_{(k+1)} \quad \text{for } k = 1,2,...,m-1 \\ 1 & \text{if } x \geq x_{(m)} \end{cases}$$

where $x_{(1)}, x_{(2)}, ... x_{(m)}$ are the stock estimates for that year, ordered from smallest to largest. Conditional on initial parameter estimates, the SDE is used to generate multiple realisations for each year, of which the distribution of order statistics is defined as

$$S_n(x) = \begin{cases} 0 & \text{if } x < y_{(1)}, \\ \frac{k}{n} & \text{if } \mathrm{y}_{(k)} \leq x < y_{(k+1)} \quad \text{for } k = 1,2,...,n-1 \\ 1 & \text{if } x \geq y_{(n)} \end{cases}$$

where $y_{(1)}, y_{(2)},...y_{(n)}$ are the SDE-simulated stock estimates for that year, in ascending order.

The Kolmogorov-Smirnov two-sample test statistic for each year, *t*, is given by

$$D_t = \max_x \left| S_m(x) - S_n(x) \right| \qquad (8)$$

which, over all years, yields the criterion function for parameter estimation

$$\varphi = \prod_t^T l(D_t) \qquad t\text{=1981,….,1997} \qquad (9)$$

where

$$l(D) = 1 - 8\sum_{i=1}^{v} (-1)^{i-1}(D^2 / n)$$

and

$$v = 1 + \text{floor}(\sqrt{m})$$

Parameter estimates are obtained by maximising this criterion function using a search algorithm in parameter space.

In providing the simultaneous estimation of drift and diffusion parameters, this method facilitates a scientific assessment of both the beliefs and the doubts of participating nations, without consideration of the strategies and tactics involved in stating their negotiating positions. The explicit modelling of uncertainty permits variation in the magnitude of simulated order statistics both contemporaneously and inter-temporally. The greater the variation across national negotiating positions, the more important will be the stochastic (diffusion) component and the less important the trend (drift) in perceived biomass dynamics.

3.1.1 Parameter Estimates

Parameter estimates for equations 2, 4 and 6 are presented in Table 1. The reported standard errors indicate that these estimates are precise, although the plotted trajectories of each estimated equation (Figure 2) reveal substantial differences in matching the data.

Table 1

Parameter Estimates (with Standard Errors) for SDEs.

Parameter	Parameter Estimate (Standard Error)		
	Logistic Diffusion (equation 2)	Quadratic Diffusion (equation 4)	Linear Diffusion (equation 6)
α	0.075 (0.011)	0.080 (0.007)	0.144 (0.018)
k	1.572 (0.105)	1.003 (0.427)	1.573 (0.149)
β	0.503 (0.039)	0.634 (0.053)	0.466 (0.049)

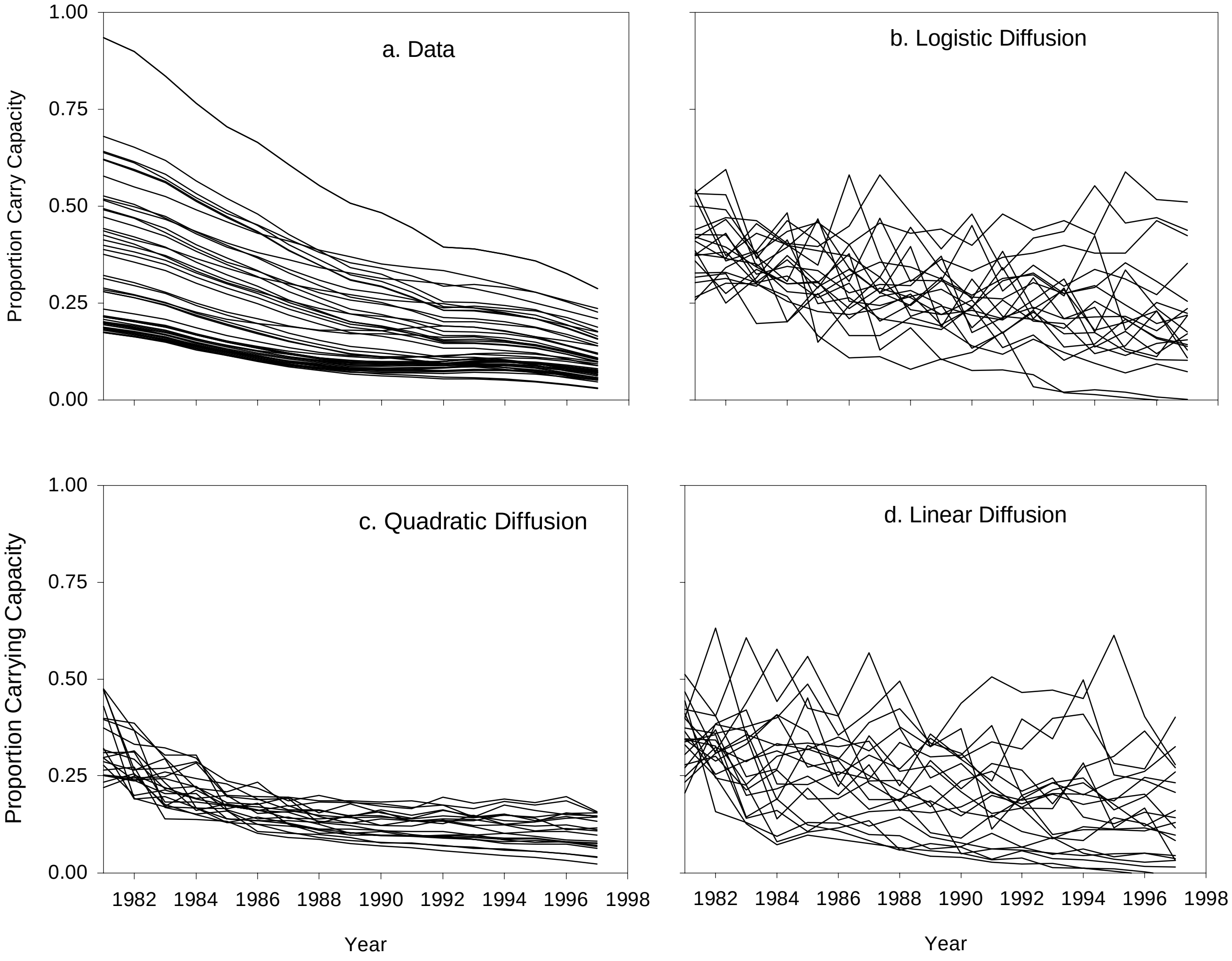

Figure 2. Plots of biomass trajectories: a. VPA estimates spanning the national negotiating positions; b. equation 2 (logistic diffusion); c. equation 4 (quadratic diffusion); and d. equation 6 (linear diffusion).

Figures 3, 4 and 5 show the trajectories for each model of separated drift and diffusion components. The trajectories from equations 2 and 6 (logistic and linear diffusion, Figures 3 and 5) are influenced strongly by the diffusion component. Interestingly, Figure 5 reveals that equation 6 admits a rapidly increasing drift, moderated by a large diffusion with a negative bias. Equation 4 (quadratic diffusion) provides the most compressed set of trajectories in Figure 2 and these are clearly driven by the drift and a low-variation diffusion, as indicated in Figure 4.

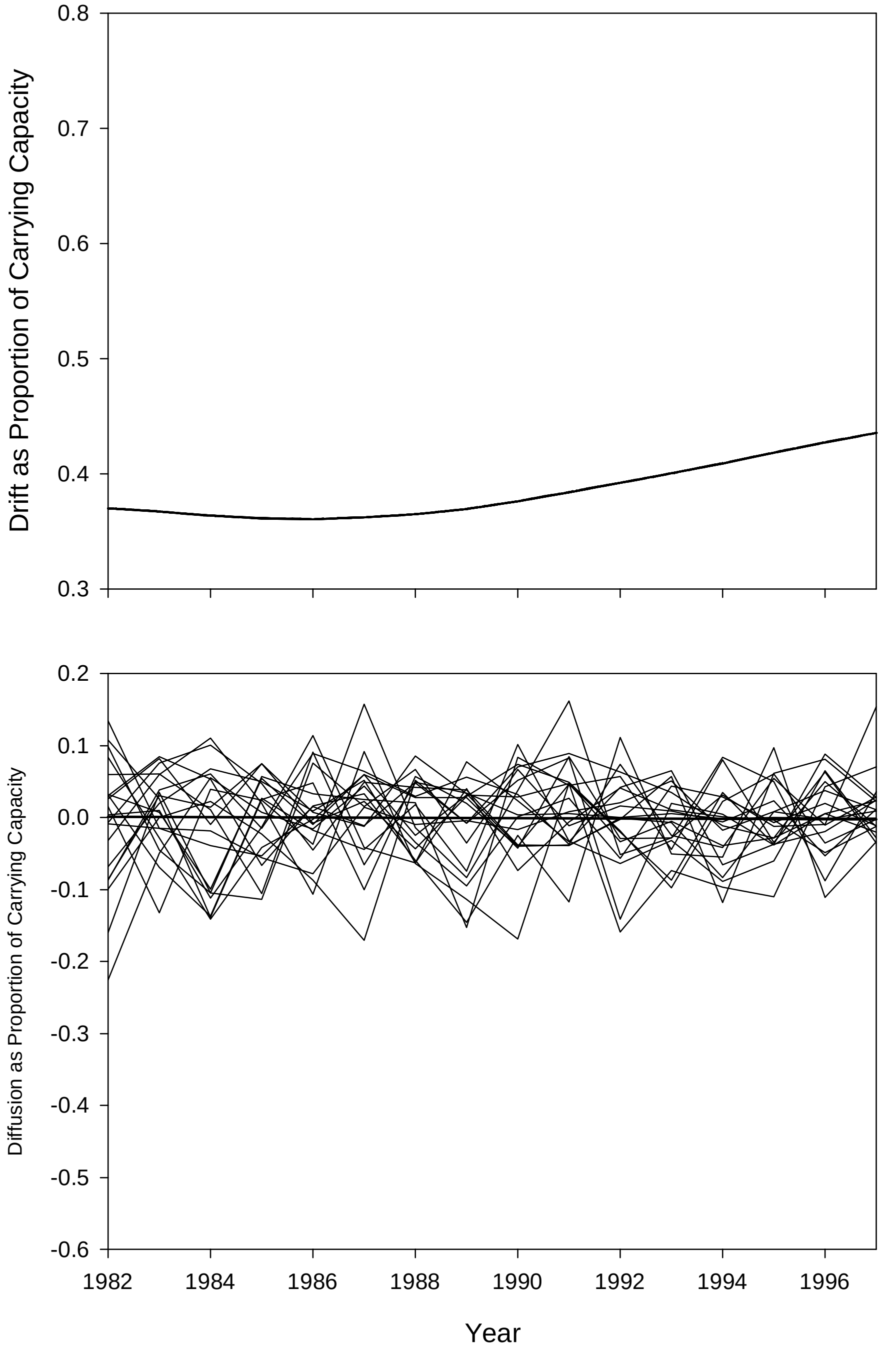

Figure 3. Drift and diffusion for Equation 2 (Logistic diffusion).

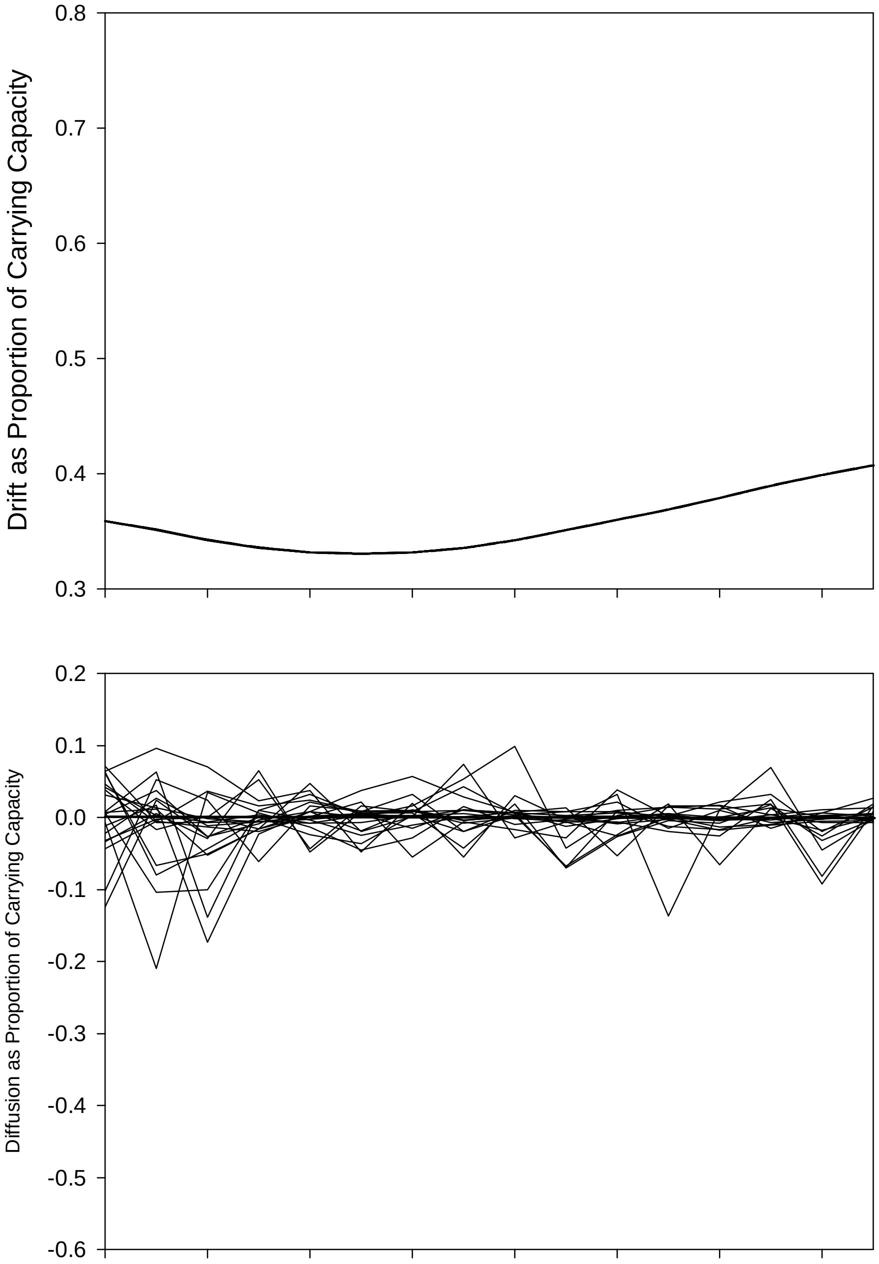

Figure 4. Drift and diffusion for Equation 4 (Quadratic diffusion).

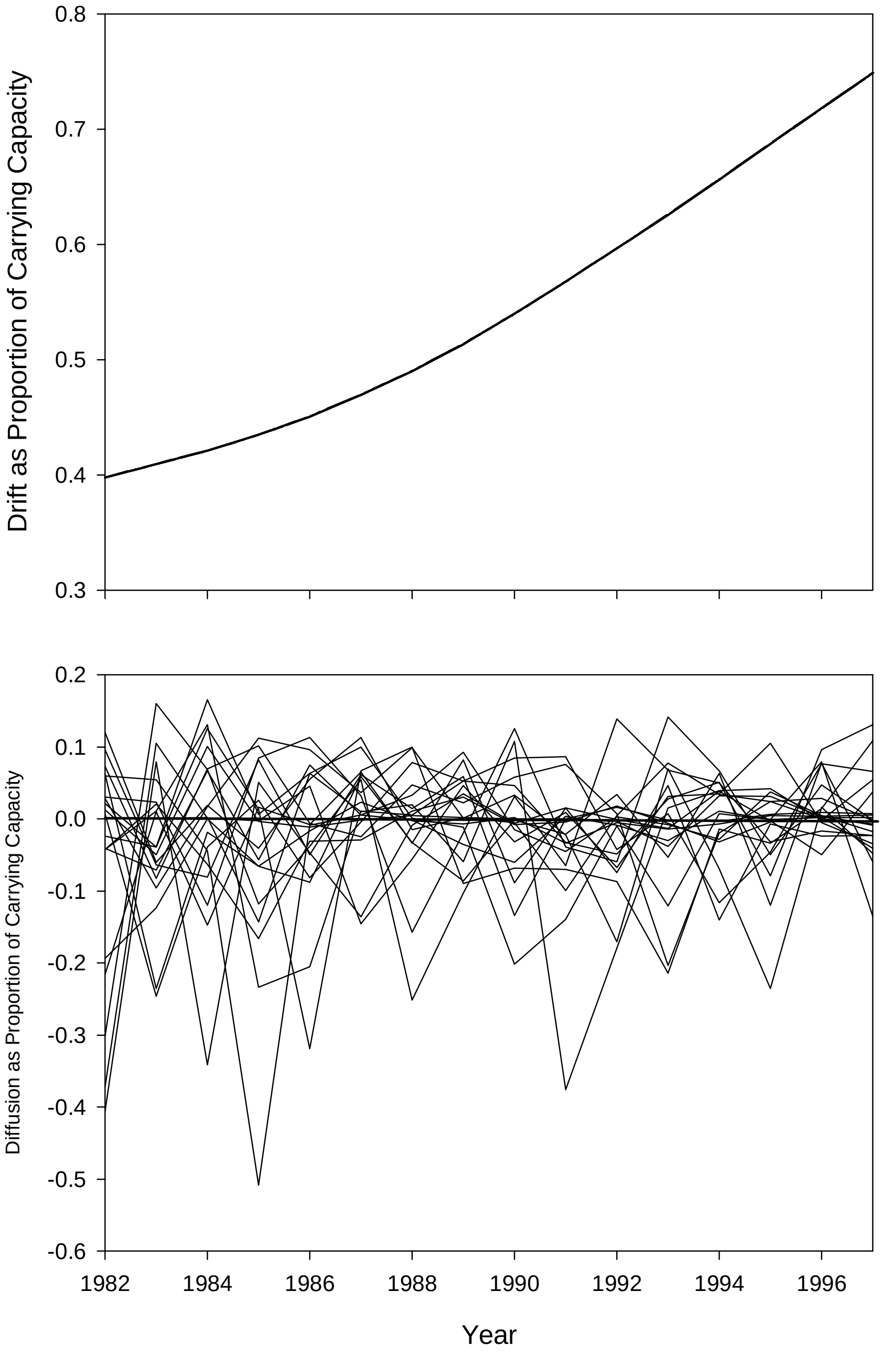

Figure 5. Drift and diffusion for Equation 6 (Linear diffusion).

The differences among the estimated equations evident in Figures 2-5, are substantial, representing three different views that a biopolitical consensus can take. By examining management response to each, we seek to show how the management action may be sensitive to different consensus views of SBT biomass dynamics.

3.2 Management Response to a Biopolitical Consensus on Stochastic Dynamics

Our examination of management responses involves an optimal harvest rule derived from the objective of maximising the flow of expected discounted net revenue from the SBT fishery, subject to the stochastic dynamics of the fish stock. The optimal harvest feedback rule for a similar problem was derived analytically by Sandal and Steinshamn (1997). In the present paper, however, we adopt a numerical approach because an explicit analytical solution does not exist for the optimisation problem specified below.

The dynamic optimisation problem is

$$V(y) = \max_{h} E\left\{\int_0^\infty e^{-\delta t}\Pi(x_t,h_t)dt\right\} \tag{10}$$

$$x_0 = y$$

$$\prod\ (x_t,h_t) = p(x_t,h_t)h_t$$

$$p(x_t,h_t) = a + (b + \frac{h_t}{x_t^{.01}})I(x_t,d)$$

$$I(x_t,d) = \begin{Bmatrix} x_t, x_t < d \\ d, x_t \geq d \end{Bmatrix}$$

subject to the stock dynamics given by equation 1 and appropriate boundary conditions. E is the expectation operator, δ is the discount rate, V(.) is the optimal value function, and $\Pi(.)$ is the revenue function with p(.), the price function, for each representation of perceived stock dynamics. The revenue function was evaluated using Japanese market data after estimating the parameters reported in Table 2. .

The value function is the solution of the Hamilton-Jacobi-Bellman equation, a non-linear second order partial differential equation. We solve this equation numerically to obtain the optimal policy. The optimal control is in feedback form, i.e. it is only a function of the present stock level. Thus this control maximises the flow of expected discounted net revenue. The optimal feedback policy is the series of catch quotas expressed as harvest rates , that maximise the flow of expected discounted net revenue from the fishery, subject to the stochastic dynamics of the fish stock (equations 2, 4 and 6).

Table 2 Parameter estimates and their standard errors (SE) for the revenue functions appropriate for each SDE specification of stock dynamics

	Logistic		Quadratic		Linear	
parameter	value	SE	value	SE	value	SE
A	-5321.0	1177.2	-8816.3	1773.9	-5825.9	1218.8
B	55271.5	7581.8	115193.8	17015.3	63451.7	8517.0
C	-562834.1	132431.6	-885436.2	226454.3	-629150.5	143641.7
D	.2223		.1371		.2028	
R^2_{adj}	0.789		0.762		0.796	

The numerical method that we use involves approximating the continuous process by discrete controlled Markov chains (Kushner and Dupuis, 2001). With the revenue function discretised, the continuous problem is reduced to a discrete problem that can be solved by policy iteration methods (Kushner and Dupuis, 2001: Bertsekas, 1999). This solution converges to the solution of the continuous problem and yields the sought-after optimal harvest rates.

Figures 6-8 display the relationship between stock and optimal harvest for equations 2 (logistic diffusion), 4 (quadratic diffusion) and 6 (linear diffusion) , for several discount rates (2,5,7 and 10%). For ease of comparison, actual catches and their corresponding stocks (enumerated from equation 2 or 4 or 6) are also displayed, as are the estimated deterministic growth functions of the stock (the drift).

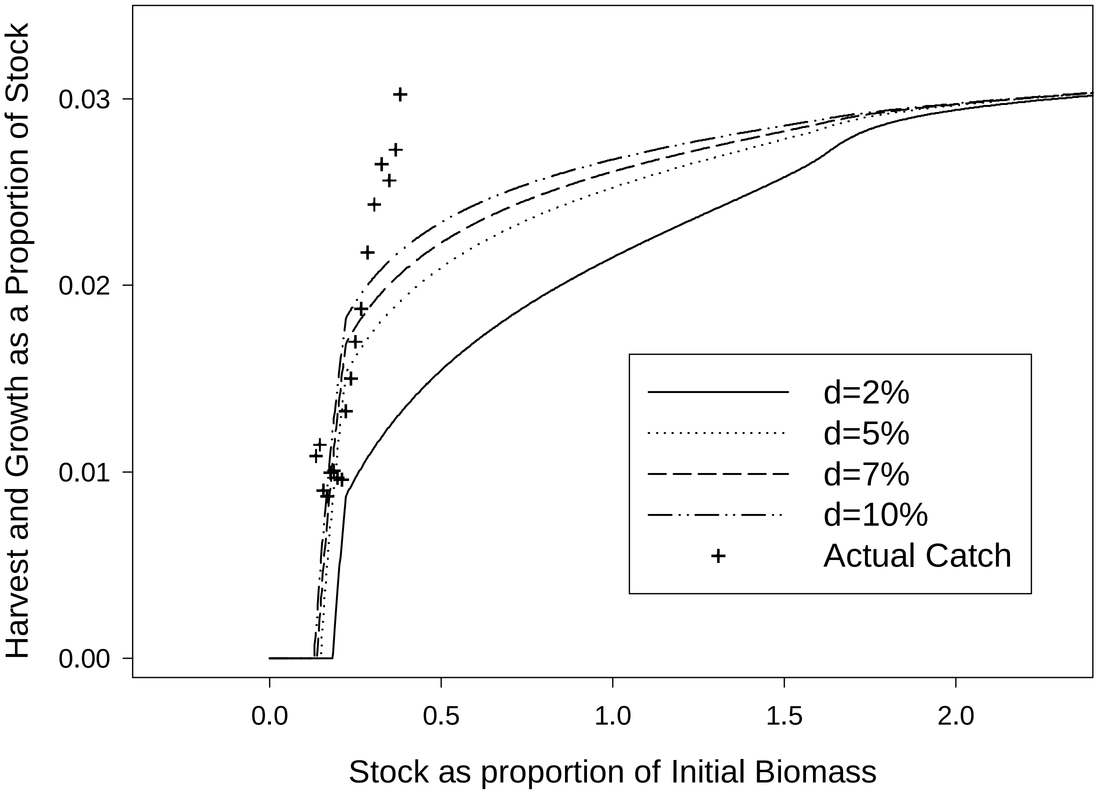

Figure 6. Optimal harvest for discount rates 2%, 5% 7% and 10%, actual harvest for equation 4 (logistic diffusion) as a function of stock size.

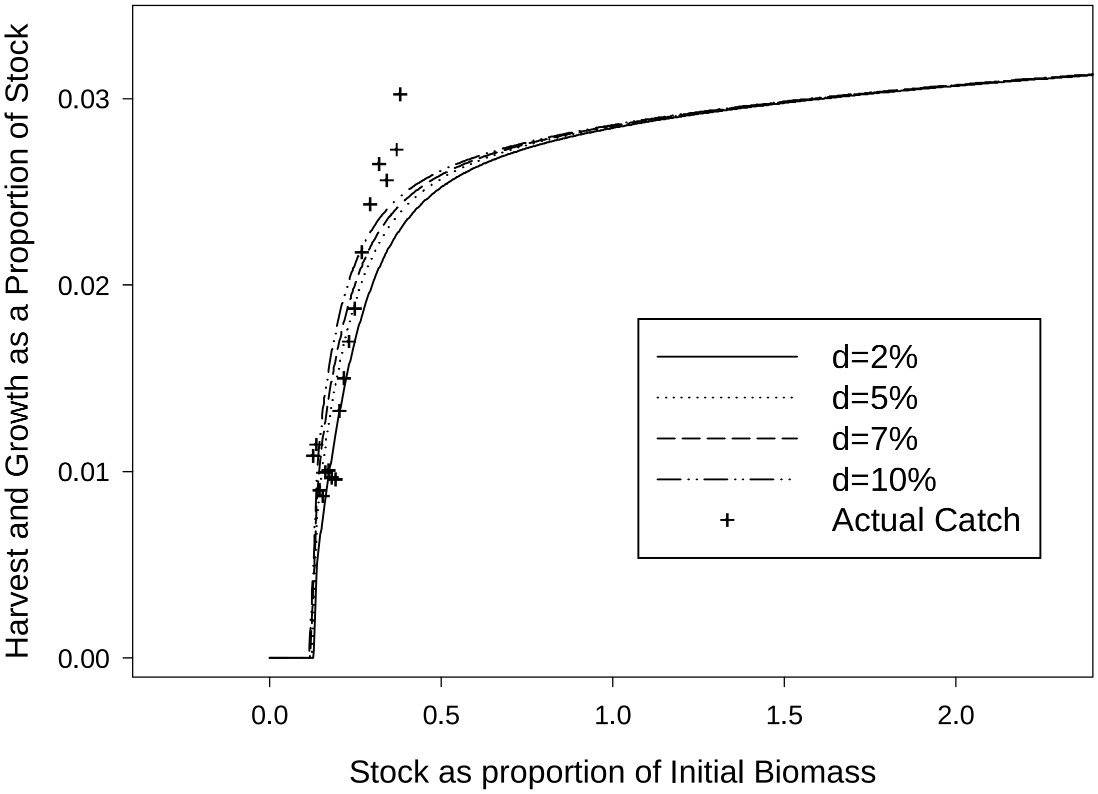

Figure 7. Optimal harvest for discount rates 2%, 5% 7% and 10%, actual harvest for equation 4 (quadratic diffusion) as a function of stock size.

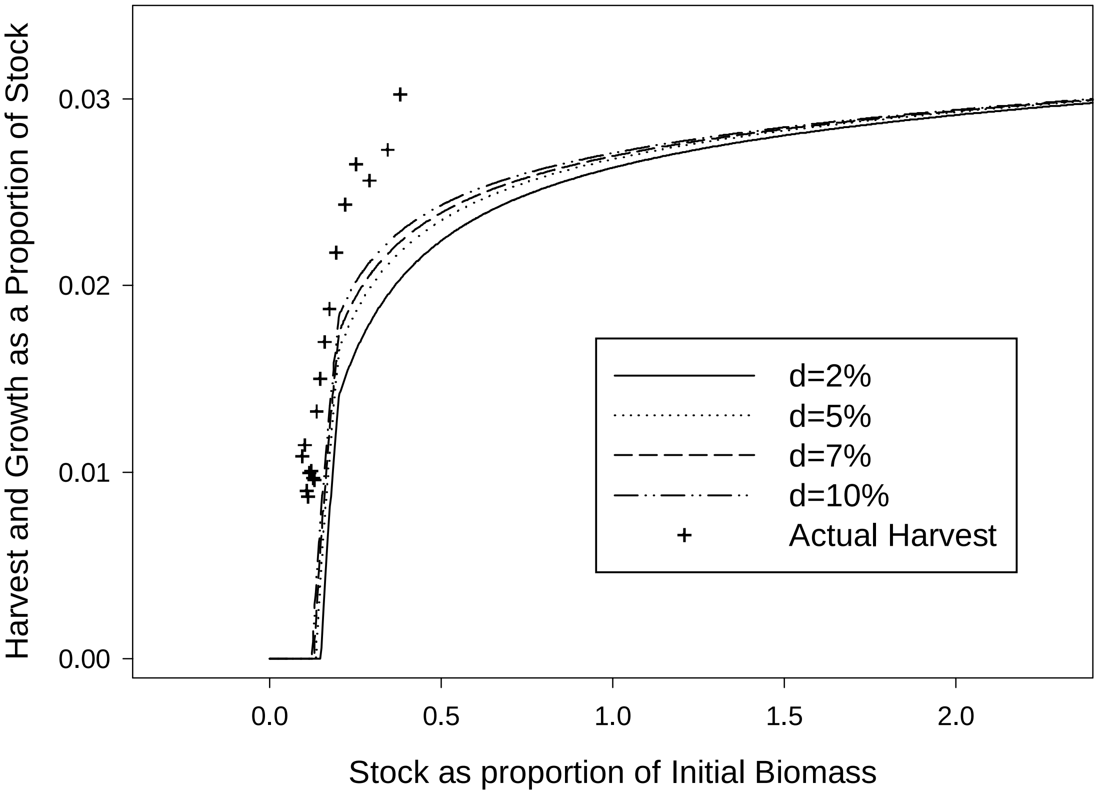

Figure 8. Optimal harvest for discount rates 2%, 5% 7% and 10%, actual harvest for equation 4 (linear diffusion) as a function of stock size.

Several observations arise from examining these figures. First, for each biopolitical consensus view of the stock dynamics, increasing the discount rate shifts the optimal harvest curve to the left, until it converges towards a common moratorium stock level (that is, the stock level at which optimal harvest is zero). Second, increasing the magnitude of the diffusion relative to the drift, such as from equation 4 (quadratic diffusion) to equation 6 (linear diffusion), increases the moratorium stock level, in a fashion similar to that observed with decreasing discount rate. Third, for large stock levels the optimal harvest is similar for all estimated equations and discount rates. Fourth, low discount rates and larger-magnitude diffusions in the present case yielded more precautionary optimal harvest rates. Fifth, in combination with the logistic drift three forms of the diffusion term span the national negotiating positions which range from a combination of high productivity and modest virgin biomass to a combination of low productivity and large virgin biomass.

Given that the alternative SDE forms in this paper were chosen somewhat arbitrarily, it is inappropriate to recommend only one for management purposes. It is sensible, however, to view them as a group to determine whether the historical catches, that arose under the auspices of the CCSBT, are similar to the optimal harvest rates enumerated from the optimisation problem posed in equation 10, subject to the estimated equations 2, 4 and 6. We make such a comparison to check whether any of our proposed consensus views of stochastic dynamics merit further examination in the context of an operating transboundary fishery.

Figures 6-8 reveal a consistent pattern of optimal harvest rates that are well within the range of historical catch rates. At low discount rates the optimal harvests are below historical catches, particularly at high and very low stock levels. Also of note are the significant historical catches at or below the moratorium stock level for all discount rates and for each of the SDE forms examined. At intermediate stock levels, optimal harvest rates are broadly consistent with historical catch rates. The proposed method for inferring a biopolitical consensus view of stochastic dynamics deserves further consideration for practical application to the management of transboundary fisheries such as the SBT fishery. Not only does the method offer a new input into reaching agreement on perceptions of the state of the fish stock, what is proposed herein also offers a mechanism for enumerating catch quotas as part of implementing management decisions.

4. Conclusion

A simple SDE model has been proposed for inferring a biopolitical consensus view of fish stock dynamics from a collection of different national negotiating positions and historical catch data. Estimates of the drift and diffusion terms of three SDEs have been obtained using data from the SBT fishery with a method based on the Kolmogorov-Smirnov goodness of fit statistic (McDonald and Sandal 1999). These estimated equations are interpreted as representing alternative biopolitical consensus views of SBT stock dynamics.

The estimated SDEs were each used in combination with a management response model to generate optimal harvest rates as a proportion of stock. The optimal harvest rates were then compared to actual harvests recorded for SBT over the period 1981-1997.

Although the empirical results cannot be interpreted as being general in any sense, it appears that the fitted SDEs yield optimal quotas that are reasonably close to historical catches, over a range of discount rates. Given that the alternative SDEs yield quotas that are plausible, these results indicate that the suggested method for inferring a biopolitical consensus view of stock dynamics has merit and is worthy of further investigation and development for application to transboundary fishery management.

References

Aqorau, T. (2000), "Current legal developments. Pacific Ocean. The draft convention for the conservation and management of highly migratory fish stocks in the western and central pacific ocean", *International Journal of Marine and Coastal Law,* Vol. 15, No. 1, pp. 111-149.

Aqorau, T. (2000), "Illegal fishing and fisheries law enforcement in small island developing states: the pacific islands experience", *International Journal of Marine and Coastal Law,* Vol. 15, No. 1, pp. 37-63.

Aston, J. (1999), "Experience of coastal management in the pacific islands", *Ocean and Coastal Management,* Vol. 42, No. 6-7, pp.483-501.

Barston, R. (1999), "The law of the sea and regional fisheries organisation", *International Journal of Marine and Coastal Law,* Vol. 14, No. 3, pp.333-352.

Bertsekas, D. (1999) "Dynamic Programming and Optimal Control", Athena, Massachusetts.

Bjorndal, T., Kaitala, V., Lindroos, M. and Munro, G. R. (1998) "The management of high seas fisheries", *Work. Pap. Cent. Res. Econ. Bus. Adm.,* pp.19.

Boyle, A. E. (1999), "Problems of compulsory jurisdiction and the settlement of disputes relating to straddling fish stocks", *International Journal of Marine and Coastal Law,* Vol. 14, No. 1, pp.1-25.

Campbell, H. Herrick, S. F Jr. and Squires, D. (2000), “The role of research in fisheries management: the conservation of dolphins in the eastern tropical pacific and the exploitation of southern bluefin tuna in the southern ocean”, *Ocean Development and International Law,* Vol. 31, No. 4, pp. 347-375

Churchill, R. R. (1999), “The Barents Sea loophole agreement: A “coastal state” solution to a straddling stock problem”, *International Journal of Marine and Coastal Law,* Vol. 14, No. 4, pp.467-490.

Datta, M. and Mirman, L. J. (1999), “Externalities, market power, and resource extraction”, *Journal of Environmental Economics and Management,* Vol. 37, No. 3, pp.233-255.

De La Fayette, L. (1999), “The fisheries jurisdiction case (Spain v. Canada), judgment on jurisdiction of 4 December 1998”, *International and Comparative Law Quarterly,* Vol 48, No. 3, pp.664-672.

deLone, E. (1998), “Improving the management of the Atlantic tuna: the duty to strengthen the ICCAT in light of the 1995 straddling stocks agreement”, *New York University Environmental Law Journal.*

Ellis, J. (2001), “The straddling stocks agreement and the precautionary principle as interpretive device and rule of law”, *Ocean Development and International Law,* Vol. 32, No. 4, pp. 289-311.

Gezelius, S. S. (1999), “Limits to externalisation: the EU NAFO policy 1979-1997”, *Marine Policy*, Vol. 23, No. 2.

Grafton, R. Q., Sandal, L. K. and Steinshamn, S. I. (2000), “How to improve the management of renewable resources: the case of Canada’s northern cod fishery”, *Americal Journal of Agricultural Economics* 82: 570-580

Hayashi, M. (1993), “The management of transboundary fish stocks under the LOS convention”, *International Journal of Marine and Coastal Law*, Vol. 8, No.2, pp 245-261.

Hayashi, M. (2000), “The southern bluefin tuna cases: prescription of provisional measures by the international tribunal for the law of the sea”, *Tulane Environ. Law J.*, Vol. 13, No. 2, pp361-385.

Kaitala, V. (1986), “Game theory models in fisheries management – a survey, *in T.Basar, ed., Dynamic Games and Application in Economics,* pp. 252-266. *Lecture Notes in Economics and Mathematical Systems, Springer-Verlag, Berlin.*

Kaitala, V. and Lindroos, M. (1997), “Sharing the benefits of cooperation in high seas fisheries: A characteristic function game approach”, *Foundation for Research in Economics and Business Administration,* Working paper No. 45/1997, Bergen, 28pp.

Kaitala, V. and Pohjola, M. (1988), “Optimal recovery of a shared resource stock: A differential game model with efficient memory equilibria”, *Natural Resource Modeling* 3: 91-119.

Kennedy, J. O. S., Pasternak, H. (1991), “Optimal Australian and Japanese harvesting of southern bluefin tuna”, *Natural Resource Modeling,* Vol 5, No. 2 pp213- 238.

Kushner, H. and Dupuis, P. (2001), “Numerical Methods for Stochastic Control Problems in Continuous Time”, *Springer.*

Lindroos, M. and Kaitala, V. (2000), “Coalition game of Atlanto-Scandian herring”, *International relations and the common fisheries policy (CEMARE Misc. Publ.)* University of Portsmouth, Portsmouth (UK), No. 49 pp171-186.

Maric, B. A. (2001), “Multilateral high-level conference: convention on the conservation and management of highly migratory fish stocks in the western and central pacific ocean, and final act”, *International legal materials. Washington DC,* Vol. 40, No. 2, pp. 277-316.

McDonald, A. D. and Sandal, L. K. (1999), “Estimating the parameters of stochastic differential equations using a criterion function based on the Kolmogorov-Smirnov Statistic”, *J. Statis. Comput. Simul.,* Vol 64, pp. 235-250.

McDonald, A. D., Sandal, L. K. and Steinshamn, S. I. (2002), “Implications of a nested stochastic/deterministic bio-economic model for a pelagic fishery”, *Ecological. Modeling.,* Vol. 149, pp. 193-201.

McKelvey, R. W. (1997), “Game-theoretic insights into the international management of fisheries”, *Natural Resource Modeling,* Vol. 10, No. 2, pp. 129-171.

McKelvey, R. W., Sandal, L. K. and Steinshamn, S. I. (2001), "Fish wars on the high seas: a straddling stock competition model", *International Game Theory Review*, Vol 4, No.1, pp. 53-69.

Molenaar, E. J. (2000), "The concept of "real interest" and other aspects of cooperation through regional fisheries management mechanisms", *International Journal of Marine and Coastal Law*, Vol. 15, No. 4, pp.475-531.

Polacheck, T., Klaer, N. L., Miller, C., and Preece, A. (1999), "An initial evaluation of management strategies for the southern bluefin tuna fishery", *ICES Journal of Marine Science* 56:811-826.

Sandal, L. K., and Steinshamn, S. I. (1997), "A stochastic feedback model for optimal management of renewable resources", *Natural Resource Modeling*, Vol.10, No. 1, p.31-52

Schaffer, M.B.(1954) "Some aspects of the dynamics of populations important to the management of the commercial marine fisheries", *Bulletin, Inter-American Tropical Tuna Commission*, Vol.1, pp. 25-56

Stokke, O. S. (2000), "Managing straddling stocks: the interplay of global and regional regimes", *Ocean and Coastal Management*, Vol. 43, No. 2-3, pp.205-234.

Tahindro, A. (1997), "Conservation and management of transboundary fish stocks: Comments in light of the adoption of the 1995 agreement for the conservation and management of straddling fish stocks and highly migratory fish stocks", *Ocean Development and International Law,* Vol. 28, No. 1, pp.1-58.

Thebaud, O. (1997), "Transboundary marine fisheries management. Recent developments and elements of analysis", *Mar. Policy,* Vol. 21, NO. 3, pp. 237-253.

United Nations 1995. United Nations Conference on Straddling Fish Stocks and Highly Migratory Fish Stocks. Agreement for the implementation of the provisions of the United National Convention of the Law of the Sea of 10 December 1982 relating the conservation and management of straddling fish stocks and highly migratory fish stocks. Sixth Session, New York, 24 July-4 August, 1995. United Nations. A/CONF. 164/37, 8 September 1995.

Valencia, M. J. (2000), "Regional maritime building: prospects in northeast and southeast Asia", *Ocean Development and International Law,* Vol. 31, No. 3, pp.223-247.