Economic Performance of Fishers: Stochastic or Chaotic?

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Abstract. Economic performance of different fleet segments varies considerably from year to year, with some segments experiencing increased profitability while others experience decreased profitability. This variation is generally considered to be a consequence of the stochasticity in the industry. However, there is growing evidence that fisheries may not be as stochastic as generally thought. In this paper, a spatial bioeconomic model is developed of a multi-species multi-gear fishery, which assumes individual profit maximising behaviour. It is shown that inter-annual variations in profits are a function of the spatial behaviour of the fishers, which tends to vary chaotically over time.

Keywords: Economic performance, chaos, bioeconomic model, spatial model

1. INTRODUCTION

The increase in information available on the economic performance of fishers over the last decade has allowed a common feature to be identified, namely that fishing incomes are highly variable from year to year. These trends are apparent in a wide range of fisheries subject to varying management conditions (see, for example, ABARE 1999 and earlier issues, LEI-DLO 1999 and earlier issues, Danish Institute of Fisheries Economics (SJFI) 1999 and earlier issues). While overall trends in respective fisheries are influenced by the underlying levels of exploitation of the stocks, the economic performance of different fleet segments within these fisheries tends to fluctuate around the general trend, with one segment performing better than another one year and worse the next.

The intra-fleet variation is often attributed to chance, as fisheries are generally considered highly stochastic. This stochasticity is generally considered a result of the process of hunting for an unseen mobile resource (the finding of which contains an element of “luck”), environmental fluctuations and fluctuations in the market. Different groups have “good” years and “bad” years that tend to average out over time.

Empirical evidence for substantial variation in individual performance can be traced back to the earliest studies of catching power (Gulland 1956, Houghton 1977), though until fairly recently few such studies considered the issue of stochasticity in much detail. One important exception is the work by Hilborn and Ledbetter (1985), which reported that some two-thirds of the variation in catching power amongst fishermen in the British Columbia purse seine fleet was due to 'chance' while the remaining one-third was attributable to differences in fishing skill and vessel equipment. Generally, though, the assumption that stochastic influences must inevitably play an important role in explaining why individual fishermen or groups are more successful than others at exploiting the same resource has been taken as axiomatic.

Recent studies of efficiency in fisheries, however, suggest that much of the variation in catches between individuals is a function of skipper skill or other quantifiable characteristics, with the purely random element being less than might be assumed given the general assumption of stochasticity. Further, increased interest has been taken in considering the applicability of chaos theory in explaining fishery performance over time.

In this paper, the empirical evidence for stochasticity in fisheries is examined by considering recently published studies of efficiency in fisheries. A review of the arguments for chaotic behaviour as an alternative explanation of this variation is also presented. A model of a hypothetical fishery is presented that demonstrates that fluctuating economic performance can be explained by profit maximising behaviour of individuals in a fishery with a spatially variable (but deterministic) stock.

2. INDIVIDUAL VARIATIONS IN CATCHING ABILITY

The assumption that fisheries are highly stochastic has recently been inadvertently challenged empirically through the increasing interest in technical efficiency in fisheries. These have sought to estimate the contribution of systematic factors to variation in individual performance of fishers. These systematic factor determine the technical efficiency of the boats, and may be a feature of boat characteristics (e.g. age, size, electronics etc) or skipper characteristics (e.g. age, experience, skill). Non-systematic variations in performance are attributed to random variation.

A general stochastic production frontier model can be given by:

$$\ln q_j = f(\ln \mathbf{x}) + v_j - u_j \qquad (1)$$

where q_j is the output produced by firm j, $\mathbf{x}$ is a vector of factor inputs, v_j is the stochastic error term and u_j is the estimate of the technical inefficiency of firm j. Both v_j and u_j are assumed to be independently and identically distributed (iid) with variance σ_v^2 and σ_u^2 respectively.

The proportion of total variation in individual performance (taking account of the other inputs used in the production process) that can be assumed perfectly random is given by $\sigma_v^2 / (\sigma_v^2 + \sigma_u^2)$, while the proportion that is assumed to be attributable to differences in efficiency is given by $\sigma_u^2 / (\sigma_v^2 + \sigma_u^2)$. Various combinations of σ_v^2 and σ_u^2 are estimated during the MLE estimation of the production frontier. From these, we can derive an estimate of $\gamma = \sigma_u^2 / (\sigma_v^2 + \sigma_u^2)$ [1].

The estimate of γ derived from the MLE results is only an approximation of the contribution of inefficiency to total variance as the true variance of u_i is proportional but not exactly equal to σ_u^2 (Coelli, Prasada Rao and Battese 1999). The corrected relative contribution of inefficiency, γ^*, is given by (2) (Coelli 1995).

$$\gamma^* = \gamma / [\gamma + (1-\gamma)\pi / (\pi - 2)] \qquad (2)$$

From this, the proportion of individual variation in production that is estimated to be stochastic is given by $1-\gamma^*$.

[1] In some studies (e.g. Sharma and Leung 1999), the value of γ was estimated directly in the MLE estimation procedure. For the other studies it was derived from the model results.

To date, only a few studies of technical efficiency in fisheries have been published. However, from those that have, estimates of the proportion of variation between individuals that may be considered purely random ranges from as low as 5 per cent to 67 per cent (Table 1). Output in these studies has been catch (either in quantity or value terms) rather than profits, but an assumption is generally made that the relative economic performance is related to the relative level of output.

The effects of fluctuations in stock on individual performance have been removed from these analyses by incorporating stock into the production frontiers. However, as these studies have not been able to capture the exact conditions facing the individual fisher (e.g. the stock abundance in the exact areas fished compared with the average stock over the fishery as a whole), spatial fluctuations in stock abundance will manifest themselves as random variations in performance. This not withstanding, in three of the five fisheries examined, systematic variations in performance (i.e. differences in technical efficiency) accounted for over half of the variation in fisher performance.

Table 1. Contribution of "luck" to variation in production between individual fishers

Fleet type	Source	γ	γ^*	$1-\gamma^*$
Dredgers	Kirkley *et al* (1995)	0.57	0.33	0.67
	Kirkley *et al* (1998)	0.78	0.56	0.44
Trawlers	Coglan *et al* (1999)	0.79	0.58	0.42
	Eggert (2000)	0.98	0.95	0.05
Long-liners	Sharma and Leung (1999)	0.68	0.44	0.56

While fisher characteristics may be as important as "luck" in determining performance with a given stock level, inter-annual fluctuations in performance are largely due to stock fluctuations. These are often assumed to be as much a function of random environmental fluctuations as catch levels and existing stock size, as attempts to develop stock recruitment relationships have generally proved unreliable. However, there is a growing literature suggesting that these fluctuations may not be as random as generally supposed.

If stock fluctuations are not random, why do they appear random, and why do some areas seem to have greater stock abundance than others? One answer to this is that they may be chaotic. That is, the apparent random fluctuations may be deterministic. To investigate this further, and to establish the extent to which these stock fluctuations are truly random, we develop a bioeconomic model of a hypothetical fishery with a spatially dispersed set of sub-stocks. This is presented in section 4 of the paper, following a brief review of the literature on chaotic behaviour in fisheries.

3. CHAOS THEORY AND FISHERIES: A REVIEW

The possibility that natural resource systems may exhibit chaotic behaviour has been recognised since the 1970s (May 1974, 1976, May and Oster 1976), though it is only comparatively recently that the implications of chaos for commercial fisheries has been considered in any detail.

Two points should be noted at the outset. Firstly, the origins of chaotic behaviour in fisheries are likely to stem not simply from the population dynamics of the fish stock but also from the economic characteristics of the harvesting process. This point is well made by Conklin and Kolberg (1994), who address the question of whether market-driven harvest activity exerts a stabilising or destabilising influence on stock fluctuations. They conclude that 'chaos may be lurking in unexpected places in renewable resource models when harvest is market-driven' (p. 179). They test their predictions in the context of the Pacific Halibut fishery, and conclude that their model is capable of exhibiting chaotic behaviour under a range of plausible market conditions (p. 180). Secondly, while it is relatively straightforward to demonstrate mathematically that deterministic chaos is potentially important in fisheries, it has yet to be established how far the fluctuations in system outputs (biomass, yield, etc.) which are typically observed in the real world are due to chaos rather than to stochastic influences. Indeed, the assertion by Wilson *et al.* (1994) that fisheries are 'probably chaotic' (p. 305) has been challenged by Fogarty (1995), who claims that relatively few examples of chaos in ecological systems have been documented (p. 438). Referring again to the study by Conklin and Kolberg (1994), the authors are careful to stress that even though their model exhibited many of the features of chaos (e.g. dramatic instability under certain circumstances), the Pacific Halibut fishery to which it was applied was not necessarily on the verge of behaving chaotically (p. 180).

To the extent that some fisheries are chaotic or could become so if the conditions dictated, what does this imply for their analysis and management? To start with it seems to be generally accepted that attempts at long-term forecasting of system outputs will be a largely vacuous exercise due to sensitive dependence on initial conditions. Short-term forecasting may still be possible, however, though its accuracy will depend on the type of forecasting model used. As McGlade (1994) points out, the predictive power of short-term forecasting will be poor when chaotic time series are modelled using a linear stochastic process. Nevertheless, while the long-term unpredictability of chaotic fisheries systems may undoubtedly complicate the task of resource managers, it does not negate the management function completely. As Fogarty (1995) asserts, the issues of predictability and control are separate. It is far from clear, however, precisely what the best approach to managing chaotic fisheries should be. Grafton and Silva-Echenique (1997) argue that the uncertainty caused by chaos does not necessarily imply a 'precautionary' approach to fisheries management but rather a 'mixed strategy' approach (i.e. using more than one regulatory instrument). This will provide managers with more options for controlling fisheries even when the dynamics of the system are not known. Wilson *et al.* (1994) see the solution in terms of a shift away from the traditional management approach of controlling the number and quantity of fish taken and towards measures which address the 'relatively stable parameters of fisheries systems - habitat and basic biological processes, and that this demands management attention to the fine as well as the broad scale attributes of the system' (p. 290). They interpret this as requiring rules aimed at controlling fishing practices ('how') and which recognise the spatio-temporal characteristics of the fishery ('when' and 'where').

4. A HYPOTHETICAL MODEL OF SPATIALLY INDUCED CHAOTIC BEHAVIOR

4.1 Model description

Although the model is based on a hypothetical fishery, it is similar in many respects to many inshore fisheries along the UK coast, particularly the English Channel. The hypothetical fishery is based on five adjacent ports. Boats in the ports can target a variety of species and can travel to adjacent regions to fish if the expected returns are greater than those expected to be achieved by fishing directly out from the port. Only two generic 'species' are assumed to exist: 'shellfish' and 'finfish'. The fishery is assumed to consist of five separate sub-stocks of each of the two species, with one sub-stock of each species adjacent to a main fishing port. The stocks are arranged linearly, and some migration takes place between adjoining sub-stocks. Hence, the stock size in any one period is a function of the natural growth in the sub-stock and the migration into and from adjacent regions. The spatial distribution of the fishery is illustrated in Figure 1.

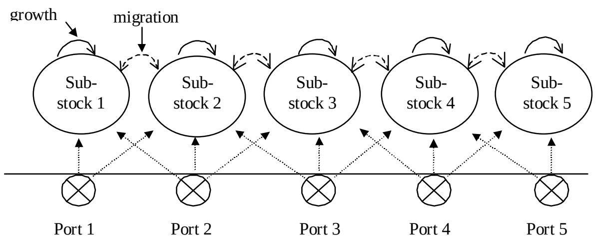

Figure 1. Spatial distribution of the fishery

Each boat has a total number of days available to participate in the fishery. The available days are allocated between fishing time and steaming time (i.e. the time taken to reach the fishing ground). The boats in each port can allocate their effort between the two species and between the stocks. However, the amount of steaming time required to reach the fishing area increases the further the boat travels from the port. Hence, boats can maximise their fishing time by fishing in the adjacent fishing areas to their port. Alternatively, boats can move to other areas, but reduce the potential time available to fish by doing so (and incur greater steaming costs).

Prices were assumed to vary with the quantity landed. A separate price was estimated for each port based on the quantity landed in the port and the total landed in the fishery as a whole. This prevented the product from being harvested and landed only in the most dense areas of the fishery.

The model is run in two stages. In the first stage, the equilibrium level of boats in each port, effort allocation and catch was estimated. The stock of each species was assumed to have a simple logistic growth (Gordon 1954, Schaefer 1954), with each sub-stock having a separate growth model incorporating the carrying capacity of that area. The allocation of boats and fleet size is based on the short run profit maximising combination (i.e. revenue less variable costs). Fixed and capital costs were not included in the model so an estimation of resource rent is not obtainable. However, if the fishery was subject to free and open access, an appropriate assumption would be that the fixed costs are equal to the resultant gross margin such that the level of rent in the fishery is zero.

While the movement of the boats between areas was unrestricted (and hence could be considered a series of sequential open access fisheries), it is assumed that no new boats would enter and none leave. While zero rents would discourage new entrants, any reduction in rents would not force existing boats out in the short term due to the non-malleability of capital.

The second stage of the model is dynamic rather than static. The equilibrium fleet is fixed in each port. However, the catch-effort relationships faced by the fleet are essentially linear in the short term. Effort can be applied to either the fish or shellfish stocks (or both). Because of the profit maximising assumption underpinning the model, effort is applied such that marginal returns are equated across the fishery – either in the home region or adjacent regions – taking into account the cost of steaming to the adjacent region. This is consistent with the models of multi-purpose boats proposed by Anderson (1982). Stocks varied from year to year based on the difference between the surplus growth and the catch.

4.2 Mathematical specification of the model

The model was developed as a non-linear programming model written in GAMS (General Algebraic Modelling System) (Brooke *et al* 1992). The key equations used in the model and associated data are presented below.

Biological component

The biological model was assumed to be spatially linear (Figure 1), and adopted from Sanchirico and Wilen (1999). The stock was assumed to consist of 5 sub-stocks, with migration occurring between adjacent stocks. Other functional forms of the spatial structure are available (see Sanchirico and Wilen 1999), although have not yet been applied in the model.

Catch and effort relationships

The model incorporates a basic catch effort relationship, given by

$$Q_{p,s,a} = q_s E_{p,s,a} S_{s,a} \tag{3}$$

where $Q_{p,s,a}$ is the catch of boats from port p in area a of species s, q_s is the catchability coefficient of species s, $E_{p,s,a}$ is the level of effort expended by the boats from port p in area a on species s and $S_{s,a}$ is the stock size of species s in area a.

In the equilibrium model, the total level of catch of each species had to equal the level of surplus production from the stock, plus the equilibrium level of immigration less the equilibrium level of emigration (defined as the levels of immigration and emigration when all stocks are in equilibrium). A logistic growth model (Schaefer 1954) was assumed, such that

$$\sum_p Q_{p,s,a} = r_s S_{s,a}(1 - S_{s,a}/k_{s,a}) + \sum_{a1} I_{a,a1} S_{s,a1} - \sum_{a1} E_{a,a1} S_{s,a} \qquad (4)$$

where r_s is the instantaneous growth rate and $k_{s,a}$ is the carrying capacity of the stock in each area, $I_{a,a1}$ is the immigration rate of fish from area *a1* to area *a* and $E_{a,a1}$ is the emigration rate of fish from area *a* to area *a1*. The migration (both immigration and emigration) rates between adjacent regions were assumed to be 0.1 for the shellfish species and 0.2 for the fish species.

In the long run equilibrium model, the stock size of each species is endogenous to the model. In the dynamic portion of the model, the stock size is exogenous. The initial stock size (year one) is taken as the equilibrium stock size, estimated by equating catch to the surplus growth in (4). In the dynamic model, the stock size in the following years is calculated between model runs, and is given by

$$S_{s,a,t} = S_{s,a,t-1} + r_s S_{s,a,t-1}(1 - S_{s,a,t-1}/k_{s,a}) - \sum_p Q_{p,s,a,t-1} + \sum_{a1} I_{a,a1} S_{s,a1,t} - \sum_{a1} E_{a,a1} S_{s,a,t} \qquad (5)$$

That is, the stock in year t is the stock in the previous year plus the growth in the previous year less the catch in the previous year.

The level of effort that can be expended by boats is limited by the available fishing time and the time taken to reach the fishing ground, such that

$$\sum_s \sum_a E_{p,s,a}(1 + T_{p,a}) = tB_p \qquad (6)$$

where $T_{p,a}$ is the additional time required to steam from port *p* to area *a*, *t* is the number of days a boat can fish (with t=1 for all boats) and B_p is the number of boats in each port. Steaming time was assumed to be increase as a proportion of time available, with $T_{p,a} = 0$ for $p=a$, increasing to $T_{p,a}=1$ if the port and area are at opposite ends of the fishery (i.e. port 1 and area 5 or vice versa).

In the equilibrium model, the number of boats in each port was endogenous to the model. In the dynamic model, the number of boats was fixed at the level produced by the equilibrium model.

The parameters in the model used in the catch and effort relationships are given in Table 2. The values were assumed the same for all areas

Table 2. Catch and effort relationship parameters

	Shellfish	Fish
r_s	0.5	0.5
$k_{s,a}$	1	2
$q_{s,a}$	1	1

Revenue and costs

The revenue in each port is estimated as the product of the quantity landed and the price. Price was assumed to vary based on a linear price-quantity relationship, given by

$$P_{p,s} = p_s^* - \beta_1 \sum_a Q_{p,s,a} - \beta_2 \sum_p \sum_a Q_{p,s,a} \qquad (7)$$

where p^*_s is the maximum price (i.e. the intercept, $p^*_{shellfish}$= 4, p^*_{fish}=2), and β_1, β_2 are the slope coefficients of the demand curve relating to local landings and total landings respectively (β_1 = 0.1, β_2 = 1). Hence, the market price was assumed to be affected by both the quantities landed locally as well as the total landings in the fishery.

Costs are assumed to be a function of the level of effort only. The total costs in each port are given by

$$C_p = f \sum_a \sum_s E_{p,a,s}(1 + T_{p,a}) \qquad (8)$$

where *f* is the fuel cost per unit of time ($f=0.2$), where time include both fishing time and steaming time.

The total gross margin in each port (G_p) is given by

$$G_p = \sum_p \sum_s \sum_a P_{p,s} Q_{p,s,a} - C_p \qquad (9)$$

while the total gross margin for the fishery as a whole (the objective function of the model) is given by

$$OBJ = \sum_p G_p \qquad (10)$$

4.3 Simulation results

The model was run over a 50 year period. The starting values (year 1) for the model was the equilibrium solution (i.e. fleet number, effort allocation and equilibrium stocks).

Although initially in equilibrium, moving from a long run catch-effort relationship to a short run relationship resulted in a reallocation of effort and initial fluctuations in catches of the two species. With an equilibrium yield curve, there are diminishing returns to effort for each species. With the short run yield curve, there are constant returns to effort. Hence, greater effort was initially applied to the more valuable species (shellfish) than under equilibrium conditions. This resulted in the stocks of this species declining and a consequent reallocation to the alternative species (fish) in the second year.

As a result, the fishery tended to oscillate with shifts in effort between species occurring each year rather than maintain an equilibrium position. In addition, effort moved to adjacent regions when the marginal value of fishing in those adjacent regions were higher than remaining in 'home' region.

The estimated profit in each port and for the fishery as a whole is shown in Figure 2. From this, it can be seen that the profits fluctuate considerably over time in each port. These fluctuations do not necessarily form a regular pattern for each port (i.e. 'good' year followed by a 'bad' year). Instead, they are characterised by an occasional 'good' year, followed by a number of years that may be considered 'average', with the occasional 'bad' year'. Further, the fluctuations differ in each port, with one port having a 'good' year while another may be having an 'average' or 'bad' year. This is consistent to what is often observed in real fisheries, where economic performance of fishers varies across a fishery.

At the level of the fishery as a whole (i.e. all ports), the fishery profits declined rapidly from their equilibrium level. With the exception of a couple of years, the apparent inter-annual variation in profits at the aggregate level was less than at the port level. Aggregate profits tended to stabilise at a level below the equilibrium level in the latter part of the simulation.

The equilibrium profits, as well as the mean over time and coefficient of variation (CV)[2] relating to each port is given in Table 3. Despite the initial identical resource base, price and cost structure, the average profit of boats in the centre region was marginally greater than that of the boats from the outer regions (ports 1 and 5), although it was subject to higher variability. As the cost of exploiting other regions

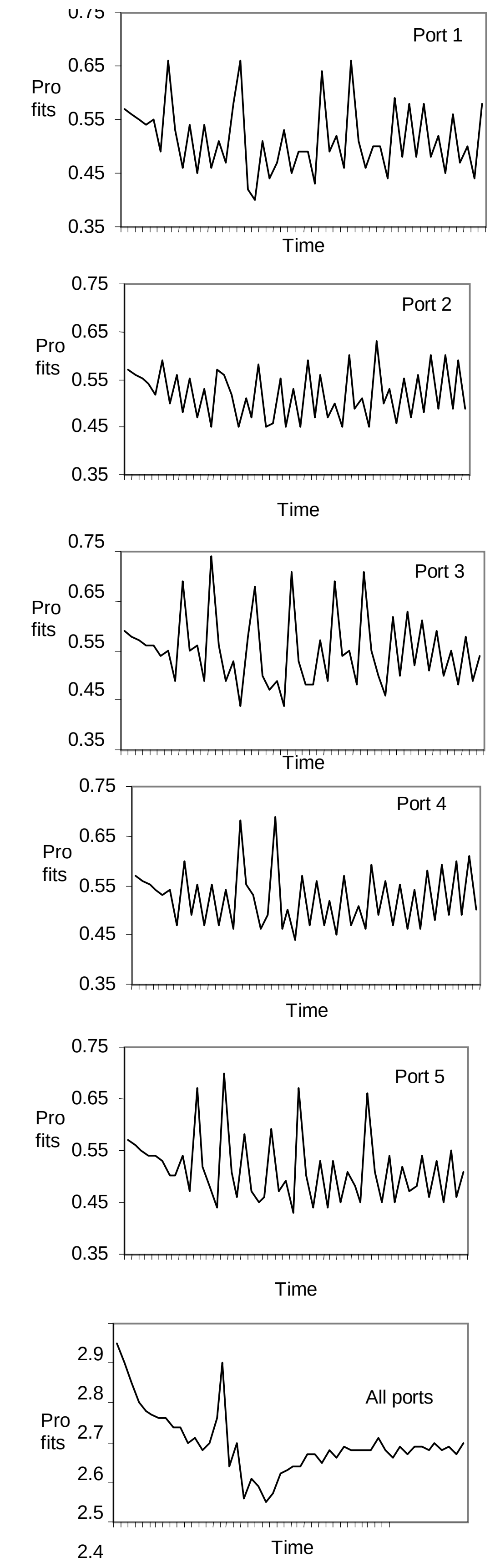

Figure 2. Simulated profits by port and total fishery over time

[2] This is a relative measure of variability derived by dividing the standard deviation by the mean and presenting the result as a percentage.

increased the further away the region, boats on the 'edge' of the fishery were penalised by costs in exploiting more than their own and one adjacent region. Other regions could be exploited but at a higher cost. In contrast, boats in the centre ports (2, 3 and 4) could each exploit two additional regions for the same additional cost.

Table 3. Summary statistics relating to each port

	Port 1	Port 2	Port 3	Port 4	Port 5	All ports
Equilibrium profits	0.57	0.57	0.57	0.57	0.57	2.85
Mean over time	0.51	0.52	0.53	0.52	0.51	2.60
CV	12%	10%	14%	11%	12%	3%

The sub-stocks adjacent to the centre ports also had migration to and from the two adjacent areas, whereas the peripheral stocks had migration to and from only one adjacent area. As a result, these sub-stocks fluctuated by a greater amount than the peripheral sub-stocks (Table 4). In Figure 3, the stocks in areas 1 and 3 (a peripheral area and the central area) are compared for the two 'species'. It can be seen that not only do the fluctuations vary in intensity, but also that the areas are subject to different relative stock abundance (i.e. 'high' in one area but 'low' in the other in the same year). With a linear relationship between stock size and catch, then the catches of the boats adjacent to these stocks would follow a similar pattern. While boats were able to move from one area to another, the additional cost of doing this reduced the incentive unless the differential in profitability in the areas exceeded the cost.

Table 4. Summary statistics relating to each stock

	Area 1	Area 2	Area 3	Area 4	Area 5
Shellfish					
Equilibrium stock	0.54	0.54	0.54	0.54	0.54
Mean over time	0.44	0.44	0.45	0.44	0.44
CV	9%	12%	10%	12%	8%
Fish					
Equilibrium stock	1.54	1.54	1.54	1.54	1.54
Mean over time	1.69	1.67	1.66	1.66	1.68
CV	7%	8%	10%	9%	7%

The disequilibrium dynamic simulation also produced another interesting result. The higher unit price for shellfish (and common cost of effort) resulted in this species being targeted more in each area. As a result, the average shellfish stock was less than the equilibrium level. In contrast, the average fish stock was higher than in equilibrium as less effort was generally applied to fish in the dynamic simulations.

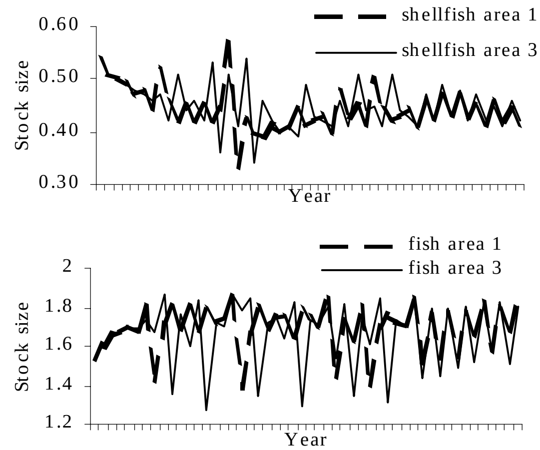

Figure 3. Estimated stock abundance in areas 1 and 3 over time

As a consequence, because of the chaotic behaviour of the stocks and the response to this by fishers, the equilibrium situation is not achieved, even over a 50 year time period. Further (as previously noted), profits in the long run are less than what could be achieved in a controlled fishery, even without new entrants.

5. STABILISATION POLICIES

As with the model of Conklin and Kolberg (1994), the above model results are consistent with chaotic behaviour, and are purely deterministic – the result of profit maximising behaviour in a non-linear ecological and economic system. Had these fluctuations in stocks and economic performance been observed in a true fishery, they would have been taken as further evidence of the stochastic nature of fisheries.

What does it mean, though, for fisheries management if fisheries are chaotic? Like highly stochastic events, chaotic events are impossible to predict with any accuracy both in the short and long run. As a result, knowing a fishery is actually deterministic but chaotic is of little benefit to fisheries managers when trying to estimate future yields. Similarly, estimating an appropriate total allowable catch is equally problematic for either a stochastic or chaotic fishery.

As Wilson *et al* (1994) pointed out, knowing fisheries are chaotic can lead to different forms of management being appropriate. In particular, as chaos derives from the large number of non-linearities in the ecological and economic system, measures to stabilise some of these parameters may stabilise the fishery.

Two further simulations were undertaken using the model. The first simulation held prices constant at the equilibrium level while the second simulation allowed prices to vary but prevented fishers from operating outside the area adjacent to their port. The purpose in these simulations was to estimate the effects of reducing some of the potential interactions in the system on the flow of profits in the fishery.

In both cases, reducing the potential interactions in the model resulted in lower variance in the results at the port level (Table 5). Holding prices constant also resulted in higher average profits that in the base run. However, at the fishery level, the amount of variation was substantially greater. This is because the effects of regional 'good' and 'bad' years tended to even out across the fishery in the base run.

Table 5. Constant prices and restricted movement

	Port 1	Port 2	Port 3	Port 4	Port 5	All ports
Constant prices						
Mean over time	0.56	0.56	0.56	0.56	0.56	2.79
CV	7%	7%	7%	7%	7%	7%
No movement						
Mean over time	0.51	0.53	0.52	0.52	0.53	2.61
CV	11%	10%	11%	9%	11%	2%

Prevening movement of boats out of the areas not adjacent to their ports had little impact on the average profits in the model results (Table 5). These were found to be marginally higher in ports 2 and 5 and marginally lower in port 2. With the exception of port 2 (which remained the same), variability in profits was generally lower.

While the impact of these restrictions are marginal at the port level, the impact at the fishery level is substantial. Restricting the movement of the boats results in a much more stable fishery, with the large fluctuations in profits being avoided (Figure 4). In contrast, holding prices constant results in much greater inter-annual fluctuations in the fishery as a whole, with the fishery alternating from high to low profits of equal amounts each year. Hence, while constant prices reduce the overall variance in the system at the port level, allowing prices to fluctuate tends to have a stabilising effect (rather than destabilising) on the fishery as a whole.

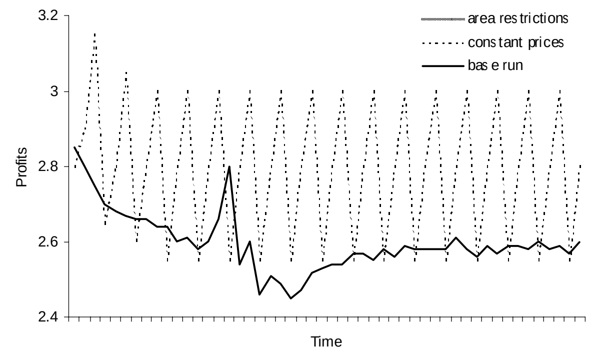

Figure 4. Fishery level profits under the different scenarios

6. DISCUSSION AND CONCLUSIONS

Studies of technical efficiency of individual fishers have generally found that around half of the variation in performance is due to differences in efficiency and the other half due to random events. However, while these studies have been able to incorporate inter-annual variations in stock abundance (assumed exogenous and random), they do not generally take account of spatial differences in abundance. Such variation would manifest itself as 'noise' in the technical efficiency studies.

In this paper, we have demonstrated that such noise may be the result of a spatially diverse environment. Further, in such an environment the fluctuations in abundance may be a direct result of the profit maximising behaviour of the fishers rather than random events.

While most countries have licence programs that limit access to particular areas, these are generally geographically large. From the results of this model, smaller geographical definition of fisheries for the purpose of licensing may be beneficial if stability is an objective of management. Ironically, the ability of fishers to change fishing areas and gears in response to fluctuations in stock abundance is generally regarded as a desirable feature of a fishery. This is because the greater flexibility is thought to have a stabilising effect on incomes. However, from the results in this paper, this flexibility may be contributing to the fluctuations. Hence, while the effect of fluctuating stocks in any one year on incomes may be mitigated by changing area or gear, this perpetuates the fluctuations.

The model does not allow for any random component. While the results suggest that fluctuations in stock may be consistent with deterministic but chaotic behaviour, there is most likely still some element of randomness in fisheries. Although not presented in this paper, introducing a random shock into one are of the model fishery in one year was found to have a substantial destabilising effect. Again, however, restricting access of the boats resulted in the greatest stabilising effect.

Wilson *et al* (1994) suggested that the existence of chaos in fisheries meant that fishery managers may need to move away from the traditional mix of controls on how much fish to be caught, and to look at how and where they are caught. The results of this study tend to support these suggestions.

7. REFERENCES

Anderson, L. G., The economics of multi-purpose fleet behavior, in *Essays in the Economics of Renewable Resources* L. J. Mirman and D. F. Spulber, eds. Amsterdam, New York and Oxford: North-Holland Publishing Company, 203-226, 1982.

ABARE, *Fisheries Survey Report*, ABARE, Canberra, 1999 (and earlier issues).

Brooke, A., Kendrick, D. and Meeraus, A., *GAMS: A user's guide*. USA: Boyd and Fraser Publishing Company, 1992.

LEI-DLO, *Visserij in cijfers, 1997*, Periodieke Rapportage 31-97, LEI-DLO, The Hague, 1999 (and earlier issues)

Coelli, T., Estimators and hypothesis tests for a stochastic frontier function: A monte carlo analysis. *Journal of Productivity Analysis* 6, 247-268, 1995

Coelli, T., A guide to FRONTIER version 4.1: a computer program for frontier production function estimation. CEPA Working Paper 96/07, Department of Econometrics, University of New England, Armidale, Australia, 1996.

Coelli, T.J., D.S Prasada Rao and G.E. Battese, *An Introduction to Efficiency and Productivity Analysis*, USA: Kluwer Academic Publishers, 1998.

Coglan, L., S. Pascoe and R.I.D. Harris. Measuring efficiency in demersal trawlers using a frontier production function approach, *Proceedings of the Xth European Association of Fisheries Economists, The Hague, The Netherlands, 1-4 April 1998*, LEI: The Netherlands, 236-257, 1999.

Conklin, J. E. and Kolberg, W.C. Chaos for the Halibut? *Marine Resource Economics*, 9(2), 159-182, 1994.

Danish Institute of Agricultural and Fisheries Economics (SJFI), *Fiskeri-regnskabsstatistik 1998*. Minsteriet for Fødevarer, Landbrug og Fiskeri, Københaven (Copenhagen), 1999 (and earlier issues).

Eggert, H., Technical efficiency in the Swedish Trawl Fishery for Norway lobster, Paper presented at the XII Annual Conference of the European Association of Fisheries Economists, University of Southern Denmark, Esbjerg, Norway.

Fogarty, M.J., Chaos, complexity and community management of fisheries: an appraisal, *Marine Policy*, 19(5), 437-444, 1995.

Grafton, R.Q. and J. Silva-Echenique, How to manage nature? Strategies, predator-prey models, and chaos. *Marine Resource Economics*, 12(2), 127-143, 1997.

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

Gulland, J., *On the fishing effort in English demersal fisheries*, in Fishery Investigations, Ser. 1 Vol. V. Ministry of Agriculture, Fisheries and Food, London 1956.

Hilborn, R. and M. Ledbetter, Determinants of catching power in the British Columbia salmon purse seine fleet, *Canadian Journal of Fisheries and Aquatic Science*, 42, 51-56, 1985.

Houghton, R.G., The fishing power of trawlers in the western English channel between 1965 and 1968. *Journal du Conseil Internationale et Exploration du Mer,* 37: 130-136, 1977.

Kirkley, J.E., D. Squires, and I.E. Strand, Assessing technical efficiency in commercial fisheries: The Mid-Atlantic Sea Scallop Fishery, *American Journal of Agricultural Economics*, 77(8), 686-97, 1995.

Kirkley, J.E., D. Squires, and I.E. Strand, Characterizing managerial skill and technical efficiency in a fishery, *Journal of Productivity Analysis*, 9, 145-160, 1998.

May, R.M., Biological populations with non-overlapping generations: stable points, stable cycles and chaos. *Science*, 186: 645-647, 1974

May, R.M., Simple mathematical models with very complicated dynamics. *Nature*, 261, 459-467, 1976.

May, R.M. and G. Oster, Bifurcations and dynamic complexity in simple ecological models, *American Naturalist*, 110, 573-599, 1976.

McGlade, J.M., Chaos and its implications for marine resources science, in *Marine Environmental Management: Review of Events in 1993 and Future Trends.* Vol 1, Paper No. 15: 57-60, 1994.

Sanchirico, J.N. and J.E. Wilen, Bioeconomics of Spatial Exploitation in a Patchy Environment, *Journal of Environmental Economics and Management*, 37(2), 129-150, 1999.

Schaefer, M. B., Some aspects of the dynamics of populations important to the management of the commercial marine fisheries. *Bulletin of the Inter-American Tropical Tuna Commission*, 1(2), 26-56, 1954.

Sharma, K.R and P. Leung, Technical Efficiency of the Longline Fishery in Hawaii: An application of a Stochastic Production Frontier. *Marine Resource Economics*, 13(1999), 259-274.

Wilson, J.A., J.M. Acheson, M. Metcalfe and P. Kleban, Chaos, complexity and community management of fisheries, *Marine Policy* 18(4), 291-305, 1994.

Economic performance of fishers: stochastic or chaotic?

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Outline

- “Random” variations in economic performance
- Contribution of stochasticity to individual performance
- Potential for chaotic behaviour
- Model of chaotic behaviour
  - function of spatial distribution of stock and profit maximising behaviour
- Policy implications

Variations in economic performance

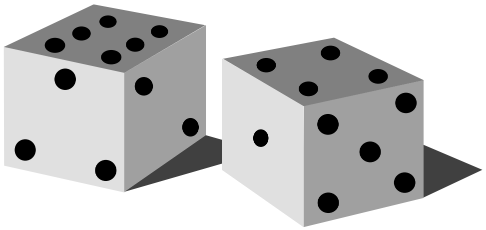
- Within any population of fishers
  - some have ‘good’ year
  - some have ‘bad’ year
- between years also have ‘good’ and ‘bad’ years
- Generally assumed that variation due to stochasticity e.g. environmental fluctuations

Individual variation in performance

- studies of technical efficiency
  - separate efficiency from stochastic variability
  - $\gamma = \sigma_u^2 / (\sigma_v^2 + \sigma_u^2)$
  - $\gamma^* = \gamma / \left[\gamma + (1-\gamma)\pi / (\pi - 2)\right]$

Fleet type	Source	γ	γ^*	$1-\gamma^*$
Dredgers	Kirkley et al (1995)	0.57	0.33	0.67
	Kirkley et al (1998)	0.78	0.56	0.44
Trawlers	Coglan et al (1999)	0.79	0.58	0.42
	Eggert (2000)	0.98	0.95	0.05
Long-liners	Sharma and Leung (1999)	0.68	0.44	0.56

- random component ranges from 5 to 67 per cent
  - exclude spatial variation in stock



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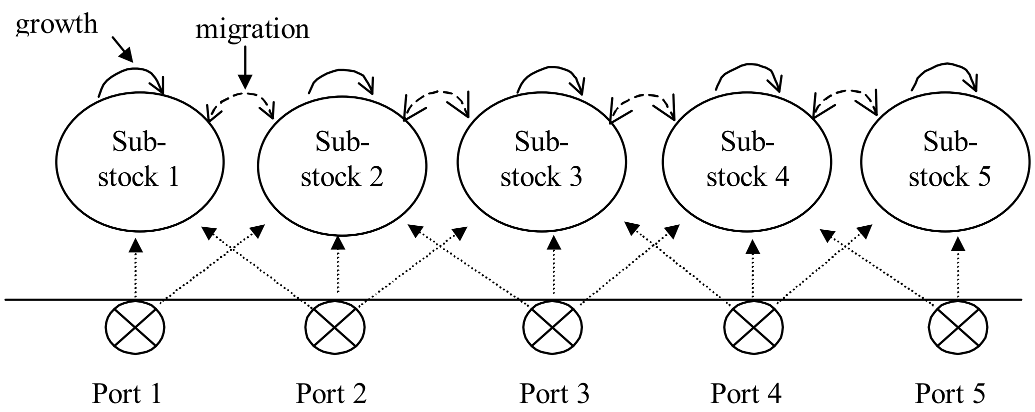
Chaos theory and fisheries

- “stochastic” element of performance may not be “luck”
- fluctuations in performance may be due to “non-linearities” in the ecological and economic system
  - stock-recruitment, predator-prey
  - prices, targeting behaviour of fishers
- Several suggestions that variations may be chaotic rather than stochastic

Model of spatial fishery

- 5 areas
- 5 ports (fleets)
- 2 stocks
  - fish, shellfish



- fishers can switch between areas and species
- prices vary due to total and local landings in each port

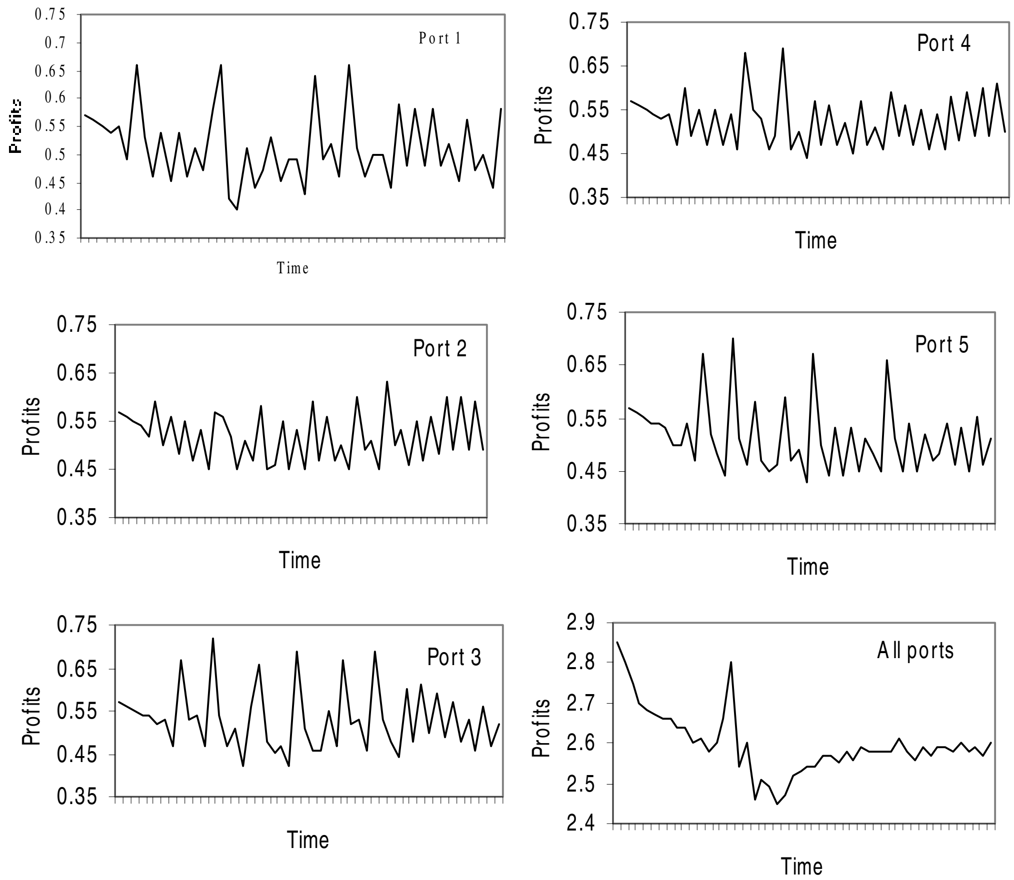
Simulation

- Model run over 50 years
- $catch_t = f(stock_t, effort_t)$
- $stock_t = f(stock_{t-1}, migration, catch_{t-1})$
- starting point was long run equilibrium
  - catch = surplus growth

Results: profits

- ‘random’ fluctuations in profits from year to year

	Port 1	Port 2	Port 3	Port 4	Port 5	All ports
Equilibrium profits	0.57	0.57	0.57	0.57	0.57	2.85
Mean over time	0.51	0.52	0.53	0.52	0.51	2.6
CV	12%	10%	14%	11%	12%	3%



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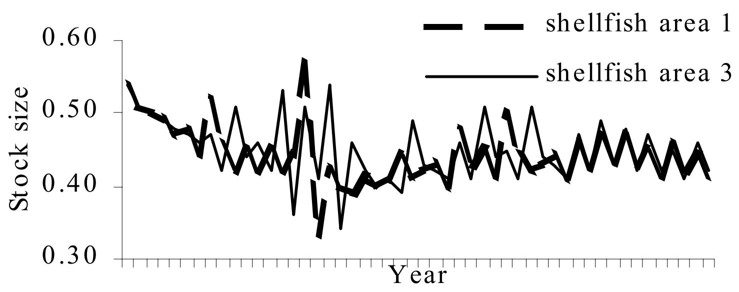
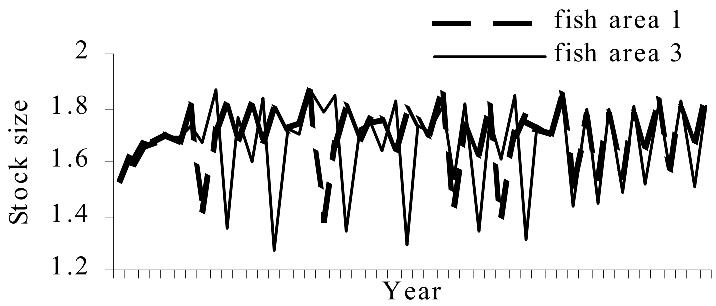
Results: stocks

- Apparent 'random' fluctuations in stocks

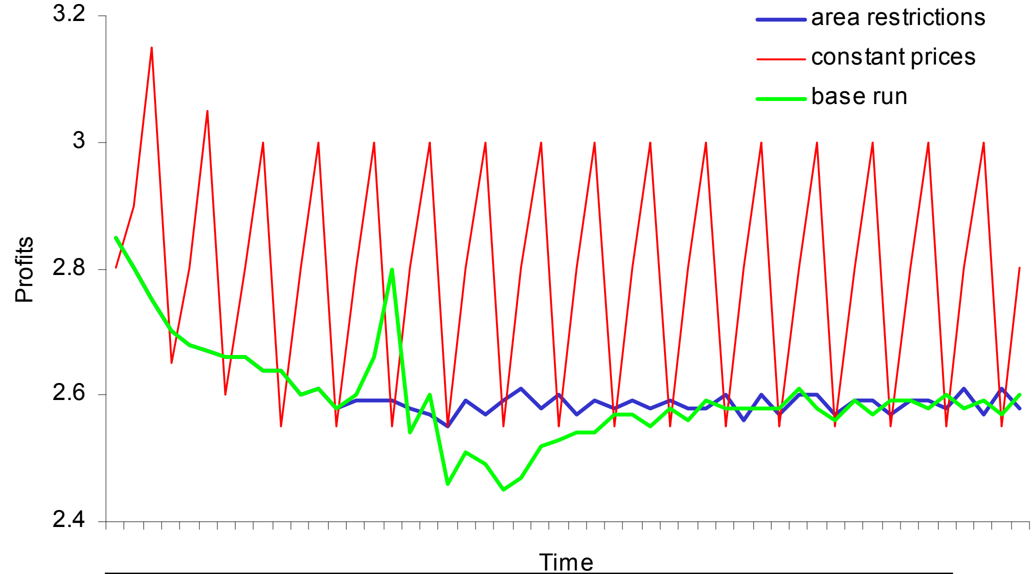
	Area 1	Area 2	Area 3	Area 4	Area 5
Shellfish					
Equilibrium stock	0.54	0.54	0.54	0.54	0.54
Mean over time	0.44	0.44	0.45	0.44	0.44
CV	9%	12%	10%	12%	8%
Fish					
Equilibrium stock	1.54	1.54	1.54	1.54	1.54
Mean over time	1.69	1.67	1.66	1.66	1.68
CV	7%	8%	10%	9%	7%





Stabilisation policies

- Reduce 'non-linearities' in the system
  - prices
  - movement between areas



	Port 1	Port 2	Port 3	Port 4	Port 5	All ports
Constant prices						
Mean over time	0.56	0.56	0.56	0.56	0.56	2.79
CV	7%	7%	7%	7%	7%	7%
No movement						
Mean over time	0.51	0.53	0.52	0.52	0.53	2.61
CV	11%	10%	11%	9%	11%	2%

Conclusions

- Fisheries may be less random than thought
  - variations due to profit maximising behaviour and a spatially diverse resource
- While this doesn’t make fisheries predictable, has implications for how fisheries managed
  - greater restrictions on movement in fisheries may be desirable