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DISSIPATION OF SPATIAL CLOSURE BENEFITS AS A RESULT OF NON-COMPLIANCE

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1. Introduction

Spatial closures are imposed by resource managers to prevent the operation of fishing fleets in certain areas of a stock's distribution. In Queensland, east coast trawl closures are usually located in shallow waters to prevent fishing of prawns before they reach an optimum marketable size and migrate offshore [1]. The success of such fishery controls should be measured by careful analysis of the benefits to fishery production, and the costs and practicality of enforcing the regulation. The potential of simulation models to investigate optimising fishery production by adjusting the starting date, length and extent of a fishing closure has been established in the Torres Straits tiger prawn fishery [2]. It was predicted that by modifying the length and starting dates of seasonal closures that gains of up to 15% in yield-per-recruit and value-per-recruit could be achieved [2]. By comparison, the best gains predicted by adjusting the boundaries of permanent spatial closures were less than 10% of value-per-recruit and negligible for yield-per-recruit (unpublished data).

Enforcing fisheries regulations is expensive and especially difficult in the case of spatial closures. Most fishers are aware of this difficulty and some fish in closed areas because of the competitive advantage and the short-term benefits this practice provides. Therefore, it is important to evaluate the level of non-compliance which would dissipate the benefits gained from any closure regulations. In this paper the effect of cheating is evaluated by value-per-recruit and egg-per-recruit analysis.

2. Methods

A computer simulation program called SIMSYS has been developed over the last two years by the authors and collaborators with the purpose of evaluating alternative closures in tropical prawn fisheries. Full descriptions of the fishery data, original program and subsequent program modifications have been presented elsewhere [2,3,4]. The program is based on a utility-per-recruit model [5] implemented as a discrete time simulation of the fishery system. Up to 12 monthly cohorts are incorporated into a population of prawns which grow, age, and survive natural and fishery induced mortality. Individual growth is entirely deterministic and prawns within a monthly cohort have the same age and size. The program calculates population size, catch, value of the catch and egg production at each time step and provides yearly values when the stationary equilibrium is reached. The population is divided into two groups which occupy areas either open to fishing, or legally closed to fishing, and which move from one area (closed) to the other (open) as they age and grow. Prawn migration is modelled by speed of movement between the open and closed areas. A migration speed variance is also incorporated into the model in order to simulate the observed geographical spread of individuals of the same monthly cohort. The fishing fleet is also divided in two groups, those that comply with the regulation (legal) and those that do not (illegal or cheaters). The intensity of effort in any given month is assumed to be a function of the accumulation of biomass in the fished grounds. Therefore the simulated pattern of fishing effort is different between the legal and cheating portion of the fleet because they have access to different population groups at different times. The program investigates several alternative spatial closure strategies by stepping through a vector of values which represent the geographical area of the closure (the distance between the reef-edge of untrawlable juvenile grounds and the closure line).

Estimates of many fishery model parameters are not precise, thus simulation results obtained from a single parameter set do not convey the real uncertainty associated with the model predictions. To evaluate this uncertainty the program allows for the incorporation of a vector of values instead of point estimates. Values of parameter-vectors were selected to represent the estimated probability distribution associated with each parameter. Only those parameters to which the model predictions were sensitive (prawn mortality and migration speeds) to were incorporated as vectors in the program. All model parameters were assumed to be uncorrelated, therefore, for a given closure strategy the number of predictions is equal to the product of the number of elements in each parameter-vector. In the present paper we present results on the average predicted change in value-per-recruit and egg-per-recruit relative to a no-closure scenario. The percentage of parameter combinations which predict increases in fishery production relative to the scenario without a closure are also presented. All predictions were found to be very sensitive to the value of migration speed, thus all figures presented show predictions for values of migration speed ranging between 67 and 200% of the best estimate.

3. Results

The effect of non-compliance was evaluated at different levels of cheating, from no cheating to 50% cheating, and for a range of closure extensions from no closure to a closure located 50 nautical miles off the reef-edge. Seasonal fishing mortality patterns of the legal and illegal fleet groups differ (Figure 1). Fishing mortality induced by the illegal fleet group peaks earlier in the year than for the legal fleet group because offshore biomass peaks occur later in the year. The extent of the closure determines the population group available for capture to the legal fleet, thus the location of the closure line

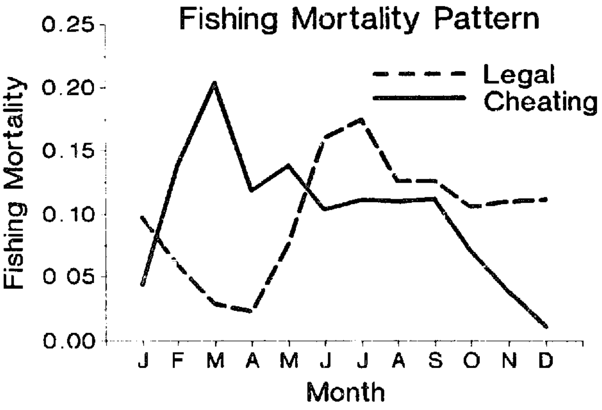

Figure 1: Fishing mortality pattern for a 20-nautical-mile closure and 50% compliance.

determines the degree of disparity between the operation of the two fleet groups.

Assuming the whole fleet complied with the spatial closure regulation, average value-per-recruit is predicted to increase as a result of the closure relative to a no-closure scenario (Figure 2a) This increase in value-per-recruit reaches a peak of about 8%. The extent of the closure which yields such an increase is 16, 24 and 50 nautical miles for prawn migration speeds of 67%, 100% and 200% respectively. In the presence of high levels of compliance (10% of the fleet cheats) the value-per-recruit benefits of the closure would be reduced to about 6% at the same closure line distances as above (Figure 2b). A moderate level of compliance (20% of the fleet cheats) would result in increases in value-per-recruit of only about 4% (Figure 2c). A low level of compliance (50% of the fleet cheats) would not reduce the gain further than 4%, but it would require much wider closures to achieve it (Figure 2d), ie. closure lines would have to be located at 20, 32 and more than 50 nautical mile for prawn migration speeds of 67%, 100% and 200%, respectively. To put the effects of cheating into perspective, if a 20-nautical-mile closure was imposed and assuming the best estimate of prawn migration speed is correct, the model predicts that levels of cheating of 0%, 10%, 20% and 50% would result in increases in value-per-recruit of 8%, 6%, 4% and 2% respectively.

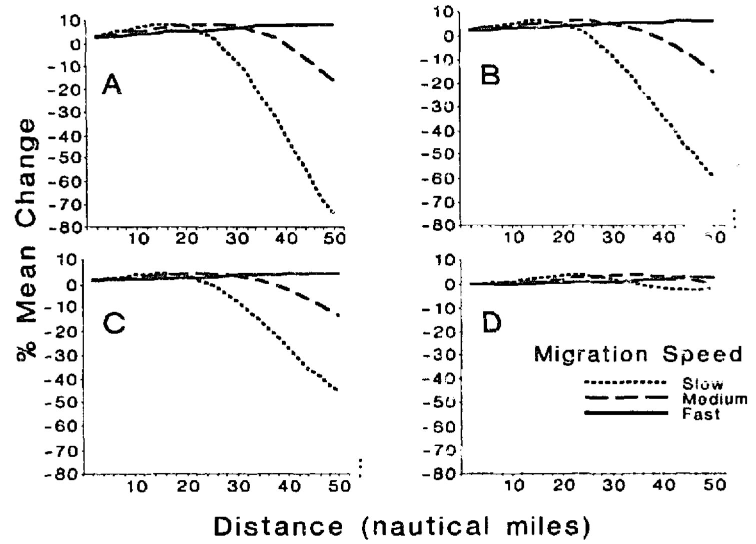

Figure 2: Percent change in value-per-recruit ($) relative to a no-closure scenario for different levels of cheating A) 0%, B) 10%, C) 20% and D) 50% at three assumed migration speeds: slow (67% of best estimate), medium (best estimate) and fast (200% of best estimate).

Average predictions of changes in value-per-recruit, presented above, have to be viewed within the context of uncertainty analysis. The percentage of parameter combinations which resulted in predicted gains in value-per-recruit are a measure of the risk of a given closure strategy. If all vessels comply with the closure, simulation results predict that all closures up to 15 nautical miles have a positive effect on value-per-recruit (Figure 3a). For levels of non-compliance of 10% and 20% the furthest closure lines which ensured a positive effect were 8 and 6 nautical miles respectively (Figure 3b-3d). If only 50% of the fleet complies a positive effect is ensured for closures between 26 and 32 nautical miles. Again to put these effects into perspective, if a 20-nautical-mile closure was imposed, and assuming the best estimate of prawn migration speed is correct, the model predicts that levels of cheating of 0%, 10% 20% and 50% will produce positive gains in value-per-recruit in 99%, 97%, 94% and 100% of the cases respectively.

Percentage mean change in egg-per-recruit increases as the closure line distance increases (Figure 4a). In the presence of cheating the increase in egg-per-recruit is reduced (Figures 4b-4d). For instance, if a 20-nautical-mile closure is imposed, and assuming the best estimate of prawn migration speed is correct, levels of cheating of 0%, 10%, and 20% predict increases in egg-per-recruit of 40%, 34%, 23%, respectively. If only 50% of the fleet complies a 2% reduction in egg-per-recruit is predicted.

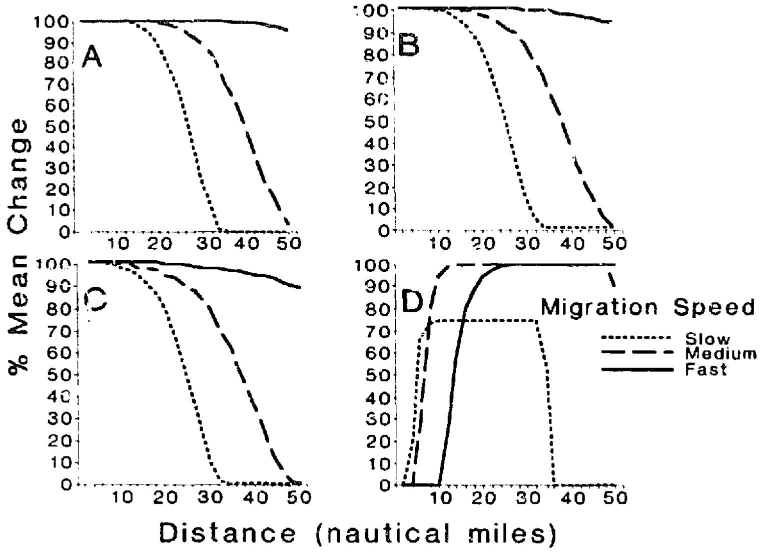

Figure 3: Percent of parameter combinations predicting increases in value-per-recruit ($) relative to a no-closure scenario for different levels of cheating A) 0%, B) 10%, C) 20% and D) 50% at three assumed migration speeds: slow (67% of best estimate), medium (best estimate) and fast (200% of best estimate).

4. Discussion and conclusions

Simulation modelling provides an excellent framework for evaluating the effects of fishery regulations. The scientist must, however, remind the manager that advice given on the basis of simulation results is only reliable if the simulation model has been validated. Utility-per-recruit models are well established in the fishery literature, and it can be argued that they have " high face validity" (sensu [6]). This means that the model herein is appropriate in the context of optimising the contribution of a single recruit, ie. the model assumes there is no stock-recruitment relation for the stock. This assumption has been accepted as dogma for most tropical penaeids and until recently has not been questioned [7]. To compensate for the inherent weakness of a utility-per-recruit approach when there is a stock-recruitment relationship the analyst may estimate egg-per-recruit. By doing so the scientist can provide advice on the extent to which reproductive output is affected by a regulatory change, thus providing some insight on possible effects on recruitment.

Although the model's core is a utility-per-recruit formulation, the fleet dynamics and spatial closure dynamic modules of the program are not part of it. Most of the relationships incorporated in these later two modules were validated by empirically testing their assumptions against real data. For instance, the migration module is the result of analyses on tagged prawn movements [3], and the fleet dynamic module is the result of analysing the seasonal pattern of fishing effort in the Torres Strait fleet under different closure regimes. The model uses only one spatial dimension (the east-west axis for the Torres Straits) because analysis of prawn movement, abundance and effort distribution indicate that there is not much variation along the other spatial dimension (the north-south axis). As prawns and gear interact on the bottom surface of the sea the vertical axis is likely to be unimportant. Analysis of prawn migration and fleet movement has revealed they are both unidirectional [3]. Prawn cohorts recruit initially to the reef, and progressively move further away from it, closely followed by the fishing fleet. A possible problem of the model currently being investigated, relates to evidence (Reg Watson, unpubl. data) suggesting that different sized prawns are moving out of the reef at different times. If this were true it would violate the model's assumption about a constant size at recruitment. Such complexity could be incorporated in the future.

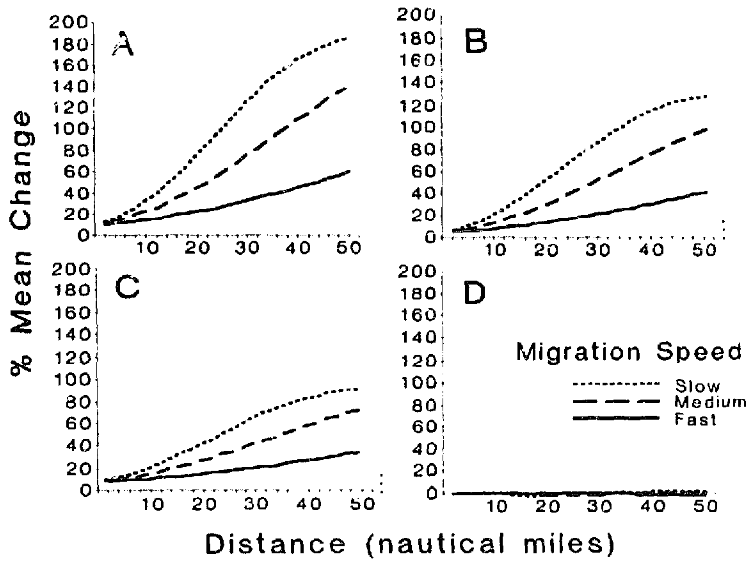

Figure 4: Percent changes in average egg production-per-recruit relative to a no-closure scenario for different levels of cheating A) 0%, B) 10%, C) 20% and D) 50% at three assumed migration speeds: slow (67% of best estimate), medium (best estimate) and fast (200% of best estimate).

Even accepting all the model's shortcomings it is important to highlight some of the conclusions from this research. The effects of cheating are substantial and quickly erode the benefits obtained from imposing a closure. This is specially the case for the beneficial effects the closures may have on egg-per-recruit. It seems, however, that the risk of a given closure strategy (measured as the percentage of negative outcomes predicted by the simulation) is not affected significantly by the level of cheating. This means that although the benefits of closures are dissipated by those boats that do not comply, the risk of imposing a detrimental closure does not increase. It must be highlighted that no analysis was performed on the relative benefits of the closure to each of the two fleet groups (legal and illegal). It is likely that the imposition of a closure may be more beneficial to those boats which do not comply with the regulation, thus increasing potential conflicts between fishers.

Acknowledgments

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