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Simulations Relevant to the 1/3 Harvesting Rule for Northern Cod

by

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Abstract

The one-third rule for harvesting of northern cod specifies that one third of the offshore catch must be taken from each of the NAFO divisions 2J, 3K, and 3L, within which the stock is found. The rationale for this rule has been that historically the relative biomasses of the stock in the three areas has not differed significantly from equal proportions in each of the three divisions. In this paper I present results of simulations in which I examine the likely long-term effects of this type of management rule relative to other possibilities. The simulations are conducted using a stochastic simulation model of the stock dynamics, including movement of fish between areas and harvesting in the areas using different harvesting rules. The simulations resulted in the following conclusions: (i) given that the fleet has a preference for one area (3K), some rule for harvest allocation among the three areas must be used to ensure that the substock in 3K is not overfished, (ii) due to stochastic variability and stock-recruitment feedback, the static one-third rule is likely to result in overharvesting in at least one area in the long-run and (iii) a dynamic harvest allocation rule, in which the proportions allocated to the three areas are set using the most recent information of the actual relative biomasses in the three areas, will produce the lowest likelihood of overharvesting in the long-run.

Résumé

D'après la règle de un tiers appliquée à la récolte de morue du nord établit que les prises hauturières doivent être capturées à raison de un tiers dans chacune des divisions 2J, 3K et 3L, où se trouve le stock de morue du nord. Cette règle s'appuie sur le fait que, historiquement, la biomasse relative du stock est demeurée répartie en proportions à peu près égales entre ces trois divisions. Dans le présent document, j'expose les résultats de simulations que j'ai utilisées pour examiner les effets vraisemblables, à long terme, de ce type de règle de gestion, comparativement à d'autres possibilités. Les résultats en question ont été obtenus à l'aide d'un modèle de simulation stochastique de la dynamique des stocks, notamment du mouvement du poisson entre les divisions et de la récolte fondée sur des règles différentes. Ces simulations ont débouché sur les conclusions suivantes : i) étant donné que le flotte de pêche a une préférence pour une division (3K), une règle quelconque régissant la répartition de la récolte des allocations entre les trois divisions s'impose pour empêcher la surpêche dans le sous-stock de 3K ; ii) en raison de la variabilité du modèle stochastique et de la rétro-action stock recrutement, la règle fixe de un tiers aboutira vraisemblablement à une surpêche dans au moins une des divisions à long terme; iii) une règle dynamique de récolte des allocations, dans laquelle les proportions allouées dans les trois divisions s'appuieraient sur les informations les plus récentes en matière de biomasses relatives réelles des trois divisions présenterait les plus faibles risques de surpêche à long terme.

Introduction

The northern cod stock is spread over three NAFO divisions: 2J, 3K, and 3L. The spawning populations in these three areas are thought to be distinct (J. Baird, pers. comm.). For the years in which there are data, it appears that the biomass of the spawning stock is approximately evenly split among the three areas, that is, about one third of the stock is present in each of the three areas. However, the areas are not equally accessible to the offshore fishing fleet. If given the choice, the fleet would fish most or all of its quota in 3K because that area is most accessible by ship (J. Baird, pers. comm.). If the fleet were permitted to do this, there is the fear that the spawning potential of the sub-stock in division 3K would decline, thus reducing the productivity of the northern cod stock and perhaps jeopardizing the persistence of this sub-stock. This situation has led to the management rule for northern cod referred to as the 1/3 rule, in which the offshore fleet is required to harvest 1/3 of its northern cod quota in each of the three divisions.

Simulations

To examine the likely effect of this type of management rule I have conducted simulation experiments using a general model of fish population dynamics. The model is general because it is not a model of northern cod *per se*, but is designed to look at the general problem of the long-term effects of areal quotas for sub-stocks. I examined the consequences of four types of fishing behaviour, two in which areal quotas are not set and two in which they are:

(1) **Preference**: The fleet is permitted to decide where to fish and the fleet has a preference for a particular area. For the northern cod case this is equivalent to having no areal quotas and a fleet with a preference for 3K. It is assumed that each year the fleet attempts first to fish in its preferred area. If the biomass in the preferred area is reduced to a certain level (termed the "switching level", expressed as a percent of the unexploited sub-stock biomass), the fleet moves to another area to fish. However, the next year it again attempts to fish in its preferred area.

(2) **Inertia**: Again the fleet is permitted to decide where to fish but in this case the fleet does not have a preference for any particular area. It chooses an area at random and if it finds fish there it stays there (perhaps for several years) until the biomass declines to below the switching level. At this point the fleet switches to another area and again stays there until the biomass reaches the switching level.

(3) **Even Split**: Areal quotas are set such that the fleet is forced to take equal amounts of fish from all areas (This is equivalent to the 1/3 rule in the northern cod case).

(4) **Proportional**: Areal quotas are set such that the total quota is divided among the areas in proportion to the estimated relative biomasses of the areas.

The Model

The model is a stochastic simulation model of a fish stock divided into two sub-stocks (Figure 1). Time in the model occurs as discrete steps, representing half-year periods (seasons). Figure 2 illustrates the annual cycle of events in the model. First the biomass in each sub-stock is assessed and the quota for the year is set. If areal quotas are to be applied these are also determined at this time. Then recruitment, natural mortality and movement of fish between the areas (optional) occurs. Fish are then removed from the areas according to the specified type of fishing behaviour (four types above); the total is limited to the total quota. Further recruitment, natural mortality and between-area movement then occur before the next year's biomass assessment is made.

The stock-recruitment relationship assumed in the model is illustrated in Figure 3. Recruitment is assumed to be highly variable. The curve in Figure 3 gives the maximum possible recruitment, given a certain sub-stock biomass. However, the actual recruitment value used each time step in the model is chosen at random (uniform distribution) from between 0 and the value of the curve, for the given sub-stock biomass value in that season. The results of the simulations are not sensitive to the particular form of the recruitment function used, but the function must include the following two characteristics: (i) recruitment must decline with sub-stock size and (ii) there must be stochastic variability in the recruitment level at a given sub-stock size.

Movement rate is the fraction of the biomass present in one area that moves into the other area. The rate of movement between the two areas is assumed to be the same so that the *amount* of movement is density-dependent, but the *rate* is not. Each season (Figure 2) the movement fraction is chosen at random from a normal distribution with a mean given for that simulation (below), and coefficient of variation (CV) of 0.2.

Natural mortality rate is the fraction of the biomass dying due to natural (not fishing) causes each season (Figure 2). It is modelled as a lognormal deviate. The mean survival rate is given by $e^{\frac{1}{L}ln(S_F)}$, where L is the maximum lifespan of the fish and S_F is the fraction of the original recruits that survive to the maximum age (in the absence of fishing). L is set at 24 seasons (12 years) and S_F is set at 0.01 in the present simulations. The mean seasonal mortality rate is therefore 0.175. The CV of the lognormal is set at 0.1.

Simulations

I conducted simulations for each combination of the following three parameters: (i) each of the four fishing behaviours - **preference, inertia, even split, proportional-** , where the preferred area in the **preference** option is area 1, (ii) each of seven between-area movement rates - **0.0, 0.001, 0.005, 0.025, 0.125, 0.25, 0.5** - , and (iii) each of five fleet switching levels - **0%, 1%, 2%, 5%, 10%** of the unexploited sub-stock biomass. Two sets of the simulations were conducted using different random number seeds. A total of 280 simulations was therefore conducted. In all cases the total quota was set such that the exploitation rate was 40% of the total stock biomass, as determined at the beginning of the year when the biomass counts are made (Figure 2). Each simulation was run for 250 years; only the final 200 years were used in summarizing the results to remove the effects of the transient period in the dynamics. For example, any sub-stock that became extinct during the 250 years was extinct by the 50th year.

The following values were calculated to summarize the output: mean annual total catch, mean total biomass, CV of the mean total biomass, and mean biomass in each area. The two replicate sets of simulations produced qualitatively identical results. Therefore the results from only one of the sets is reported here. The overall catch, biomass, and CV of biomass values for switching levels 0%, 2% and 10% are shown in Figures 4 to 6. The biomass in the individual areas for switching levels 0% and 10% are shown in Figure 7.

Conclusions and Recommendations

As expected, the results from the **preference** fishing behaviour indicate that this should be avoided. The **preference** behaviour is representative of the fleet behaviour that is expected if the northern cod quota is not sub-allocated by division; in this case it is expected that the fleet will show a strong preference to fish in NAFO division 3K. The simulations predict that this would result in low stock biomass, low catches and high CV's. The sub-stock in 3K (as in area 1 in the simulations) would be depressed. The problem is most severe when the between-area movement rate of fish is low. It is therefore certainly advisable to set areal quotas for the different divisions.

However, the simulations suggest that the 1/3 rule is probably not an appropriate method for setting the areal quotas. The 1/3 rule is modelled here as the **even split** fishing behaviour. The problem with the 1/3 rule is that, due to variability in recruitment between areas, one area will inevitably have lower biomass than the others at some point. If the 1/3 rule is applied, the stock in the reduced area will suffer a higher than intended exploitation rate, reducing its biomass further, and possibly reducing its recruitment rate. As the 1/3 rule continues to be applied, the reduced area eventually declines to 0 biomass.

In effect, under the **even split** rule equal biomasses in the three divisions represents an unstable equilibrium point for the system. As long as the biomass in each of the three areas remains exactly even, the 1/3 rule is optimal. However, a small perturbation from this situation is exacerbated by the **even split** rule, driving the system to a new equilibrium in which the biomass in at least one area is inevitably reduced to zero. Note that this problem will arise for any areal allocation rule that does not allow for response to fluctuations in the relative biomasses of the different areas.

The simulations also show that this scenario for the 1/3 (or **even split**) rule is particularly important when the movement rate of fish between the areas is low (less than 0.1). For higher movement rates the incoming fish rescue an area that has been reduced temporarily, so the negative effect of the 1/3 rule is no longer evident. In evaluating the likely long-term impact of the 1/3 rule it is therefore very important to have some understanding of the rate of interchange of fish among the sub-stocks within the northern cod stock. Since the current feeling appears to be that this rate of interchange is low (J. Baird, pers. comm.), it is clear that the 1/3 rule should be abandoned.

The question remaining is then: what should replace the 1/3 rule? As discussed above, areal quotas must be set to avoid the consequences of area preference and inertia of the fleet. The simulations suggest that application of **proportional** areal quotas would be preferable to the 1/3 rule. Application of this strategy depends on the availability of some annual measure of the relative biomasses in the three divisions. I suggest using the autumn survey relative biomass estimates for this purpose. Although the survey occurs several months before the peak of the offshore fishery, this is accounted for in the simulations because in the simulations there is a delay between the biomass counts and the fishing, during which recruitment, natural mortality, and inter-area movement occurs. Furthermore, there is some recent evidence that the fall survey biomass estimates are correlated with the relative biomasses later in the season (J. Baird, pers. comm.).

Acknowledgments

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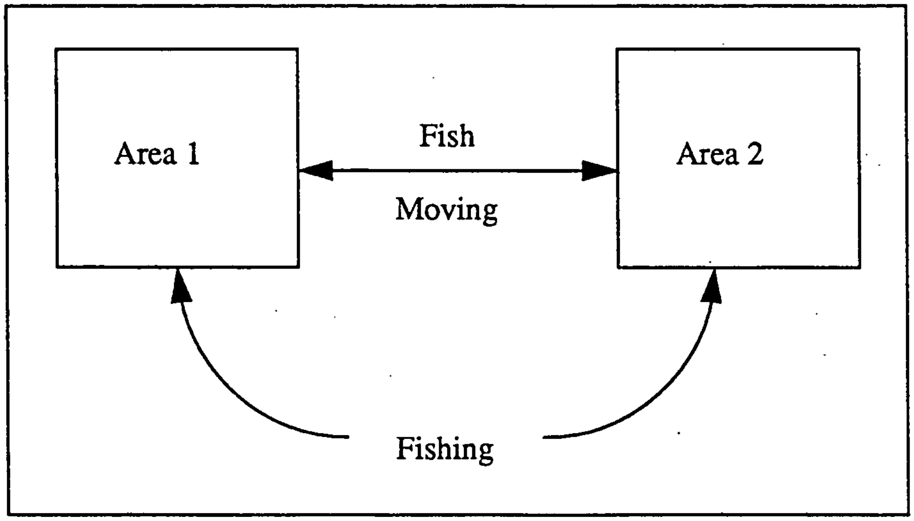


Figure 1. Set-up of the model stock.

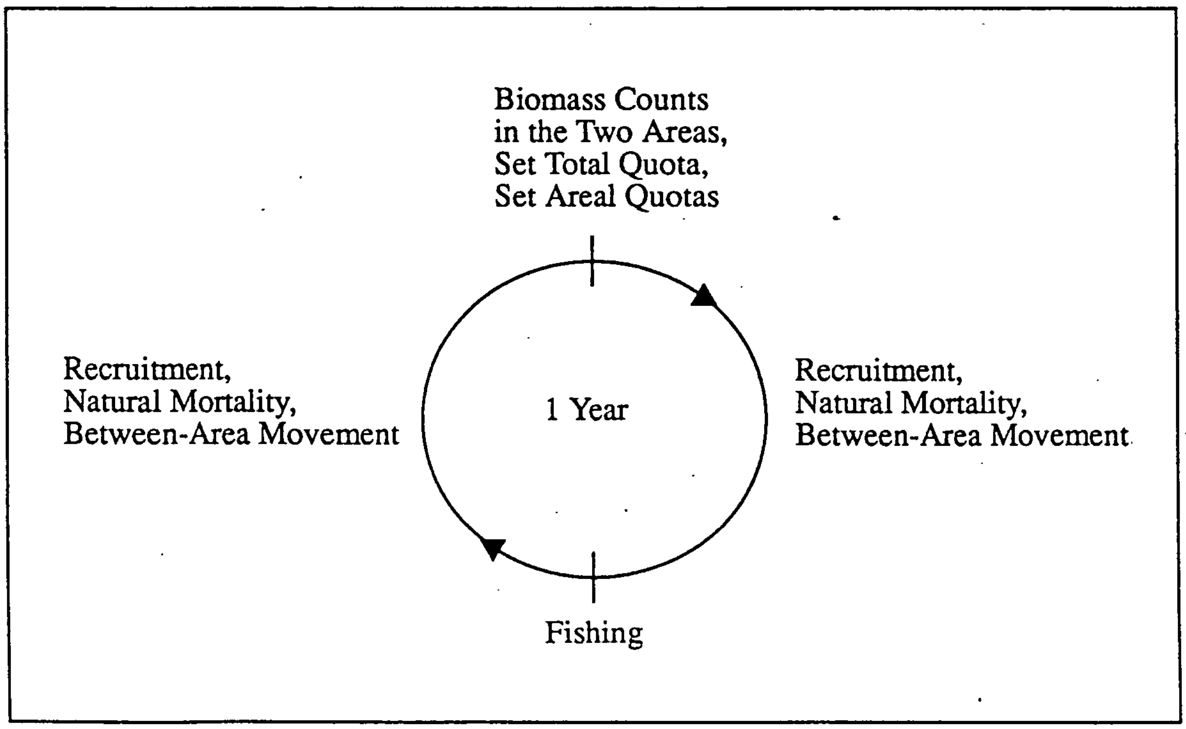
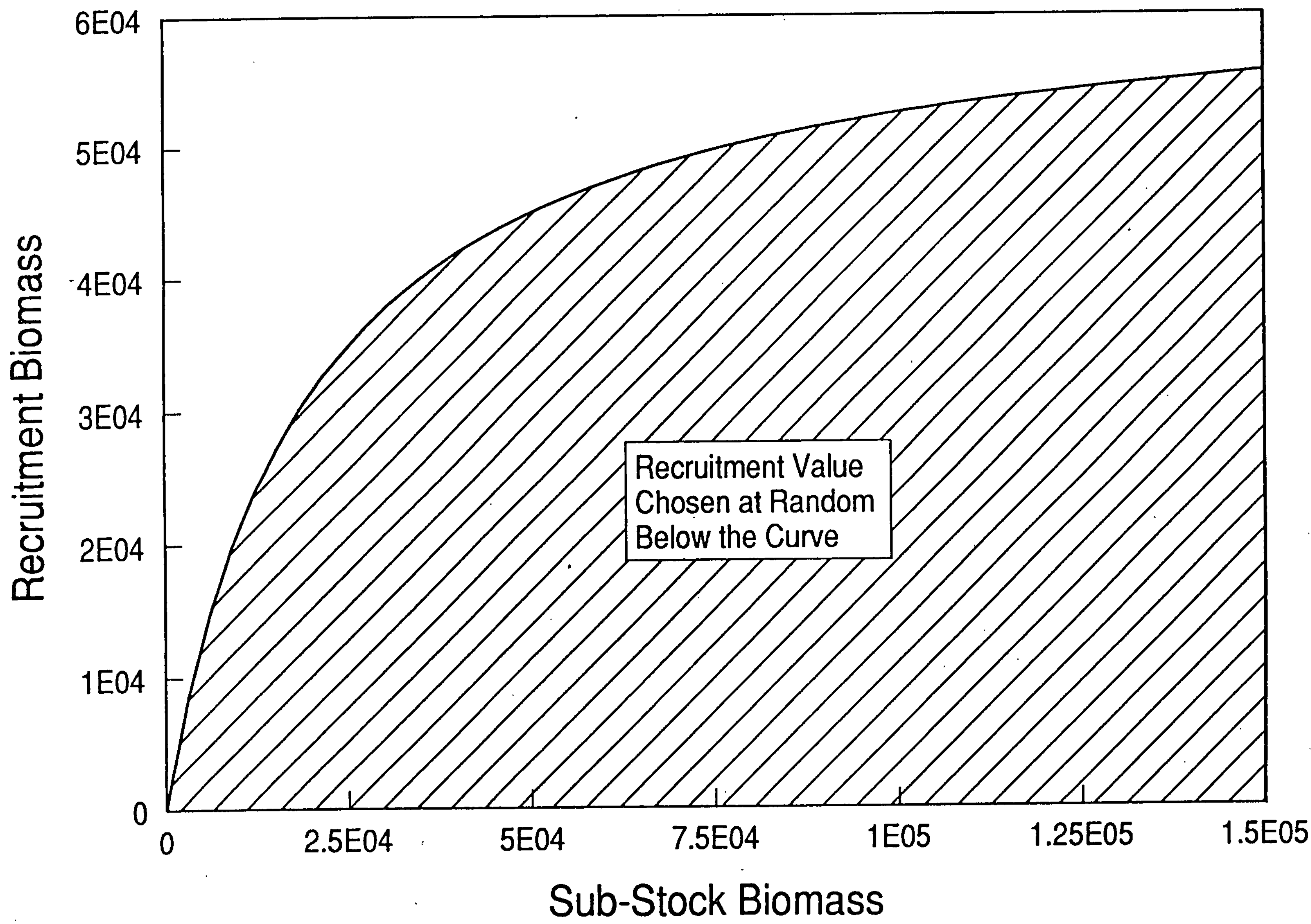


Figure 2. Annual sequence in the simulation model.

Figure 3. Stock-Recruitment Relationship for Sub-Stocks in the Model



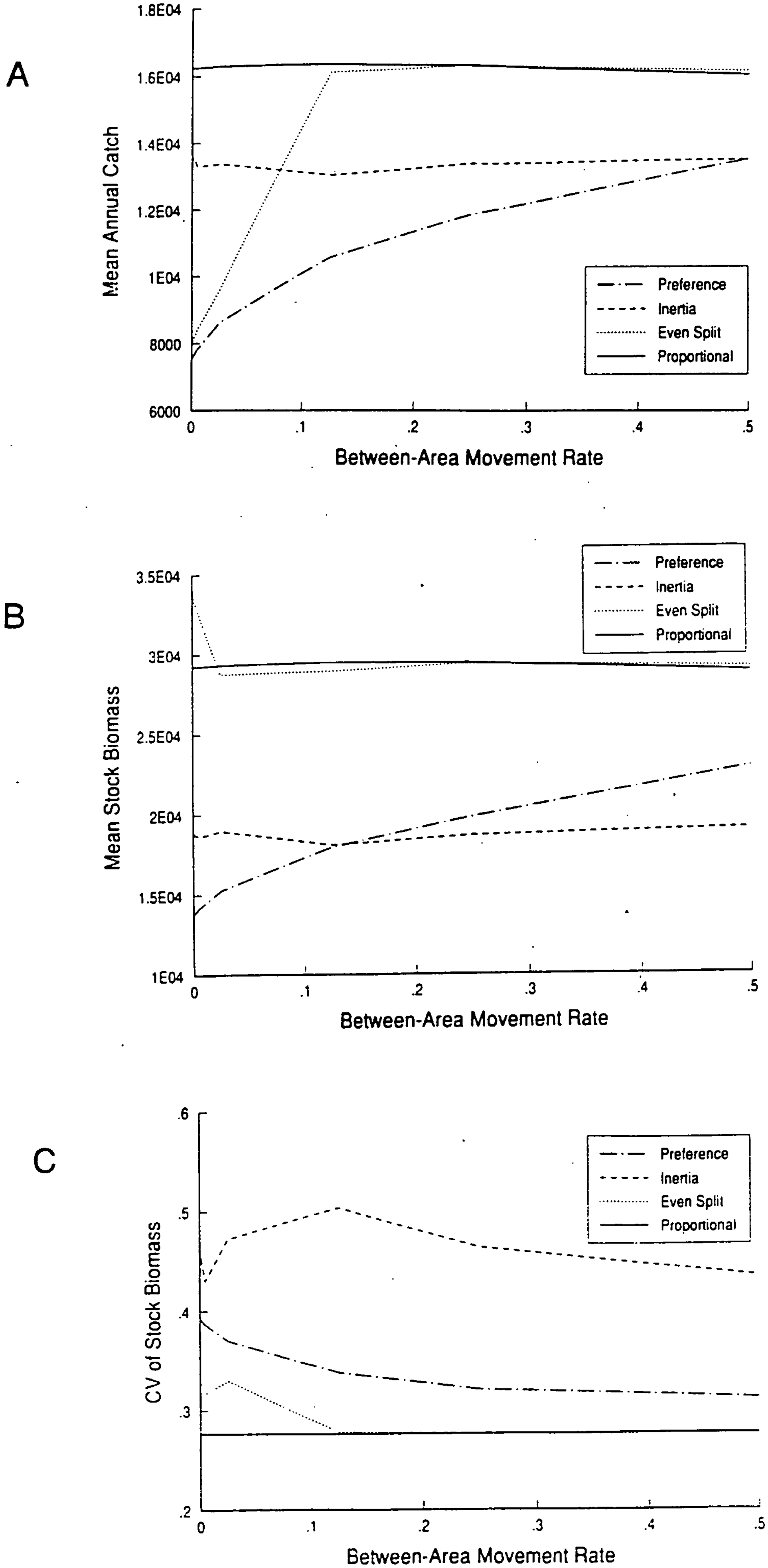


Figure 4. Simulation results: Mean annual catch vs. movement rate. Switching level = 0% unexploited biomass.

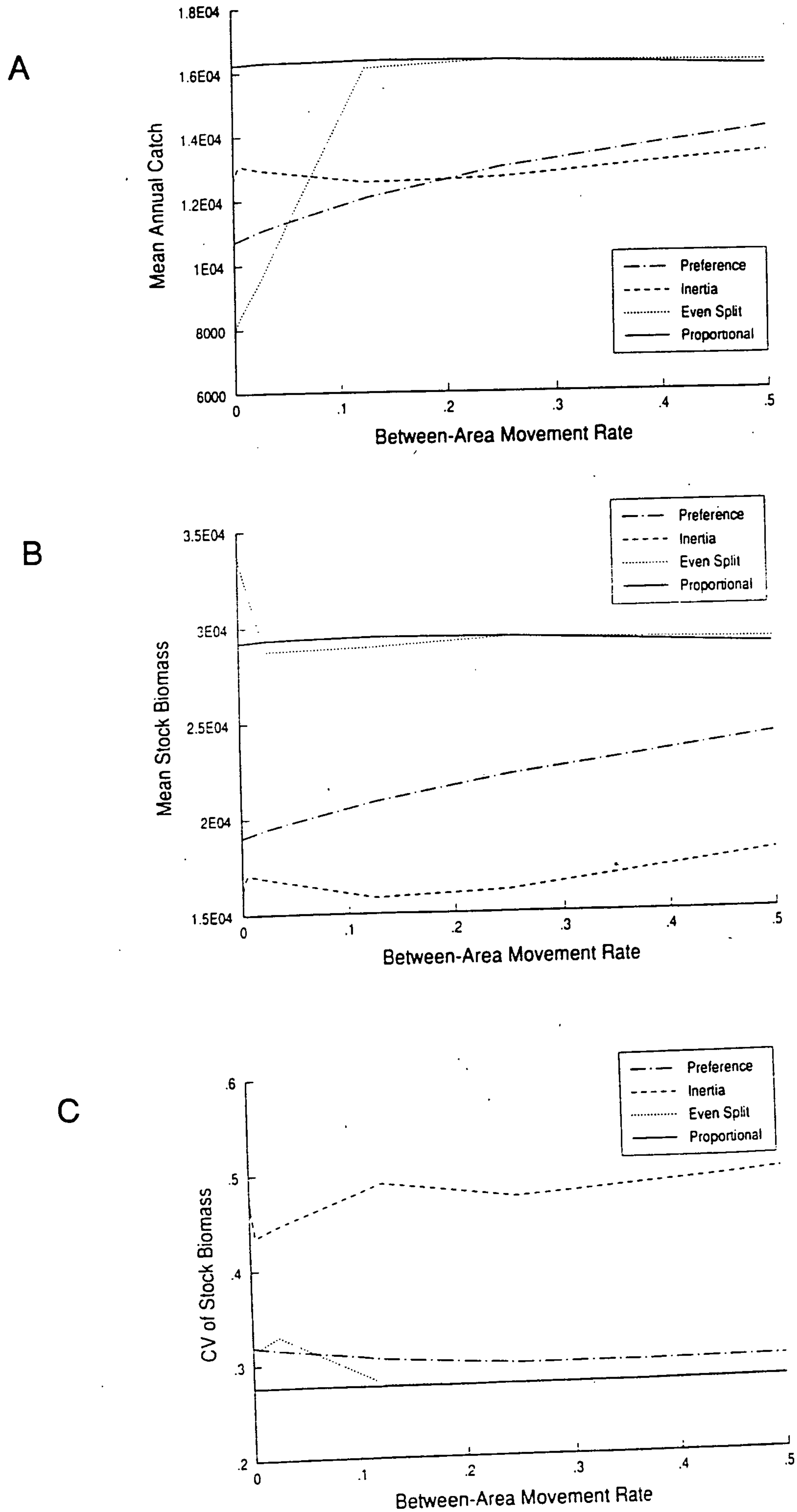


Figure 5. Simulation results: Mean annual catch vs. movement rate. Switching level = 2% unexploited biomass.

A

B

C

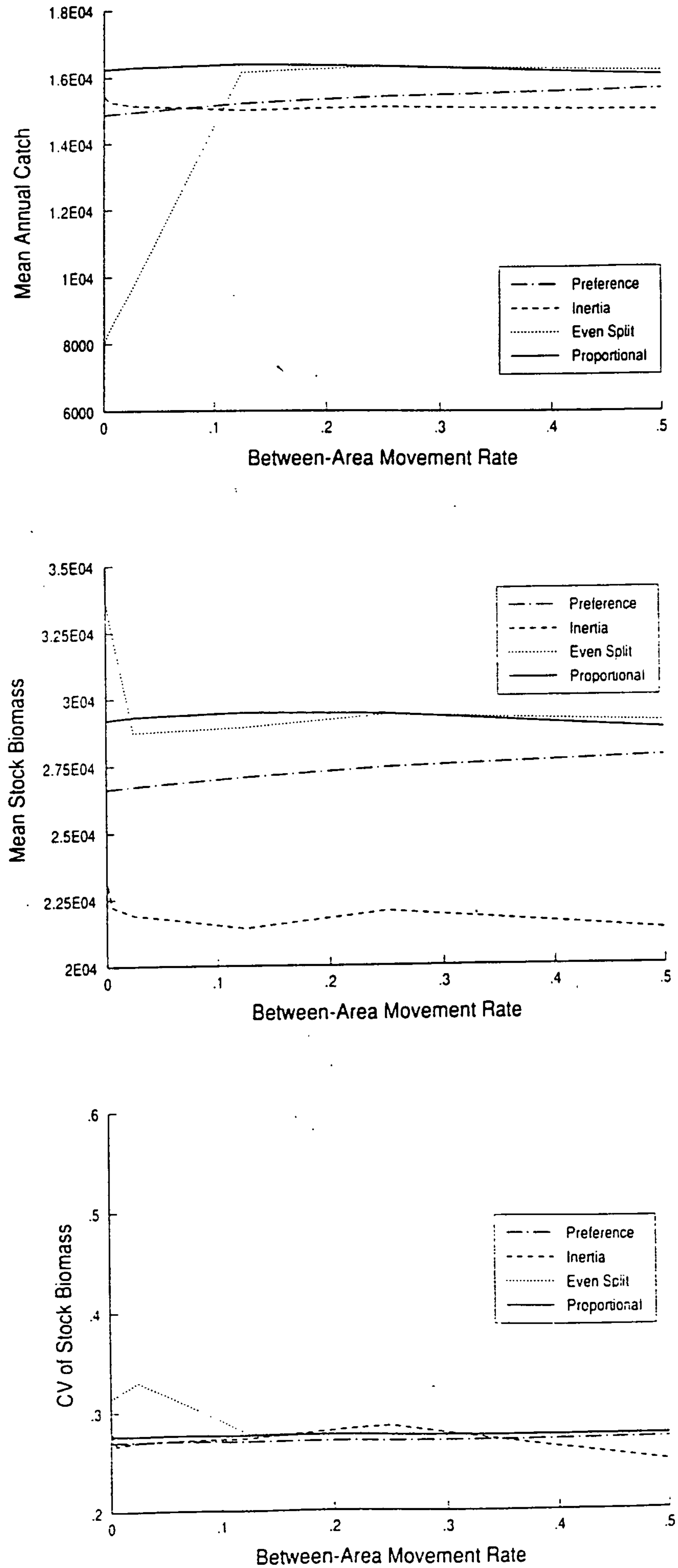


Figure 6. Simulation results: Mean annual catch vs. movement rate. Switching level = 10% unexploited biomass.

Figure 7. Simulation results: Biomass in each of the two areas vs. movement rate. A: Switching level = 0% unexploited biomass. B: Switching level = 10% unexploited biomass.