Information Flow among Fishing Vessels Modelled Using a Bayesian Network

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Abstract: Reaction of fishers is an essential source of uncertainty in implementing management decisions. Provided they realistically capture fishers' use of information, fleet dynamics models provide the basis for simulating the impact of proposed management strategies that may not yet be implemented. Vessel interaction however, has not been the focus of fleet dynamic models, although it might play an essential role in the adaptation of a fleet to changes. In this paper, a spatially explicit model of vessel fishing behaviour is developed for a line fishery on the Great Barrier Reef. Vessel behaviour is conditioned on data of past catch and effort at a spatial resolution of 6 x 6 minute grid cells. The decision of where to fish is modeled as a stochastic process across grid cells. The probability of fishing a grid cell is based on past income per unit effort experienced by a vessel in that grid cell, and the daily cost of steaming to it. A particular vessel's probability distribution incorporates the probability distributions of other vessels with a Bayesian-network information propagation routine. This uses a link matrix to describe the learning from other vessel probability distributions. Thus, one vessel's knowledge affects another with the associated link parameter inversely related to the distance between vessel home ports.

Keywords: Influence Networks; Belief Networks; Management strategy evaluation

1. INTRODUCTION

Population models used for fisheries management are becoming more spatially explicit because information is needed for assessing the efficacy of spatial management strategies. As they do, the ability to realistically simulate the spatial allocation of fishing effort becomes more crucial because the performance of management strategies may depend on fisher behaviour through the spatial distribution of fishing mortality.

Individual- or agent-based fleet dynamics models attempt to simulate the decisions and actions of individual vessels [Dreyfus-León 1999]. In such models, however, there is a concern that agents act independently of each other when in reality this may not be true. Decisions by vessel operators on where to fish may, for example, be made based on active sharing of catch information among vessels, or by passive observation of where other vessels direct their effort.

Because a Bayesian approach can accommodate learning from different information sources, a Bayesian belief networks approach, described by Varis [1998], is used in this paper to model information flow among vessels in an agent-based fleet dynamics model. For the current model, the information a vessel gains from other vessels comes from the passive "observation" of where other vessels direct their effort.

2. THE MODEL

The software framework used for the model is the Effects of Line Fishing Simulator [ELFSim, Mapstone et al. in prep].

2.1 ELFSim

ELFSim is a decision support tool designed to evaluate management options for the coral trout (*Plectropomus* spp., particularly *Plectropomus leopardis*) fishery on the Great Barrier Reef, Australia. It contains many components, including output visualisation and run management, but the most important are a biological model of coral trout population dynamics, and a model of fishing behaviour. ELFSim operates at a monthly time scale, in two modes. In the historical mode, the historical catch data are combined with assumptions about fish density per reef in the absence of exploitation, and used to determine the initial conditions for the projection mode. In that mode, the fleet dynamics (effort allocation) model is used to allocate the total amount of effort (specified by the user) across reefs. The reef-specific effort then determines the reef-specific catch, which is in turn used by the biological model to project the reef-specific populations forward in time.

2.1.1 The biological model

The biological model incorporates many of the features of the models of coral trout population dynamics developed by Walters and Sainsbury [1990] and Mapstone et al. [1996]. Coral trout is assumed to consist of many local populations. Each population is associated with a single reef. The population dynamics model is age, sex and size structured, assumes that the number of zero year olds is related to the size of the reproductive component of the population according to a stock-recruitment relationship, and allows for larval movement among reefs. Several processes such as variation in natural mortality and larval survival are included. The model allows for multiple fleets.

The size-structure of the population is modelled by dividing each cohort into ten growth groups. The model allows for movement of larvae but ignores the possibility of movement of animals aged 1 and older between reefs. This is because there is little evidence for movement of such animals [Davies, 1995].

2.1.2 The effort allocation algorithm

The current effort allocation algorithm in ELFSim determines the spatial (i.e. 6x6 nautical mile grid cell) distribution of fishing effort at each monthly time step, given a specification for the total annual fishing effort. This algorithm is not intended to mimic the individual decisions of skippers but instead represents the net effect of these at the fleet level. By applying the effort allocation algorithm to the entire fleet or to groups of vessels in particular regions, both data requirements and computer search time are reduced without necessarily sacrificing the ability of the model to mimic historical, and predict future, effort.

2.2 A Fleet Dynamics Model

The effort allocation model that is currently employed by ELFSim assigns an average amount of effort to a grid cell, based on the ranking of historical CPUE in that grid cell. No attempt is therefore made to mimic the behaviour or characteristics of individual vessels (or fishers) even though this may affect which areas are fished. For example, vessels have different home ports, which may be close or far from certain fishing grounds, affecting the ease with which they can fish them.

In this paper we take an alternative, more individual-based approach, and allow fishing vessels, with their own characteristics, to make decisions on where to fish. This decision would be based not only on the vessel's own past information, but also on the information it gathers from the effort distribution of other vessels. Such an approach might provide a better representation of reality.

The individual-based fleet dynamics model constructed has the following characteristics:

- fishing effort is exerted among grid cells by individual vessels.
- individual vessels have 2 key characteristics which influence the grid cells they fish
    - home port location
    - cost of movement to a grid cell
- the decision to fish a grid cell is based on a probability distribution
- the probability of a vessel v fishing a grid g depends on its potential profitability, i.e.
- $$P(profit_{v}^{g}) = \alpha(price \times CPUE_{v}^{g} - \mathrm{cost}_{v} \times dist_{x,g}) \qquad (1)$$

  where $dist_{x,g}$ is the distance between grid cell g and the vessel's home port, price and cost are constant, and α is a scaling coefficient. $CPUE_v^g$ is the catch rate for vessel v when fishing in grid cell g.

- Annual effort is a management variable specified by the ELFSim user, and the monthly effort is calculated from the seasonal distribution of effort observed in historical data.
- In each month effort is allocated to vessels in the following manner. To start, a vessel is randomly chosen, and the grid cell corresponding to the mode of the probability density for that vessel is assigned the average daily amount of effort the vessel exerts in that month. The reason for using the mode was that it represented the grid cell perceived to return the highest profit. This is repeated to allow as many vessels to fish as possible.
- If the user-specified total effort level is not all allocated in the previous steps then vessels use the remaining effort by assigning their average daily amount of effort randomly to grid cells. The probability that a grid cell receives this effort is proportional to a constant plus the expected returns from that grid cell. This is repeated among vessels until all of the effort is allocated, and allows grid cells that have never been fished, and therefore have no catch data, the possibility of being fished.

Although vessels are expected to make decisions based on their own experience, the data used in ELFSim, are currently not vessel specific. All vessels in the fleet dynamics model therefore, begin with the same historical CPUE data, but vessel experiences diverge as time progresses. It is also assumed that vessels go out to fish and come back to port the same day.

2.2.1 Information flow

Where a vessel will fish is influenced by factors other than just reef catch rate, namely where other vessels are fishing. This information flow among vessels is modelled here using a Bayesian-network information propagation routine. This method, based on Varis [1998], depends on a link parameter (scaled between 0 and 1) that describes the degree of information sharing. The higher the value of this parameter, the more information is shared between two vessels, and the more similar their perceptions of the relative profitability of the grid cells will be. In the current model, the link parameter is proportional to the distance between the home ports of the vessels sharing information, and the current annual profitability. The current annual profitability is important because as fishers start to make close to their average annual profit we believe that they are more willing to use information from other vessels, whereas when profitability is low they rely mainly on the information they themselves know. The link parameter L from vessel 2 to vessel 1 is defined by

$$L_{v1,v2} = \frac{\rho_c}{\overline{\rho}} e^{-dist_{v1,v2}} \tag{2}$$

where

$dist_{v1,v2}$ = distance between the home ports of vessel 1 and vessel 2

ρ_c = current annual profit of vessel 1

$\overline{\rho}$ = average annual profit of vessel 1

and thus the posterior probability of a vessel v* fishing grid cell g, is given by:

$$P(proft_{v*}^g \mid effort_v^g) = \alpha P(profit_{v*}^g)\pi_v^g \tag{3}$$

where

$$\pi_v^g = \mathbf{M}P(effort_v^g) \tag{4}$$

α = scaling constant

$\mathbf{M}$ = link matrix with elements $m_{i,j}$

$$m_{i,j} = \frac{1}{n_r} + L_{v*,v} \times (1 - \frac{1}{n_r}) \tag{5}$$

n_r = number of rows

$L_{v*,v} \geq 0 : i = j = 1,\dots,n_r$

$L_{v*,v} < 0 : i = n_r - j$

$$m_{i,j} = \frac{1}{n_r - 1}\left[1 - \left[\frac{1}{n_r} + L_{v*,v} \times (1 - \frac{1}{n_r})\right]\right] \tag{6}$$

$L_{v*,v} \geq 0 : i \neq j$

$L_{v*,v} < 0 : i \neq n_r - j$

More detailed explanations of Bayesian networks can be found in Pearl [1986a,b], and Charniak [1991].

3. RESULTS

This individual-based fleet dynamics model was examined using ELFSim for a small (106 reef) portion of the Great Barrier Reef (Figure 1). For simplicity the model included only three vessels; two had a home port of Cairns, and the other came from Cooktown (referred to hereafter as Cairns 1, Cairns 2 and Cooktown).

Although the models in ELFSIM are stochastic allowing for multiple Monte Carlo simulations, the results of only a single simulation are shown here. Also although reef-specific biological information is available in ELFSIM, for brevity it is not reported.

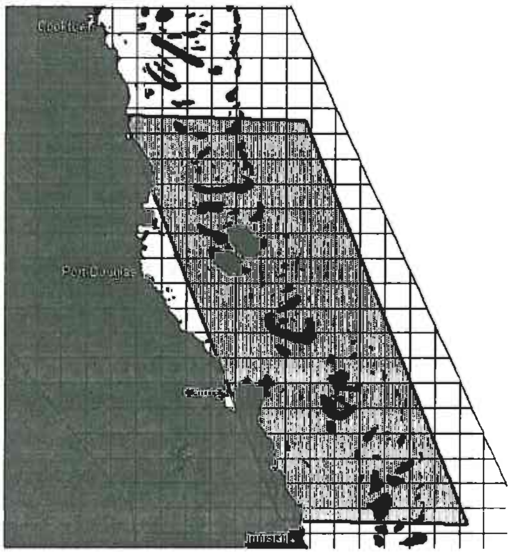

Figure 1. Area of Great Barrier Reef and eastern Australia used in the current model.

The historical period (1965– 98) was followed by a projection period to 2025 in which the annual effort was 1080 boat days. This is lower than the peak annual effort for the area of 4000 boat days in 1997. Consequently, with lower effort being exerted in the projection period, the fish biomass recovers (Figure 2), and catch rates increase.

Figure 3 shows the spatial distribution of effort when each vessel acts independently of the others; Cairns 1 concentrated mainly in the southern part of the area while Cairns 2 and the Cooktown vessel concentrated mainly in the northern portion.

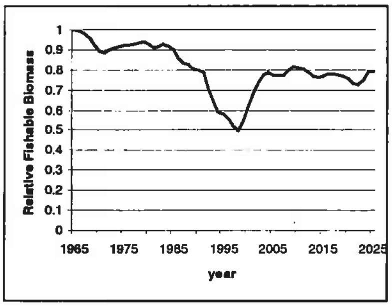

Figure 2. Time trajectory of the relative fishable biomass.

When vessels shared information using the Baysian network they tended to fish fewer but the same grid cells (Figure 4). They did this because their experience and the information received from other vessels all indicated that these were the best places to fish. When effort distributions are similar, reflecting a common choice in grid cells, then the uncertainty of fishing a grid cell in the posterior distribution is reduced. This is reflected in the effort distributions of Cairns 1 and Cairns 2, which were more similar when they shared information than when they acted independently (Figures 3 and 4). The

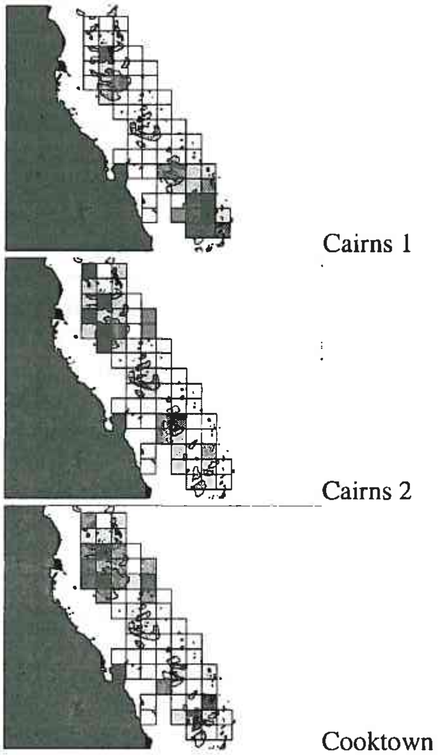

Figure 3. The spatial distribution of effort summed across all years in the projection period (1999 to 2025) for the three vessels when they do not share effort information.

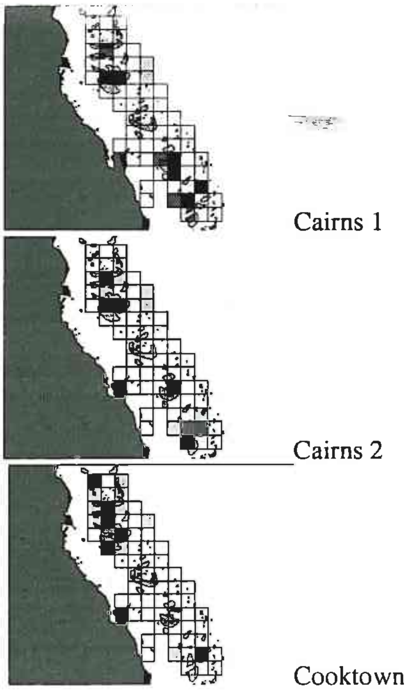

Figure 4. The spatial distribution of effort summed across all years in the projection period (1999 to 2025) for the three vessels when they share information.

Cooktown vessel concentrated also on many of the same grid cells but mainly in the northern part of the range, presumably because it incurred less travelling cost.

The relative catch obtained by each of the vessels is shown in Figure 5. For the Cooktown vessel, the catch was consistently lower when information was shared. However, these catches were taken closer to the home port so the cost associated with fishing was lower.

To illustrate further how information flow between vessels can influence the spatial distribution of effort, Figure 6 shows how the Cooktown vessel responds when a section of the northern part of the area is closed. Figure 7 shows that the profit of the Cooktown vessel tended to be higher when it used information from other vessels. There are two reasons for this: a) the grid cell that took most of the vessel's effort was the one closest to its home-port and so the cost in getting to the grid cell was low and b) this grid cell was one of the most productive grid cells that was open in the northern part of the region, and the other vessels directed a relatively high amount of effort to it compared to others grid cells in the north.

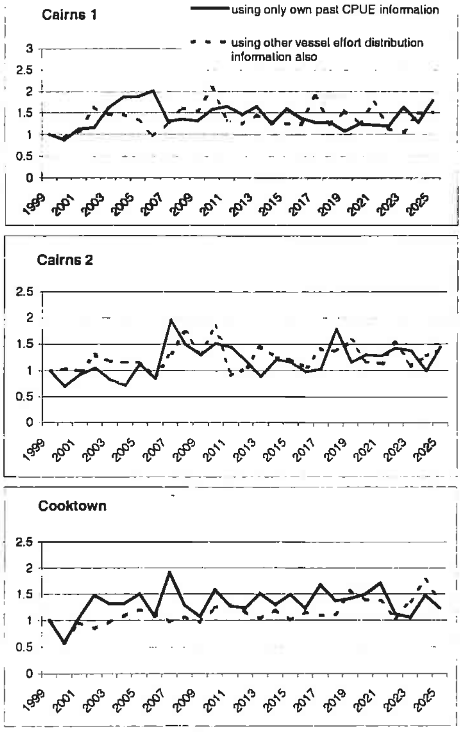

Figure 5. Catch by vessel in projection period under two information sharing scenarios.

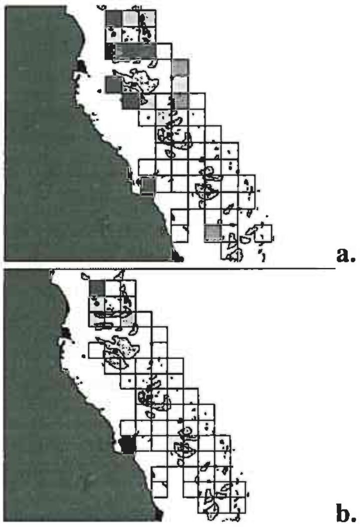

Figure 6. The response of the vessel from Cooktown to a closure in the northern part of the area. a. only using own past CPUE to determine where to fish, b. also sharing information with other vessels.

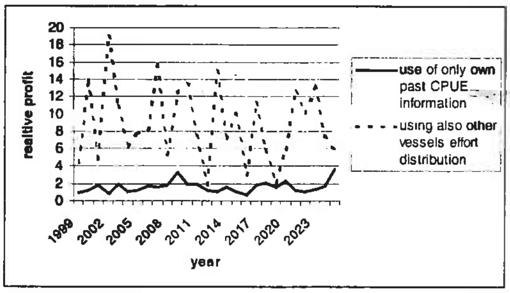

Figure 7. Relative profit of the Cooktown vessel when a section of the northern part of the range is closed.

4. DISCUSSION

The model scenario considered above is very simple, and it is not surprising that, in general, vessels increased their catches when they shared information. The variability in vessel probability distributions is reduced when vessels expend their effort in the same places. One of the reasons why vessels tended to fish the same grid cells was because the total annual effort in the area had been reduced from historically high levels. Therefore, the biomass was increasing, and as soon as the most productive grid cells were found, vessels tended to direct their effort towards them.

A different situation might have occurred had effort remained constant or increased because vessels would direct their effort away from the most depleted reefs to where their own experience told them where the best fishing was. They would also incorporate the effort distribution of other vessels, and because this information is indicative of effort not catch rate, it could differ from the vessel's own experience. The result of incorporating information that is contrary to a vessel's own fishing knowledge would be an increase in uncertainty in where to fish, as two separate beliefs are incorporated into the same probability distribution [Varis 1998]. Thus, information flow between vessels would lead to more erratic fishing behaviour.

The model presented did not allow vessels to propagate false-information as Allen and McGlade [1986] discuss. In a Bayesian-network framework, false information should have an effect of creating more erratic fishing behaviour by reducing the association between effort and available biomass.

Nonetheless, we have shown how information flow among vessels in an individual-based fleet dynamics model can change the spatial allocation of effort. We have also shown how such behaviour can change under different management options. This underscores the significance of realistically representing fisher behaviour for the purpose of evaluating management strategies.

5. ACKNOWLEDGEMENTS

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