An Investigation of Pasture Sampling Methods using Cellula Automata

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1. INTRODUCTION

The estimation of pasture mass on a paddock is a difficult problem due to large sampling errors. The purpose of this study was to investigate the use of a cellula automata model to simulate cattle grazing at pasture, and to investigate different sampling strategies to estimate population parameters for the quantity of pasture present.

The evolution of a grazed pasture is notable for the formation of clumps at one or more scales. Dale & MacIsaac [1989] discussed methods to estimate the scale of spatial pattern in vegetation. Variation in pasture mass (or height) in a paddock is a combined result of differential regrowth, regrowth time, preferential grazing, and grazing time. Differential regrowth is primarily affected by application of animal excreta (dung and urine). It is a localised effect, occuring within and at the boundaries of the areas directly affected. Due to these processes the frequency distribution of pasture mass is non-normal, exhibiting skewness and sometimes bimodality. Gibb & Ridout [1986], and Sheath & Boom [*unpubl.*] both show evidence of these features.

These effects were examined using a cellula automaton (CA) model that describes the dynamic behaviour of the system, where space and time are treated discretely as in Wolfram [1984, 1986]. A cellula automaton represents a system as a grid of cells, described by their state and local rules. The local rules apply to each cell, and determine through time, what the state of the cell will be as a function of it's current state and that of it's immediate neighbours. Cellula automata model the global behaviour of a system using a rule set describing local interactions within the system. For our model, each cell represents an area of pasture, and may have one of a range of states, reflecting the height (or mass) of pasture present, and also the influence of urine or dung deposition.

Sward structure has been addressed by other authors in terms of pasture cover and plant population densities e.g. Neuteboom *et al.* [1992]. The spatial dimension provided by our cellula automata model allowed the evolution of pasture structure, in terms of height and spatial variability, to be followed. With the full knowledge of the pasture population available, our model provides, within limits, a framework to compare pasture sampling methods to estimate population parameters, in particular the mean and variance.

2. METHODS

2.1 Pasture height and mass

Our model simulates the quantity of pasture present in a given area. We generally use height (cm) as a measure of the amount of pasture present. Webby & Pengelly [1986] tabulate a relationship between pasture height (cm) and mass (kgDM/ha) for North Island (New Zealand) hill country. We use height and mass interchangeably to refer to the quantity of pasture present.

2.2 The Model

Cellula automata have been used to study plant populations by various authors e.g. Silvertown *et al.* [1992]. For our study, a grid of square cells was used to represent an area of pasture under grazing, and subsequent regrowth. Specification of an area (ha) for the grid allowed ready physical interpretation. For a 100x100 grid representing 1ha, each cell corresponded to $1m^2$. An initial pasture distribution was assigned to the grid, with height assumed normally distributed, and with mean and standard deviation specified.

The model proceeds on a daily time step, simulating pasture growth, animal grazing and defecation processes. The system is evolved through time, allowing the evolution of the pasture structure itself to be observed. At a suitable time the simulation is stopped, and specific pasture sampling techniques may be compared.

2.3 Animal grazing

The grazing of a mob of cattle is simulated by specifying the number of animals present, and an appropriate daily intake per head. Intake is of the order of 10 kgDM/hd/day for a growing animal weighing 300kg (Poppi *et al.* [1987]). In our model, grazing takes place by randomly selecting a cell, and reducing it's height (state). This process is repeated until the total intake requirement of the animals present has been met.

2.4 Animal excreta

Animal defecation and urination are then simulated, with the assumption that both are randomly applied to the pasture. Camp effects, due to factors such as congregation of animals, around drinking troughs, was not considered. Dung patches are usually considered a major source of waste during grazing and their effect has been discussed by many authors. Hirata *et al.* [1991] incorporated field results into a model of the effects of dung on pasture, and suggested that patchy grazing by to be primarily responsible for observed heterogenity in leaf mass distribution. Marten & Donker [1964] found that dung affected herbage was refused for up to 3 months by dairy heifers and steers. Tayler & Rudman [1966] reported that beef cattle grazing management affected the area and quantity of herbage in 'grazed' and 'dung patch' categories. Smith *et al.* [1995] looked at the effects of cattle slurry applied to pasture in terms of positive effects, primarily boosts to pasture growth from nutrients applied, and negative effects caused by smothering and scorch.

Urine and dung affect the palatability of the pasture to the animals i.e. they will preferentially graze unaffected areas. Pasture affected by cattle urine typically has a short rejection time, in the order of a few days (Roberts [*pers. comm.*]). Cattle dung takes from 60 to 90 days to decompose, during which the affected pasture is rejected (Marten & Donker [1964]) unless grazing pressure is intense. Pasture covered by dung does not grow until the dung has decayed, although there is a boost to the growth in the area immediately surrounding the dung patch. This growth is also rejected by the animals.

The nitrogen content of the urine and dung provides a boost to pasture growth, extending outside the immediate area of application, as suggested by Doak [1952]. The area affected by a cattle urine patch is approximately $0.65m^2$ (Neuteboom *et al.* [1992]), but varies widely. Estimates for the nitrogen boost from urine range from 400 kgN/ha suggested by Neuteboom *et al.* [1992], up to 1000 kgN/ha suggested by Roberts [*pers. comm.*]. We selected an equivalent application rate of 500kgN/ha, ignoring losses such as those attributable to ammonia volatilisation discussed by Safley *et al.* [1986].

2.5 Pasture growth

We assume constant pasture growth over the time period simulated. The only factor in our model to affect pasture growth is the boost from nitrogen present in excreta, and the initial inhibition of growth in areas directly affected by dung patches.

2.6 Pasture sampling

The simulation was run to a predetermined time (21 days). At this time, two simple pasture sampling techniques were compared. Within the limitations of the model of pasture growth and grazing outlined above, we have full information on the pasture mass population. The first sampling method was to simply sample randomly, in which a grid point is selected at random, and it's height recorded. The alternative method was sampling along a line transect. With the latter we also compared the "raw" results with those obtained from applying a smoother to the sampled values. The smoother used is SMOOFT from Press *et al.* [1989]. The number of points sampled were adjusted to be the same for both the point estimate and line transect methods.

Finally a normally distributed sampling error (with mean 10% of the population value sampled) was added to the value for each point sampled to simulate the actual measurement process that occurs when sampling in the field i.e. values measured in the field are subject to a sampling error.

3. RESULTS

The computer program used for this study displayed results on the screen using colour coding to represent height ranges of pasture. A relative frequency histogram of pasture heights was also displayed. The dynamic nature of the display enabled the user to observe the evolution of the pasture structure.

Pasture and animal parameters could be adjusted by the user, allowing the CA to demonstrate the gross features we would expect under varying grazing pressures. Visual observation indicated that the CA was able to replicate the development of clumps of taller (rank) pasture as observed under appropriate grazing pressures. Thus we see CA as a simple tool to investigate grazing strategies.

Simulation of cattle under continuous grazing, and under rotational grazing was conducted. In both cases the initial pasture heights for grid elements were normally distributed with mean 7cm and standard deviation of 2cm (fig. 1). Pasture growth rate was set at 30kgDM/ha/day.

The continuous grazing simulated consisted of 7 animals, with an intake of 7.5kgDM/hd/day, grazing for 21 days. The affect of this in a field situation would be to reduce pasture height to a lower, approximately uniform, level.

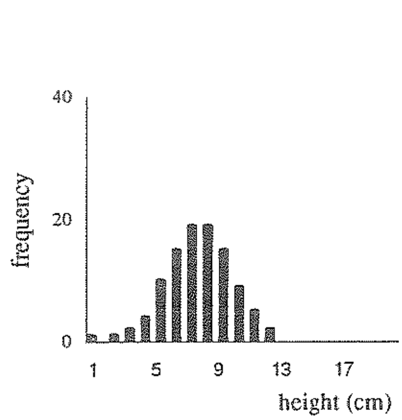

Fig 1. Initial height distribution for both continuous and rotational grazing simulations.

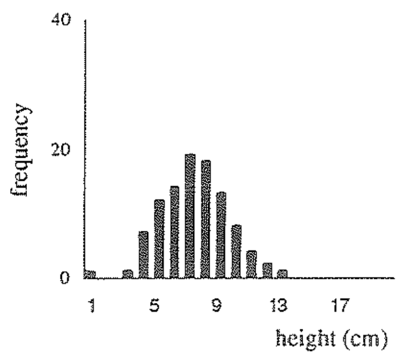

Fig 2. Continuous grazing - day 1

In a similar manner, we simulated a rotational grazing situation where 20 animals, with daily intake of 10kgDM/hd/day, were grazed for 1 day, and the pasture left to recover for 20 days.

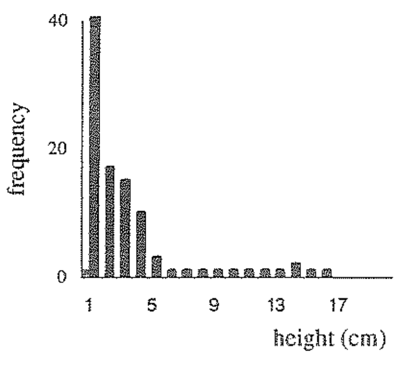

Fig 3. Continuous grazing - day 21

In this case, we would anticipate a generally higher pasture level, with a greater spread of heights after 21 days,. Relative frequency histograms are displayed showing the initial pasture height distributions (fig. 1), and the height distributions after day 1 (fig. 2 and 4), and day 21 (fig. 3 and 5). Figures 3 and 5 show that the program successfully mimicked the anticipated behaviour of the pasture under these grazing regimes. For the continuous grazing situation, fig. 3. clearly shows the development of a uniformly short pasture, with minimal taller pasture. Fig. 5 shows the relative frequency distribution of heights for the rotationally grazed pasture after 21 days. This pasture is clearly longer than that in fig. 3, as anticipated, and there are higher proportions of longer pasture as a result of the 20 days uninterrupted regrowth. The pasture falls into two categories, either very short, or very long.

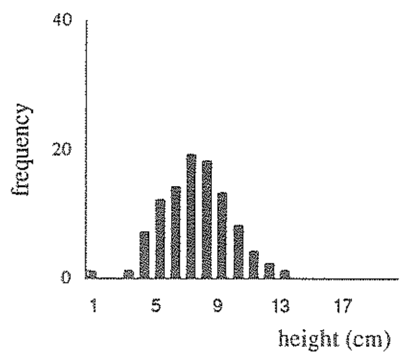

Fig 4. Rotational grazing - day 1

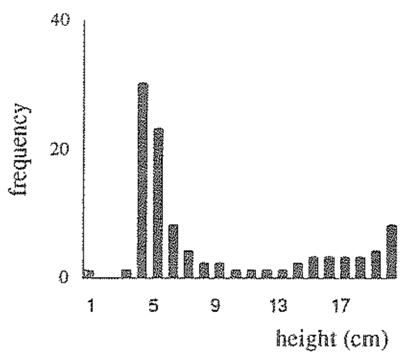

Fig 5. Rotational grazing - day 21

Tables 1 and 2 present results from the pasture sampling methods applied to the continuous and rotational grazings simulated. After 21 days, the sampling methods discussed in 2.6 were applied, and mean and sample variance values recorded. The population mean could be calculated as the CA grid provided full population height data, a task that is infeasible in the field situation. Results calculated for random sampling are presented (Rand), along with sampling along a transect (Line), and smoothing the results from the transect sample (smooth).

The 100x100 grid consisted of 10000 cells, representing the pasture population, which was then sampled. From this grid, 20 line transect samples were taken, each of length 10 units. This entailed sampling from 200 points (grid cells). In order that the same number of points were compared for each method, 200 random point samples were taken. This sampling procedure was then repeated for 100 different grids.

Table 1. Mean pasture height (cm).

Graze	Popn	Rand	Line	smooth
Rotn	7.8139	7.8149	7.8501	7.8495
Cont	2.6017	2.5739	2.6080	2.6080

Table 2. Sample variances for mean pasture height.

Graze	Rand	Line	smooth
Rotn	0.0744	0.0774	0.0777
Cont	0.0576	0.0483	0.0477

Table 1 and 2 show that there was no significant difference between random sampling and sampling along a transect line. In particular, the covariance structure from the transect sampling method did not provide significant additional information. Smoothing the results from the transect line showed no benefit.

DISCUSSION

A cellula automata model was successfully used to simulate aspects of the spatial structure evident in the evolution of a grazed pasture. The availability of spatial information provided the opportunity to compare two simple pasture sampling techniques.

Gibb & Ridout [1986] fitted frequency distributions to height measurements on pastures grazed by steers to differing target heights. They discuss the effect of management factors such as grazing pressure, and the resultant lack of symmetry in the distribution of pasture heights. An application of our CA model could be to track the evolution of the pasture height distribution.

Decision support tools such as STOCKPOL, described by Marshall *et al.* [1991], rely on accurate pasture assessment to drive animal growth models. The skewness of height measurement frequencies shown by Gibb & Ridout [1986], and our results indicate that use of a single mean to represent sward height is potentially misleading.

CONCLUSIONS

A cellula automata model of grazed pasture provided information on the spatial distribution of pasture mass. Comparison of two simple sampling schemes concluded there was no advantage to be gained from sampling along transect lines. The pasture height distribution information may improve the quality of pasture information used to drive animal growth models.

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