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Edge effects on between-fire interval in landscape fragments such as fire-prone terrestrial conservation reserves

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ABSTRACT

When a parcel of land, a reserve, is isolated from its fire-prone landscape context, its fire interval can potentially be altered simply due to diminished access to external fire. A model is developed to depict this situation. Cutting off the external access of randomly-oriented fires along an infinite edge reduces the proportion burnt per year at the edge to one half; the average interval doubles there. Well away from the edge, the fire interval remains the same as it was before fragmentation. When very long strips from which external fires are cut off from both sides are considered, edge effects from the two sides overlap internally such that the average interval between fires in the strip, overall, increases. Overlap increases as width decreases. The same phenomenon occurs in a modelled circular, or other shaped, reserve with the central area being the least affected. Modelled results, expressed as average interval per reserve, were consistent with changes in fire interval in fragments of different size in a mallee-vegetation complex of the wheat belt of south-western Western Australia. Such effects would be at a maximum in small irregularly-shaped reserves. If historical fire regimes are to be maintained for biodiversity conservation purposes, then management intervention will be necessary where this effect occurs.

1. Introduction

Fragmentation is considered to be one of the major topics of contemporary conservation biology (Hobbs and Yates, 2003; Laurance, 2008) and one that sparks debate over what size, number and shape of reserves – should be used for the conservation of biodiversity (Kunin, 1997; Williams, 2002) – including connectivity links (Chester and Hilty, 2010). For example, fragments such as small conservation reserves are subject to: "altered disturbance regimes, edge effects, invasion of species from elsewhere, [and] altered ecosystem processes" (Hobbs and Yates, 2003; see also Cochrane, 2009), usually leading to decreased conservation value.

The importance of changed fire regimes associated with fragmentation has been widely recognised (e.g. Davies et al., 2013; Hobbs and Yates, 2003; Laurance, 2008). 'Fire regimes' are disturbance regimes defined in terms of frequency (or its mathematical inverse 'interval'), intensity, season of occurrence and type (above or below ground) (Gill, 1975, 1981). Regimes in reserves have changed from historical norms due to a number of causes. They have been altered due to: creation of contrasting regimes in adjacent landscapes (e.g. Cochrane and Laurance, 2002, in South America; Russell-Smith and Dunlop, 1987, in northern Australia); changed patterns of fire starts and increased suppression activity, often due to the proximity of high value economic assets (e.g. see Regan et al., 2010); and, prescribed burning by managers, especially near urban areas and exemplified by the burning of "asset protection zones" (e.g. see Gill and Stephens, 2009).

Although changes in fire regimes have occurred as the result of fragmentation, there has been no attempt to quantitatively, or semi-quantitatively, examine the precise influences at work. The problem has not been unpacked. Changes in fire regimes in a reserve in comparison to the surrounding landscape (or 'matrix') may vary from none at all when the surrounding country is the same as that in the reserve, to an extreme when the land-use of the surrounding landscape is intense and all fires are prevented from entering the reserve or other fragment. A contrasting extreme occurs when there is increased fire activity in the surrounding landscape, as in the Amazon region (Cochrane, 2009): encroaching fires there impact on the conservation status of the outer parts of original vegetation unless the fragment is isolated from such influences.

Our aims in this paper are to:

(i) model the average proportion burnt per year for all sites in a reserve from its edge to its centre when it is completely isolated from matrix fires;

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(ii) model the effect of isolation from external sources of fire on the average between-fire interval of reserves of various sizes and shapes, assuming no compensatory effect; and,
(iii) discuss the results in the light of conservation-reserve management and the necessity, or otherwise, for management intervention to maintain historic fire conditions.

2. Passive fragmentation effect on between-fire interval: model development

2.1. Standardised proportion burnt as a function of distance from an edge

Consider a vast (infinite) region in which there are randomly distributed fires not biased in any way as to their alignment with the wind or topography. These fires have a range of areas: there are many small ones, few large ones (Williams and Bradstock, 2008). Now imagine that all fires are eliminated from half the region (e.g. due to land development or fire suppression), thereby leaving only one half with fire presence – the 'intact', or 'reserve', region. We assume that the boundary, or edge, defining this intact region is a straight line. The standardised proportion burnt in the intact region is given by:

$$S_{p1}(D_e) = 1 - \frac{1}{2}\exp(-aD_e) \quad (1)$$

where $S_{p1,}$ is the temporally-averaged standardised proportion burnt per year; '1' on the right hand edge represents the norm (before half the fires were cut off from entry to the area – the '1/2' constant); a is a constant; and, D_e is the distance in km from the border of the two regions into the intact area. The reduction in fire occurrence in the intact area due to prevention of spread into the reserve half of the area is the 'passive edge effect'.

The function S_{p1} has to asymptote to the norm (unity). Larger values of a correspond to shorter average fire lengths, so that as a increases a larger proportion of the intact region will continue to be burnt; that is, $S_{p1} \to 1$ as $a \to \infty$. Conversely, smaller values of a correspond to longer average fire lengths, so that $S_{p1} \to 0.5$ as $a \to 0$. Maximum lengths of forest fires in 2009 in moderately populated Central Victoria, Australia, reached more than 50 km from a single ignition (i.e. the "Kilmore East" fire; see Fig. 7 of Cruz et al., 2012) but lengths of fires, c.f. area, are rarely reported. A power law distribution of fire areas is common, but other distributions have also been observed (see Cui and Perera, 2008, and references); translating such distributions into lengths is fraught because of the many shapes fire perimeters may take.

Now consider that the intact region becomes an infinite strip, i.e. with parallel edges. The edge effect will be the same from each side because the fires are not aligned to any direction in this analysis. However, with the two edges being involved, there is the potential for interactions to occur, reducing the standardised proportion burnt in the centre of the strip particularly. The interaction will be negligible if the strip is so wide that overlap of the influences from the two sides is slight.

The equation from the left hand edge is given by Eq. (1) while that from the right hand edge is:

$$S_{p2}(D_e) = 1 - \frac{1}{2}\exp(-a(D_m - D_e)) \qquad 0 \leqslant D_e \leqslant D_m \quad (2)$$

where S_{p2} is the temporally-averaged standardised proportion burnt per year from the right hand edge of the strip and D_m is the width of the infinitely-long strip in km. The net effect of fire being cut off from both sides from the strip is given by the sum of the values below unity from the two graphs.

The resultant graph, shown in the Fig. 1 for different values of a and D_m, is given by:

$$S(D_e) = 1 - \frac{1}{2}\exp(-aD_e) - \frac{1}{2}\exp(-a(D_m - D_e)) \quad (3)$$

where S is the resultant standardised proportion burnt per year. Fig. 1 shows that the standardised proportion burnt tends to flatten out, i.e. less is burnt, as a decreases, in accordance with the relationship between the parameter a and average fire length discussed above. As the width of the strip of 'intact landscape', D_m, decreases, interactions become more spatially significant: the effect of overlapping curves becomes apparent (Fig. 1).

Rearranging Eq. (3) so that the function is axisymmetric gives:

$$\begin{aligned} S(D_e) &= 1 - \tfrac{1}{2}\exp\left(-a\left(\tfrac{D_m}{2} + D_e\right)\right) - \tfrac{1}{2}\exp\left(-a\left(\tfrac{D_m}{2} - D_e\right)\right) \\ &= 1 - \exp(-ad)\cosh(aD_e), \qquad -d \leqslant D_e \leqslant d, \end{aligned} \quad (4)$$

where $d = D_m/2$, the reserve half width.

If the area of interest, the 'reserve', is considered to be a circle rather than a long strip, a switch from the Cartesian co-ordinate D_e to the radial coordinate, r, is appropriate. In terms of the radial coordinate the function in Eq. (4) is expressed as:

$$S_C(r) = 1 - \frac{1}{2}\exp(-aR)\cosh(-ar), \qquad 0 \leqslant r \leqslant R. \quad (5)$$

$S_C\,(r)$ is the average proportion burnt per year along radii of a circular region of radius R.

2.2. Average proportion burnt per year for an area and its inverse, average between-fire interval

The spatially-averaged proportion burnt per year over an area, $\bar{S}_C$, as opposed to along radii, is equal to the average value of $S_C(r)$ over the circular region of radius R:

$$\bar{S}_C = \frac{1}{\pi R^2}\int_0^{2\pi}\int_0^R S_C(r) r dr\, d\theta \quad (6)$$

Evaluating the integral yields the formula:

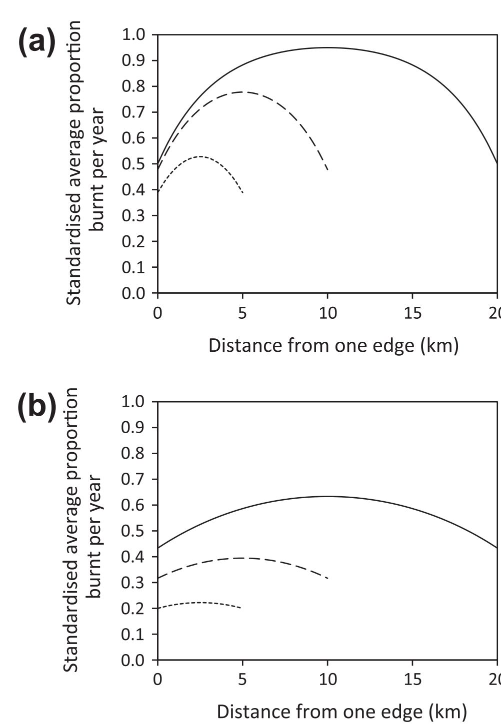

Fig. 1. Graph of the function S (Eq. (3)) with (a) a = 0.3, and (b) a = 0.1. In each panel: D_m = 20 km (solid line), D_m = 10 km (large dashed line) and D_m = 5 km (small dashed line).