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Number 15 | **October 2017**

Fuel beds for repeatable laboratory fire experiments

Laboratory experiments enable study of the mechanisms of propagation in free-burning fires which are difficult to isolate in the field. Highly uniform beds of 'artificial' fuel (such as wood shavings) are often used to reduce experimental variability but results can be difficult to translate into the real world. This study showed that fire behaviour in natural heterogeneous fuel beds was highly repeatable and suitable for experimentation.

Empirical study of bushfires

All operational models of bushfire behaviour used in Australia are derived from empirical study of large-scale field fire experiments and wildfires. However, such studies are complex and difficult to conduct, primarily because the factors that determine fire behaviour in the field, such as fuel structure and type, weather and topography, are highly variable over space and time and hard to control. True experimentation, where a particular factor is purposefully changed to observe the change in a fire's behaviour, is virtually impossible under such situations, requiring a large number of experimental fires to provide sufficient statistical power to construct robust models.

The alternative has been to conduct laboratory-based fire experiments in which burning conditions are stringently controlled and manipulated. Relationships between fire behaviour variables can be observed in greater isolation from variation in potentially confounding factors. Furthermore, laboratory-scale fires may be safely observed at close range and can incorporate a high degree of instrumentation placed in the right location relatively easily. The trade-off is that such experiments cannot recreate the behaviours observed in wildfires and it is more difficult to transfer findings to the real world.

Laboratory experimentation

Laboratory experiments are typically designed to reduce variability in factors such as air flow characteristics (i.e. turbulence), fuel moisture content and structure. The type of fuel has been a crucial component of laboratory-scale fire experiments. Four generic types of fuel bed are used:

1) homogeneous artificial fuel beds (e.g. wood splints or shavings, and more recently laser-cut cardboard);
2) heterogeneous artificial fuel beds (a mix of wooden splints and excelsior);
3) homogeneous natural fuel beds (leaves or needles of similar size and shape); and
4) heterogeneous natural fuel beds (a mix of leaves or needles, twigs and bark).

Figure 1. Oblique view from behind the ignition line of experimental fires burning in pine needle (left) and eucalypt litter (right) fuel beds in the CSIRO Pyrotron.

Artificial fuel beds are generally uniform and fine-scale spatial variation is low compared with natural fuel beds. This high degree of uniformity is desirable because it increases fuel bed repeatability between experiments and is assumed to increase the repeatability of fire behaviour. However, artificial fuel beds relate poorly to natural fuel complexes and further work is required to apply experimental results to field situations.

Fuel beds consisting of natural fuel (Fig. 1) are more variable in particle geometry, chemical composition and structure. Heterogeneous natural fuel beds exhibit the most variability in both fuel particles and structure, more closely modelling surface fuel complexes found in nature.

However, these have seldom been used for in laboratory experiments because they are difficult to reproduce consistently and thus are assumed to introduce unwanted variation in fire behaviour between replicates.

'Error variance' is a term that encompasses all the variation in a response variable, such as rate of spread, that cannot be directly attributed to the factors being controlled in an experiment and may arise from unknown sources. Where error variance is low, experiments can detect small differences between treatments using relatively few replicates. Where error variance is high, the effects of experimental treatments are more difficult to detect and either more replicates are required or only large differences between treatments will be detected.

The purpose of this work was to quantify the magnitude of error variation introduced into laboratory-scale fire experiments from two types of heterogeneous natural fuel beds in the CSIRO Pyrotron (Figure 1, Sullivan et al. 2013) to determine which would be the most suitable fuel for subsequent experiments.

Results

Figure 2 summarises the overall mean rates of spread from six replicate experiments in eucalypt litter and pine needles under three different wind speeds. While the rate of spread was highest in the pine needle fuel, so too was the variation in observed rates of spread. The coefficient of variation (a measure of variability) range for pine was 12.5-26% but only 11.4-13.2% for eucalypt where spread was much more consistent across all wind speeds.

Error variance was investigated using a standard model that took into account effects and interactions of air speed, fuel type and source, fuel moisture content, fuel load and fuel particle size. Error variance in both fuels was low compared with the effects of air speed and fuel type with a coefficient of variation of only 3.1%. Such a low error variance means that significant effects of experimental treatments can be found using relatively few replicates in heterogeneous natural fuel beds, avoiding the need for artificial fuel beds.

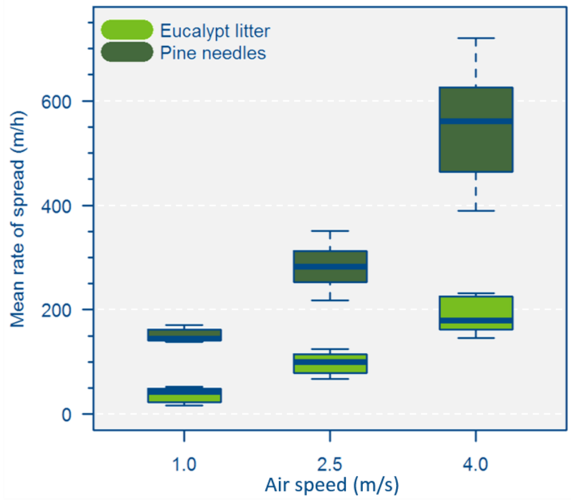

Figure 2. Plot of overall mean rate of spread of fires burning in eucalypt litter (light green) and pine needles (dark green).

Implications

Using the estimate of error variance, decisions about the minimum number of replicates for an experiment can be determined using power analysis, a practically impossible step for field experiments. Figure 3 shows that the minimum effect size that can be detected in the Pyrotron reduces with increasing number of replicates with the maximum reduction occurring with four replicates.

Such results enable the Pyrotron to provide cost-effective insights into the mechanisms of bushfire spread, such as growth, acceleration and fireline interactions, by providing definitive criteria for conducting rigorous and statistically powerful experiments.

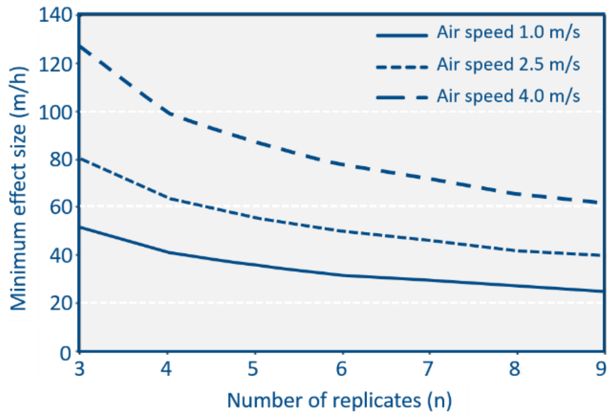

Figure 3. Power analysis using estimates of experiment error variance helps determine the most appropriate number of replicates to detect changes in fire spread rate.

Further reading

Mulvaney JJ, Sullivan AL, Cary GJ, Bishop GR (2016) Repeatability of free-burning fire experiments using heterogeneous forest fuel beds in a combustion wind tunnel. *International Journal of Wildland Fire* 25, 445–455.

References

Sullivan AL, Knight IK, Hurley R, Webber C (2013) A contraction-less, low-turbulence wind tunnel for the study of free-burning fires. *Experimental Thermal and Fluid Science* 44, 264–274.

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