Risk Factor as a Strategy to Validate the Prioritization of Areas for Wildfire Protection[1]

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Abstract

The limited availability of resources for wildfire management necessitates prioritizing forest areas for protection. For this purpose, criteria such as fire risk are used to generate thematic maps intended to support decision-making. However, prior to this, the information must be validated under a statistically robust process. Unfortunately, no such process currently exists, so it must be formulated from the most basic aspect, which is the definition of the sampling unit. This was the objective of this study, where different-sized reference sites (RSs) were tested under four sampling intensities randomly distributed throughout the state of Jalisco, Mexico. Within each RS, the number of fires was determined for the period 2005-2013. It was found that variability in the number of fires decreased as the size of the RS increased, until reaching an asymptotic behavior (around 100 km^2). In this way it was determined that a RS of 100 km^2 captures the variability in the number of fires, which was termed Risk Factor (RF). Finally, the use of this parameter will support the definition of the risk validation process. In addition, the standardization of the RS will generate information, in different regions, that is not only comparable but also compatible.

Keywords: Priority areas, risk factor (RF), reference sites (RS)

Introduction

Wildfires are one of the major causes of forest cover loss in the country. An estimated 8,900 wildfires occur in Mexico every year (Cibrián et al., 2014), of which 97% are caused by human activities (CONAFOR, 2010). Because of this, the

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National Forestry Commission, through the National Wildfire Prevention Program, has implemented a general strategy for wildfire prevention and control. However, because human and economic resources are limited, it is necessary to define areas requiring priority attention (CONANP, 2009). For this reason, systems have been developed that evaluate the factors that determine the occurrence of fires and their behavior (Dentoni and Muñoz, 2012; July, 1990). These factors are generally integrated into criteria such as risk, hazard and vulnerability (Hardy, 2005), each of which is based on the evaluation and weighting of a number of specific variables (Red et al., 2001). This weighting can be done under different approaches, such as multicriteria analysis (Golubov et al., 2014), where groups of experts establish comparisons among the variables used, and decide by means of different methods those which have the greatest influence and assign them priority values. Based on this, it is possible to generate cartography and statistics, which allow locating and dimensioning areas requiring priority protection against wildfires (Ager, Vaillant & Finney, 2010; CONAFOR, 2010).

However, the use of information pertaining to priority wildfire protection areas is totally conditioned upon the verification of their results, since one can fall into the error of addressing areas that are not, in fact, priority areas or, on the contrary, not addressing priority areas. However, on this topic there are few papers that refer to some form of validation. Moreover, there is no standardized methodology which allows for a systematic validation process, neither for the prioritization in general, nor for each of the criteria that define it (Salvati & Ferrara, 2015). For example, in the case of risk criterion, there are various strategies, such as: a) logistic regression analysis to establish the most important variables, through the random sampling of 10 km^2 units (determined by the spatial resolution of the information used) and the evaluation of the goodness of fit of the logistic regression model (Hosmer and Lemeshow test) (Carillo, 2012; Mohammadi, Bavaghar & Shabanian, 2014); b) use of the Moran Index and Geary's C-Coefficient to validate the risk index defined by spatial autocorrelation (Pérez et al., 2013); c) use of databases with a history of 160 days, chosen systematically and randomly (5 days per month and for each of the seasons of the study period) (July, 1990); d) use of satellite images (e.g. Modis active fire) to supplement the recorded fire data (Yeguez & Ablan, 2012; Chuvieco et al., 2007).

On the other hand, it has been found in this type of study that the size of the sampling unit, which is used for validation, is not adequately justified. And again, there are different ways in which this sampling size is determined, such as: i) the variables are mapped to a spatial resolution of 1 km^2 (Chuvieco et al., 2007). Regardless of the method used, in all cases the selection of the sampling unit size is arbitrarily made. Accordingly, one of the first points that must be defined, in the process of validating fire risk areas, is a methodology that allows standardizing both processes and the size of the sampling unit. Therefore, the purpose of this study was to determine the statistically appropriate site size to support such validation. Such areas are referred to as Reference Sites (RSs), while the number of fires that are located in each RS is called the Risk Factor (RF). Thus, a specific risk validation would basically consist of a comparative analysis between the RF determined at a given point and the RF corresponding to a certain wildfire risk class. Traditionally, these classes are defined by dividing the sum of the weighted values of each variable by the number of classes to be considered (Castillo et al., 2013; July, 2010). However, this paper proposes determining the ranges of number of fires based on their probability of occurrence (that is, considering a certain number of variances for each wildfire risk class to be determined).

Materials and methods

To define the wildfire risk reference area, information was used for the state of Jalisco, which is located in western Mexico: to the North 22^{0} 45´ and to the South 18^{0} 55´ of North latitude, to the East 101^{0} 30´ and to the West 105^{0} 42´ of East longitude (*figure 1*). It covers a 78,588 km² area, where a warm sub-humid climate predominates in 68 % of the territory state (coast and center), a temperate sub-humid climate in 18 % (upper mountain areas) and a dry/semi-dry one in 14 % (North and Northeast). The mean annual temperature is 20.5° C and the average annual rainfall is approximately 850 mm, although in the coastal zones it is more than 1,000 mm. Conifer and oak forests dominate, followed by deciduous and sub-deciduous forests (sierra bordering the coast); there are also grasslands (North and Northwest of the state), scrub and grass-covered areas, palm groves, mangroves and tulare wetlands (coastal zone) (IIEG, 2014).

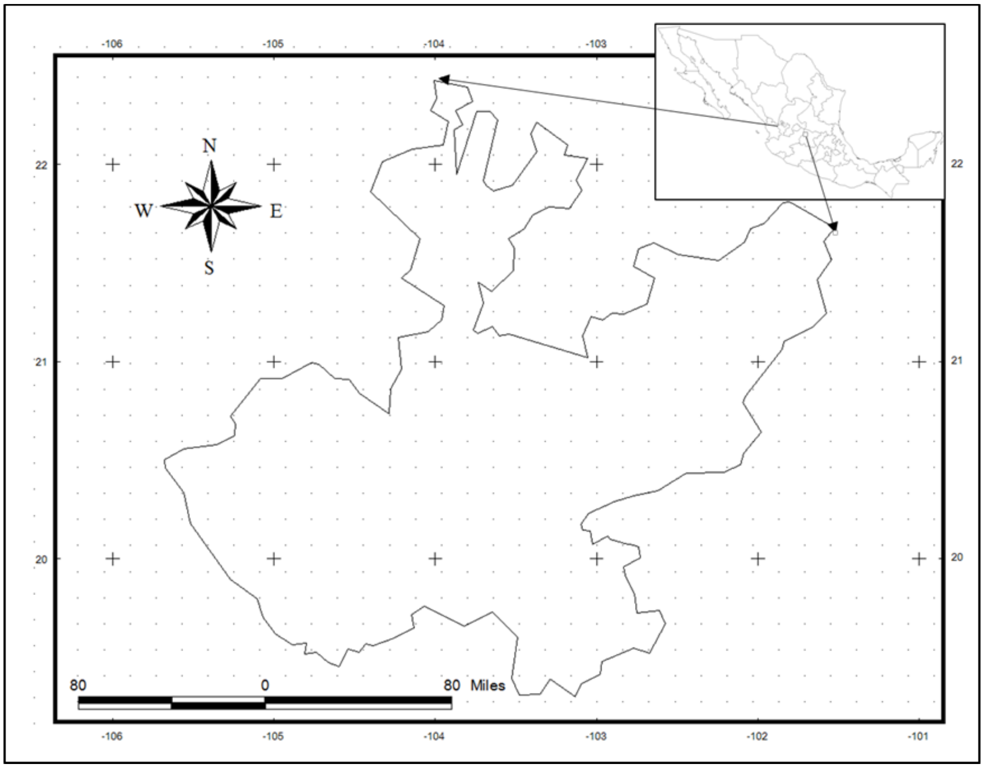

Figure 1— Location of the study area, corresponding to the state of Jalisco, Mexico.

Wildfire occurrence

On average, in the state of Jalisco, between 17,000 (SEMADET, 2014) and 20,761.58 (figure estimated based on data from the CONAFOR Database, 2015 fire occurrence record) hectares are burned each year, with an average number of 500 (SEMADET, 2014) to 566 (CONAFOR, 2015) fires per year. The type of vegetation most affected is grassland, with an average of almost 7,000 ha per year, followed by forest areas with shrubs and scrub, where each year an average of almost 6,000 ha are burnt. On average, 2,500 ha of areas with adult trees are burnt per year (SEMADET, 2014).

Reference sites

This project defines the sampling unit area that would be most suitable for capturing variability in the number of wildfires. For this purpose, a number of areas, termed reference sites (RSs), were analyzed. These sites were circular polygons, defined with the following areas: 1, 2, 4, 8, 10, 15, 30, 50, 70, 100, 150 and 200 km². These polygons were located concentrically in the sampling sites. And subsequently, based on statistical fire information obtained from CONAFOR (2005 - 2013) (*figure* 2), each of the wildfires reported was located geographically. This allowed for making a count and record of the fires that were located within each RS (*figure* 3). On the other hand, four sampling intensities (100, 300, 500 and 1000 points) were established in order to capture the variability in the number of fires that could occur due to the density of sampling points. In all cases, sampling was distributed completely at random throughout the state of Jalisco, Mexico.

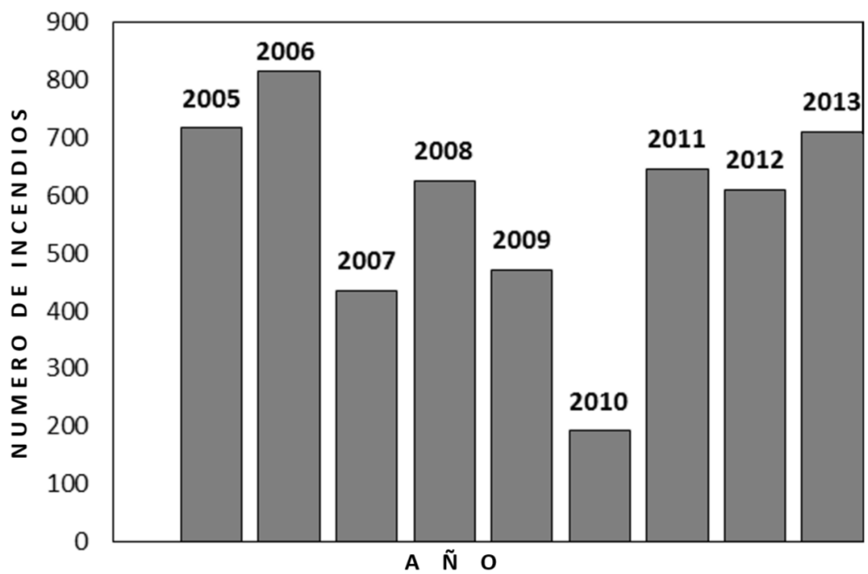

Figure 2— Number of fires per year in the state of Jalisco, from 2005 to 2013 (CONAFOR, 2015).

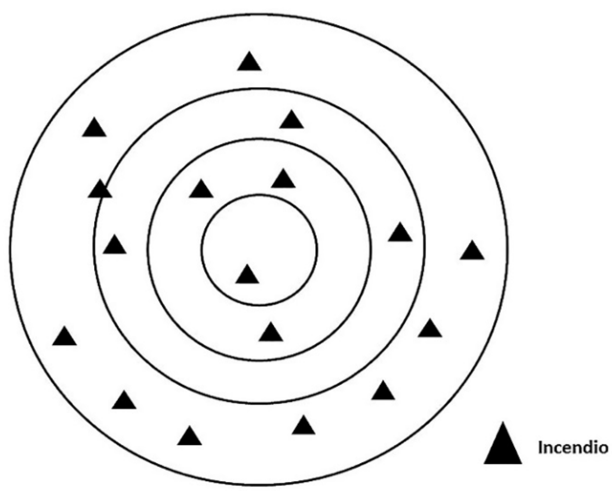

Figure 3— Theoretical schematization of the location of wildfires in reference to the variation in areas analyzed.

Analysis of variability

Considering each one of the four sampling intensities indicated, the number of fires in each of the corresponding RSs was determined. Based on this, descriptive statistics were generated in relation to the number of fires for each of the twelve areas analyzed. On the other hand, through analysis of variance and Tukey's range test, we determined whether the difference between the number of fires per area was significant. Subsequently, to define the RS area that captures the variability in the number of fires, the variation in this variability (coefficient of variation) in relation to the 12 RS sizes was plotted. As a criterion of variability, the coefficient of variation was used, since it describes the amount of variability (in relation to the mean) without being based on the units. Therefore, unlike standard deviation, the dispersion of the different sampling intensities used in this study can be compared, regardless of the difference in their means. These graphs were generated independently for each of the four sampling intensities tested. In these graphs the RS area where the variability trend initiates an asymptotic behavior was determined. This, in turn, enabled determining the Risk Factor, which means the number of fires that are located within this area (RS).

Results and discussion

RS statistics

Based on the four sampling intensities tested (100, 300, 500 and 1000 sites), the statistics corresponding to the different site sizes evaluated were calculated (*table* 1). Regardless of site size, the minimum value was zero fires, while the maximum number of fires per site was from 8 (in 1 km^2) to 276 (in 200 km^2). On the other hand, according to the means and modes, it can be deduced that in most of the sampled RSs there was no fire. As for the variability, considering the coefficient of variation, it begins to stabilize from the 70 km^2 site size.

Table 1— *Statistics on the number of sites that are located by site size, in relation to the sampling intensities*.

	Intensidad de	Tamaño del sitio (km^2)											
Estadístico	**muestreo**	**1**	**2**	**4**	**8**	**10**	**15**	**30**	**50**	**70**	**100**	**150**	**200**
Media	100	0.01	0.06	0.16	0.37	0.49	0.74	1.5	2.44	3.33	4.66	6.75	8.97
	300	0.05	0.09	0.23	0.47	0.55	0.8	1.48	2.45	3.32	4.62	7	9.41
	500	0.05	0.11	0.21	0.42	0.53	0.77	1.41	2.36	3.31	4.73	7.36	9.89
	1000	0.04	0.08	0.15	0.3	0.38	0.61	1.26	2.11	2.92	4.18	6.31	8.53
Error típico	100	0.01	0.03	0.05	0.12	0.16	0.21	0.37	0.57	0.76	0.94	1.22	1.57
	300	0.02	0.03	0.09	0.15	0.16	0.2	0.3	0.45	0.56	0.7	0.96	1.19
	500	0.01	0.03	0.05	0.09	0.11	0.15	0.24	0.36	0.44	0.58	0.83	1.06
	1000	0.01	0.01	0.02	0.04	0.04	0.06	0.12	0.18	0.22	0.3	0.41	0.53
Desviación estándar	100	0.1	0.28	0.53	1.24	1.6	2.14	3.67	5.72	7.55	9.41	12.24	15.7
	300	0.34	0.55	1.51	2.59	2.74	3.5	5.25	7.8	9.67	12.21	16.61	20.62
	500	0.25	0.77	1.23	2.09	2.55	3.45	5.47	8.14	9.89	12.88	18.48	23.83
	1000	0.31	0.43	0.69	1.15	1.41	1.96	3.66	5.62	7.1	9.39	13.09	16.82
Varianza de la muestra	100	0.01	0.08	0.28	1.55	2.56	4.6	13.46	32.73	57.07	88.49	149.8	246.5
	300	0.12	0.3	2.28	6.68	7.51	12.24	27.53	60.8	93.48	149.1	275.9	425.1
	500	0.06	0.6	1.51	4.37	6.49	11.89	29.96	66.22	97.89	166	341.5	567.8
	1000	0.1	0.19	0.47	1.33	1.99	3.84	13.43	31.53	50.44	88.26	171.5	283
Coeficiente de variación	100	10	4.63	3.29	3.36	3.26	2.9	2.45	2.34	2.27	2.02	1.81	1.75
	300	6.43	6.12	6.66	5.46	4.95	4.35	3.55	3.18	2.91	2.64	2.37	2.19
	500	5.19	7.19	5.87	5.03	4.83	4.5	3.89	3.45	2.99	2.72	2.51	2.41
	1000	8.36	5.74	4.62	3.86	3.73	3.22	2.91	2.67	2.43	2.25	2.07	1.97

Risk Factor (RF)

Figure 4 defines the variability, based on the coefficient of variation, in relation to site size, where it can be seen that the variability in the number of fires decreases as the RS size increases. This occurs at all sampling intensities, until reaching an asymptote, where the coefficient of variation values tend to stabilize. In the case of the sampling intensity of 100 sites, the coefficient of variation (CV) begins to stabilize at a site size of 40 km^2, reaching an asymptotic behavior when the RS area is between 80 and 100 km^2. For the sampling intensity of 200, the asymptote of the curve starts at the 100 km^2 RS. On the other hand, the sampling intensities of 300 and 500 sites defined similar trends in the CV decrease, with the CV beginning to decrease, approximately, at a site size of 80 km^2, while CV stabilization is defined between the RSs of 120 and 140 km^2. Finally, the variability trend in the 1000-site sampling intensity starts an asymptotic behavior between 60 and 80 km^2, approximately reaching the lowest CV at a RS size of 100 km^2.

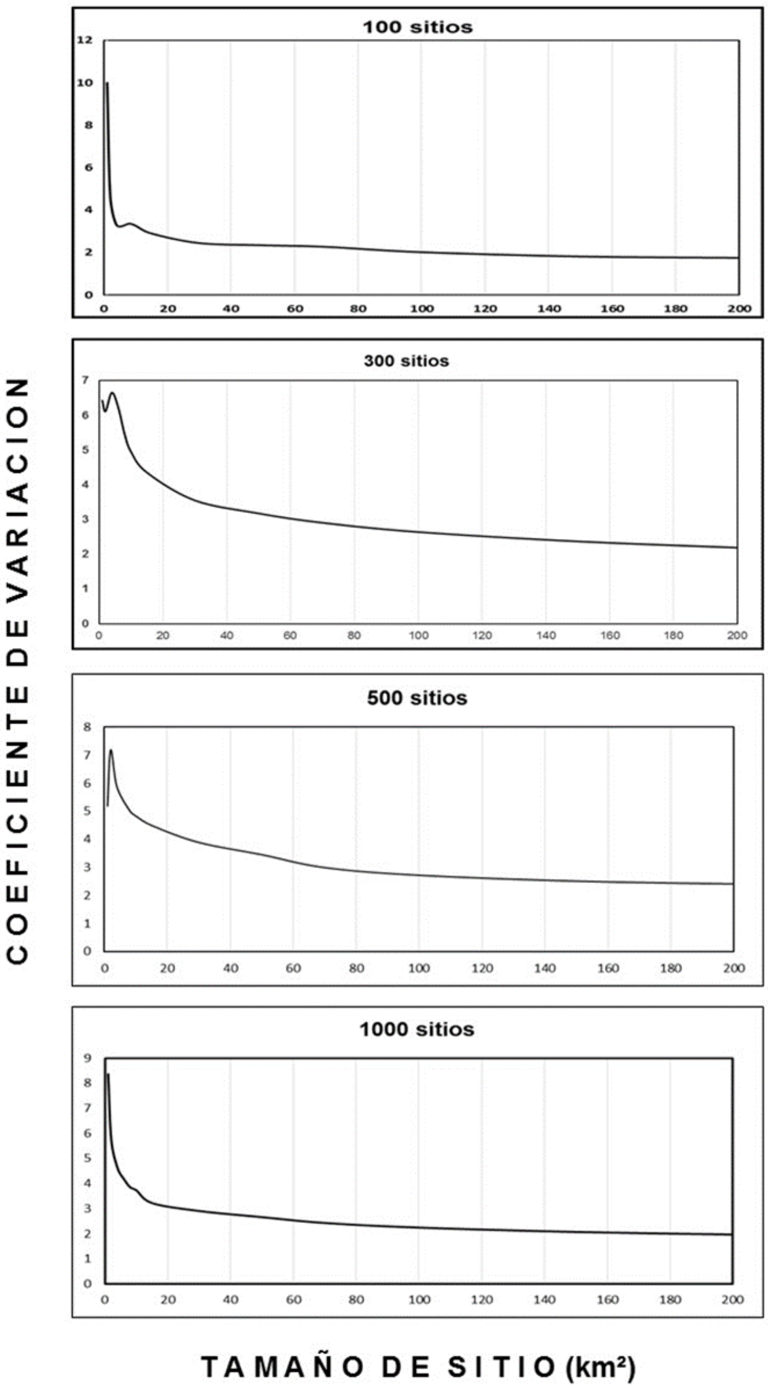

Figure 4—Coefficient of variation trend in relation to site size, for different sampling intensities.

According to the above, it is considered that, in general, the asymptotic behavior of the CV occurs at a RS size of approximately 100 km^2; therefore, this area was used to define the Risk Factor. Although, in the cases of the sampling intensities of 300 and 500 sites, the asymptotic behavior is more clearly defined in between the RSs of 120 and 140 km^2, the reduction of the CV that is achieved, in relation to the 100 km^2 RS, is not significant. This is corroborated by comparing the CV values that are determined at each of the sampling intensities tested (*table* 1); the CV values are very similar among the different sampling intensities, considering a RS of 100 km^2, being 2.01864, 2.64275, 2.72100 and 2.24920 respectively for 100, 300, 500 and 1000 sites sampled. Based on all this information, the risk factor is conceptualized as the number of fires that are located in a circular 100 km^2 area.

Number of fires per hectare

The Risk Factor (number of fires in 100 km^2) can also be referred to as the number of fires per hectare (NFH). *Figure 5* shows the NFH trend, estimated based on the number of fires located on average in each of the site sizes tested, which, in turn, are differentiated by each of the sampling intensities tested. NFH values ranged from 0.00010 to 0.00060. As can be seen, there is a high variability in the number of fires per hectare in the RSs of less than 30 km^2, even when considering the different sampling intensities. On the other hand, after the 30 km^2 RS size, the NFH average stabilizes between 0.00040 and 0.00050. The sampling intensity that showed the greatest variability was that of 100 sites, while the intensities of 500 and 1000 sites showed a more constant trend. Finally, the RS size of 100 km^2 defines a stabilization in the number of fires per hectare.

Considering the above, analyses of variance were performed for the sampling intensities of 500 and 1000 sites. In both cases the differences were significant ($p= 0.0001$). This implies that there is a difference between the numbers of forest fires that are located in each of the 12 site sizes. *Figure* 6 shows the comparative relationships resulting from the Tukey test, with which each site size was compared to all others. It is noteworthy that, for the sampling intensities of both 500 and 1000 sites, the means of the RSs of 100, 150 and 200 km^2 turned out to be different in comparison to the rest of the RSs.

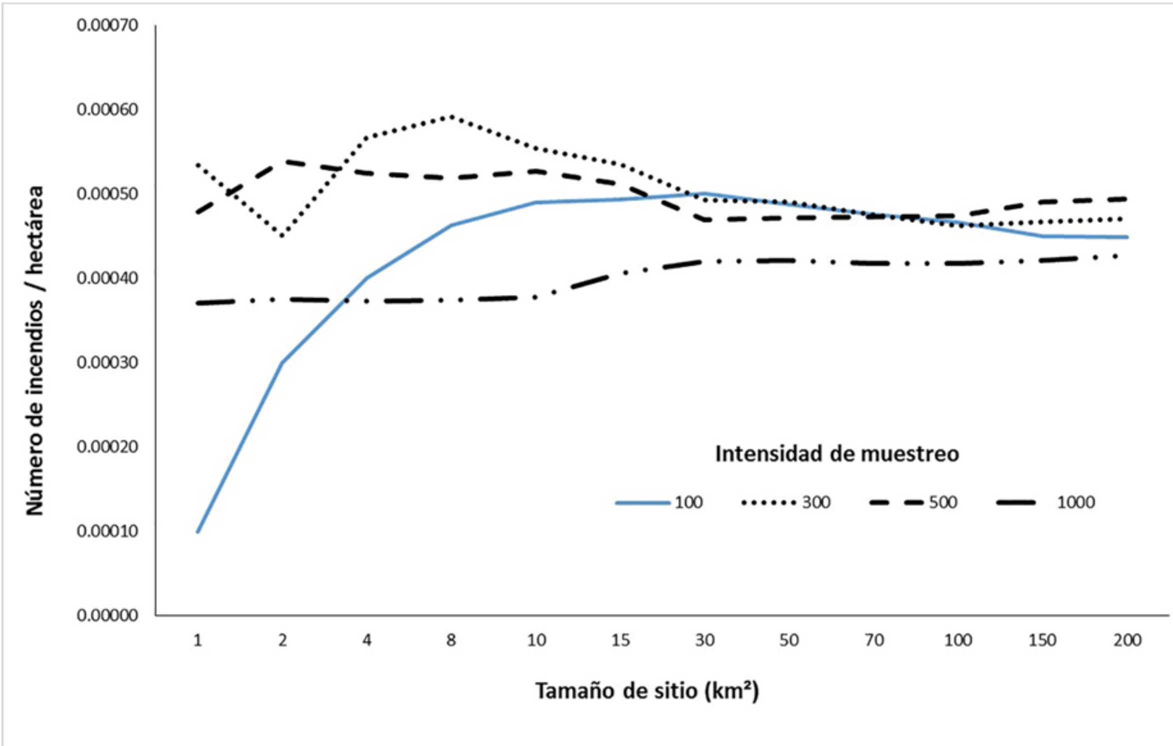

Figure 5—Behavior of the mean number of wildfires per hectare, by site size and sampling intensity.

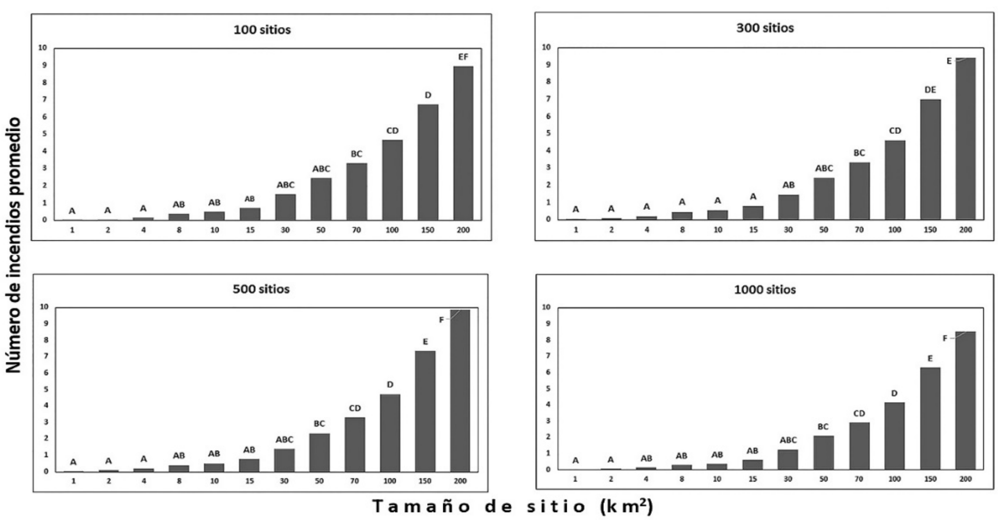

Figure 6—Results of the comparison of means (Tukey's test) of the different site sizes in relation to the sampling intensities

Conclusions

Based on the results of this study the following conclusions are defined:

1) The variation in the number of fires begins to stabilize, approximately, at a RS size of 100 km^2.

2) The different sampling intensities defined similar trends in terms of the variability of the number of fires.

3) The Risk Factor (RF) is conceptualized as the number of fires detected within a circular 100 km^2 area.

4) There is a significant difference in the number of fires located in the different RS sizes.

5) Although it is possible to define the number of fires per hectare (NFH), its estimate is based on the RF definition. Therefore, it should only be used for comparative purposes when the area to be analyzed is less than 100 km^2.

6) The RF can be used to support the definition of a standardized validation strategy in the definition of wildfire risk areas.

7) Based on the RF, the number of wildfires in a number of sampling sites can be determined. Therefore, one can not only make comparisons, but also share information between different areas.

References

Ager, A.A., Vaillant, N.M. & Finney, M.A. 2010. A comparison of landscape fuel treatment strategies to mitigate wildland fire risk in the urban interface and preserve old forest structure. Forest Ecology and Management, 259: 1556-1570.

Calkin, D.E., Cohen, J.D., Finney, M.A. & Thompson, M.P. 2014. How risk management can prevent future wildfire disasters in the wildland-urban interface. PINAS, 111(2): 746-751.

Calkin, D.E., Thompson, M.P., Finney, M.A. & Hyde, K.D. 2011. A real-time risk assessment tool supporting wildland fire decision-making. Journal of Forestry, 109: 274–280.

Carrillo, G. R., Rodríguez, T.D, Hubert, T., Monterroso, R. & Santillan, P. 2012. Análisis espacial de peligro de incendios forestales en Puebla, México. INTERCIENCIA, 37(9), 678-683.

Castillo, S., Garfias, S., Julio, A. & Correa, J. 2013. Riscos: Naturais, Antrópicos e Mistos. Incendios forestales en Chile. Análisis general de riesgos. Universidad de Coimbra. Portugal.

Chuvieco, E., Aguado, I., Yebra, M., Nieto, H., Martín, M., Vilar, L., Salas, J. 2007. Generación de un Modelo de Peligro de Incendios Forestales mediante Teledetección y SIG. Ed. Martin. Pp. 19-26.

Cibrian, T., Martínez, D. & Raygoza M. 2014. Incendios forestales. Centro Nacional de Prevención de Desastres (CENAPRED) Serie Fascículos. Secretaria de Gobernación. CONAFOR. México. 44 p.

Comisión Nacional de Áreas Naturales Protegidas (CONANP). 2009. Estudio de inventario de combustibles y generación de información base para el Programa de Manejo Integrado de Fuego en los Chimalapas. México: Secretaria de Medio Ambiente y Recursos Naturales.

Comisión Nacional Forestal (CONAFOR). 2010. Incendios forestales. Guía práctica para comunicadores. 3a ed. México: Autor.

Dentoni, M. C., & Muñoz, M.M. 2012. Evaluación de peligro de incendios. Informes técnicos. Sistemas de evaluación de peligro de incendios. Informe técnico N. 1. Argentina. Plan Nacional de Manejo del Fuego. Programa Nacional de Evaluación de Peligro de Incendios y Alerta Temprana.

Golubov, J., Mandujano, S., Guerrero-Eloisa, R., Mendoza, Koleff, González, A., Barrios, Y. & Born, G.-SCHMIDT. 2014. Análisis multicriterio para ponderar el riesgo de las especies invasoras, en R. Mendoza y P. Koleff (coords). Especies acuáticas invasoras en México. Comisión Nacional para el Conocimiento y Uso de la Biodiversidad, México, pp.123-133.

Hardy, C.C. 2005. Wildland fire hazard and risk: Problems, definitions, and context. Forest Ecology and Management, 211: 73-82.

Instituto de Información Estadística, Geográfica. (IIEG). 2014. Conociendo Jalisco. Gobierno del Estado Jalisco. México: Autor.

Julio, A. 1990. Diseño de índices de riesgo de incendios forestales para Chile. Bosque, 1(2): 59-72.

Martín I., M.P. & Rejalaga N., L.K. 2010. Cartografía de incendios forestales en Paraguay mediante imágenes Aqua-Modis. Serie Geográfica, 16: 61-70.

Mildrexler, D., Yang, Z., Cohen, W.B. & Bell, D.M. 2016. A forest vulnerability index based on drought and high temperatures. Remote Sensing of Environment, 173:314-325.

Mohammadi, F., Bavaghar, M. R. & Shabanian N. 2014. Forest fire risk zone modeling using logistic regression and GIS: an Iranian case study. Small-scale Forestry, 13, 117-125.

Pan, J., Wang, W. & Li, J. 2016. Building probabilistic models of fire occurrence and fire risk zoning using logistic regression in Shanxi Province, China. Nat Hazards, 81: 1879-1899.

Pérez, V., Márquez, L., Cortés, O. & Salmerón, M., 2013. Análisis espacio-temporal de la ocurrencia de incendios forestales en Durango, México. Madera y Bosques, 19 (2): 37-58.

Rojo, M., Santillán, P., Ramírez, M. & Arteaga M., B. 2001. Propuesta para determinar índices de peligro de incendio forestal en bosque de clima templado en México. Revista Chapingo. Serie Ciencias Forestales y del Ambiente, 7(1): 39-48.

Salvati, L. & Ferrara, A. 2015. Validation of MEDALUS Fire Risk Index using Forest Fire Statistics through a multivariate approach. Ecological Indicators, 48, 365-369.

Schroeder, W., Csiszar, I., Giglio, L., and Schmidt, C.C. 2010. On the use of fire radiative power, area, and temperature estimates to characterize biomass burning via moderate to coarse spatial resolution remote sensing data in the Brazilian Amazon. Journal of Geophysical Research, 115: 1-10.

SEMADET. 2015. Consultado 13 de enero de 2016 en http://incendios.semadet.jalisco.gob.mx/estadísticas.

Vilar, H. L., Martín, I. M.P. & Martínez, V. F. J. 2011. Logistic regression models for human-caused wildfire risk estimation: analysing the effect of the spatial accuracy in fire occurrence data. Eur J Forest Res, 130, 983-996.

Yeguez, M. & Ablan, M. 2012. Índice de riesgo de incendio forestal dinámico para la cuenca alta del río Chama. Revista Forestal Venezolana, 56 (2): 127-134.