Analysis of Helicopter Activities in Forest Fire-Fighting

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Abstract

In Southern European countries wildfires are the most natural threat to forests and wooded areas. Over the last decade, public and scientific debates on forest fire management have increased. Helicopters and airtankers are extremely effective fire suppression means, but they are also very expensive. Studies on the improved performance of suppression for the enhancement of firefighting organization are still needed. Consequently to make a plan for the distribution of financial resources to be divided between fire suppression and fire prevention actions in terms of fuel management is not possible. The aim of this study is to compare the helicopter's forest fire-fighting activity in Tuscany (central Italy) over two periods: between 1998–2000 and 2001–2005 when five and ten helicopters were respectively assigned. For both periods (1998–2000 and 2001–2005) the following were analyzed: the number of forest fires and the burned area with or without helicopter intervention and the position of the helicopter bases in relation to the fire. The results showed that a fleet of 10 helicopters is oversized, in relation to the fire regime of Tuscany, suggesting the need to evaluate a reduction in the fleet. Financial resources may be thus made available for more profitable fire prevention activities, such as, active fuel management. The results also showed where there is the need to improve the helicopter efficiency via the re–management as regards the positioning of their bases.

Keywords: fire-fighting, helicopter, spatial distribution, maps, circular statistics

1. Introduction

Wildfires are the most important natural threats to forests and wooded areas in Southern European countries (Spain, Portugal, Italy, Greece and France). Over the last decade (2002–2011), the average annual number of forest fires throughout Southern Europe exceeded 53,000, although 11.8% less than the previous decade (1992–2001) (European Commission 2010). The average annual burnt area in the period 2002–2011 was around 381,000 hectares, which resulted in 8.7% less than the previous decade (1992–2001). Portugal and France experienced an increase of burnt area respectively: 47.5% and 48.8% while Greece (– 33.6%), Spain (– 23.1%) and Italy (– 29.2%) saw a reduction.

Over the last decade public and scientific debate about the fire management has intensified. Forest experts and managers of many European countries acknowledge the improvement of firefighting organization as the most important measure in forest fire prevention and suppression (Raftoyannis et al. 2014). Since '70s, airtankers and helicopters have been utilized in firefighting in several countries of Southern Europe (Vélez Munoz 2002). Helicopters and airtankers are extremely effective fire suppression means, especially when used during the early stages of fire growth (Vélez Munoz 2002) but they are also costly (Greulich and O'Regan 1982, Greulich 2003). In fact, several researchers argue that firefighting organizations should have had a decisive positive effect by now, at least in reducing the burnt area, if the problem was only a matter of fire suppression, especially when considering the corresponding global increase in firefighting budgets (Xanthopoulus 2007). Furthermore, even though fire suppression organization has improved, the frequency of occurrence of large fires increased in the last decades in many Mediterranean countries and a new approach to fire management has been recommended (Xanthopoulus 2007, Fernandes et al. 2011).

Despite this ongoing debate, detailed studies on the performance improvement of suppression, due to an enhancement of firefighting organization, are still needed, and it is very difficult to develop a cost-benefit analysis related to firefighting organization improvement. This does not allow for the planning of a redistribution of financial resources between fire suppression and prevention, in terms of fuel management.

The purpose of this study was to analyze the impact of helicopter fleet enhancement in fire suppression efficiency and effectiveness in Tuscany Region (central Italy), in order to contribute to public and scientific debate on forest fire management approach. The activity of the helicopters deployed in forest fire-fighting over two periods, with 5 helicopters between 1998–2000 and 10 between 2001–2005, was monitored. This analysis may also be useful in fire prevention management and may represent an effective dataset for planning helicopter's use in forest fire fighting. The study combines the analysis of the following: helicopter's pilot forms, fire databases, circular statistics and GIS.

2. Materials and methods

2.1 Study area

The Region of Tuscany in central Italy has a surface of 22,998.24 km^2 of which 10,861.60 km^2 are covered by forests. Helicopters for forest fire-fighting have been used in Tuscany since the 1970s for slowing fire growth and helping ground suppression crews to improve their control action (Favilli and Barberis 1976, Boncompagni 1978, Marchi et al. 2013).

In Italy both Regional helicopter fleets and national aerial means are used in forest firefighting activities. Both helicopters (such as Ericson S64, Agusta Bell AB 412, Boeing CH47) and airplanes (Canadair and Airtractor) are used in the national fleet. The deployment of the aerial means at nationwide level is planned by the National Civil Protection administration. The deployment of regional helicopters and the rules of helicopter management are decided by each Regional Administration. In Tuscany Region the evaluation of the needs and the request of the helicopter intervention is the responsibility of the incident commander who manages the firefighting resources when forest fires arise. All the aerial means are used in firefighting to drop water on the fire line, with or without fire retardant.

In mountainous areas helicopters are sometimes used to transport firefighters close to the fire line. When the regional helicopter system is working at full capacity or when airtankers or helitankers with a greater water capacity are needed, the incident commander may ask for the cooperation and support of the national aerial means.

2.2 Helicopter characteristics

In the period 1998–2000 and 2001–2005, the Tuscany Region Administration was provided with 5 and 10 helicopters, respectively, during the period of high fire risk, i.e. the summer, according to the data of the fire risk model developed by the Tuscany Region. The helicopters were equipped with helibucket (capacity 800 litres) and were chartered from private companies, which is a usual practice in forest firefighting activities in Italy (Marchi et al. 2013). The helicopter fleet was made of Eurocopter SA315 B »Lama«, AS 350 B3 »Ecureuil« and Bell 407. Each helicopter was deployed in a different base. In July–August 1998–2000 three helicopters were deployed in the northern part of Tuscany (Mondeggi – close to the city of Florence; Villa Cognola – close to the city of Arezzo; Calci – close to the city of Pisa) one in the Island of Elba (Elba) and the last one in the south of Tuscany (Alberese – in Grosseto province) (Fig. 1). In July – August 2001–2005, one helicopter was deployed in each Tuscan province, except »Macchia Antonini« that covered two provinces (Prato and Pistoia), and »Elba«, which was in charge for the islands of the Tuscan Archipelago. In addition to these bases, other temporary helibases for refueling were available, allowing to reduce the refueling time during extinction operations and were located so that a maximum of 10 minutes was needed to reach a temporary base from any operation point.

The Tuscany region chartered the firefighting helicopters by means of a call of bidders based on a set of specific parameters (number of helicopters availability in each season, maximum flight hours per each charter period of five years, etc.).

In the first period (1998–2000) the contract included the availability of at least 1 helicopter for the whole year and up to five helicopters during the summer period (i.e. maximum of 5 helicopters during summer for 90 days). The average flight hours included in the contract were 900 per year (i.e. 4,500 hours in five years). The average hourly cost in this period was 1,161 Euros.

In the second period (2001–2005) the contract included the availability of 2 helicopters for the whole year and up to ten helicopters during summer (i.e. maximum of 10 helicopters during summer for 90 days). The average flight hours included in the contract were 1,600 per years (8,000 hours in five years). The average hourly cost in this period was 1,239 Euros.

In general, the helicopter cost of a five–year contract increased by 90% between the first and the second period, while the number of the available flight hours increased by 77%.

2.3 Data collection and analysis

Data about single operative helicopter flight concerning July – August of each year between 1998 and 2005, which are the most critical months in Tuscany with the highest number of forest fires and burned area (Marchi 2009) were collected from the forms filled in by the pilots. The analyzed data included: date, fire location, helicopter type, helicopter take off base, name of the pilot, time of take–off, operational time (time on fire), total time, and number of water drops. When more than one flight was needed for a single fire both in one as in more consecutive days, the data about operative times were added together and expressed as per single fire event. The burned forest and total area per fire event were obtained from a regional database, including date and fire location.

The data collected were analyzed in order to highlight the differences between the two periods (1998–2000 with 5 helicopters and 2001–2005 with 10 helicopters). The number of fires and burned areas of the two periods were compared by separating fires that required firefighting helicopter activities and fires that did not. A detailed description of the helicopter activity in the different periods was made, taking into account the number of fires per helicopter and year and the number of fires that require one or more helicopters. The total number of days that require helicopters activity was determined in relation to the number of helicopters used.

Using a GIS software (ArcView Gis 3.2), fires and helicopter bases were georeferenced and the direction of each flight was calculated. The distance between the helicopter base and the fire location of each flight was also determined by GIS, and then analyzed.

Finally the operational times, i.e. the time spent in firefighting, were analyzed in relation to both the number of helicopters on each fire and the time periods.

2.4 Statistics

Data were analyzed using Statistica 7.1 (2007) Software. All the data were checked for normality (Kolmogorov–Smirnov test) and homogeneity of variance (Levene test). Cubic root transformation was applied to normalize distances between helicopter base and fire location of each flight. The Mann–Whitney non-parametric *U* test was used to compare the significance of differences in the number of fires per year, annual number of days with flights and number of fires per helicopter between the two periods. A one-way ANOVA was applied in order to test the effect of the increased number of helicopters on the average distance between helicopter base and fire location, for either all helicopters or the only five helicopters allocated in both two periods. One–way ANOVA was also applied to distances, to verify differences among helicopters in the same period. The post hoc HSD test per unequal N was used to compare the significance of differences among means. The Kruskal–Wallis non–parametric multiple-comparison test was used to test the effect of the number of helicopters per fire on operational time, per fire or per helicopter, in regards to the forest burnt area. A circular statistics was applied to determine the mean vector of each helicopter activity. Two descriptive measures – namely the circular mean and circular variance – were then computed. GIS was finally applied to map helicopter base, fire distribution and mean vector, which may be useful in helicopter firefighting planning. This analysis was carried out by means of a spreadsheet specifically built in Excel. By circular distribution statistics (Batschelet 1981), azimuth angles were calculated in order to determine the mean direction of fire locations for each helicopter base. The circle origin was a single helicopter base. Angular data were grouped on the basis of arcs of equal length and the sampled points (fire location in which each helicopter was used) in each arc were counted. The arcs were established on a geographic basis: 0° corresponded to North and angle width increased in clockwise direction. The circle was subdivided into 12 arcs of equal length (30°). The mean values and the number of fires, which occurred in each sector, were used to determine the mean vector direction for each base. As a measure of dispersion, rc, corrected value of the mean vector length, was used (Batschelet 1981). The rc value spans from 0 to 1. When rc approaches 0, the distribution is dispersed; when rc approaches 1, the distribution is concentrated.

3. Results

3.1 Distribution, number and extent of fires

In the summers 1998-2005, forest fires occurred in most of the Tuscan territory (Fig. 1). Most of the fire events, however, were located in Northern and Eastern Tuscany.

In the periods 1998–2000 and 2001–2005, 688 and 1,361 forest fires occurred in Tuscany, respectively,

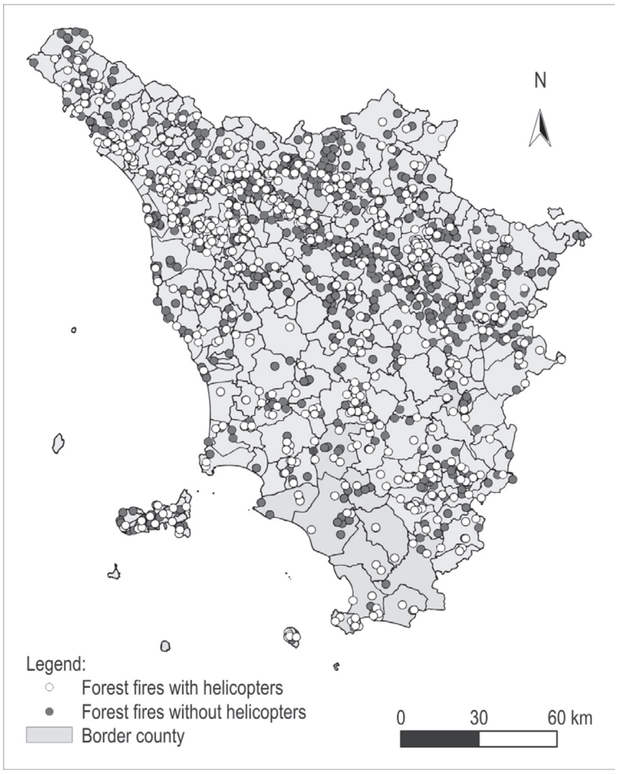

Fig. 1 Distribution of forest fires with or without use of helicopters in the summers 1998–2005 in Tuscany

over a total burned forest area of 7,288 ha (Table 1). The average annual number of fires put out with or without helicopters, did not show significant differences between the two periods. Helicopters were used in 34% (years 1998–2000) and 36% (years 2001–2005) of fires, where 6,265 ha of forests were burned, i.e. 86% of the total burned forest. Helicopters, in fact, were used in the largest fires, as shown by the mean area per forest fire. Nevertheless, as suggested by the median value, helicopters were used in fires that were ≤ 1.0 ha for half of the fires. The average forest and total burnt areas, during fires that required the helicopter support, were not significantly different between the periods, while significant differences were recorded in fires without helicopter support. In fact, the average burnt area was higher in the first period (1998–2000) than in the second one (2001–2005). Taking into consideration the total number of fires, both total and forest average burnt areas were significantly higher in the first period. Taking into consideration the whole period, both total and forest average burnt areas were significantly higher when helicopters were used.

In the period 1998–2000 the highest number of heliattacks was made by the Calci base, followed by Villa Cognola, and Mondeggi (Table 2). All these bases are located in the North–East of Tuscany. In the period 2001–2005 the highest number of heliattacks was

Table 1 Number of forest fires and burnt area (±SE) in July – August 1998–2000 (5 helicopters) and 2001–2005 (10 helicopters) in Tuscany*

	Period	Fires		Burned area						
				Forest				*p* level	Total	*p* level
		Total	Average	Total	Median	Max	Mean		Mean	
		N	N/year	ha	ha/fire	ha/fire	ha/fire		ha/fire	
Fires with helicopters	1998–2000	232	77.3 (±42)	2,312	1.0	700	9.97 (±3.19)		13.29 (±4.05)	
	2001–2005	485	97.0 (±32)	3,953	1.0	471	8.15 (±2.21)		12.81 (±2.80)	
	p level		>0.05				>0.05		>0.05	
	Total	717	89.6 (±19)	6,265	1.0	700	8.74 (±1.82)	a	12.97 (±1.37)	a
Fires without helicopters	1998–2000	456	152.0 (±67)	575	0.1	90	1.26 (±0.20)[a]	0.000	2.02 (±0.24)[a]	0.000
	2001–2005	876	175.2(±52)	448	0.1	40	0.51 (±0.15)[b]		0.75 (±1.08)[b]	
	p level		>0.05				0.002		0.000	
	Total	1,332	166.5 (±46)	1,023	0.1	90	0.77 (±0.12)	b	1.18 (±1.01)	b
Total	1998–2000	688	229.3 (±107.5)	2,887	0.3	700	4.20 (±1.42)[a]		5.82 (±1.46)[a]	
	2001–2005	1,361	272.2 (±83.3)	4,401	0.2	471	3.23 (±0.66)[b]		5.05 (±0.99)[b]	
	p level		>0.05				0.049		0.000	
	1998–2005	2,049	256.2 (±65)	7,288	0.2	700	3.56 (±0.65)		5.31 (±0.82)	

*Different letters show significant differences among values

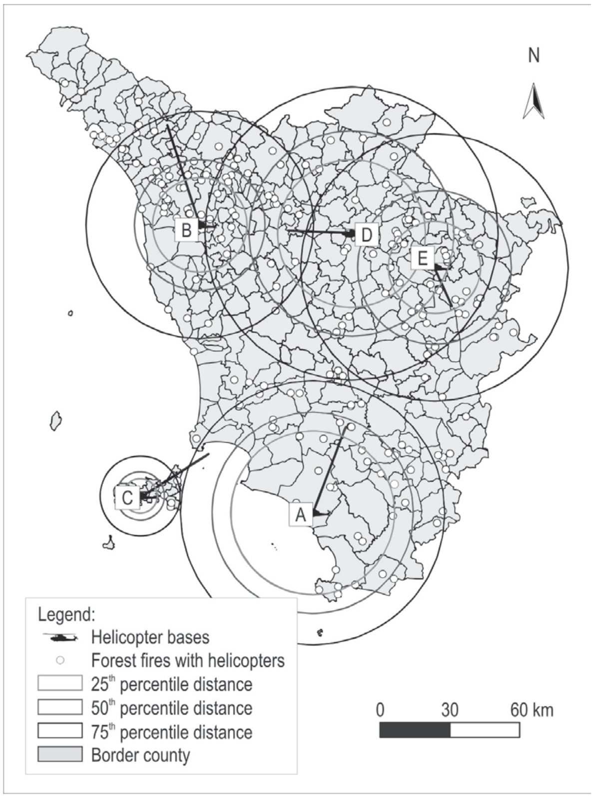

Fig. 2 Helicopter activity in Tuscany, July – August 1998–2000

made by the Tassignano base, followed by Calci, and Macchia Antonini. Also these bases are located in the North–East of Tuscany. The average number of heliattacks did not significantly differ between the periods. In the two periods, 1998–2000 and 2001–2005, only one helicopter was used to support ground suppression crews in 82% and 66% of fires in Tuscany, respectively, (Table 3). In 15 and 23% of fires, two helicopters were used. Three or more helicopters on the same fire were rarely used and more than 5 helicopters were never used.

During the summer period, however, helicopter activity was not continuous. In some days, all helicopters were inactive. In other days, several helicopters were active. Only in 63% (117 days) and 60% (186 days) of the July – August period, at least one helicopter was used in the first and second period, respectively (Table 4).

3.2 Heliattack distribution and distance

Tuscan helicopters were generally used close to their bases, even though they can sometimes cover large areas (Table 5, Fig. 2 and 3). Therefore, the mean distance flight between the base and the fire was generally low, i.e. <52 km. The helicopters of Pentolina (Siena) and Riparbella (Livorno) showed the longest flight distances, while the helicopter of Elba showed

Table 2 Number of fire per helicopter in July – August 1998–2005 in Tuscany*

Helicopter base	Year			Sub–total	Year					Sub–total	Total
	1998	1999	2000		2001	2002	2003	2004	2005		
Alberese	21	26	12	59	24	5	34	5	9	77	136
Calci	41	20	17	78	19	3	46	12	13	93	171
Elba	6	5	2	13	7	n.a.	3	1	1	12	25
Mondeggi	24	28	14	66	13	3	44	10	13	83	149
Villa Cognola	33	12	22	67	19	n.a.	34	9	9	71	138
Cinquale	Not present in these years				14	1	36	7	9	67	67
Macchia Antonini					9	2	56	11	9	87	87
Pentolina					26	4	37	4	10	81	81
Riparbella					n.a.	3	25	4	3	35	35
Tassignano					26	3	58	11	16	114	114
Total	125	91	67	283	157	24	373	74	92	720	1,003
Average	94				144						*p* level >0,05

* Every base has only one helicopter. The sum of number of fire per helicopter is higher than the number of »fires with helicopters« showed in Table 1 because two or more helicopters were used together in many fires
n.a. – not available

Table 3 Number of forest fires where 1–5 helicopters were used in July – August 1998–2005 in Tuscany*

Helicopters per fire	Fires											
	1998	1999	2000	2001	2002	2003	2004	2005	Total 1998–2000		Total 2001–2005	
N	N								N	%	N	%
1	83	59	49	68	14	155	39	45	191	82.3	321	66.2
2	15	13	6	27	5	57	10	13	34	14.7	112	23.1
3	1	2	2	9	0	20	5	3	5	2.2	37	7.6
4	1	0	0	2	0	6	0	3	1	0.4	11	2.3
5	1	0	0	0	0	4	0	0	1	0.4	4	0.8
Total	101	74	57	106	19	242	54	64	232	100	485	100

*No more than 5 helicopters were used on the same fire in the whole period

Table 4 Number of days with helicopter flights in July – August 1998–2005 in Tuscany

Helicopters	Days with flight			
	1998–2000		2001–2005	
N	N	%	N	%
1	44	37.61	55	29.57
2	39	33.33	38	20.43
3	26	22.22	25	13.44
4	6	5.13	21	11.29
5	2	1.71	19	10.22
6	-	-	15	8.06
7	-	-	8	4.30
8	-	-	3	1.61
9	-	-	1	0.54
10	-	-	1	0.54
Total	117	100	186	100
Average, N/year	39.0 (±8.9)		37.2 (±6.9)	p level >0.05
Total days available, 31*2month*years	186		310	
	62.9%		60%	

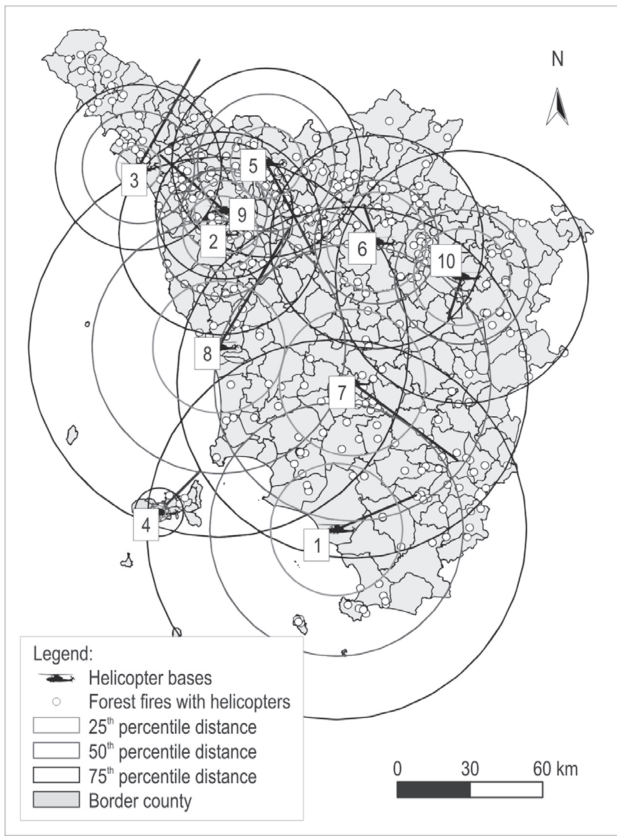

Fig. 3 Helicopter activity in Tuscany, July – August 2001–2005

the shortest distances. Comparing the distances of the helicopters used in both periods, only Mondeggi showed a significant reduction of the average value in the second period.

Black lines (Fig. 2 and 3) show the mean vector direction and length (x100 km) of each helicopter base. Starting from the base, each circle radius shows the distance corresponding to the 25th, 50th, and 75th percentile, respectively.

Fire distribution around the bases was random (Fig. 2 and 3, Table 6). The highest dispersion was found in the Calci, Mondeggi and Villa Cognola bases.

Table 5 Distance between base and fire location in July – August 1998–2000 (5 helicopters) and 2001–2005 (10 helicopters) in Tuscany*

Base	Period 1998–2000			Period 2001–2005			
	Mean, km	Max., km		Mean, km	Max., km		*p* level
Alberese	47.5 ($\pm$3.1)^{a}	167		41.4 ($\pm$2.7)^{ab}	151		>0.05
Calci	32.8 ($\pm$2.7)^{b}	157		30.8($\pm$2.5)^{cd}	142		>0.05
Elba	25.0 ($\pm$10.6)^{b}	117		18.8 ($\pm$6.9)^{d}	146		>0.05
Mondeggi	47.3 ($\pm$3.1)^{a}	132	a	33.9 ($\pm$2.6)^{bc}	143	b	0.000
Villa Cognola	39.3 ($\pm$3.2)^{ab}	136		36.9 ($\pm$2.8)^{abc}	109		>0.05
Cinquale	Not available			23.4 ($\pm$2.9)^{d}	118		
MacchiaAntonini				30.4 ($\pm$2.7)^{cd}	139		
Pentolina				50.6 ($\pm$2.7)^{a}	106		
Riparbella				51.6 ($\pm$4.0)^{ab}	106		
Tassignano				23.4 ($\pm$2.2)^{d}	160		
p level	0.000			0.000			
Period mean	40.4 ($\pm$1.5)^{a}			34.0 ($\pm$1.0)^{b}			0.000

*Different letters show significant differences among values

Table 6 Mean vector direction (α) and length (r_c) for each helicopter base in the summers 1998–2000 and 2001–2005*

Base		Period 1998–2000					
		α		r_c	S^2	S	
		rad	(°)			rad	(°)
A	Alberese	0.56	31.8	0.43	1.13	1.06	61.0
B	Calci	5.95	341.1	0.46	1.07	1.03	59.3
C	Elba	1.09	62.7	0.32	1.37	1.17	67.0
D	Mondeggi	4.65	266.7	0.30	1.39	1.18	67.5
E	Villa Cognola	2.98	170.5	0.16	1.68	1.30	74.4
		Period 2001–2005					
1	Alberese	1.16	66.5	0.34	1.32	1.15	65.9
2	Calci	0.57	32.7	0.11	1.78	1.33	76.2
3	Cinquale	0.56	32.1	0.49	1.03	1.02	58.4
4	Elba	0.78	44.7	0.23	1.54	1.24	71.0
5	Macchia Antonini	2.62	150.1	0.41	1.17	1.08	61.9
6	Mondeggi	5.96	341.5	0.15	1.70	1.30	74.5
7	Pentolina	2.21	126.6	0.51	0.97	0.99	56.7
8	Riparbella	0.54	30.9	0.54	0.92	0.96	55.0
9	Tassignano	5.45	312.3	0.32	1.35	1.16	66.5
10	Villa Cognola	3.46	198.2	0.17	1.65	1.29	73.9

*S^2 – angular variance, 2 * (1 – r_c); S – mean angular deviation, RADQ (2 * (1 – r_c))

Cinquale, Riparbella and Pentolina showed the most concentrated fire distribution.

3.3 Operational time

The operational time is the time the helicopter works on a fire. If the operational time was greater than the operating range, time to go back and forth for refueling was also included.

In both periods, the operational time per fire was significantly higher if two or more helicopters were used (Table 7).

No statistical relationships were recorded between operational time and burned area in every fire. This discrepancy may be explained by the variability in fire spreading, eventual support of national aircrafts, and, most importantly, by the activity of ground suppression crews.

4. Discussion

The results did not show significant statistical differences in the number of fires and burnt areas between the two time periods.

The performance of wildfire suppression is often monitored using statistics related to area burned and time to contain a fire (Plucinski 2012). A high number of helicopters should contribute to reduce the burnt area. However, in our study, the average forest and total burned area of fires with helicopter support did not show statistically significant differences between the two time periods, which suggests that an increasing number of helicopters did not have significant effect in terms of suppression effectiveness. However, in both periods, helicopters were used in ≤1.0 ha burnt area for half of the fires, as suggested by the median value, i.e. when used during the first phase of fire growth, a fast initial attack by the helicopter may prevent small fires becoming larger (Plucinski 2012).

The average burnt area for fires without helicopter support was significantly higher in the first period (1998–2000) than in the second (2001–2005). This is most likely because of the increasing use of helicopters in small fires when ten helicopters were available. In fact, about 66% and 64% of fires did not require helicopter support in firefighting in the first and second period, respectively. However, median and average values of burnt areas, both forested and total, in fires

Table 7 Helicopter operational time (±*SE*) on forest fires in July – August 1998–2000 (5 helicopters) and 2001–2005 (10 helicopters) in Tuscany*

Period	Helicopter per fire	Average forest burnt area	Flight time			
			Average operational time			
			Per fire		Per helicopter	
	N	ha/fire	min./fire	N	min./helic.	N
1998–2000	1	2.2 (±4.4)[a]	94.2 (±4.7)[a]	191	94.2 (±10)[a]	191
	2	9.9 (±19.8)[b]	339.5 (±45.6)[b]	34	169.8 (±18.3)[b]	68
	3	42.9 (±71.3)[b]	729.2 (±240.5)[b]	5	243.1 (±53.6)[b]	15
	4	637.0 (-)	2760 (-)	1	690 (±160.9)[b]	4
	5	700.0 (-)	3173 (-)	1	634.6 (±170.3)[b]	5
p level		0.000	0.000		0.001	
2001–2005	1	1.4 (±3.5)[a]	96.6 (±4.1)[a]	321	96.6 (±4.1)[a]	321
	2	14.6 (±57.6)[b]	331.8 (±30.3)[b]	112	165.9 (±11.9)[b]	224
	3	33.4 (±92.1)[c]	684.4 (±76.0)[b]	37	228.1 (±20.3)[c]	111
	4	43.1(±55.8)[c]	1053.5 (±223.9)[b]	11	263.4 (±38.1)[c]	44
	5	41.2 (±25.9)[c]	2018.5 (±681.3)[b]	4	403.7 (±80.5)[c]	20
p level		0.000	0.000		0.000	

*No more than 5 helicopters were used on the same fire in the whole period. Different letters show significant differences among values without helicopters were lower than in fires with helicopters, suggesting that ground suppression provided the necessary effectiveness.

The lack of significant statistical difference in the number of heliattacks between the two periods may be explained by the lack of difference in the number of fires. Usually, a large fire needs many helicopters in order to be suppressed. Nevertheless, even though the number of helicopters was double in the second period, the maximum number of helicopters per fire did not exceed five, i.e. the maximum number of helicopters per fire recorded in the previous period. This fact can be explained by difficulties in managing a large number of aircrafts on the same fire. Moreover, in very large fires the incident commander requires the support of more effective aerial means from the national fleet. However, the higher the number of available helicopters, the lower the number of fires where only one helicopter was used to support ground suppression crews.

In the second period more than seven helicopters were used in a few days. Overall, the helicopters were used only in 186 days out of the 310 available. Therefore, 9 and 10 helicopters were rarely needed, suggesting the need to evaluate a reduction in the fleet. Financial resources may be thus available for more profitable fire prevention activities, such as, active fuel management (Agee and Skinner 2005).

In fact, among the elements affecting the fire behavior, the fuel is the only factor that can be regulated in terms of quantity, spatial distribution and composition. Several studies have shown the role played by fuel reduction activity in terms of minor severity of the flame length (Agee and Skinner 2005, Agee et al. 2000, Omi and Martinson 2002, Pollet and Omi 2002, Martinson and Omi 2003), which also means a reduction of aerial and ground suppression needs.

The forest fuel reduction treatment is one of the most valuable tools to effectively address the problem of forest fires (Xanthopoulus et al. 2006). Fuel management should be planned using principles of fire-safe forests: reduction of surface fuels, increasing the height to live crown, decreasing crown density, and retaining large trees of fire-resistant species. Thinning and prescribed fire can be useful tools to achieve these objectives. Low thinning will be more effective than crown or selection thinning, and management of surface fuels will increase the likelihood that the stand will survive a wildfire (Agee and Skinner 2005). However, its application does not exclude the start and spread of the fire, and it is therefore necessary to include it in the context of the planning of fire prevention activity (Corona 2004).

In this study, increasing the number of helicopters in the period 2001–2005, did not translate into a significant reduction of flight distances travelled by the same helicopters present in the first period (1998–2000), with the exception of the helicopter at the base of Mondeggi. This suggests that the new helicopters were not well distributed among the bases.

Considering all the helicopters in both periods, the average distance traveled to reach the fire was reduced significantly from 40 to 34 km.

Often circular statistics is applied to very different biological (Batschelet 1981) or geographical problems (Mardia 1975) such as neuronal discharge patterns during locomotion (Drew and Doucet 1991) and journey to work (Corcoran et al. 2009). In forest science, circular statistics has been mostly used to study the effects of wind (Rentch 2010), the distribution of branching (Faravani et al. 2009) and plant species (Tremblay and Castro 2009). Its use in the analysis of helicopter activity in forest fires suppression is innovative and will help to assess the best location of the bases. Our results showed a high dispersion value of fire around the bases, which means a quite good positioning of the helicopters, as helicopters can operate efficiently in almost all directions. Higher values of rc were recorded at three bases (Cinquale, Riparbella and Pentolina), suggesting that the helicopters preferentially flew close to the mean vector direction. In particular, the bases of Cinquale and Riparbella were located close to the seaside and thus had a wide area on the West side where fire cannot occur. Therefore, they should be moved toward North-East, thus reducing the average distance to reach the fires. Moreover, the rc and mean vector direction values suggest that the Pentolina base should be moved toward South–East in order to improve its efficiency.

5. Conclusions

This study analyzed the activities of the helicopters used in forest fire-fighting in Tuscany Region (Italy) during two periods, characterized by a fleet of 5 (1998–2000) and 10 helicopters (2001–2005). The result showed that a fleet of 10 helicopters is oversized in relation to the current fire regime in the area, suggesting the need to evaluate a reduction in the fleet. However, it is important to highlight that our results do not consider the potential future fire regime, as a result of climate change.

A planning of the size and spatial distribution of helicopter fleet should include: environmental, social and economic aspects; »vulnerable« areas, i.e. areas of special importance from an environmental or landscape point of view; ground crew organization, with special reference to its travel time for reaching potential fire; availability of a suitable forest road network and finally available budget. Our results highlight the needs of a fire prevention and suppression planning revision for improving the financial resources distribution between suppression and prevention activities, with particular attention to fuel management.

Information from the pilot forms is recommended as a useful tool for describing and evaluating the helicopter activity in forest firefighting. Processing such data, together with data about landscape and other components of firefighting organization, helps to assess and address the planning of this activity. The results for this case study in Tuscany also show that:

⇒ Helicopters were used in about 35% of fires and 86% of the total forest burned area,

⇒ The median burnt forest area shows that, in half of the fires, helicopters were used in fires that were ≤1 ha. This suggests that, when used during the first phase of fire growth, a fast initial attack by helicopter may prevent small fires becoming larger,

⇒ Only in 60% (186 days) of the July – August period, at least one helicopter was used,

⇒ The higher the number of helicopters deployed, the higher the number of helicopters used on the same fire to support ground suppression crews.

The location of helicopter bases in Tuscany was usually well planned, according to both the distribution of fires and the circular statistics results. However, a reallocation of three bases is recommended, in order to minimize the flight distances and raise the helicopter effectiveness.

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