Integrating Teledetection and Economic Tools in the Evaluation of Wildfires Impacts. The Alhama de Almería Fire (Spain) Case[1]

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Abstract

Valuation of natural resources requires a multifunctional vision incorporating market and nonmarket values like environmental services and landscape goods. Though widely used in forest firest analysis, teledetection has never been used in the economic valuation of forest fires damages. Application of this tool in the valuation of forest fires damages provides a versatile tool with many benefits. For example, it allows identification and valuation of large forest fires inexpensively compare to on the ground monitoring by providing periodic information of vegetation post-fire behavior.

Using Landsat 8 satellite images and the economic procedure in Visual SEVEIF we provide an economic valuation of the damages caused by the Alhama de Almeria fire (3,260 ha). The satellite images are an important source of georeferenced information and can be used to determine the resource net-value-change based on fire intensity by classifying the vegetation indexes as resource depreciation rates. For the Alhama de Almeria fire the dNBR index provides a more robust representation of fire severity than RdNBR because of the boosting effect caused by the pre-fire NBR due to the areas scant vegetation, low precipitation and intense sun light. The economic valuation of the damages caused by this fire was estimated at 656,981 € or 201.53 €/ha. The most important resources in the valuation were landscape goods because of their closedness to the province capital. Over 57% of the total losses correspond to landscape goods and environmental services.

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Introduction

The increasing climate and socioeconomic changes are provoking a paradigm shift in forest management adopting a multifunctional function with landscape goods and environmental services as its main actors (Contanza et al. 1997). An integrated valuation of natural resource damages is fundamental for an effective disturbances planning to mitigate the disturbance impacts on rural populations (Vélez 2009). Within the Mediterranean environment a methodological procedure integrating net-value change variables and economic tools has practical utility at the post-fire and the preventative level. The Geographic Information Systems (GIS) become essential not only for the development of fire protection plans but also in their optimization (Chuvieco et al. 2010). For this reason we develop the methodological procedure anchored on a GIS to facilitate the spatial-temporal monitoring maps and a decision aid for restoration and forest fires control.

The economic valuation of fire damages on a large forest fire requires an intense field work, commanding a large number of economic and human resources, often not available. In related developments studies have shown the potential of satellite images to identify the area burned and different levels of fire severity or damages on a forest fire (Chivieco at al. 2005). The benefits associated with teledection are its capacity to measure large areas, low cost per area, and availability of periodic information. However, its use also present some limitations particularly in the lower stratum of the forest canopy or some type of forests (Miller and Thode 2007, Soverel et al. 2010); and in the economic valuation because its difficulty in measuring some variables (Rodríguez y Silva et al. 2013a). Therefore, the use of satellite images requires field work for validation and calibration.

Using vegetation indeces like the Normalized Difference Vegetation Index (NDVI), the Normalized Burn Ratio (NBR), and the Relative difference Normalized Burn Ratio (RdNBR) we can identify the different fire severity or damage levels by the spectral differences existing immediately pre- and post-fire (Key and Benson 2006, Miller and Thode 2007). Even after considering the spectral differences associated with seasonality, the reflectance property of different soils, and time since the fire occurrence these works have reached a high level of robustness in determining damage levels. Likewise, a study using MODIS images done by our own fire laboratory was quite accurate for several large fires in southern Spain (Rodríguez y Silva et al. 2013). In this study, though the fire is large enough to use MODIS imagery (per our preliminary findings) we dediced to use Landsat 8 images. The change in remote sensing imaging is justified by the higher quality of spatial resolution; as well as for the improvements in natural resources mapping.

The general objective of this study is the development of a georefenced economic valuation of forest fires impacts. Fire damages economic valuation requires the following: a prior characterization of resources, identification of the fire different intensity levels, and an accurate representation of the relationship between vegetation damage and each pixel reflectance.

Materials and methods

Study site

The methodology was applied in Almeria (Spain), the most southeastern province of the Iberian Peninsula (Figure 1). The factors for selecting this fire included its size (3,260 ha), seasonality (winter, outside of the maximun fire risk, large private property presence (difficult to inventory), and the landscape diversity wit large dense forest zones, low density forest zones, and zones without forest cover.

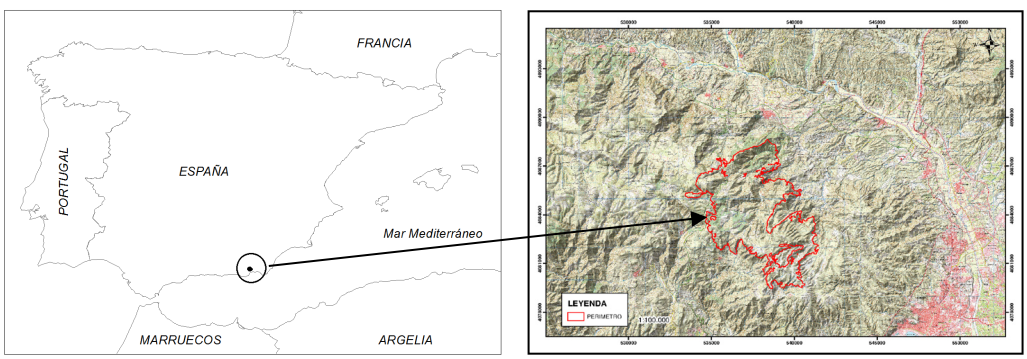


Figure 1- Alhama de Almería fire location

Methodological procedure

The economic valuation of forest fires impact, integrating economic and teledetection tolos, requires four interrelated phases (Ruíz 2015) (Figure 2):

- Economic valuation of the natural resources
- Spatial identification of the different levels of damage
- Identification and testing of the severity levels
- Identification of resources net-value-change

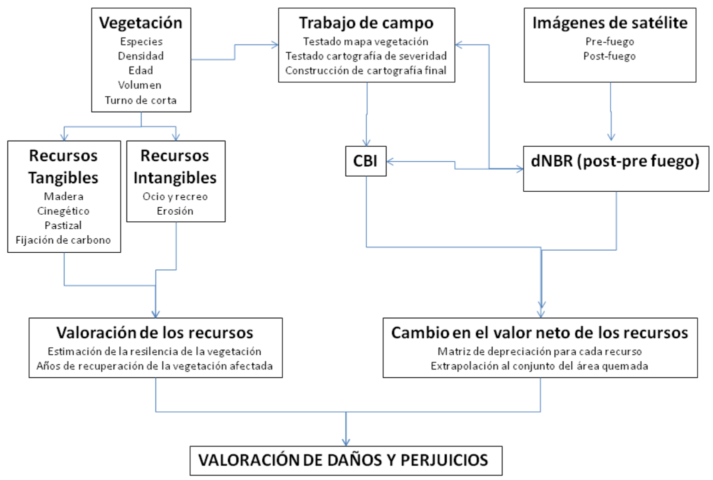


Figure 2- Methodological framework for the economic valuation (Ruíz 2015)

Economic valuation of natural resources

The natural resources economic valuation was done using the mathematical formulas in Visual SVEIF (Rodríguez y Silva et al. 2013a, 2013b). For the Alhama fire we included four market goods: timber (rodrígue y Silva et al. 2012), hunting (Zamora et al. 2010), pastoral use (Molina et al. 2011), and carbon sequestration (Molina et al. 2009); and fire nonmarket goods: protection of erosion, biodiversity, landscape, leisure and recreation, and non-use (Molina et al. 2009). Formulas in Figure 3 were used to compute their values considering local technicians experience for determing harvesting rotation turn or maturity, vegetation groups' resilience, and age of affected stands. Stands volume was computed using information from the National Forestry Inventory and from public forests planning projects. The pastoral and hunting rent was coumputed using the existing hunting technical and exploitation plans approved by the Regional Authority. The biodiversity valuation was conducted using a study by the University of Cordoba, based on the level of protection for the existing species in the area. For the indirect valuation of nonmarket landscape values, and due to the absence of information for the study are we used the average value of a similar burned area with urban centers nearby. The annual visitation rate to the area was developed using the expert opinion of the local environmental rangers.

Recurso	Fórmula	Estado del recurso	Fuente
Maderero	$V_{mad} = (1,7*E*B)/(E+0,85*B)$	Maduro e inmaduro	Rodríguez y Silva y otros 2012
	$E = C_0*p\ [i^e + g(i^e - 1)] + A*(i^e - 1)$	Inmaduro	
	$E = (C_{0/z}*t\ [i^e + g(i^e - 1)] + (C_0/z)*0,5*(i^e - 1)$	Latizal	
	$E = [P*V - P_1*V_1] + P*V\ [(i^{(T-e)} - 1)/(i^{(T-e)})]$	Fustal	
	$B = [(V*P*1,025^n)/1,04^n]*[1-(1,025/1,04)^e]*[1 + X*h*p]$	Inmaduro	
	$B = V*h*t[R*P + (1 - R)*P_1]$	Maduro	
Aprovechamiento de leñas	$V_{leñas} = P_x*R_x*[((1+i)^n - 1)/(i*(1+i)^n]$	Maduro	Martínez, 2000; Molina y otros 2011
Cinegético	$V_{cin} = P_x*R_x*[(1+i)^n - 1)/(i*(1+i)^n] + S$	Coto de caza	Zamora y otros 2010
Fijación de carbono	$V_{carb} = CF*PM + IF*PM*RC*[((1+i)^{T-e} - 1)/(i*(1+i)^{T-e}]$	Masa arbolada	Molina, 2008
Control de la erosión	$V_{eros} = R_1*P_1 + R_2*P_2\ [((1+i)^n - 1)/(i(1+i)^n)]$	-	Molinay otros 2009
Biodiversidad faunística; Recurso paisajístico; Recurso ocio y recreo; Recurso no uso	$V_{biod/pai/oci/nouso} = Rx*[((1+i)^n - 1)/(i*(1+i)^n]$	Presencia especies singulares	Molina, 2008

donde E es la valoración maderera en base al planteamiento tradicional español (€/ha), B es la valoración maderera adaptada del Modelo Americano (€/ha), Co es el coste de repoblación de una hectárea de terreno (€/ha), p es el porcentaje de la masa afectada por el fuego, i es el tanto por uno de interés anual, g es anualidad dependiente del turno de la especie, A es el valor de una hectárea de suelo sin arbolado (€/ha), e es la edad estimada de la masa en el momento del incendio, V es el volumen de madera expresado en m^3/ha, P es el precio del m^3 de madera apeada (€), n es el número de años que restan hasta el hipotético turno de corta, X es el coeficiente de mortalidad dependiente de la severidad de las llamas, h es el porcentaje de la especie en el dosel, z es la reducción del coste de repoblación por el fenómeno auto-regenerativo en función del turno, P_1 es el precio de la madera dañada con aprovechamiento comercial (€/m^3), V_1 es el volumen de madera dañada con aprovechamiento (m^3/ha), Px es el precio por unidad de medida del recurso (€), Rx es la renta anual por unidad de superficie, S es el stock reproductivo por unidad de superficie (€), CF es la cantidad de CO_2 retenida en el momento del incendio (t/ha), PM es el precio de la tonelada fijada (€/t), IF es el incremento anual de CO_2 retenido (t/ha), RC es la renta generada al fijar una tonelada de carbono en un año (€), R_1 es la cantidad de suelo media perdida el primer año (t/ha), P_1 es el precio estimado para la tonelada (€), R_2 es la cantidad de suelo media perdida hasta la recuperación de la cobertura original (t/ha).

Figure 3- Mathematical formulas from the SEVEIF application for naturla resource valuation (Rodríguez y Silva 2013a, 2013b)

Spatial identification of the different damage levels

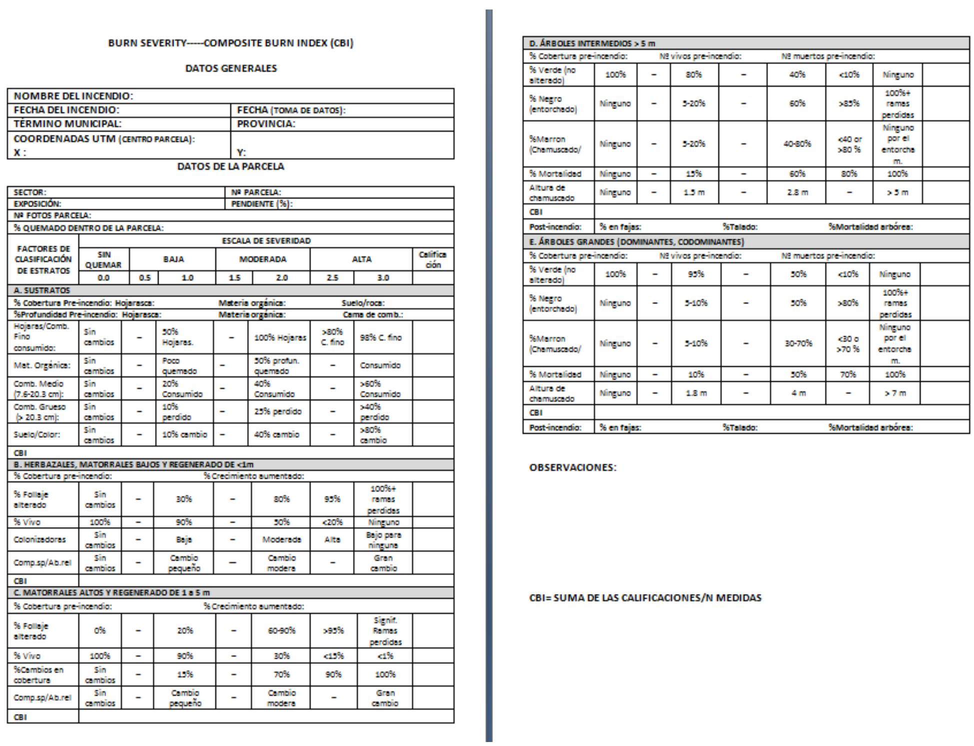
The pre- and post-fire images used were Landsat 8 LDCM (Landsat Data Continuity Mission). We used three vegetation indeces to test the spatial identification of the different fire severity levels (Table 1); selecting the most statistically robust one for the study area given the local reflectance characteristics.

Table 1- *Tested vegetation indeces for severity levels identification*

Vegetation index	Equation	Range
NBR	$NBR = \frac{(R5 - R7)}{(R5 + R7)} * 1000$	-1000 a 1000
dNBR	$dNBR = (NBRpre - NBRpost)$	-2000 a 2000
RdNBR	$RdNBR = \frac{dNBR}{\sqrt{Abs(NBRpre)}/1000}$	-2000 a 2000

<u>*Identification and testing of severity levels*</u>

The information derived from the vegetation indeces was field tested in the fall prior to the fire. The severity was tested using the Composite Burned Index (CBI) protocol (Key and Benson, 2005) that cuantify damage levels from variables easily identified in field inventories such as soil color, presence of organic matter, loss of leaves, changes in vegetation color, and vegetation mortality for each of the ecosystem components: soil, pastureland, scrub and regeneration, trees < 5 meters, trees >5 meters (Figure 4).


BURN SEVERITY-----COMPOSITE BURN INDEX (CBI)

DATOS GENERALES

NOMBRE DEL INCENDIO:	
FECHA DEL INCENDIO:	FECHA (TOMA DE DATOS):
TÉRMINO MUNICIPAL:	PROVINCIA:
COORDENADAS UTM (CENTRO PARCELA): X :	Y:

DATOS DE LA PARCELA

SECTOR:	Nº PARCELA:
EXPOSICIÓN:	PENDIENTE (%):
Nº FOTOS PARCELA:	
% QUEMADO DENTRO DE LA PARCELA:	

FACTORES DE CLASIFICACIÓN DE ESTRATOS	ESCALA DE SEVERIDAD							
	SIN QUEMAR	BAJA		MODERADA		ALTA		Calificación
	0.0	0.5	1.0	1.5	2.0	2.5	3.0	
A. SUSTRATOS								
% Cobertura Pre-incendio: Hojarasca:			Materia orgánica:			Suelo/roca:		
%Profundidad Pre-incendio: Hojarasca:			Materia orgánica:			Cama de comb.:		
Hojaras/Comb. Fino consumido:	Sin cambios	–	50% Hojaras.	–	100% Hojaras	>80% C. fino	98% C. fino	
Mat. Orgánica:	Sin cambios	–	Poco quemado	–	50% profun. quemado	–	Consumido	
Comb. Medio (7.6-20.3 cm):	Sin cambios	–	20% Consumido	–	40% Consumido	–	>60% Consumido	
Comb. Grueso (> 20.3 cm):	Sin cambios	–	10% perdido	–	25% perdido	–	>40% perdido	
Suelo/Color:	Sin cambios	–	10% cambio	–	40% cambio	–	>80% cambio	
CBI								
B. HERBAZALES, MATORRALES BAJOS Y REGENERADO DE <1m								
% Cobertura pre-incendio:			%Crecimiento aumentado:					
% Follaje alterado	Sin cambios	–	30%	–	80%	95%	100%+ ramas perdidas	
% Vivo	100%	–	90%	–	50%	<20%	Ninguno	
Colonizadoras	Sin cambios	–	Baja	–	Moderada	Alta	Bajo para ninguna	
Comp.sp/Ab.rel	Sin cambios	–	Cambio pequeño	–	Cambio modera	–	Gran cambio	
CBI								
C. MATORRALES ALTOS Y REGENERADO DE 1 a 5 m								
% Cobertura pre-incendio:			%Crecimiento aumentado:					
% Follaje alterado	0%	–	20%	–	60-90%	>95%	Signif. Ramas perdidas	
% Vivo	100%	–	90%	–	30%	<15%	<1%	
%Cambios en cobertura	Sin cambios	–	15%	–	70%	90%	100%	
Comp.sp/Ab.rel	Sin cambios	–	Cambio pequeño	–	Cambio modera	–	Gran cambio	
CBI								

D. ÁRBOLES INTERMEDIOS > 5 m								
% Cobertura pre-incendio:		Nº vivos pre-incendio:			Nº muertos pre-incendio:			
% Verde (no alterado)	100%	–	80%	–	40%	<10%	Ninguno	
% Negro (entorchado)	Ninguno	–	5-20%	–	60%	>85%	100%+ ramas perdidas	
%Marron (Chamuscado/	Ninguno	–	5-20%	–	40-80%	<40 or >80 %	Ninguno por el entorcham.	
% Mortalidad	Ninguno	–	15%	–	60%	80%	100%	
Altura de chamuscado	Ninguno	–	1.5 m	–	2.8 m	–	> 5 m	
CBI								
Post-incendio:	% en fajas:		%Talado:			%Mortalidad arbórea:		
E. ÁRBOLES GRANDES (DOMINANTES, CODOMINANTES)								
% Cobertura pre-incendio:		Nº vivos pre-incendio:			Nº muertos pre-incendio:			
% Verde (no alterado)	100%	–	95%	–	50%	<10%	Ninguno	
% Negro (entorchado)	Ninguno	–	5-10%	–	50%	>80%	100%+ ramas perdidas	
%Marron (Chamuscado/	Ninguno	–	5-10%	–	30-70%	<30 o >70 %	Ninguno por el entorcham.	
% Mortalidad	Ninguno	–	10%	–	50%	70%	100%	
Altura de chamuscado	Ninguno	–	1.8 m	–	4 m	–	> 7 m	
CBI								
Post-incendio:	% en fajas:		%Talado:			%Mortalidad arbórea:		

OBSERVACIONES:

CBI= SUMA DE LAS CALIFICACIONES/N MEDIDAS

Figure 4- Field forms for evaluating the Composite Burn Index

The CBI parcel (30 meters radius and spaced 90 m between them) evaluation was stratified by each severity level representativeness. Once the inventory was completed a statistical analysis was performed using the CBI as an independent variable, and the indeces value as the dependent variable. The SPSS$^{(C)}$ software allowed us to estimate the confusion matrix and the Kappa statistic identifying the best vegetation index for the study zone.

Identification of the resources net-value change

We used satellite images together with the field inventory for a prior identification of severity, allowed us to estimate a resources net-value change (NVC) (Rodríguez y Silva and González-Cabán 2010) based on damage levels. The NVC is not homogeneus for all resources, but will be estimate individually in terms of an identifiable parameter in the field inventory. Like in other studies (Zamora et al. 2010, Molina et al. 2011, Rodríguez y Silva et al. 2012), for its simplicity of identification in-situ, we use the flame length as the variable to measure the degree of resource degradation.

Initially, we considered the depreciation rates from these previous works and the FIREMAP, SINAMI and INFOCOPAS research studies based on a large number of fires in Andalusia; as the field work will permit adjetment and validation for the study area local conditions.

Results

Natural resources economic valuation

The natural resources total economic value of the area burned was 1,074,798 €; equivalent to 329.69 €/ha. Percentage wide, there was little difference in the economic value of market (timber, hunting and pasturelands) and nonmarket (landscape, leisure and recreation, and non-use values) goods with a 40.95% and a 40.85% respectively. Hunting, which is the principal economic activity of these forest areas was also highly valued at 298,601 €.

Spatial Identification of damage levels

Independently of using a continuous or categorical classification the severity levels identification showed uneven results in terms of the vegetation index used. The worst results were for the NDVI; results improved by using the dNBR and RdNBR indeces; thogh they still also showed differences between them (Figure 5). Using the dNBR index a 66.92% of the area burned was identified as moderate severity; while using the RdNBR brings this number to only 17.84%. This is due to a more unfavorable result for the RdNBR index, which identify a larger area in the high severity category.

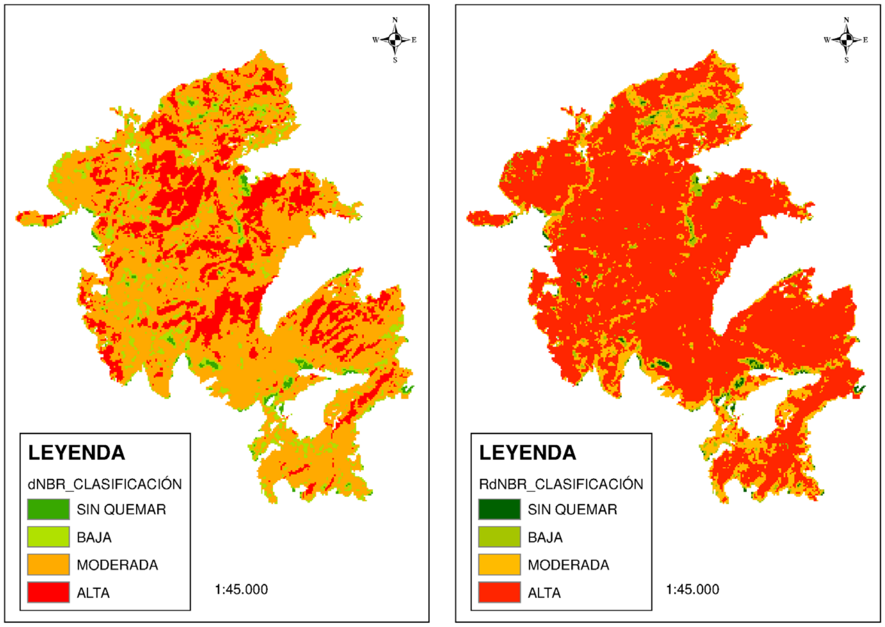


Figure 5- Severity identificación using dNBR and RdNBR (Ruíz 2016)

Identification and testing of severity levels

Statistical testing of the severity field work with information from satellite images showed a general tendency towards models with a potentially relationship between the reflectance level and CBI. The dNBR vegetation index provided a more robust information than the RdNBR index as measured by the coefficient of determination or R^2 with 0.706 vs. 0.604 respectively. The R^2 increased significantly when considering the forested zones to 0.827.

Likewise, the confusión matrix showed better results for the dNBR (82%) than for RdNBR (50%). The principal errors in the fire severity level were associated with the lower levels (moderate and low severity); with the low severity level showing the higher number of incorrect classifications for both the CBI-dNBR and CBI-RdNBR. The Kappa statistic values for dNBR was 0.751.

Identification of resources net-value change

From the fire severity analysis (relationship between the CBI and vegetation indeces) we determided an unique categorical representation: low, medium and high severity. However, the existance of pole and timber stands, and thicket areas lead us to determine the insufficiency of using only three levels to represent the resources NVC for all the area burned. Therefore, we developed a new classification using the six fire intensity levels (FIL) based on the average flame length from the field inventories (Table 2).

Table 2-*Vegetation indeces tested for identifying fire severity levels*

Vegetation	Category	Flame length (m)	FIL
Areas without trees	Low severity	< 2	I
	Moderate severity	3-6	III
Pole stands	High severity	6-9	IV
	Low severity	2-3	II
Timber stands	Moderate severity	9-12	V
	High severity	>12	VI

Fire impacts valuation

The total economic valuation of damages in the Alhama fire was 656,981 € or 201.53 €/ha. Of the total damages caused by the fire about 42.32% are associated with the market goods in the fire area (timber, hunting and pasturelands) and 39.11% are associated with nonmarket goods in the fire area (landscape, leisure and recreation, and nonuse values).

Table 3-*Individual resource economic valuation for the Alhama de Almería fire.*

Resource	Damage (€)	Representativeness (%)
Timber	99,558.78	10.52
Hunting	205,979.48	31.35
Pasturelands	2,944.61	0.45
Carbon sequestration	55,192.18	8.40
Erosion control	40,516.88	6.17
Biodiversity	26,273.04	3.99
Landscape	57,419.42	8.74
Eisure and recreation	20,004.11	3.04
Nonuse	179,545,54	27.33
TOTAL	656,981.04	

Discussion

The multifunctional reality of the Mediterranean forests is reflected on the economic valuation of the Alhama fire. The market resources in the fire area represent a relative small proportion (42.32%) of the total like in other studies (Rodríguez y Silva et al. 2013b). Even though, the study are is not within any protected natural space it is subject to a great human pressure because the hunting activities and its strategic location close to the province capital.

Given the present budgetary restrictions the use of satellite images is fundamnemtal for the evaluaton of areas burned (Chuvieco el at. 2005). Identification of fire severity levels in large fires with teledetection (Key and Benson 2006, Miller and Thode, 2007, Soverel et al. 2010) represents a support tool for prioritization of restoration actions. In addition, the use of satellite images allows of the spatial-temporal monitoring of the resources recovery at basically a zero cost. However, we must be cognizant that any teledetection work requires field validation, especially in identifying fire severity levels (Key and Benson 2005).

Contrary to Miller and Thode (2007) results, the classification of fire serverity levels through dNBR showed better results than through RdNBR. This could be due to the NBR pre-fire small values that result in exceptionally very large values of RdNBR. As expected the statistical analysis showed a better relationship between CBI and dNBR than between CBI and EdNBR possibly due to the lower pre-fire reflectance values. Though the Kappa statistic values are similar, the global precision of dNBR is larger than in other studies (Miller and Thode 2007, Soverel et al. 2010). The adjustment significance increases in forested lands due to pre-fire reflectance values.

The economic valuation of the Alhama de Almeria fire reveals a greater impact on the nonmarket goods and services (envirnmentla services and landscape values) than on the market goods (timber, hunting and pasturelands) (Table 3). This coincide with results from other studies (Rodríguez y Silva et al. 2013a). Therefore, as other authors recommend (Vélez 2009, Rodríguez y Silva and González-Cabán 2010), the economic valuation of damages must recognize the multifunctionality of Mediterranean forest and include not only the damages to marke goods like timber.

Combining the satellite images with flame length in the economic valuation of damages provides a useful tool for agencies responsable for management of forest lands (Rodríguez y Silva et al. 2013a). The availability of georeferenced information of the forest fire damage on a per hectare basis, not only at the individual resource level, but at the integrated ecosystem vulnerability is important for fire management decision making and budgets allocation (Molina et al. 2009). The greatest advantage of products and tools based on GIS (thematic mapping) and teledectation is the simplicity of incorporating additional needs or novel ideas, thus making the digital information an indispensable working tool for fire protection programs (Chuvieco et al. 2010). In addition, let's not forget that the methological procedure presented here is based on free satellite images available every 16 days (Landsat 8). Therefore, even when we have selected only one fire for development of the procedure the methodology can be extrapolated to any fire and scale of work, as long as we consider the prior knowledge of resources affected, and the necessary and mandatory adjustments for all works done with satellite images.

Conclusions

The new social paradigms for the valuation of natural resources requires the incorporation of nonmarket goods and services (environmental servies and landscape values), as many times they represent a larger proportion of the total values. Integrating satellite images and economic tools reduces the need for economic and human resources, and facilitate the spatial-temporal monitoring of areas burned. In addition, using vegetation indeces allows the incorporation of the resources NVC providing a closer representation of reality and optimizing budget allocation. The dNBR index provides a better fire severity classification for the study area than RdNBR due to high solar radiation, low precipitation and scant vegetation.

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