Evaluation of satellite-derived Burned Area products for the *Fynbos*, a Mediterranean shrubland

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Suggested running head: Fynbos fire mapping with MODIS satellite products

Additional keywords: MODIS; Western Cape; South Africa

[**word count** = 4749]

Abstract [word count = 202]

Fire is a critical ecological process in the fynbos of the southwestern area of South Africa, as is true of all dwarf Mediterranean shrublands. We evaluate the potential of currently publicly available MODIS burned area products to contribute to an accurate fire history for the fynbos. To this end we compare the Meraka Institute's MODIS burned area product, based on the Giglio *et al.* (2009) algorithm (termed the 'WAMIS' product), as well as the standard MODIS MCD45A1 burned area product, based on the Roy *et al.* (2005*a*) algorithm, with comprehensive manager-mapped fire boundary data. We use standard inventory accuracy assessment (of the number and size of individual burn scars) and confusion matrix techniques. Results show promise for both burned area products depending on the intended use. The MCD45A1 has low errors of commission (8.1 – 19.1%) and high consumer's accuracy (80.9 – 91.9%), but relatively common errors of omission, making it useful for studies that need to identify burned pixels with a high degree of certainty. However, the WAMIS product has generally low errors of omission (12.2 – 43.8%) and greater producer's accuracy (56.2 – 87.6%), and shows great promise as a tool for supplementing manager-mapped fire records, especially for fynbos remnants occurring outside protected areas.

Brief summary [word count = 50]

Can satellite products help managers accurately map fire boundaries? We test the ability of burned area algorithms run on MODIS satellite data to identify burned areas in the mediterranean shrublands of South Africa. To this end we compare these satellite-derived products with fire boundaries that have been carefully mapped in the field.

Introduction

Fire is an important ecological process in more than 50% of the world's terrestrial ecosystems (Shlisky *et al.* 2009) and most of these areas have altered natural fire regimes due to anthropogenic influences (Shlisky *et al.* 2007). Future land use and climate change is likely to continue to affect changes in fire regimes globally (Denman *et al.* 2007, section 7.3.3.1.4) and accurately mapping fires through space and time is critical to understanding the drivers of fire and ecological dynamics at regional to global scales. Knowledge of the extent of the area affected by the fire, and how the impact of the fire varied across the burned area is also necessary in order to appraise management actions, guide future endeavours (e.g. van Wilgen *et al.* 2010), and may also be required for legal purposes.

Field mapping of fires is very time consuming and costly, and for large fires, or fires in remote and inaccessible areas, it is difficult to accurately map the full extent of the burned area. The question arises as to whether currently available, automatically generated, burned area products based on data from remote sensing can assist in accurately mapping burned areas. Currently, burned area products are primarily used at regional to global scale for exercises such as fire emission modelling (Roy & Boschetti 2009). They are also occasionally used for local scale ecological and resource management applications (Roy & Boschetti 2009). Local studies of how accurate these products are an important step in evaluating the usefulness of these products at the regional and global scales at which they are more frequently used. Published evaluations show that satellite-derived burned area products are useful for many parts of the world, including Eastern Russia (Sukhinin *et al.* 2004); Siberia (Giglio *et al.* 2009); North America and the western United States (Li *et al.* 2003; Giglio *et al.* 2009); Mediterranean regions (Diaz-Delgado and Pons 2001; Chuvieco *et al.* 2005) and southern Africa (Trigg and Flasse 2001; Roy *et al*. 2005*a*, 2005*b*; Giglio *et al.* 2009; Roy and Boschetti 2009). However, the ability of satellite-derived burned area products to detect of fire events and the accuracy with which they can map the fire, can vary quite widely depending on local conditions and vegetation, before, during and after a fire event (e.g. de Klerk 2008; Roy and Boschetti 2009) and evaluating the products for specific areas is important before accepting the model output for a specific region (e.g. Roy and Landmann 2005).

As in many mediterranean ecosystems, fire in the dwarf mediterranean shrubland typical of the fynbos (Rebelo *et al.* 2006) is a vital ecological process and important for conservation management (Cowling 1987; Richardson *et al.* 1994; Bond and Keeley 2005). The fynbos biome, which occurs in the mainly winter rainfall region of the south-western tip of South Africa (Rebelo *et al.* 2006), is not only highly fire-prone, but is fire adapted and needs periodic fire to reproduce (e.g. Keeley and Bond 1997; Rebelo *et al.* 2006). The fynbos biome covers a geographically small area, but is of great conservation importance due to its high levels of species richness and endemism (these aspects are thoroughly discussed in Rebelo *et al.* 2006). Wilson *et al.* (2010) and van Wilgen *et al.* (2010) suggest that the south-western Cape is vulnerable to changes in the fire regime driven by human activity and climate change.

Fynbos is structurally and spectrally different from grassland and miombo (Wessels *et al.* 2010) where most testing of satellite burned area algorithms has been conducted (e.g. Trigg and Flasse 2001; Roy *et al.* 2005*a*, *b*; Giglio *et al.* 2009). In addition, the fynbos biome includes areas of topographically complex landscapes where shadowing may impact the accuracy of the reflectance values reaching the satellite (de Klerk 2008). Glint from extensive coastlines and light soils can also lead to spurious reflectance measurements (de Klerk 2008). The Western Cape Nature Conservation Board (CapeNature) manages formally protected areas of the Western Cape of South Africa, many of which fall within the fynbos biome. Good datasets of fire boundaries mapped by operational fire agencies in the field, which we refer to as manager-mapped fire boundaries, are available for these protected areas (see full description in the 'materials and methods' section) (de Klerk 2008; van Wilgen and Forsyth 2008). This enables us to test the Meraka Institute's new MODIS burned area product, based on the Giglio *et al.* (2009) algorithm released late in 2009, as well as the MCD45A1 burned area product, based on the Roy *et al.* (2005*a*) algorithm which data is available on the MODIS website.

In this study, we compare the two MODIS-derived products in the formally protected areas within the fynbos and succulent karoo biomes (Mucina and Rutherford 2006) with carefully mapped fire boundaries produced by reserve managers (see de Klerk 2008 for details of the database). General validation methods (after Giglio *et al.* 2009; Roy and Boschetti 2009) are used, including (1) an inventory accuracy assessment of the number and size of individual burn scars mapped by the reference and classified data sets and (2) a subset of standard confusion matrix parameters, which provides a per-pixel evaluation of the spatial fidelity of a classification's accuracy.

The additional question of whether these products can be used as a 'reliable' surrogate for mapping burned areas outside of formally protected areas, where currently there are no analogue fire history records available, is also an important one with landscape conservation initiatives on private land on the increase in the Western Cape (CapeNature 2009).

Materials and methods

Study area and Protected Area data

CapeNature (http://www.capenature.co.za/) manages formally protected areas of the Western Cape of South Africa, namely Provincial Nature Reserves (International Union for the Conservation of Nature and Natural Resources, IUCN, category II), State Forests (also IUCN category II), Wilderness Areas (IUCN category I) and privately owned Mountain Catchment Areas; the latter are jointly managed by CapeNature and private landowners (see Fig. 1). These areas are collectively referred to as 'protected areas'.

Burned area – reference data from reserve managers

Fire boundaries are mapped by CapeNature reserve managers for all fires on all land managed by CapeNature, as described above (Erasmus 2006). Managers and field staff map fire boundaries during fire operations, as well as during post-fire debriefing. They use a combination of analogue mapping onto paper maps; 'heads-up digitizing', that is digitising geographic features directly onto computers using digital topographical maps, satellite images (LANDSAT and SPOT) and aerial photos; as well as walking or flying the fire boundary with a GPS. Information from these various sources are used by the managers to produce a final vector file (ESRI shapefile format). Islands of unburned vegetation within the outer boundary of the fire are digitised as such. All fire reports and associated polygon data are lodged in a central fire database housed at CapeNature's Scientific Services. These data are referred to as manager-mapped boundaries. Updates of this fire data are provided annually for public use on the Biodiversity GIS website (http:\\bgis.sanbi.org\). Manager-mapped burned area boundaries were extracted for the time period of 1 September 2007 to 30 April 2009, in order to cover two fire seasons in the fynbos biome. Data were available for all datasets considered for this time period at the beginning of this study. Two fire seasons allowed careful checking of results for inconsistencies and errors, which may have been more difficult to identify for an analysis of many years. Broadly speaking, the fire season in the fynbos runs from September in one calendar year to April in the next calendar year (Wilson *et al.* 2010).

In order to investigate the influence of the difference in spatial resolution between the manager-mapped fire boundaries and the MODIS-derived burned area products, the manager-mapped fire boundaries needed to be 'degraded' to the same scale as the burned area rasters. The manager-mapped fire boundaries were overlaid on the 'WAMIS grid' (see below). Where the manager-mapped fire boundaries covered at least 50% of a pixel, the pixel was identified as a 'manager-mapped burned pixel'. The latter grid was vectorised for the purposes of overlay analyses, and is referred to as 'manager-mapped gridded boundaries'. We analyzed the difference between the original (ungridded) and gridded manager data and we found almost no difference in the metrics (see 'evaluation of performance' section for details on these metrics) (analysis not shown). Consequently only the results for the original (ungridded) manager-mapped boundaries are displayed.

Burned area – WAMIS \ Giglio algorithm data sets

The Meraka Institute in South Africa (http://www.meraka.org.za/), released a new MODIS-derived burned area product, based on the Giglio *et al.* (2009) algorithm, late in 2009. For brevity, this product is henceforth referred to as the 'WAMIS' burned area product. The following description is summarized from Giglio *et al.* (2009). The algorithm uses actual vegetation change by compiling a vegetation index. It then looks for a large, rapid decrease in the vegetation index relative to the variability of this vegetation index over the same time series of images. Information on persistent changes in this burn-sensitive vegetation index are combined with active fire maps, through the use of many screening processes, regional cluster growing, probability density functions and a temporal texture measure. The inclusion of active fire maps, and the use of probability density functions based on these active fire maps, allows this hybrid algorithm to function more robustly over a wide range of biomes, and identify both burned and unburned pixels with greater accuracy for training the algorithm. The regional growing phase allows good performance in large burned areas. The WAMIS burned area tiff images were downloaded from the South African Council for Scientific and Industrial Research (CSIR, http://www.csir.co.za), Meraka Institute's Wide Area Monitoring Information System (WAMIS) website (http://www.wamis.co.za) for the time period of 1 September 2007 to 30 April 2009.

*Burned area – **MCD45A1** \ Roy algorithm data sets*

The MODIS/Terra+Aqua Burned Area Monthly L3 Global 500 m SIN Grid V005 (or MCD45A1) product hdf images were downloaded for the same dates from http://wist.echo.nasa.gov. MCD45A1 is a monthly Level-3 gridded 500 m product that maps the approximate day of burning for, and extent of, recent fires (MODIS Collection 5 Burned Area Product; Boschetti *et al.* 2009; http://modis-fire.umd.edu/BA_methodology.html). It is based on the premise that burned areas are characterized by deposits of charcoal and ash, removal of vegetation, and alteration of the vegetation structure (Roy *et al.* 1999). Multi-temporal land surface reflectance data is used to locate rapid changes in the daily surface reflectance dynamics through the use of a bidirectional reflectance distribution function (BRDF) model (Roy *et al.* 2005*a*). The algorithm is applied independently to geolocated 500 m pixels (Boschetti *et al.* 2009). A statistical measure of the difference between the observed BRDF values and the predicted BRDF values, per pixel, at the viewing and illuminating angles of the observation, is used to quantify change from a previously observed state (Roy *et al.* 2002, 2005*a*; Boschetti *et al.* 2009). Large discrepancies between predicted and measured values are attributed to change (Roy *et al.* 2005*a*). A temporal constraint is used to differentiate between temporary changes, such as shadows, that are spectrally similar, from more persistent fire induced changes (Roy *et al.* 2005*a*).

All data were reprojected to UTM 34 S (Central Meridian = 21; Reference Latitude = 0; Scale Factor = 0.9996; False Easting = 500 000; False Northing = 10 000 000) and WGS84 (Hartebees94) datum, resampled to a grid cell size of 463.31 m, using one of the WAMIS images as a ‘master grid’ to ensure exact co-registration among all datasets. All area calculations were performed in UTM 34 S, as this provides good aerial and distance accuracy across the study area of the Western Cape. All grid cells falling outside of formally protected areas in the Western Cape Province were ignored for these analyses, as manager-mapped burned area data is only available inside protected areas.

Evaluation of ‘performance’

We are interested in the ability of the satellite products to accurately (1) identify burned areas and measure their size, and (2) map their boundaries. Our evaluation consists of: an ‘inventory’ analysis that identifies whether a particular fire event is mapped by all databases and compares the sizes of individual fires with a least squares regression, as well as a confusion matrix that assesses geographic accuracy.

The inventory accuracy assessment is produced by comparing the proportion of burn scars in the manager-mapped that were identified by the classified data sets (termed ‘detection ability’ and calculated as the number of burn scars in the classified data sets divided by the number in the manager-mapped data), and by comparing the sizes of individual burned areas in manager-mapped and classified data sets using the coefficient of determination (R^2) (e.g. Giglio *et al.* 2009; Roy and Boschetti 2009). The size comparisons are calculated first for all fires that occur in either or both data sets (termed 'all fire events'), and then for only those fires that occur in both data sets (termed 'shared fire events').

A confusion matrix provides a geographic accuracy assessment by evaluating the spatial fidelity of mapping on a per-pixel basis (e.g. Giglio *et al.* 2009; Roy and Boschetti 2009). The confusion matrix is a standard technique for comparing a classified image against a set of reference data (e.g. Campbell 1996). Although compilation of the error matrix is generally straightforward, preparation of the maps for comparison may be very difficult (Campbell 1996). There are many measures that can be derived from a confusion matrix, and it is suggested that a suite of measures be used to examine different aspects of the performance of a classification technique (e.g. Manel *et al.* 2001). We calculate the following parameters (definitions loosely from Campbell 1996), namely (i) percentage errors of omission (false negatives), which indicates how much the classification misses; (ii) percentage errors of commission (false positives), which indicates where the classification overmaps, or identifies fires not mapped by managers; (iii) producer's accuracy, which is the proportion of reference area in a class correctly classified in the output image, and (iv) consumer's accuracy, which is the proportion of the classification area in a class correctly classified in the output image. The consumer's accuracy shows reliability of the map as a predictive device and gives the probability that the pixels have been correctly assigned in the output classified map. Specificity indicates how accurately negative values are predicted (Fielding and Bell 1997; Manel *et al.* 2001). The confusion matrices are calculated for 'all fire events'.

The aim of the study is to compare burned area data from publicly available, standardised satellite products with manager-mapped burned areas. As managers only map fires within protected areas in our region, the study area is necessarily all protected areas (265 330 ha). Consequently, the area that has *not* been burned in an evaluation period is always likely to be considerably larger than the area that has been burned during that same period, purely due to the logical definition of the area of interest. For example, in 2008, 11 264 ha burned inside these protected areas, which is only 4% of the protected areas, leaving the vast majority of the study area 'unburned'. This creates a large, unburned class that is much easier to identify than burned areas, which are the main subject of the classification. This is akin to the situation where a map contains a large proportion of open water, a class that is easy to classify, which results in a high 'percentage correct' value regardless of the performance of the classification in other class(es) (Campbell 1996). In addition, the existence of a large unburned class creates vastly uneven sample sizes, which may impact various measures, such as the Kappa statistic (Fielding and Bell 1997). Furthermore, the absence of detected fires at a particular location does not guarantee that the location did not burn (Giglio *et al.* 2009). In this study, the manager-mapped burned area boundaries have high accuracy due to the manual effort using the variety of methods described above and because the accuracy of the boundaries have legal implications for CapeNature. However, we cannot place a 100% accuracy on these boundaries. These factors must be born in mind when interpreting measures that use 'true negatives' (putatively correctly identified unburned areas) as they could potentially falsely inflate confidence in results.

All analyses were performed in ArcGIS 9.3 and MS Excel 2007. Data are analysed per year to provide more detailed insights of errors of omission and commission.

Results

WAMIS

The correlation between the sizes of burned areas mapped by managers and the WAMIS product appears to be quite good ($R^2 = 0.84$ to 0.87, Fig. 2, although for the $\log_{10}$-transformed data R^2 values are very low value when 'all fire events' are analysed). A number of fire events that are mapped by the managers, are not mapped by WAMIS (see the low values of 33.3 to 43.1% for detection ability, Table 1). Note that while a number of points lie on the 1:1 perfect agreement line, there are a few notable exceptions.

The results of the confusion matrix (producer's accuracy, consumer's accuracy, errors of commission and omission) vary considerably between years. In general errors of omission, that is fires mapped by managers which are missed, or under-mapped, by the WAMIS product, are low (12.2 to 24%, Table 1) in 2007 and 2009, due to good spatial match between WAMIS and manager-mapped boundaries for large fires in the Jonkershoek-Hottentots Holland area in February 2009 (Fig. 3a) and the Cederberg fire in February 2009 (Fig. 3b). However, values are higher in 2008 due to under-mapping of certain fires, e.g. the southern Cederberg in February 2008 (Fig. 3c), as well as the WAMIS product missing a number of small to medium fires that have complex boundaries and occur in topographically complex areas, such as Grootvadersbosch (1705 ha), Riviersonderend (1695 ha; Fig. 3d), and Limietberg (516 ha).

Errors of commission, that is fires that were identified by the WAMIS product, but which were not mapped by the managers, or where burned areas are either under-mapped by the managers or over-mapped by the WAMIS product, are generally low (14.6 to 23.4%, Table 1). An exception is 2009 (31.9 to 32.8%, Table 1), during which time managers possibly under-mapped a fire in the GrootWinterhoek by a large amount (Fig. 3e).

Low omission and commission, and good spatial match, as described above, lead to overall good values for both producer and consumer accuracy (which vary from 56.2 to 87.6%, Table 1).

MCD45A1

The MCD45A1 product maps burned areas very conservatively. For example, in 2007, managers mapped an area of 7119 ha, whereas MCD45A1 only mapped an area of 2962 ha giving somewhat large errors of omission (40.1 to 80.8%; Table 1). This results from MCD45A1 undermapping a number of fire events (e.g. the Cederberg February 2009 fire Fig. 3b), as well as missing a few fire events, (see the data points lying on the x-axis indicating manager-mapped fires that MCD45A1 did not identify, Fig. 4b; as well as the low percentages of detection ability, Table 1). The reverse scenario is seen in one instance where managers under-mapped a fire in 2009 in the GrootWinterhoek, which

WAMIS also identified as being considerably larger than the area mapped by the managers (Fig. 3e). The MCD45A1 product seldom identifies a burned area that did in fact not burn, leading to very low errors of commission of 8.1 to 19.1% (Table 1) and high consumer's accuracy of 80.9 to 91.9% (Table 1). There are no areas identified as burned areas by MCD45A1 that are not also mapped by the managers, and this may be responsible for the fairly strong regression values (R^2 0.76 to 0.80), even though few data points are on the 1:1 line representing perfect agreement between the test and validation data sets.

Discussion

The high levels of omission seen in MCD45A1 as compared to WAMIS (cf 40.1-80.8%, vs 12.4 - 43.8%, Table 1; see fewer points along the x-axis in Figs 2 and 4) can be expected due to the approach of the MCD45A1 product (e.g. Roy and Boschetti 2009). MCD45A1 aims to map burned areas conservatively, in that it specifically aims to reduce errors of commission by "only selecting fire-affected pixels where there are burn candidates that provide persistent evidence of fire occurrence" (Roy *et al.* 2005*a*). They observed that this will necessarily lead to larger errors of omission and that fires may be missed or under-mapped, when small, particularly at the start of a fire and at the edges of large fires. The latter issue is due to strict implementation of the temporal consistency constraint (Roy *et al.* 2005*a*). The algorithm does try to adjust for this by using strong fire-affected candidate pixels as seed pixels from which neighbouring pixels can obtain an increased burn-probability (Roy *et al.* 2005*a*). In addition, they do suggest that a relaxation of the temporal consistency constraint could be applied to reduce 'false rejections' of burned pixels, but perhaps the temporal consistency constraint is still a bit over zealous, as many MCD45A1 fires miss both initial days of the fire as well as boundary pixels (e.g. Fig. 3a). Perhaps the adaptation of the temporal thresholds for regional application, as they suggest can be done in specific cases (Roy *et al.* 2005*a*), may improve on the error of omission rate, and hence the producer's accuracy. The algorithm will battle with low combustion completeness (i.e. when a cool fire doesn't burn all plant material in the burned area) or when a fire is smaller than a

MODIS 500 m pixel and at land-water interfaces (Roy *et al.* 2005*a*). Moreover, the algorithm appears to be very reliant on the post-fire presence of black ash, and the authors comment that this may pose a problem when “more reflective underlying surfaces (in MODIS bands 2, 5, and 6) are exposed by the action of fire” (Roy *et al.* 2005*a*). Such an instance will arise when the fire occurs on highly reflective soil (de Klerk 2008). Similarly, this may occur when hot fires produce highly reflective white ash (Roy and Landmann 2005). If wind and rain dissipate the ash/charcoal rapidly after the fire, the post-fire reflectance values may be higher than the algorithm anticipates (Roy *et al.* 2005*b*). The Roy algorithm is more likely to detect fires on surfaces that have a high pre-fire reflectance, than on less reflective surfaces, because the algorithm looks for a large change in reflectance from pre-burn state (mainly of dry grass) to black ash (Roy and Landmann 2005). This might be why the MCD45A1 algorithm does a poorer job in the Cederberg, where the pre-fire reflectance of dense, mature fynbos will differ from that of the dry senescent grasslands (Wessels *et al.* 2010) where much of the testing of the Roy algorithm was conducted (Roy and Landmann 2005).

WAMIS detects more small fires than MCD45A1 does, leading to lower levels of omission. The minimum detectable burned area for this product will be in the order of 13 to 120 ha (Giglio *et al.* 2009). The success of the WAMIS product over the MCD45A1 product in picking up smaller fires may be due to the integration of active fire map data into the WAMIS product (Giglio *et al.* 2006). This integration of the different types of fire information available from the MOIDS sensor is achieved through the use of the active fire maps to generate regional probability density functions and to specify prior probabilities, which both assist in the selection of burned and unburned training pixels (Giglio *et al.* 2009). The fact that active fire data can pick up fires up to 1000 times smaller than the minimum detectable size of a burned area (Giglio *et al.* 2006) allows the WAMIS product to be more sensitive to smaller fires than the MCD45A1 product. In contrast, the MCD45A1 product uses a reflectance-only approach (Roy *et al.* 2005*a*) that does not exploit active fire information (Giglio *et al.* 2009). The exploitation of active fire maps in the ‘WAMIS/Giglio’ algorithm may well give it more robustness over a wide range of biomes, as speculated by Giglio *et al.* (2009), as the WAMIS product fairs better than the MCD45A1 product in the fynbos, which has different pre- and post-burn conditions to the savanna where most of the testing of the fire products in southern Africa has taken place (Roy and Landmann 2005; Roy *et al.* 2005*b*). In additional, the regional stratification of the probability density functions in the WAMIS product will help to account for the influence of various vegetation structure and fire types on the post-fire reflectance characteristics (Giglio *et al.* 2009). The fact that the WAMIS product testing included a similar vegetation type, the Californian chaparral (Giglio *et al.* 2009), also probably improved WAMIS performance in the fynbos.

The difference between these two burned area products is particularly evident when considering the burned areas of large fires (e.g. Fig. 3b). Giglio *et al.* (2009) would probably attribute the success of the WAMIS product in mapping larger burned areas to “the inclusion of a region growing phase, which also permits the algorithm to function in the presence of extremely large burned areas”, as well as the accurate identification of both burned and unburned pixels through the incorporation of active fire pixels and through the use of both spectral and textural information.

Both products battle to map fire events, or to map their extent accurately, in topographical complex areas, as is seen where WAMIS under-mapping certain fires, such as in the southern Cederberg in February 2008. Both products miss a number of small to medium fires that have complex boundaries and occur in topographically complex areas, such as Grootvadersbosch (274 ha, Fig. 3d), Riviersonderend (1695 ha), and Limietberg (516 ha).

Conclusions

We have compared two MODIS-derived burned area products with reliable field-mapped reports for the protected areas in the fynbos biome of South Africa. In summary, the two burned area products have different strengths and may both be useful for specific applications. The MCD45A1 has low errors of commission and high consumer's accuracy, but relatively common errors of omission (40-80.8%). Alternatively, the WAMIS product has lower errors of omission and greater producer's accuracy. These results suggest that the use of the adaptable thresholds by WAMIS leads to increased sensitivity in identifying burned areas in the fynbos than the use of the static thresholds applied in the compilation of the MCD45A1 product. In addition, the inclusion of a vegetation index in the WAMIS product may also yield improved sensitivity in the fynbos. For users that wish to avoid false positives at the expense of missing many burned pixels, the MCD45A1 will be more useful. However, the less common omission errors and improved producer's accuracy of the WAMIS product are likely to make it a more useful data source to supplement and check the field mapping of burned areas.

While WAMIS shows much promise, we cannot recommend that it replace the gathering of manager-mapped fire boundaries within the fynbos protected areas. However, WAMIS may be useful in the following contexts: i) to highlight medium and large fires missed by managers (due to gaps in current institutional arrangements, or fires that rained out deep in wilderness areas before manager became aware of them), ii) to query fire boundaries that managers may have mapped too conservatively, and iii) to provide a useful *indication* of fire occurrence and extent (burned area) outside of protected areas. For some studies, such as regional-scale analysis of the fire risk, the satellite-derived products are a useful source of data that transcend problems of limited surveying outside formally protected areas or gaps in the record due to institutional changes. However, one must be cautious to use the satellite-derived products to make inferences about the boundaries, or size, of any particular fire (such as for legal purposes). Over the longer term it would be useful to fine-tune the algorithms to address the small amount of ‘under’ mapping and the few medium-sized fires missed by the current WAMIS burned area product.

The application of these burned area detection methods is likely to share the same challenges in mediterranean shrublands around the world. Shrublands tend to occur on nutrient poor soils and differ structurally from savanna, woodlands and forests (where most evaluations have been conducted). Both factors are expected to influence the performance of the algorithms in similar ways across various mediterranean ecosystems. Evaluating burned area products across a range of ecosystems around the world is useful to build confidence in their use in regions and time periods without good evaluation data.

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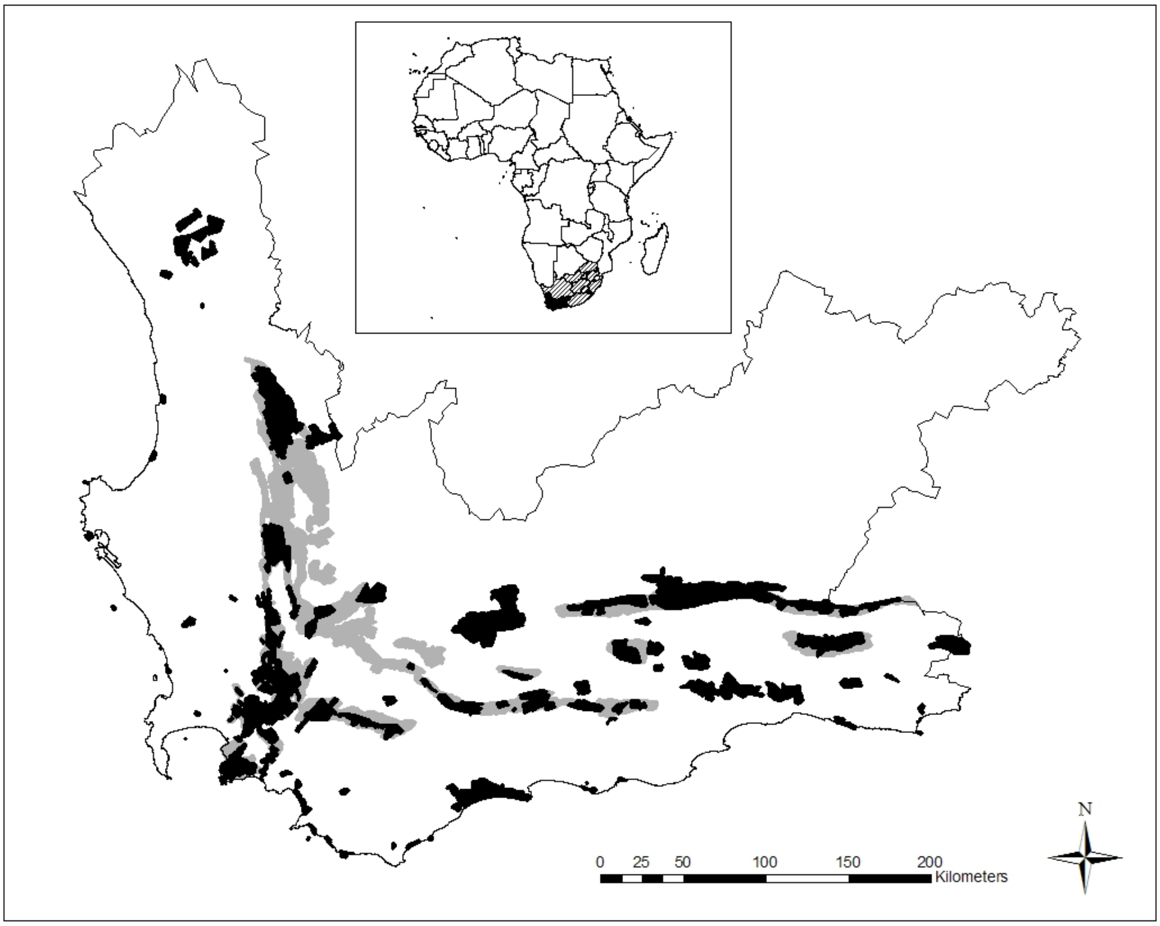


Fig. 1. Land managed for conservation purposes by CapeNature, which includes statutory Provincial Nature Reserves (International Union for the Conservation of Nature and Natural Resources, IUCN, category II), State Forests (also IUCN category II), and Wilderness Areas (IUCN category I) (solid black), and as well as privately owned, proclaimed Mountain Catchment Areas (solid grey). The insert shows the location of the Western Cape Province (solid black) in South Africa (hashing). Data for this figure are in UTM 34 S (Central Meridian = 21; Reference Latitude = 0; Scale Factor = 0.9996; False Easting = 500 000; False Northing = 10 000 000) and WGS84 (Hartebees94) datum.

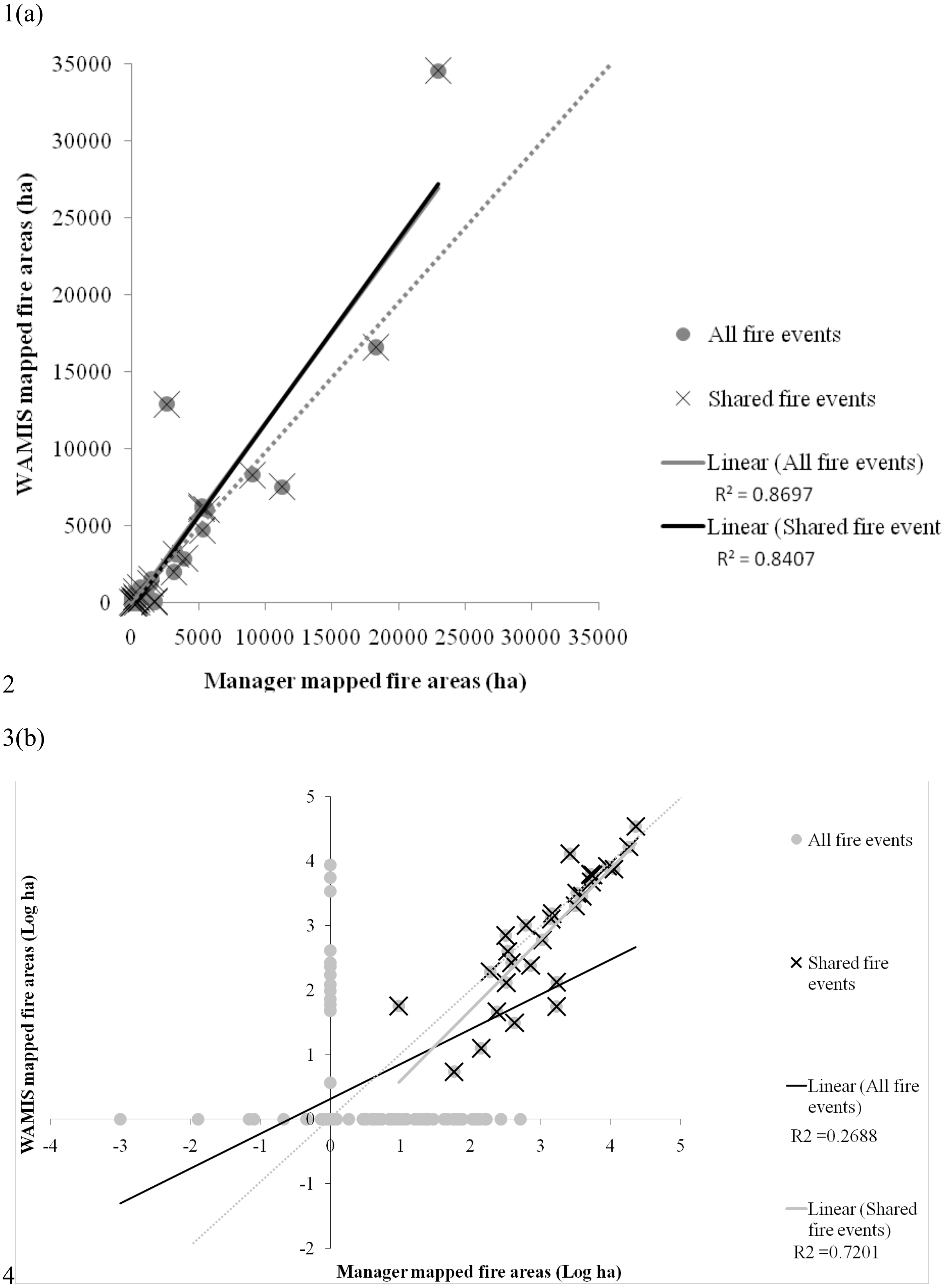
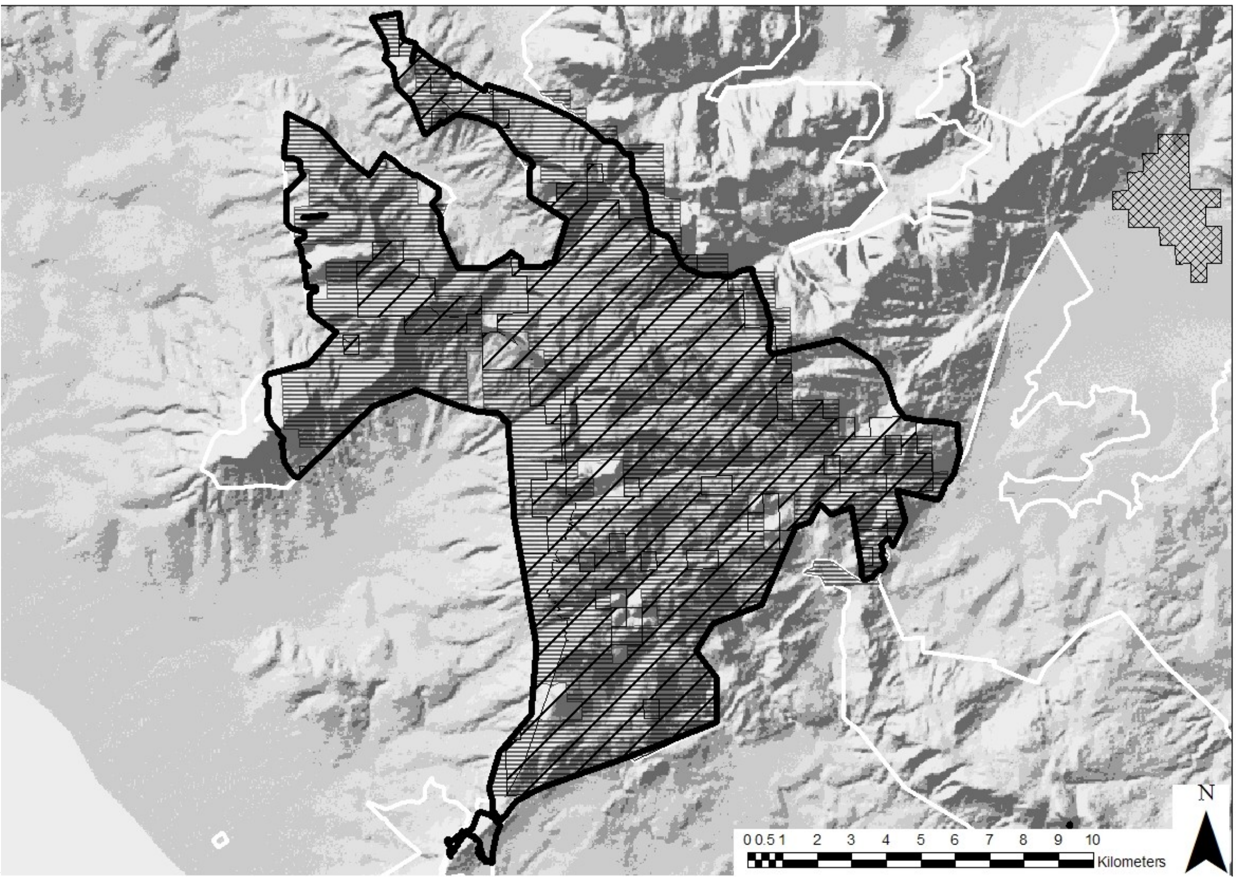


Fig. 2. Regression of the area (Log ha) of individual fire events, mapped as burned areas by reserve managers (reference data set) and the WAMIS product with (a) linear and (b) $\log_{10}$ transformed axis. The least squares regressions are presented as solid lines. The dashed 1:1 line indicates perfect agreement.

(a)



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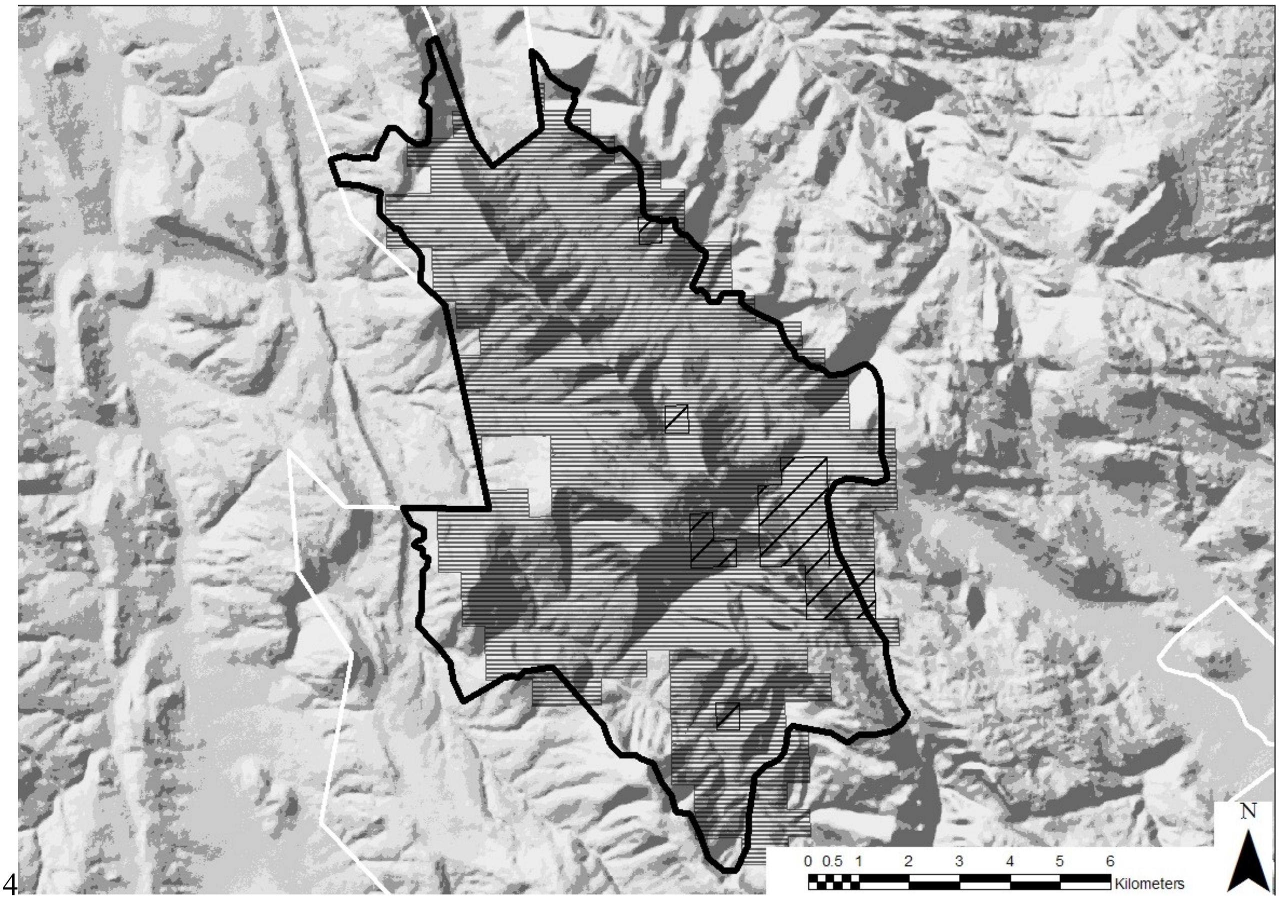

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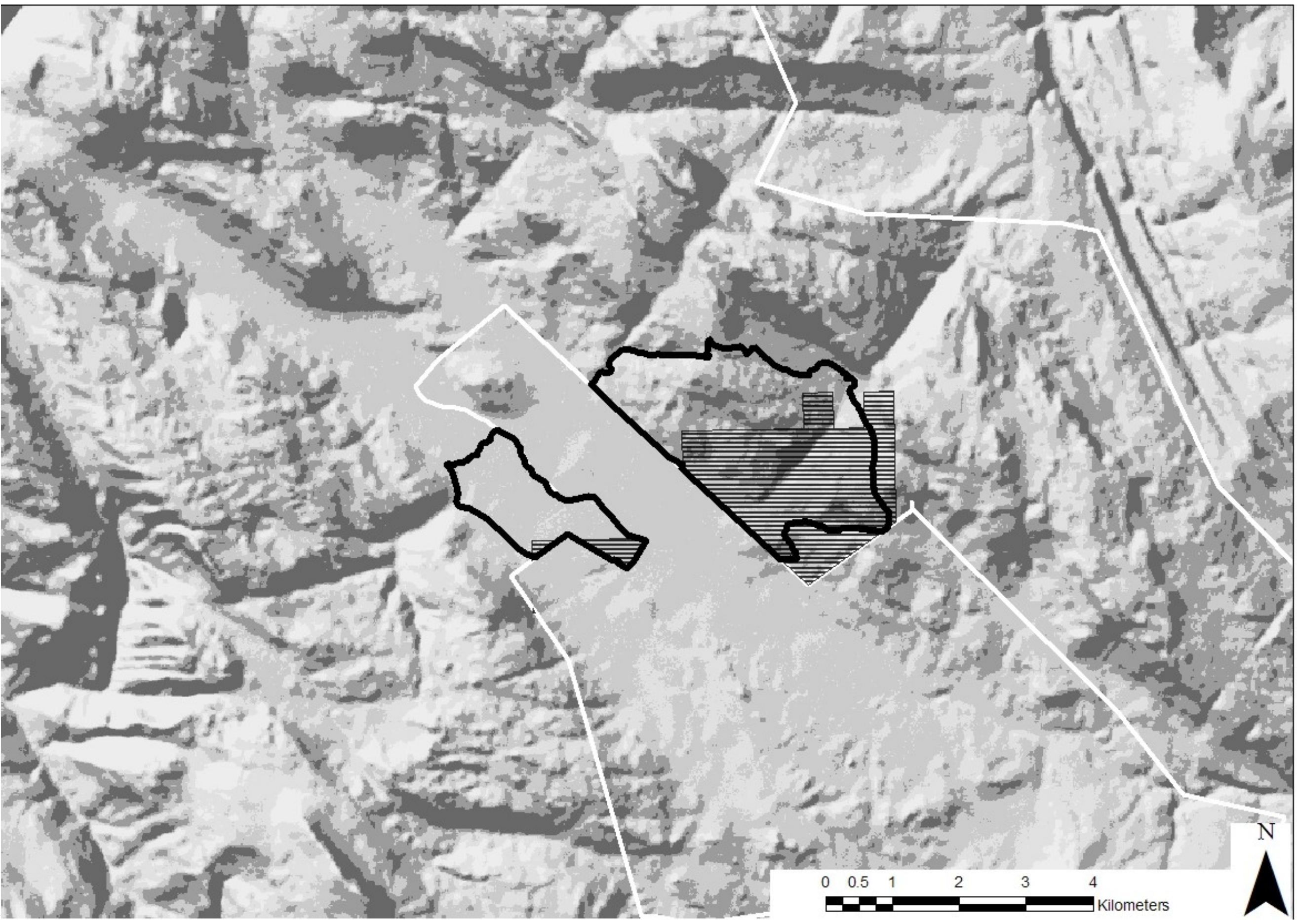
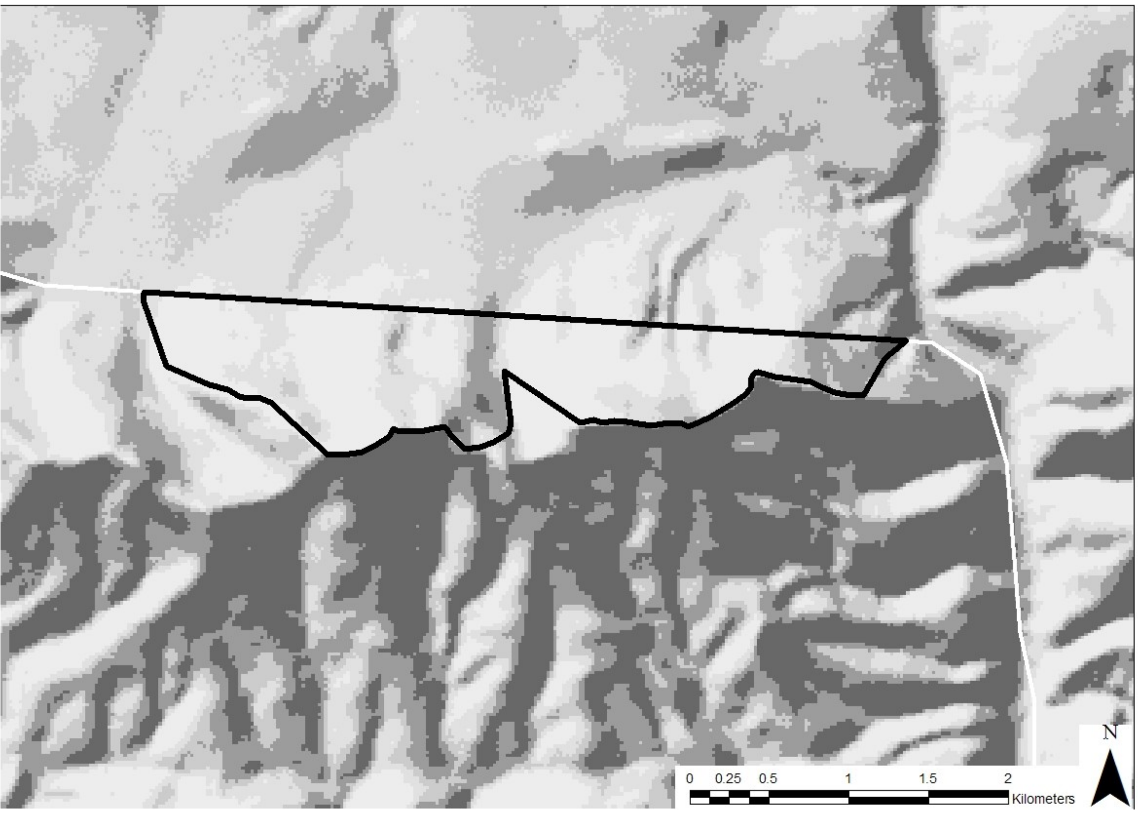


(d)



(e)

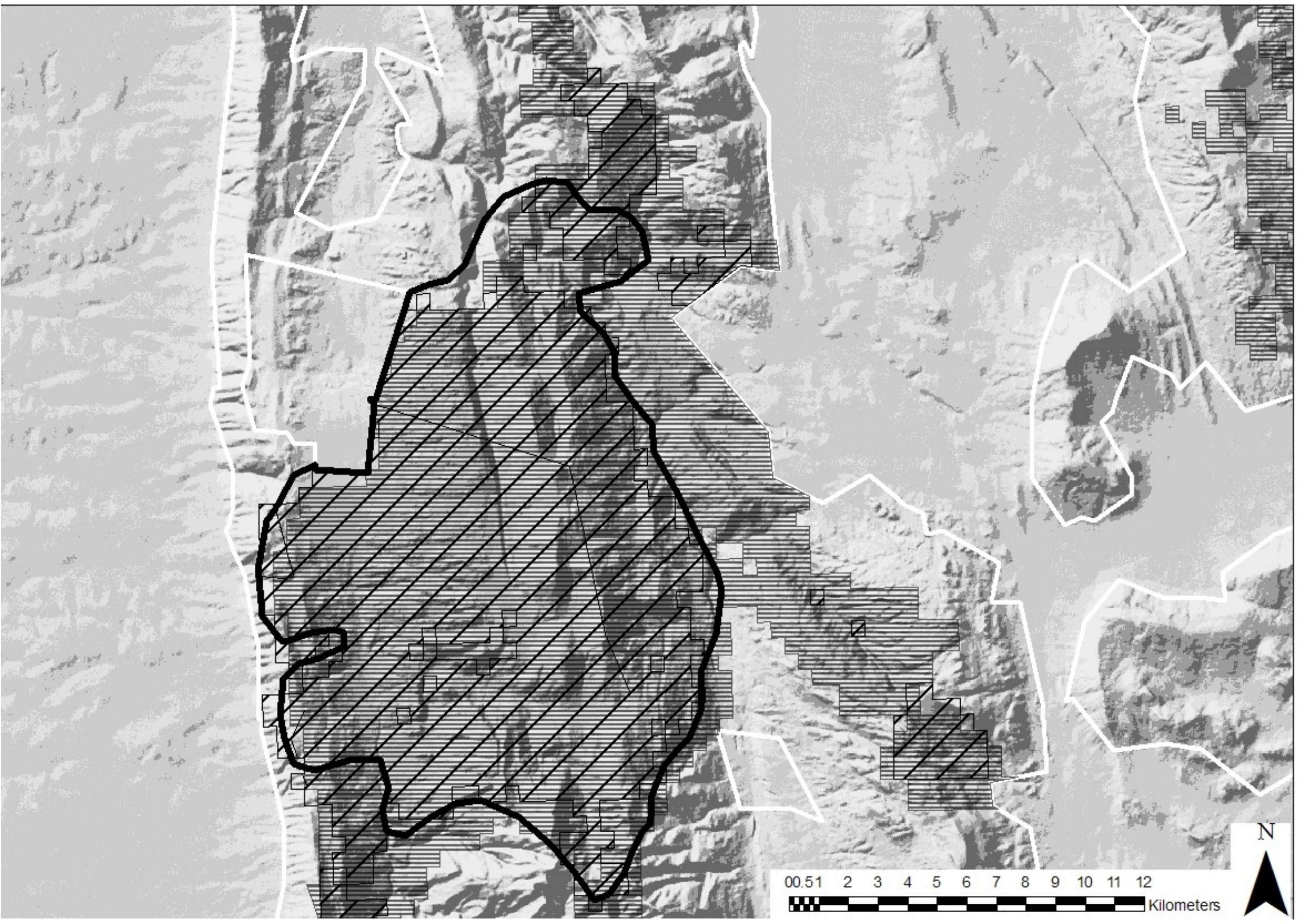
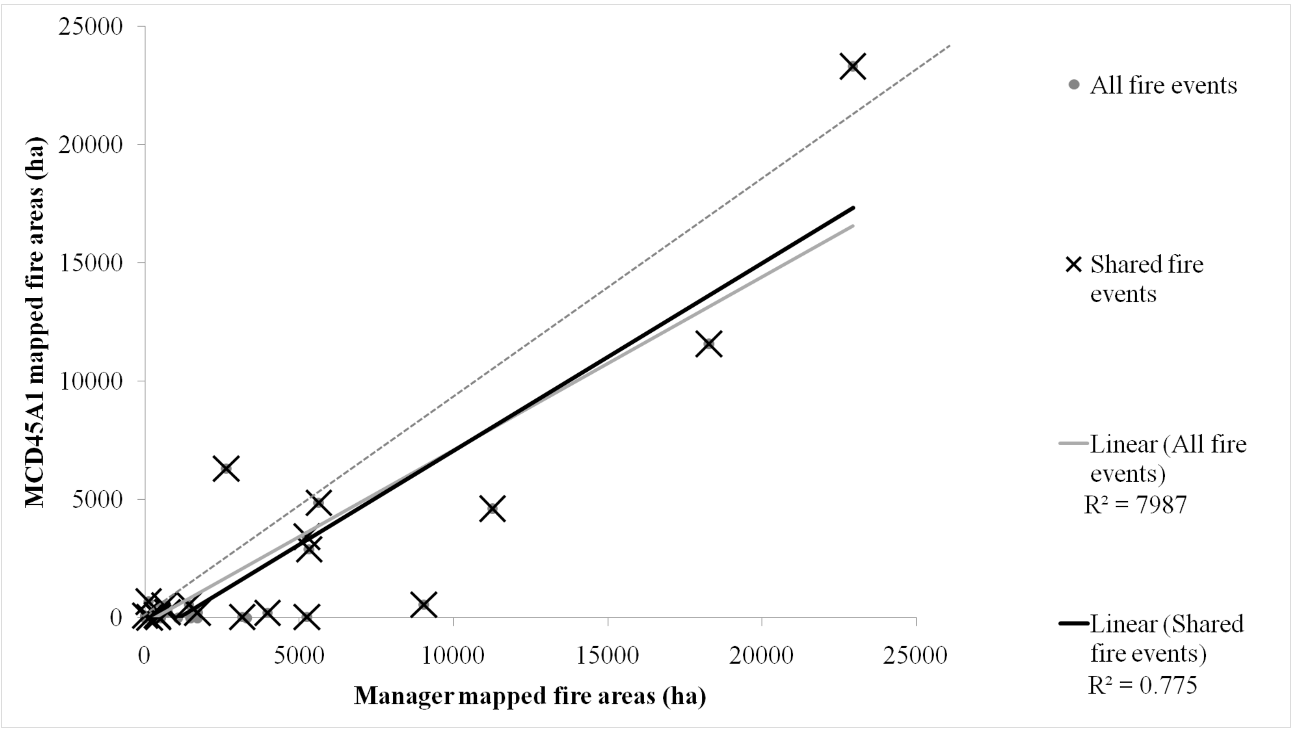


Fig. 3. Differences between burned areas mapped by the managers (black line) and the WAMIS product (horizontal hashing) and the MCD45A1product (diagonal hashing); where WAMIS maps a very similar fire extent to the managers in Jonkershoek (a) and Cederberg (b) fires in February of 2009; where WAMIS undermaps the fire extent mapped by managers in the southern Cederberg fire in February 2008 (c); or where WAMIS misses small fires mapped by managers, such as the 274 ha that burned in GrootVadersbosch in October 2008 (d). A case where both satellite burned area products (WAMIS and MCD45A1) show a larger area than mapped by the managers is seen in the GrootWinterhoek fire of February 2009 (e). Protected Area boundaries are in white.

(a)



(b)

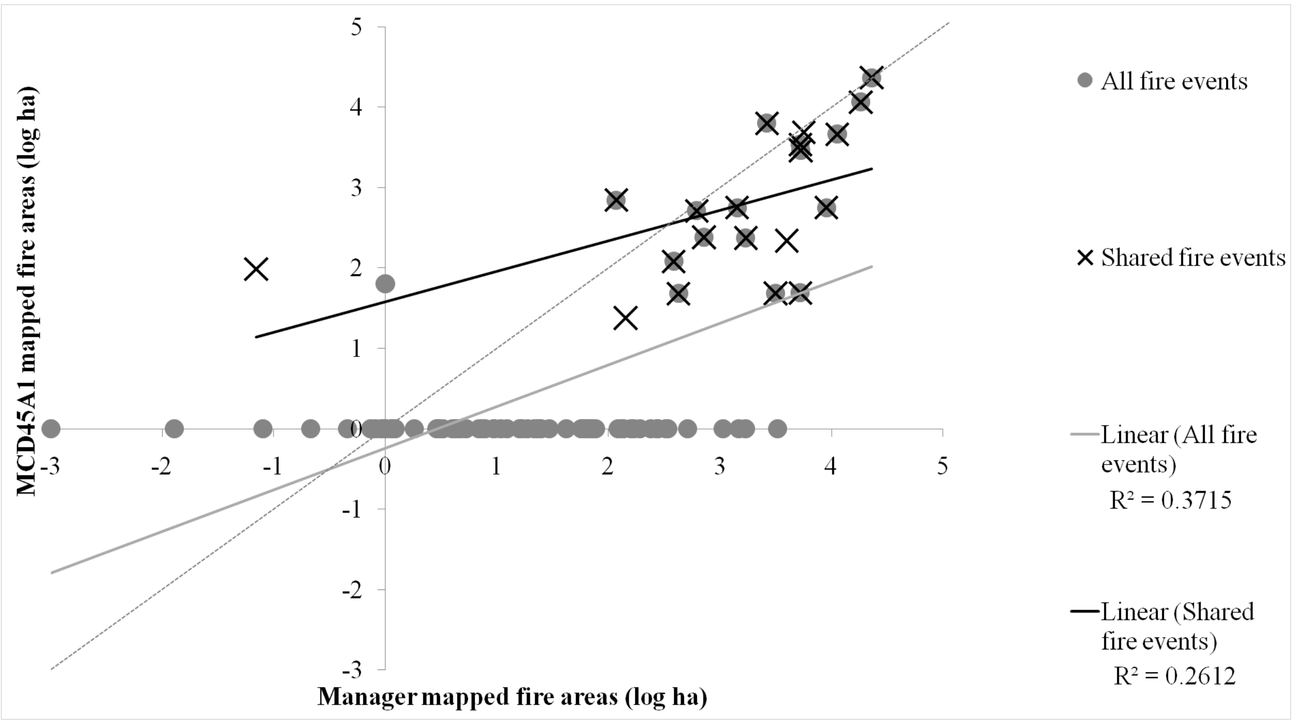


Fig. 4. Regression of the area (in ha) of individual fire events, mapped as burned areas by reserve managers (reference data set) and the MCD45A1 product with (a) linear and (b) $\log_{10}$ transformed axis. The least squares regression is presented as a solid line. The dashed 1:1 line indicates perfect agreement.

Data set	Year	True positive (ha)	False negative (ha)	False positive (ha)	True negative (ha)	% Error omission	% Error commission	Producers accuracy (%)	Consumers accuracy (%)	Specificity (%)	Detection ability (%)
WAMIS	2007	5 411	1 708	952	257 259	24	15	76	85	99.6	33.3
WAMIS	2008	19 095	14 876	5 361	225 998	43.8	21.9	56.2	78.1	97.7	43.1
WAMIS	2009	60 222	8 547	28 342	168 219	12.4	32	87.6	68	85.6	41.7
MCD45A1	2007	2 723	4 397	240	257 971	61.8	8.1	38.2	91.9	99.9	22.2
MCD45A1	2008	6 520	27 451	620	230 739	80.8	8.7	19.2	91.3	99.7	19.6
MCD45A1	2009	41 384	27 671	9 794	186 481	40.1	19.1	59.9	80.9	95	25.7

Table 1: Confusion matrix for the comparison of burned area (rounded to the nearest hectare) mapped by managers (reference data) and the WAMIS burned area product. False negative indicates the area that was mapped as burned by reserve managers but not detected by WAMIS or MCD45A1, false positive indicates the area that was not mapped by managers but was classified as burned by WAMIS or MCD45A1. Note that the high specificity values are driven by the extremely large unburned area (true negatives).