ERRORS IN ESTIMATES OF RATES OF CLEARING WITH NUMERICAL ANALYSIS OF SATELLITE IMAGERY

Brian Tunstall

Abstract

The basic characteristics of aerial photography and satellite imagery important for addressing native vegetation are identified. Results from an assessment of land clearing across NSW are used to identify the source and likely magnitude of errors associated with the use of satellite imagery. Results from this study are compared with those produced by the Australian Greenhouse Office for use in carbon accounting. The differences in results are related to the analytical methods.

Introduction

Land resource inventory in the first part of the twentieth century by way natural resources and infrastructure mapping developed using aerial photography. The desire for risk free military surveillance during the 1960s saw the transition from airborne to space platforms and an associated change from photographic film to digital data. The digital data could be readily transmitted back to earth and negated the need for manned missions.

Some of the developments associated with the satellite imagery have seamlessly meshed with past work, as with climate analysis and monitoring. However, acceptance of the new technology for land resource inventory has been patchy. The technology has been highly developed for mineral exploration and has effectively replaced film with airborne as well as satellite platforms. Also, it is now being used nationally for topographic map production in preference to aerial photography. However, there has been strong resistance to applications on native vegetation. Its use often depends on transforming the satellite imagery such that it appears the same as aerial photography.

Aerial photography differs significantly from satellite imagery due to the characteristics of film and the instability of the platform. Moreover, digital technology allows the development of information that can never be obtained using photographic film. Benefits of satellite imagery are being lost because of the need to transform the imagery such that it relates the perceptions and experience of users.

The issue relates to matching the technology to the requirements but for native vegetation the user requirements are ill-defined. Native vegetation can usually be readily recognised and distinct forms often identified, as with rainforest and mangroves. However, within an assemblage such as sclerophyll forest the differences between different forms of vegetation are ones of degree rather than type. Vegetation mapping incorporates the assumption that distinct forms of plant community exist, as arises with plant species, when this is unlikely. A continuum of environment can be expected to produce a continuum of vegetation (McIntosh 1967) so that in effect imagery is being used to map discrete entities that don't exist.

Such conceptual issues were previously central to vegetation and soil mapping if only because the available aerial photography provided little information relevant to what was being mapped. The technology now dominates will little consideration being given to what is being attempted.

From cost considerations alone, digital imagery will replace photographic film and satellite platforms will be used where possible. There is therefore a need to examine relationships between different results as results from old technologies still provide most of the reference information. The mapping of native vegetation clearing is one application where satellite imagery has been applied as it can be the only feasible technology. Consideration of the application of satellite imagery to addressing land clearing can aid the transition between technologies.

ERIC was contracted to map vegetation clearing across NSW for 1995-97 and 1997-2000 by the NSW Department of Land and Water Conservation (DLWC) which is now part of the Department of Natural Resources (DNR). The initial contract involved the development of a method as well as the production of results within the short time frame of 3 months. It levered off prior work which commenced with a vegetation mapping study funded by the Murray-Darling Basin Commission (MDBC).

Rates of clearing of native woody vegetation for the 1991-95 period were obtained in an Australia wide study on land cover change coordinated by the Bureau of Resource Sciences (BRS). For NSW this study was conducted by the Land Information Council (LIC), and built upon the mapping conducted for the MDBC.

The ERIC method reliably identified clearing but there were omissions as some clearing identified in the field was not detected. This arose in areas of low tree density where the vegetation was non-woody in the reference vegetation map. Due to the occurrence of such uncertainty ERIC undertook an assessment of errors that was outside the contract when conducting the study on rates of clearing of native vegetation across NSW for the period 1997 - 2000. The two clearing reports were posted on the DLWC web site but are apparently not on the current DNR web site.

The second ERIC report is referred to in an Australian Greenhouse Office (AGO) report on their land clearing method due to the consideration of errors (AGO 2002). The results relating to error estimation are given here as they illustrate characteristics of satellite imagery important in developing and applying the information where this has become important given the use of such results in addressing land clearing (ABS 2002, Cullen et al. 2002). Conclusions are being drawn without a good appreciation of the limitations of results.

The realised magnitudes of error can vary considerably depending on specifics of the method and the quality of the available imagery. However, some aspects of the numerical analysis of satellite imagery always apply and they differ from the experience of those familiar with the use of aerial photography. Such general constraints associated with change detection are addressed prior to the provision of examples of technological constraints.

Basic Differences between Aerial Photography & Satellite Imagery

The main differences between aerial photography and satellite imagery are the spatial stability and relative importance of spectral and spatial resolutions. Satellite imagery is geometrically very stable and so can be accurately located. Even without ground control the locations of objects in high spatial resolution imagery can be accurate to within 10m. Automated implementation of ground control now routinely provides imagery with an RMS accuracy better than 50m for the imagery used to address land clearing. The topographic maps now being produced from satellite imagery are more accurate than those produced previously from aerial photography.

Spatial resolution effectively identifies the smallest sized object that can be discriminated and for satellite imagery is nominally the pixel size. For photography it depends on the grain size of the film relative to the scale. Aerial photography typically has higher spatial resolution than satellite imagery but satellite imagery is now available that has a spatial resolutions equivalent to aerial photography provided for rural areas. NSW now uses satellite imagery that has a synthetic pixel size of 2.5m as a replacement for aerial photography.

Spectral resolution relates to relates to the ability to discriminate different wave bands ('colours') and intensities of radiation. Panchromatic film typically has lower spectral resolution than colour film and the spectral resolution of film is much lower than for digital satellite imagery. Colour film has three overlapping broad bands, typically blue, green and red, while digital hyperspectral airborne imagery has up to 256 narrow bands.

The high spatial resolution but low spectral resolution of aerial photography makes it best suited to identifying discrete objects such as roads and houses. Context by way of shape and relationships between objects is used when interpreting aerial photography. Such use of context is limited with satellite imagery, partly because of the numerical analysis and partly because of the low spatial resolution. A single pixel can contain buildings, roads, vegetation and water and so does not represent a discrete object or feature. This situation is obvious with satellite imagery that has a 1km pixel but it arises with most forms of imagery used to asses land resources.

Despite pixels comprising a mixture of entities the high spectral resolution of hyperspectral data can be used to identify if a particular object or entity comprises part of a pixel. For mineral exploration this is used to identify the occurrence of minerals by reference to their spectral signature. However, neither plant species nor communities have unique or invariant spectral signatures hence there is little if any opportunity to use a reference spectral library to identify and map particular types of vegetation. Application of this approach to vegetation depends on obtaining signatures for the entity of interest that are directly relevant to the circumstances which usually involves ground observations at the time and place of image acquisition.

Natural vegetation represents a mixture of plants, as with woodlands comprising a mixture of grasses and trees. Obtaining a reliable measure requires spatial averaging and this automatically occurs with satellite imagery. This averaging does not resolve the issue of the assumed existence of discrete forms of vegetation but it does allow the issue to be examined.

Reference for Change Detection

Change detection can simply involve determining the magnitude of difference between images for two occasions and deciding on its significance. However, for vegetation clearing it initially requires determination that the initial state (before) represents woody native vegetation and the current condition (after) is not. There is a need to be able to reliably identify an area as having been native woody vegetation as well as detecting change.

Results for a detailed study on a reasonably small area in the southern highlands of NSW identify a high level of error in discriminating woody and non-woody native vegetation (Sparks & Tunstall 2002). This error could be higher than usual because of the existence of montane grassland but the error is still high when this vegetation category is excluded. A number of classes exist that can be associated with different types of vegetation whereby a particular class is indicative of grassland and woody vegetation. With field observations the minimum error in discriminating between woody and non-woody vegetation was around 5%. Without field observations the error varies depending on the method used to set the boundary but the minimum error is 12%.

The Australian Greenhouse Office (AGO) method uses an iterative statistical procedure to derive a woody, non-woody vector applicable to the mosaiced multiple satellite scenes being analysed. Vegetation is identified as being woody or non woody and clearing is determined by the difference between such maps produced for different dates. The combined error in discriminating between woody and non-woody vegetation in an image, as applies in change determination, is around 12%. Assuming a low woody vegetation representation of 10%, the potential error in estimating clearing using this approach is ten times greater than the magnitude of change. Clearing cannot be reliably determined by numerically comparing maps of woody vegetation numerically derived from satellite imagery obtained at two dates.

The AGO method uses a conditional probability network (CPN) and procedures such as removing isolated pixels to help resolve this issue. With the CPN the consistency of the classification in a time series is used to decide whether change is considered real. The effectiveness of such an approach depends on the frequency of the sampling relative to the frequency as well as magnitude of change. It greatly reduces random error, as arises with the inability to exactly spatially match images for different dates, but cannot remove all error. It can even introduce error as rapid regeneration following clearing will negate a valid determination. No assessments have been presented that identify the residual error in the estimates of clearing following application of the CPN and other adjustments.

The AGO used different vegetation categorisations for the National Greenhouse Gas Inventory (NGGI) 2002 and the National Carbon Accounting System (NCAS) 2004. The sum of the NCAS categories of conversion and reclearing appears to represent the NGGI clearing category of deforestation[1]. Conversion represents permanent clearing of previously uncleared areas and reclearing the ‘clearing’ of previously cleared areas. However, the change detection is based on a fuzzy threshold between woody and non-woody and the ‘reclearing’ can arise for reasons unrelated to clearing such as fire and drought.

The NCAS categorisation better relates to carbon accounting requirements than the NGGI categories. Also, it places most of the uncertainty in the reclearing category as the reliability of the conversion estimate improves with multiple images before and after clearing. The NCAS does not contain figures for the NGGI reforestation category but the reclearing category would be a component of it, albeit offset in time.

The ERIC method restricted the numerical analysis of the imagery to areas of woody vegetation in a reference woody vegetation map (woody vegetation mask). Woody vegetation is dark in satellite imagery and numerical classification of the after image was used to highlight areas within the woody mask that were bright as these identify potential clearing (Fig. 1). Actual clearing was determined by visually comparing the before and after images as false identification of clearing can arise for many reasons, such as the inevitable spatial miss-registration between the reference woody vegetation map (mask) and the after image.

The extent of clearing was defined by drawing a boundary around the perimeter of areas identified as having been cleared (Fig. 2). This clearing polygon almost invariably contained pixels highlighted as having been cleared but usually also contained pixels that were not identified as being woody in the reference vegetation map.

The magnitude of potential clearing identified by highlighted pixels greatly exceeds the actual clearing: very few of the potential clearing identifications represent actual clearing. With

[1] Forestry is treated separately to land clearing in the NCAS.

automatic change detection most effort is therefore expended in attempting to prevent or remove the errors, and this is the approach used by the AGO. ERIC decided that because of the low occurrence of clearing it was easier, quicker and more reliable to exclude errors through visual checking of the results and manually recording valid determinations. With this approach the reasons for the clearing can usually be readily determined, as with discriminating between forestry, fire and periurban development.

The main issues with the ERIC method relate to the reliability and resolution of the reference woody vegetation map. While false identification of woody vegetation in the reference map can often be corrected areas not identified as being woody in the map generally cannot be identified as having been cleared. This issue is of most consequence at low densities of woody plants[2]. The nominal threshold for identification of woody vegetation in the reference map is 20% canopy cover, and this threshold is used by the AGO,. The lower threshold for woody vegetation is 0.2% in the generally cited vegetation classification system (Walker and Hopkins in McDonald et al. 1982).

Satellite imagery cannot be used to identify low densities of woody vegetation such as 0.2% but neither can aerial photography. Moreover, for communities there is a requirement that the components interact and interaction cannot occur at the very low levels of cover such as 0.2%. The attempts by some to address very low levels of woody vegetation have little ecological validity.

The issue of the lower threshold for detection of woody vegetation is of particular consequence in mapping the extent of clearing. The AGO method is pixel based hence the cleared area estimates are derived by summing the areas of individual pixels identified as having been cleared. With mapping using aerial photography boundaries are drawn around areas that can be inhomogeneous in having a range of densities of woody vegetation. The issue relates to the homogeneity of what is being mapped where that depends on the scale of observation.

The issue can be illustrated by the question, if one tree in a paddock is cleared is the entire area of the paddock regarded as having been cleared? For carbon accounting only the cleared trees are of consequence but for some clearing estimates the area of the paddock has been used.

The scaling issues are compounded by definitions of vegetation that allow the same area to concurrently be different categories of vegetation. A wheat field is considered to be native woody vegetation where it contains some native trees. In one case paddocks planted to wheat were deemed to be native woody vegetation (NSW LEC 58-2004). These paddocks were not identified as having been cleared in the relevant 1997 – 2000 period in the ERIC study as the paddocks were not identified as being woody vegetation in the reference woody vegetation map. This is realistic as with normal considerations of vegetation and land use the identification of wheat means they would not be considered as potential areas for clearing of native vegetation.

The ERIC results provide both pixel and polygon based estimates of clearing. The 1997-2000 results examine how this influences the effective lower threshold for mapping clearing.

Sources of False Identifications of Clearing

Figure 3 illustrates use of the classified after image to identify potential clearing. Comparison of the before and after images identifies that some of the area flagged as potential clearing had been previously cleared. This false identification of clearing arises because of error in the reference vegetation map and is readily corrected.

[2] This is effectively not an issue for the NCAS given the definition of forests used for carbon accounting.

Figures 4 and 5 illustrate that haze and cloud can produce areas of high intensity that are flagged as having been cleared when they occur in areas of woody vegetation. The usually distinct spectral characteristics of the cloud help prevent this being a significant error.

Figures 6 and 7 illustrate the main uncertainty that can produce false identifications of clearing with the ERIC method which arises because of unreliability in the reference vegetation map. Wet grassland in particular can appear to represent woody vegetation in satellite imagery and dry conditions can then result in false identifications of clearing. This is best resolved by producing a reliable reference map but otherwise depends on knowledge of vegetation and land use patterns in the region. With the ERIC procedure such uncertainties were crosschecked by someone with such knowledge.

Figure 8 illustrates a failure to flag clearing due to the darkness of the cleared land. This effect is typically associated with black and/or wet soils. The classification is usually sufficiently sensitive to discriminate such features hence they can be flagged once their existence is detected.

Figure 9 illustrates an uncertain clearing detection that cannot be reliably determined without ground observation. There is a large decline in woody vegetation cover which identifies the existence of clearing. However, the irregular boundary is more indicative of fire rather than clearing.

Figure 10 illustrates false detections arising from the interaction between the terrain and variations in illumination angle. The amount of shadow thrown by trees depends on the angle of illumination and is reduced when the terrain slope faces the sun. On sunlit slopes woody vegetation can appear bright similar to grassland. Differences in illumination angle between different dates of image acquisition can result in apparent changes between woody vegetation and grassland where there is no change.

Clearing Calculations

Area Estimates: Total Woody and Woody Mask (pixel)

The openness of woody vegetation is often reflected in the density of pixels identified as being woody in the reference vegetation map (Fig. 11). Areas that would be regarded as entirely woody using Air Photo Interpretation (API) are often represented as a speckle of woody vegetation in the reference woody vegetation map.

The ERIC 1995-97 study was required to produce an equivalent result to the 1990-95 study conducted by the NSW Land Information Council (LIC) which was pixel based. An estimate of clearing, referred to as the Woody Mask result, was therefore obtained by summing the areas of the individual woody pixels within a clearing polygon. The estimate is the sum of the areas of cleared 25m pixels in the reference woody vegetation map calculated using individual pixel areas in a Lat.-Long. projection.

The total woody estimate relates to the area encompassed by polygons that delineate the extent of the cleared area. This is appropriate as the clearing polygons were drawn to encompass areas that were previously woody.

Method of Determination

The calculations of area can be made in raster or vector mode. In raster mode the area is determined by the sum of the areas of all pixels that comprise the polygon. As the shape of the boundary differs between a raster and polygon representation (Fig. 12) the different modes of calculation produce different estimates.

The pixels effectively have the same size when projected on the regular Australian Map Grid (AMG) but only within AMG zones. NSW extends across three zones hence operating in AMG coordinates requires separate processing for each of the three zones. Use of Lat.-Long. coordinates allows processing of the information as a single file provided the areas of individual pixels are used in the calculations as the pixel size varies with Latitude in a Lat.-Long. projection.

The estimates of total clearing differed considerably between the raster and polygon methods. The average difference between estimates for the entire State was 6%, but a 12% difference was recorded for some individual 1:100,000 map sheets. The reasons for this difference are illustrated in Fig. 10. The smooth polygon boundary is represented by a saw tooth edge in a raster image due to the fixed size of the pixels. The area of pixels extending outside the polygon boundary was greater than the area within the polygon left blank by pixels not extending to the polygon boundary. There is no logical basis for deciding which answer is correct given the generation of the polygon information from raster images.

The discrepancy between polygon and raster based estimates depends on the algorithm used for the conversion from polygons to pixels. Use of the centre of the pixel as reference for the conversion would result in an effective expansion of the polygon by half a pixel around its perimeter. The GIS used provides an option to allow proportional representation of pixels within the polygon, which should address this discrepancy, but the function was not operational when the results were produced.

The magnitude of this discrepancy is not constant but depends on the ratio of the length of the polygon boundary to the polygon area. The discrepancy is highest with small and narrow polygons.

Rates of Clearing

Time Interval

The intervals between acquisitions depend on the availability of suitable imagery and hence can differ considerably between areas covered by different satellite images. The interval used by ERIC to calculate clearing rates was determined as the arithmetic average of the intervals for scenes on which clearing was detected.

This use of an average interval for the State introduces uncertainties due to the considerable difference in intervals between image acquisitions, and the non-uniform distribution of clearing across the State. The alternatives are to calculate separate intervals for individual map sheets, or to weight the interval proportionally to the amount of clearing on an image. The arithmetic average was used as it is the simplest and the alternatives do not confer any practical advantage.

Area Calculations

The areas of clearing for the Total Woody estimate were calculated in vector mode by summing the areas of clearing polygons. All estimates were computed using a Lat.-Long. projection.

The clearing areas for the Woody Mask estimate were obtained by converting the vector polygon clearing file to a raster representation. As the woody vegetation map and clearing raster were both binary files, the woody mask estimate of clearing can be obtained by multiplying the files. The clearing estimates were obtained by summing the areas of clearing pixels.

Results

Table 1 provides the State wide statistics of clearing for the Total Woody and Woody Mask estimates. The Woody Mask estimates are 63% of the Total Woody estimate for 1997-2000, as opposed to 50% of the 1995-97 period.

Table 1 NSW state wide statistics for the clearing of native woody vegetation for two intervals. Areas in hectares, rates in hectare per year.

	Total Woody		Woody Mask		Woody Mask / Total Woody
	Area	**Rate**	**Area**	**Rate**	**%**
1995 -1997	58490	32800	29228	16400	50
1997 - 2000	32546	14028	20456	8817	63

The difference between the Total Woody and Woody Mask estimates relates to the threshold for the discrimination of woody vegetation from the satellite imagery. This is nominally 20% crown cover for the reference woody vegetation map, and this applies to the Woody Mask estimates. However, the threshold is considerably lower for the total woody estimates.

The higher difference between the Total Woody and Woody Mask estimates for 1995-97 than 1997-2000 relates to changes in the location of clearing. The discrepancy between estimates is highest in open western woodlands and least in dense coastal forests. Proportionally more clearing occurred in coastal areas in the period 1997-2000 than 1995-97.

Error Estimation

Commission

Commission errors relate to the false identification of clearing. This was not checked for the 1997-2000 study but 49 clearing determinations field checked by DLWC for the 1995-97 study were correct.

The uncertainties in determining clearing indicate that there will be commission errors. The magnitude of this error is estimated to be around 1 to 2% on the basis of the relative occurrence of uncertain determinations.

Omission

Omission errors relate to the failure to detect clearing. This error is difficult to check in the field because clearing occupies such a small part of the area of the State, around 0.04% for the 1997-2000 study. Random or stratified random field sampling would be completely ineffective in detecting errors of omission.

An estimate of the magnitude of this error was obtained by checking the effectiveness of operators in detecting clearing. The Newcastle scene was chosen due to its complexity arising from the large number of small clearings and the seasonal conditions in the imagery. Checking of clearing determinations by a second operator indicated that up to 5% of clearings may be missed. However, as checking of scenes is routinely conducted by each operator, and as

Newcastle was a particularly difficult image due to the small size of the clearings, the average realised rate of omissions would be considerably less.

The 5% rate identified above is based on the number of polygons rather than the area of clearing. As the polygons that are initially missed are invariably small the error in area estimation would be considerably lower than 5%. Given the routine checking of results, and the small size of clearings that tend to be missed, the omission error appears to be between 1 and 2%.

Area Determination

The difference in areas calculated in AMG and Lat.-Long. coordinates was 0.1% for the State. While 0.1% of the State is greater than the level of clearing it only changes the clearing estimate by 0.1%. Its effect is not significant.

Raster estimates calculated in Lat.-Long. coordinates using the actual sizes for each pixel and an assumed average for the region differ depending on the range of Latitude covered by the region. However, the difference was always appreciable at around 5%. Use of an average pixel size provides a convenient means of rapidly producing an interim result but is inapplicable for final estimates.

The difference between calculating areas based on the vector polygons and a raster image of clearing based on the polygons averaged 6% across the State. The discrepancy exceeded 12% for some 1:100,000 map sheets and was greatest where the region contained numerous small clearing polygons.

Woody Vegetation Map

The ERIC method was developed to limit effects of error in the woody vegetation map on the clearing results. The main effect relates to the lower limit or threshold for the detection of woody vegetation. The key uncertainty relates to interpretation of what constitutes woody vegetation and this effectively remains constant while the same reference is used. Error due to the woody vegetation mask is mainly manifest as an offset that relates to the definition of the threshold between woody and grassy vegetation.

The lower threshold for the determination of clearing can be deduced but only by accepting the nominal threshold of 20% canopy cover for the woody vegetation map. The lowest ratio for the Woody Mask and Total Woody estimates of clearing for 1:100,000 map sheets in the 1995-97 study was 0.2. As this is the average for a map containing a large amount of clearing, the minimum average canopy cover determined by this procedure is below 4%.

The main effect of the unreliability in the woody vegetation map on realised error relates to the uncertainty in clearing determinations. A reliable reference would remove most of the uncertainty identified above for commission and omission errors.

Overall Accuracy

The maximum error expected from omission and commission is around 4%. However, these errors tend to compensate and the realised error should be less.

The difference between the raster and vector estimates of areas is a discrepancy rather than an error as there is no correct result ('truth') that can be used for evaluation. However, the discrepancy provides an indication of the magnitude of error associated with uncertainty in the delineation of the polygon boundaries. This is the single highest source of error, averaging 6% across the State.

From the above considerations, the maximum error in determining the area of clearing is 10%. However, given compensation between errors the realised error could be below 5%.

Comparison of ERIC and AGO Results

The ERIC Woody Mask estimates are comparable to the AGO NCAS results (NCAS 2004) in being based on a reference vegetation map with 25m pixels and a nominal 20% cover threshold for woody vegetation. However, the vegetation categorisations differ slightly. The potential differences relate to the treatment of forestry and the reclearing category in the NCAS.

The ERIC clearing results include forestry operations in native vegetation whereas this is identified as being excluded in the NCAS results. While clearing of native forests was separately identified in the ERIC 1997 - 2000 study this result was not separately reported[3]. Assuming that all clearing in Batemans Bay and Eden 1:100,000 map sheets is forestry this decreases the ERIC results by around 7%. This would be a minimum figure for the State.

The relationship between the AGO conversion and reclearing categories and the ERIC results is ambiguous. The ERIC results are based on a reference map of native woody vegetation, which makes them similar to conversion, but in western areas in particular it was obvious that some clearing was of previously cleared vegetation. The ERIC results could include some of the AGO reclearing category. However, the AGO definition of reclearing can only apply to the period of the analysis hence some of their conversion estimate will include clearing of previously cleared land. The appropriate NCAS result for comparison with the ERIC non-forestry clearing result likely lies somewhere between conversion and the sum of conversion and reclearing.

The NGGI estimates used for comparison were derived from the national figures given for the period 1972 – 2000 by Jones et al. (2004) which were 1% for deforestation. These results were apportioned to NSW on the levels of land use change carbon emissions given in the NCAS 2004 wherein NSW averages 20% of the national emissions associated with land clearing. The complexities in the translation between clearing and carbon emissions introduces uncertainties relating to temporal sequencing and the types of soils and vegetation but, given the size of the sample, the estimate should be realistic.

The NCAS conversion rates are 2.3 times higher than the ERIC results, and this increases to around 2.5 when forestry is considered. The combined conversion and reclearing rates are around 7 times greater than the ERIC estimates. The NGGI figures show least correspondence and are an order of magnitude higher.

The difference between the NGGI and combined NCAS results can arise for several reasons. One is the assumption here that the average results for the 28 year interval apply when they were likely lowest for the period 1995 - 2000. Assuming the rate halves the 11.1 decreases to around 7.

Another reason for the difference is the reanalysis of the data by the AGO. The NCAS results are based on a revised method that was only applied to Landsat TM and ETM imagery. The Landsat MSS imagery for 1972 – 1988 used in the NGGI has a nominal 80m pixel which was resampled to 50m and then to 25m. At one stage the 1988–1990 Landsat TM imagery used was resampled to 25m and then aggregated to a 50m pixel.

[3] Plantations were excluded from the ERIC results.

Table 2 Comparison of ERIC and AGO clearing estimates for NSW for the period 1995 – 2000.					
	ERIC	NCAS (conversion)	NCAS (reclearing)	NCAS (con + recl)	NGGI (deforestation)
Area, 95 - 00 (ha)	75651	175700	359500	535200	
Rate (%/yr)	0.00066	.00152		0.0046	.0074
Ratio (ERIC/AGO)		2.3		7.1	11.1

Conclusions

Vegetation description and mapping

Woody vegetation is generally characterised using 20m plots for floristics and plotless sampling for vegetation structure. The Landsat TM and ETM sample and mapping sizes are 30m and usually 25m respectively. The unit mapping size for API used in association with field sampling and description of 20m plots is usually many hectares.

The sizes of samples used in mapping and field observation influence the description of vegetation. For example, it is essentially impossible for woody vegetation to have a canopy cover less than 1 % when mapping using satellite imagery with a 30m pixel as one sizable tree occupies around 2% of the $900m^2$ pixel area. With satellite imagery vegetation categories such as isolated trees and isolated clumps of trees are mapped as mixtures (a speckle) of pixels representing woodland and grassland.

The appropriate sample size for native woody vegetation appears to be around 50m as this averages the mixture of components characteristic with such heterogeneous vegetation. That is, the reliability of mapping is improved by aggregating pixels, not by attempting to obtain higher pixel resolution.

While aggregation of pixels improves the mapping of heterogeneous vegetation it masks infrastructure and introduces uncertainties as to the location of the boundaries of features. Techniques are therefore required that use the high spatial resolution of Landsat ETM to locate feature boundaries while improving the mapping through spatial averaging. The large magnitude of error associated with delineating the boundaries of the clearing polygons indicates that the spatial discrimination of the imagery should be as high as possible. With Landsat ETM this would involve merging the panchromatic and spectral bands to achieve a 15m pixel for multi-spectral data.

These scaling issues require further consideration. Classifications of vegetation based on the capabilities of API can be adapted to satellite imagery but they do not provide the best result.

Methodological approach

The methodology used by ERIC limits the transfer of errors associated with particular processing functions to the final result. Errors that arise with processing steps such as miss-registration increase the effort required to produce the result but they do not greatly affect the accuracy of the final estimate.

The use of polygons rather than pixels when determining clearing has several benefits. These include:

- Limiting the error associated with boundaries or edges, as identified for the area determination.
- The ability to develop a method for evaluating accuracy that addresses the different forms of error that is not made ineffective by compensating errors.

As the magnitude of error associated with edges depends on the ratio of the edge (perimeter) to area of the units being considered it will inevitably be high for pixel based observations.

Overall the ERIC methodology is based on preventing the development and transfer of errors rather than editing incorrect results. This is seen as essential where the information of interest occupies such a small proportion of the image.

The AGO results evidence the large magnitude of error that arises when clearing estimates are based on numerically classifying vegetation and differencing the results for different dates. With current technologies the production of reliable results depends on personnel checking numerically derived results.

References

ABS (2002) Measuring Australia's Progress 2002. Australian Bureau of Statistics. Available on www.abs.gov.au

AGO (2002) Greenhouse Gas Emissions from Land Use Change in Australia: An integrated application of the National Carbon Accounting System. Australian Greenhouse Office. Available on www.greenhouse.gov.au

Cullen, P., Flannery, T, Harding, R., Morton, S., Possingham, H., Saunders, D., Thom, B., Williams., J., Young, M., Cosier, P. & Boully, L. (2002) Blueprint for a Living Continent A way forward from the Wentworth Group of concerned scientists. WWF Australia. Available generally on the web including on www.clw.csiro.au

Jones, S., Lowell, K., Woodgate, P., Buxton, L., Mager, A. & Liebchen, S. (2004) Update on the National Carbon Accounting System Continuous Improvement and Verification Methodology. Australian Greenhouse Office. Available on www.greenhouse.gov.au

NCAS (2004) Greenhouse Gas Emissions from Land Use Change in Australia: results of the National Carbon Accounting System 1998 – 2003. Australian Greenhouse Office. Available on www.greenhouse.gov.au

McIntosh, R.P., 1967. The continuum concept of vegetation. Bot. Rev. 33: 130-87.

McDonald, R. C., Isbell, R. F., Speight, J. G., Walker, J. and Hopkins, M. S. (1984). Australian soil and land survey. Field handbook. Inkata, Melbourne. pp 165

NSW LEC 58-2004. Director General of Land and Water Conservation vs Greentree and others (NSW LEC 584) 2004, NSW Land and Environment Court.

Sparks, T. G. & Tunstall, B. R. (2002) Errors in Discriminating between Woody and Grassy Vegetation using Landsat ETM. Poster Presentation Australasian Remote Sensing Conference, Brisbane. Presented as a paper on www.eric.com.au

FIGURES

Colour composite images are based on bands 3, 4, 5.

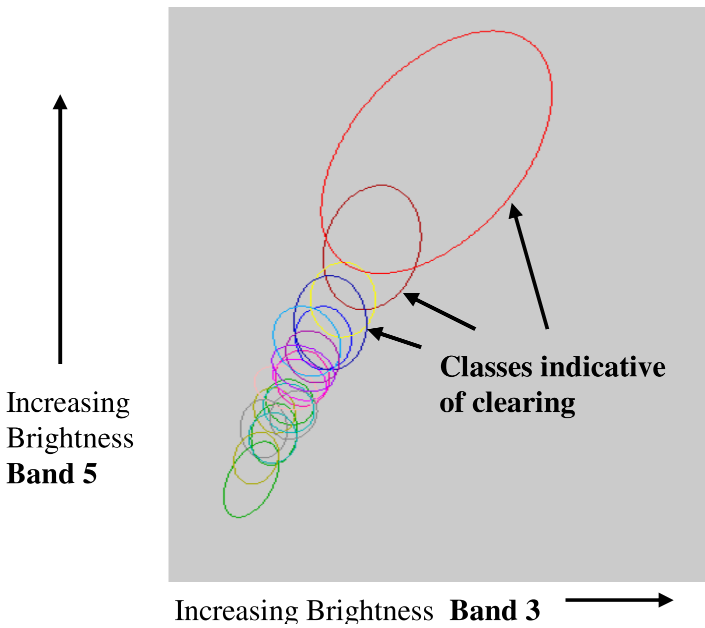


Fig. 1 Spectral characteristics of classes identified by a cross-plot of Bands 3 and 5. This shows the variation in brightness for each of the 20 classes in the classification. Classes with high values (top right) indicate potential clearing, and are highlighted.

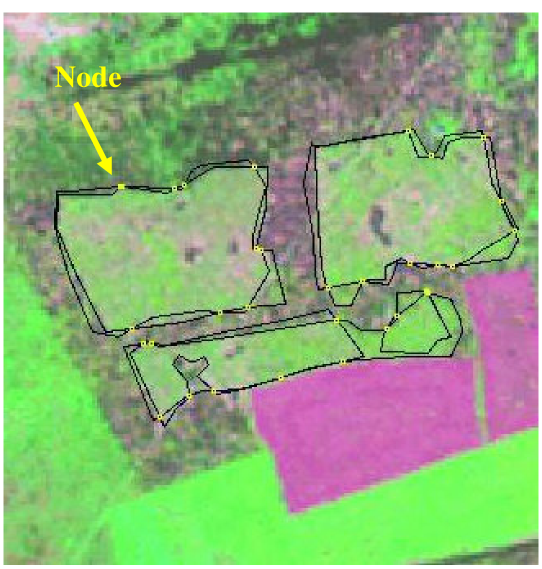
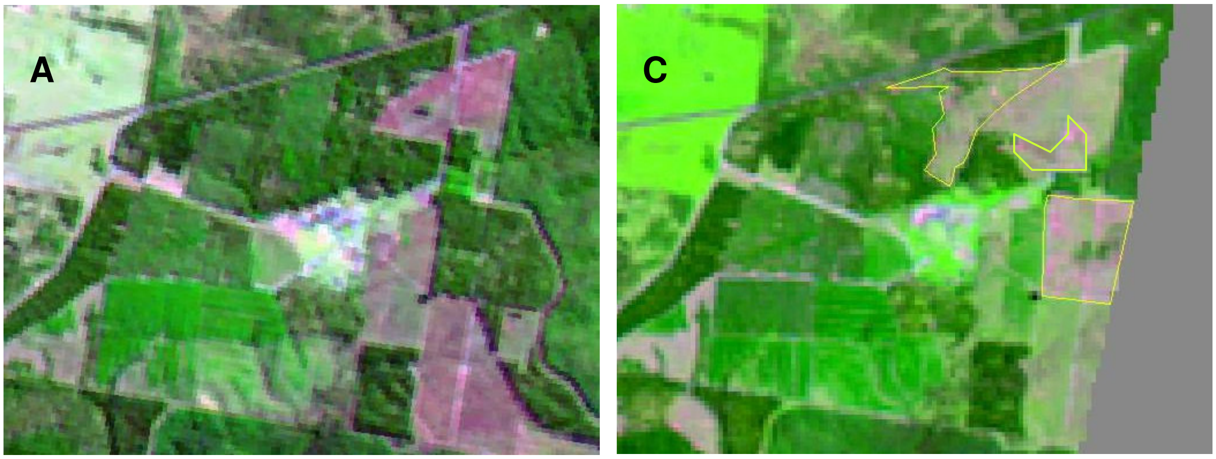


Fig. 2 Duplicate determinations of clearing in areas of image overlap. The polygons are edited to produce a single line, and one node (yellow square) per polygon.



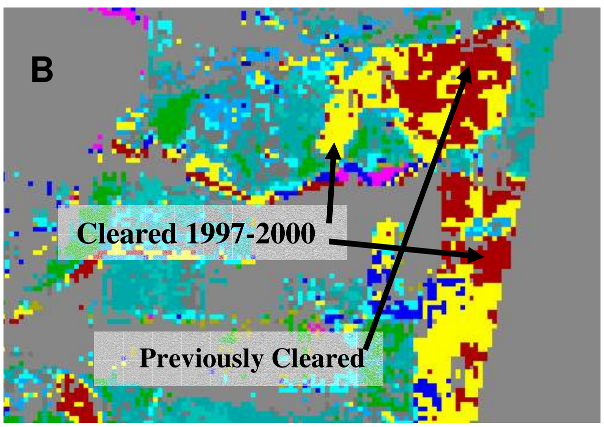


Fig. 3 A = raw 1997, B = classified masked 2000, C = raw 2000.

Yellow polygons identify areas identified as having been cleared in the period 1997-2000. Other areas detected as clearing in Fig. B were previously cleared but the clearing had not been mapped.

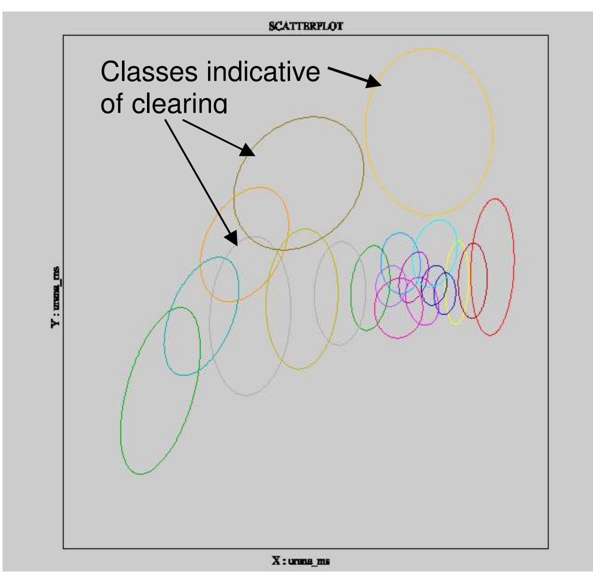


Fig. 4 Crossplot of bands 3 and 5 for a classification that illustrates an anomalous pattern due to light cloud. As the brightest classes are indicative of clearing the haze appears to have reduced rather than increased the reflectance intensity.

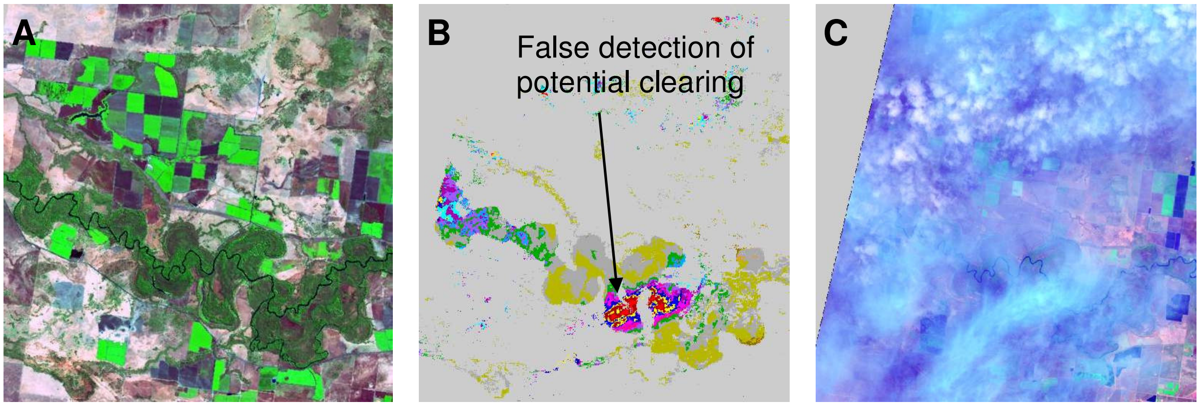


Fig. 5 Image sequence illustrating false detection of clearing due to cloud increasing the reflectance intensity form an area occupied by woody vegetation.

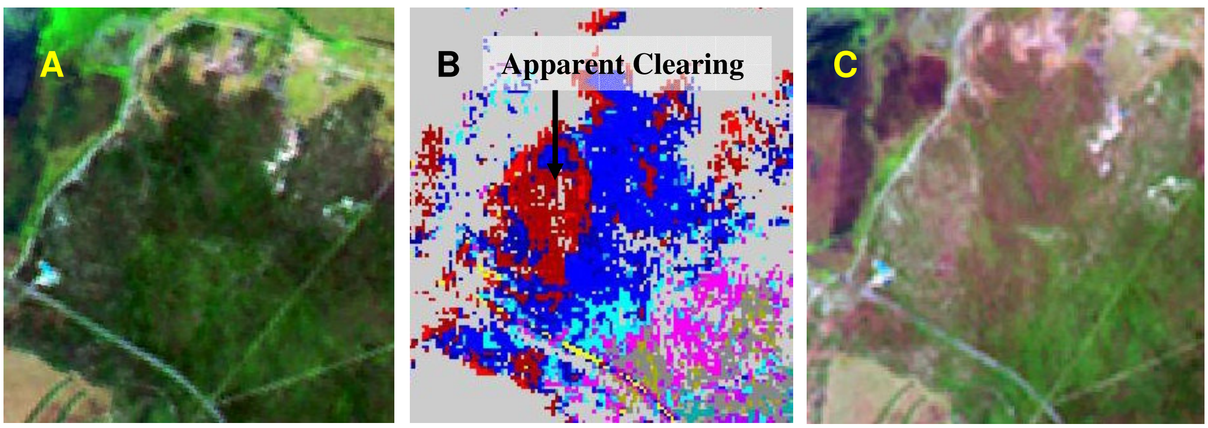


Fig. 6 Image sequence illustrating uncertain detection of clearing due to unreliable mask and changes in wetness. The blue and red classes appear to represent wet grassland rather than woody vegetation, and the changes between 1997 and 2000 represent changes in wetness rather than clearing.

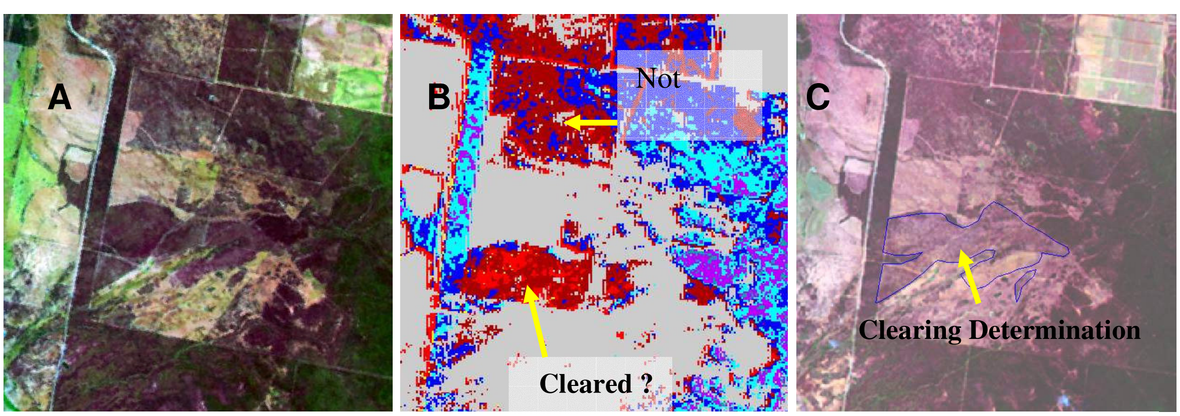


Fig. 7 Image sequence illustrating uncertain detection of clearing. The 'woody vegetation' in the 1997 image may be seasonally wet grassland.

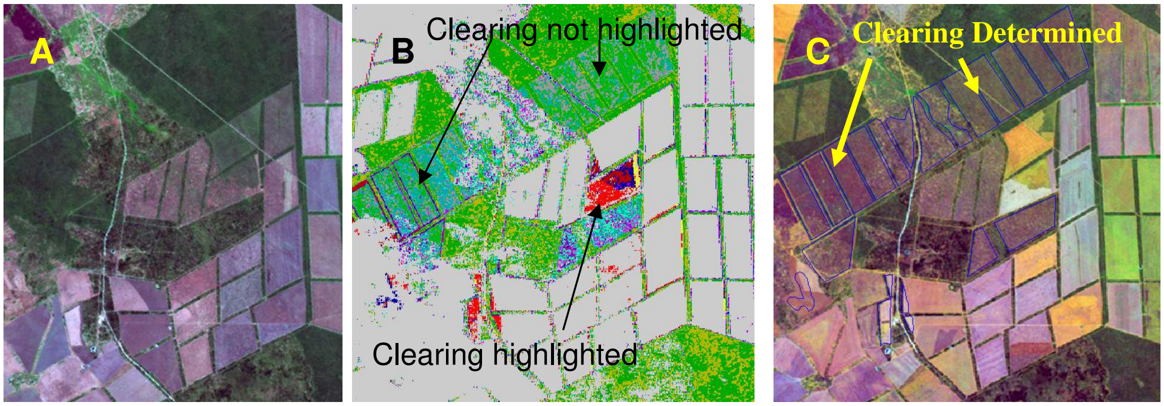


Fig. 8 Failure of bright classes to highlight potential clearing due to regrowth of vegetation. The classes indicative of the regrowth are reassigned vivid colours once this effect has been detected.

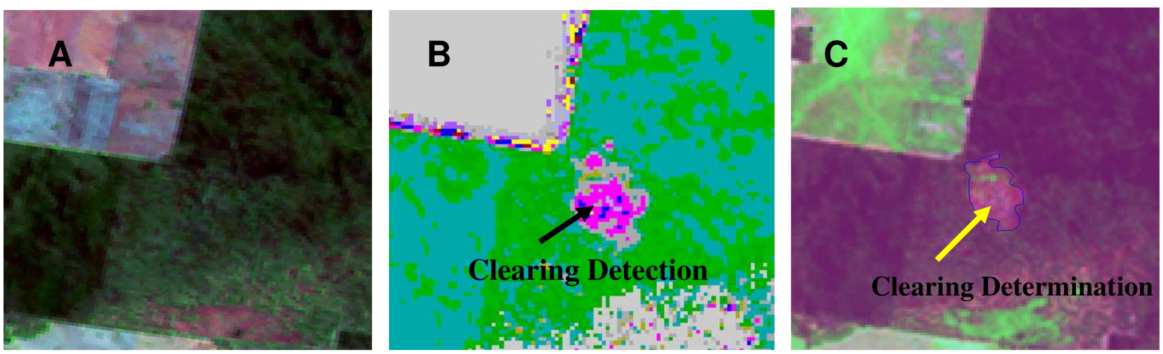


Fig. 9 Image sequence illustrating the uncertain detection of clearing. The 'cleared' area may have been defoliated by fire.

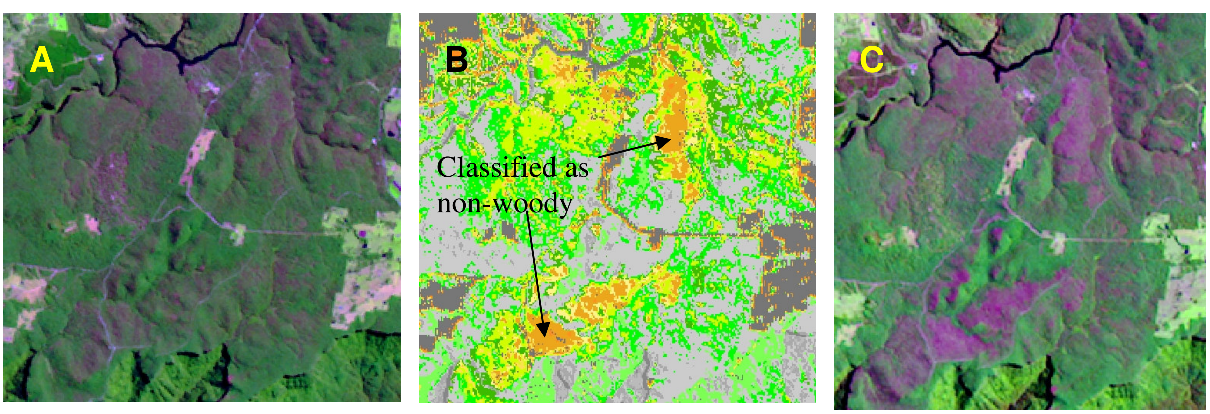


Fig. 10 Image sequence illustrating false detection of clearing due to changes in seasonal conditions. No clearing was determined.

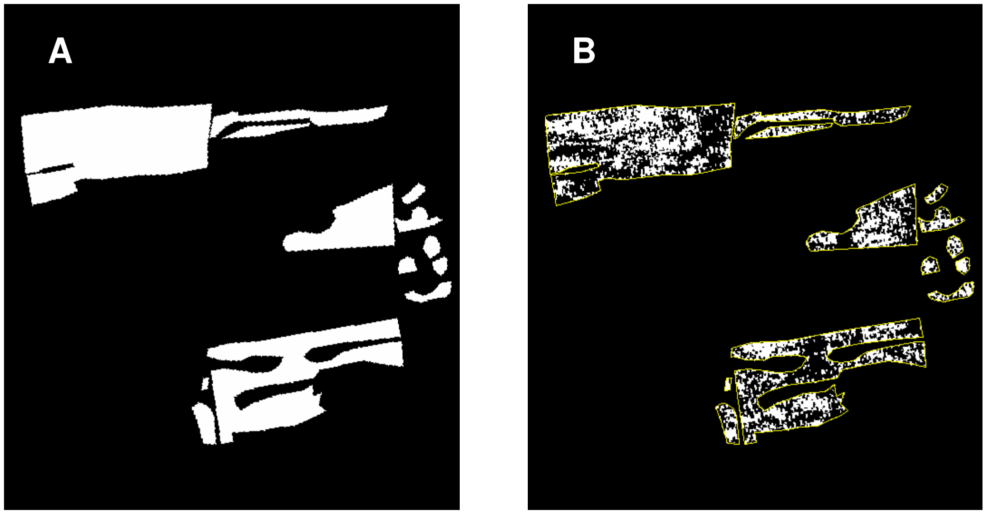


Fig. 11 Clearing polygons identifying the areas used to calculate the Total Woody and Woody Mask estimates of clearing.
The full area encompassed by the polygons is used to calculate the Total Woody estimate of clearing (A). The Woody Mask estimate (B) only considers the area of the woody vegetation map within the polygons (white areas).

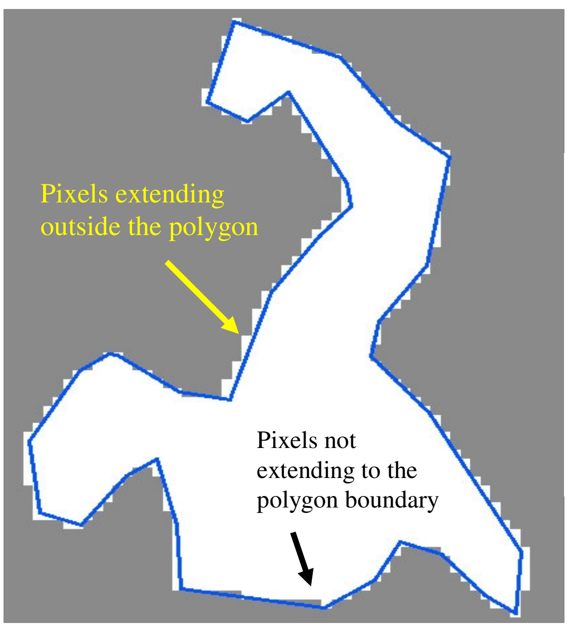


Fig. 1 Areas used in the calculation of clearing based on polygons (blue line) and pixels (white area). On average, the pixels extend outside the area of the polygon more than they fail to extend to the polygon boundary. The area defined by pixels is larger than the area of the polygon.