A review of survey techniques for the detection of weeds with particular reference to *Mimosa pigra* L. in Australia and Thailand

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Summary

Having up-to-date information on a weed's location and area of infestation is important for making decisions on weed control. Survey techniques for weeds, and their relative advantages and disadvantages, in detecting, monitoring and mapping are reviewed with special reference to *Mimosa pigra*, a weed with potential to spread over large areas of northern Australia and south-east Asia. It is concluded that literature citations, herbarium records and questionnaires will not provide the necessary data for maintaining accurate records of its distribution, and it will be necessary to develop other methods of field surveys, public reports and data recording. Investigation of remote sensing techniques for detecting and monitoring mimosa is warranted, particularly to monitor the effectiveness of chemical and biological control measures.

Introduction

Successful control or eradication of weeds relies on up-to-date information on their location and the area of infestation. This information is used to determine responsibility for control measures, to facilitate the design of management programs, to assist in estimating costs involved, to monitor the effectiveness of control measures, and as an aid in predicting potential distribution.

Mimosa pigra L. (hereafter called mimosa), a native of tropical America, has become a major weed in the northern region of the Northern Territory, northern Thailand and other parts of Asia (Chan *et al.* 1981; Miller *et al.* 1981; Napompeth 1983). This woody, prickly leguminous shrub grows to an average height of 4–5 m, forming dense monospecific stands over thousands of hectares on floodplains, in water reservoirs and beside streams — habitats which are particularly favourable for its growth (Harley *et al.* 1985; Lonsdale *et al.* 1985).

A management strategy integrating biological, herbicidal and other control practices is being developed to control mimosa in Australia and Thailand (Harley *et al.* 1985). This strategy requires the early detection of isolated infestations, information on the extent of infestations and their expansion or regression over time.

In this paper we describe the difficulties in ascertaining the distribution of mimosa in Australia and Thailand, review the methods available for its detection and mapping and indicate where further work is warranted. The principles reported and conclusions drawn may also apply to other weeds in many countries.

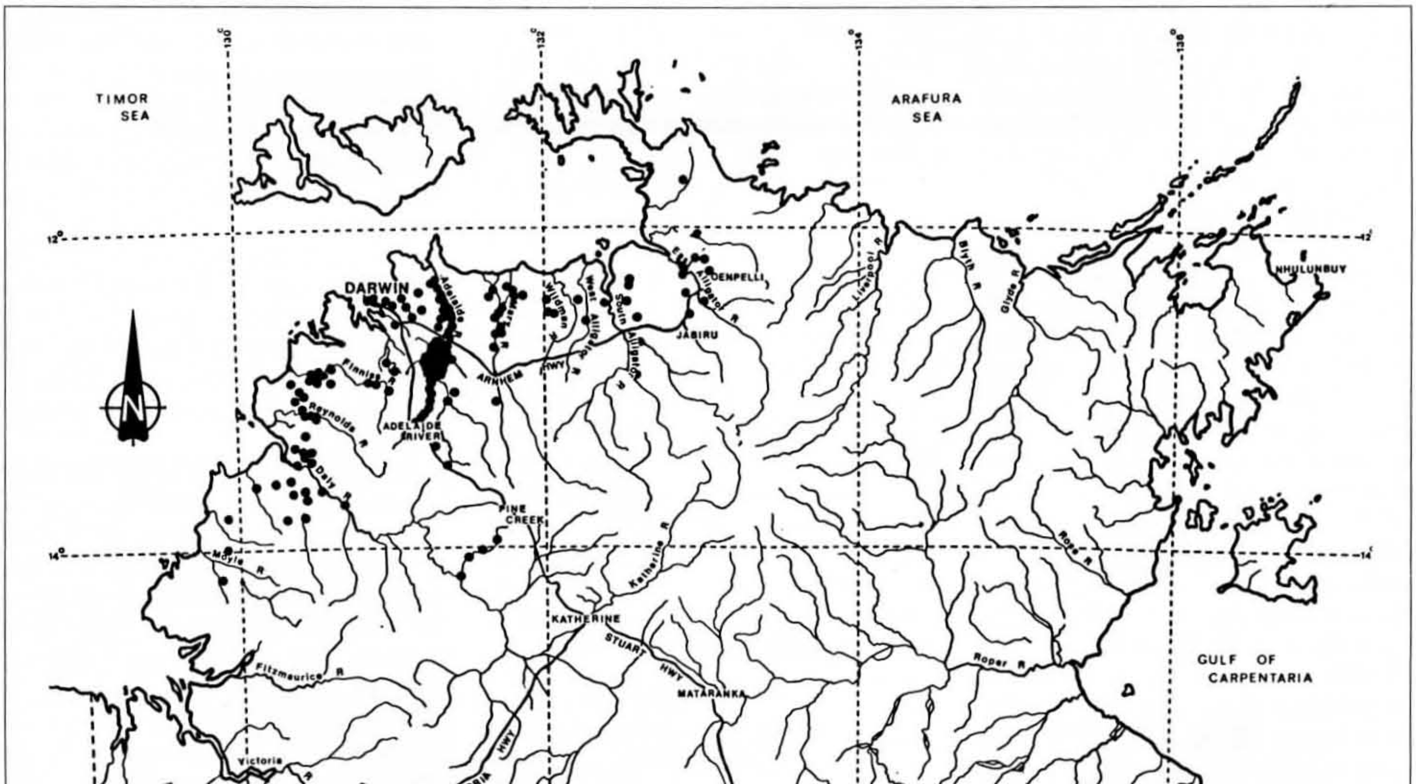

Figure 1 Known locations of *Mimosa pigra* in Australia, October 1986. (Updated from Miller et al. 1981)

Distribution of mimosa

In Australia mimosa infestations are presently confined to the higher rainfall zone of the Northern Territory (Figure 1).

It is apparent that mimosa has been present in Darwin since late last century (Miller and Lonsdale 1987) but it was not until 1952 that it was first reported in the upper Adelaide River area. Seed was eventually carried downstream to the floodplains reaching the Arnhem Highway bridge (a distance of approximately 95 km) in 1975. A rapid expansion in the area infested then occurred due to a major flood in 1977 (Miller *et al.* 1981). From the Adelaide River it has spread to other river systems. Current estimates of the area infested are 35 000 ha of dense to scattered infestations in the Adelaide River system, plus 10 000 ha in other river systems (W.M. Lonsdale, pers. comm.).

Mimosa is widely distributed throughout Thailand, occurring predominantly in the north but with scattered infestations in the centre and south of the country (Figure 2). Prior to 1975 it was confined to the northern provinces around Chiang Mai, after being introduced to this area from Indonesia in the 1960s as a green manure and cover crop in tobacco plantations. Later it was used to control ditchbank erosion (Napompeth 1983). Since then it has spread both north and south, with expansion continuing.

Mimosa has the potential to expand its area considerably in both Australia and Asia. If not controlled it may spread south-west into the northern regions of Western Australia, south-east into Queensland, to Cape York and southwards down the east coast to the Tropic of Capricorn (Miller 1983). Much of the Asian region is climatically suitable for growth of mimosa. The isolated infestations in Thailand's central plain and southern provinces could expand greatly; it has already been reported from neighbouring countries.

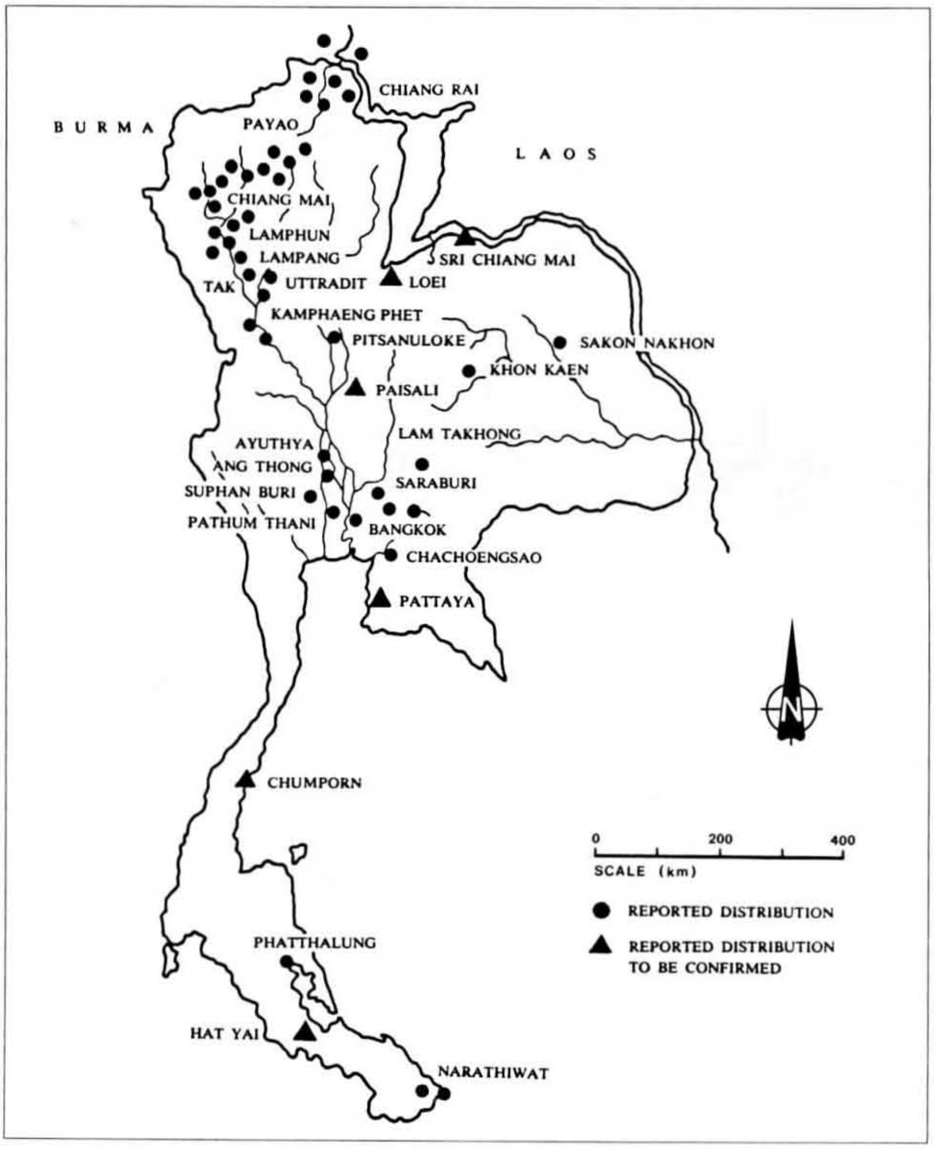

Figure 2 Distribution of *Mimosa pigra* in Thailand. (Thamasara 1985; Source: National Biological Control Research Center, Bangkok.)

Survey techniques

Literature citations and herbarium samples

Literature citations, government records and herbarium samples provide a basis for describing the distribution of weeds. Unfortunately, this material is often incomplete, inconclusive or outdated. Government records and other literature in Australia and Thailand (Miller *et al.* 1981; Robert 1982; Miller 1983; Napompeth 1983; Thamasara 1985; Miller and Lonsdale 1987) mention certain historical aspects concerning the introduction, establishment and spread of mimosa. However, due to its rapid spread these geographic references are quickly outdated.

Herbarium samples may give an indication of the range and history of spread of a weed, but are of little use in assessing the abundance (Auld 1978), rate of spread, total area infested or the success of control operations. Specimens are not usually collected from every infestation and therefore do not provide an accurate record of the weed's distribution.

Questionnaires

Recording sheets for questionnaires usually contain specific questions regarding the presence of weeds, the location and area infested and a site description. Questionnaires can provide general data on weed distribution relatively quickly (Cuthbertson 1978), but there are two major drawbacks: lack of response and lack of accurate estimates. Bias towards exaggerating a weed problem is an important limitation (Auld 1971). This survey method is not appropriate for regions with a low population density where land managers may not see all areas regularly, or for areas that are seasonally inaccessible as are parts of the Northern Territory.

Where population densities are much greater, different problems may be encountered. For example, in Thailand most of the areas infested with mimosa are more accessible from the ground than those in Australia, but there are a mixture of cultures and dialects, particularly in northern Thailand, and a number of illiterate people. Posted questionnaires are rarely returned, even by educated people and such surveys often require an interview with assistance from a dialect interpreter. People may also exaggerate the extent of infestation on their land in the hope that authorities will act swiftly to assist in controlling the problem (B. Napompeth, pers. comm.), resulting in an over-estimation of the total area infested.

Field surveys

Field surveys, both ground and aerial, provide much useful information on the occurrence and distribution of weeds. Depending on the sampling intensity involved, this method may have the following advantages. It does not require the purchase of specialized equipment; areas are surveyed by people who are usually experienced in the appearance, locations (past and present) and control of the weed; surveys may be concentrated in areas under greatest threat of invasion; and the presence of individual or small groups of plants may be noted.

Field surveys do, however, have several disadvantages: new infestations may remain undiscovered for a long period of time if surveys cannot be done regularly and comprehensively; some information is difficult to obtain in the field, e.g. exact locations or extent of infestations due to inaccessibility; data collection is relative ly slow, laborious and expensive in terms of manpower and vehicle costs. Consequently, this method may be unsuitable when resources are inadequate or where the infestation is very large.

In Thailand and the Northern Territory, government survey and control personnel supply most of the information, supplemented with reports by other government officials and the general public.

In the Northern Territory, survey data for mimosa are transferred to 1 : 100 000 topographic maps. This has the advantage of providing relatively detailed site information and at present covers all infestations on only 20 maps. Information on these maps is transferred to a generalized location map (Figure 1). A computerized system has been introduced to improve the accuracy and efficiency of infestation recordings and information retrieval (Schultz 1987). In Thailand only a generalized locations map is produced at a scale of approximately 1 : 9 000 000 (Figure 2).

Due to the rapid spread of mimosa and the large area to be surveyed (approximately 13 x 10^6 ha) by only two control teams (four persons) in the Northern Territory, it is impossible to conduct comprehensive field surveys for the total area each year by means of existing ground-based methods. In Thailand, by contrast, approximately 5960 agricultural extension officers throughout the country (approximately 51.4 x 10^6 ha) are being trained to identify and report mimosa infestations to the Department of Agricultural Extension. This information is collated and mapped by the National Biological Control Research Center (B. Napompeth, pers. comm.).

Remote sensing

Remote sensing includes aerial photography, radar, multi-spectral scanners and other sensors. The physical links between the targets observed and the remote sensing device are composed of electromagnetic energy, acoustic waves and force fields associated with gravity and magnetism. The most important medium for crop and vegetation surveys is electromagnetic radiation. Its use has been reviewed by Curtis (1978) and Cuthbertson (1978).

Since vegetation surveys demand repeated observations over large and sometimes relatively inaccessible areas, remote sensing techniques are useful for mapping and monitoring purposes (Curtis 1978). Furthermore, these techniques may be more cost effective for extensive areas as they require less input of manpower per unit area than field surveys.

The utilization of remote sensing techniques for weed surveys and control programs requires prior consideration of the target weed and how it differs from the background (Crown 1977). The aim is to prescribe the optimum type, time and scale of imagery to best discriminate target from background. The final selection of imagery type and scale will depend on the aim of the study, the degree of accuracy required, and technological and financial constraints.

Aerial photography. Aerial photography has been used extensively as an aid for vegetation mapping in a wide range of investigations including forest inventories, land-cover studies, vegetation communities and weed infestations (Barrett and Leggett 1979; Menges 1979; Everitt *et al.* 1984; Everitt 1985). It may also provide useful information about the target area such as access points, tracks, fencelines and watercourses. The most widely used technique has involved vertical aerial photography but the oblique and horizontal modes have also been used. The film types used are black and white (monochrome), colour, and colour-infrared. The usefulness of aerial photography depends on the quality of image produced, a factor determined by environmental conditions, film, filter and camera (Cuthbertson 1978).

Aerial photography can utilize a spectral range and resolution beyond the sensitivity of human eyesight and cloudy or hazy periods can be avoided. Different scales can be selected by varying the altitude of the aircraft or the focal length of the lens. The precise geometry of aerial photography allows for accurate determination of size, shape and position of objects (Kermond 1979), and height differences in vegetation or topography can be identified by stereoscopic viewing of overlapping prints.

A disadvantage of aerial photographic techniques which utilize wavelengths in the visible spectrum (0.4 to 0.7 micrometres), is that they are markedly affected by smoke and haze in the atmosphere. Accordingly, the clarity of the image diminishes and important detail may be lost unless conditions are ideal. In the Northern Territory and Thailand this is of particular importance as cloud cover during the wet season and haze and smoke from fires during the dry season are very common, thus reducing the opportunities for aerial photography.

Since 1953 the whole of Thailand has been covered by aerial photography at a scale of 1 : 50 000 and more recently at 1: 15 000. Data are available to government agencies and research organizations (Supajanya 1986). Black and white aerial photography at 1 : 80 000 covers the entire Australian land mass, and in many areas this data is supported by other scales and types of aerial photography (W.R. Stuchbery, pers. comm.). The usefulness of the 1 : 80 000 aerial photography for vegetation survey work is restricted by its chronology and type; however, it does provide a basis for comparison with recent data. Colour aerial photography at a scale of 1 : 15 000 has already been used to map the distribution of mimosa on the Adelaide River floodplain in the Northern Territory by scoring for presence or absence in 4-ha cells (W.M. Lonsdale, pers. comm.).

Vegetation identification from aerial photographs is highly dependent on variation in colour, tone and texture. Interpretation costs are a very significant component of the total cost and in one study exceeded material costs by 75% (Benson 1974). With monochrome photography, interpretation costs increase to compensate for the decrease in interpretation speed and accuracy. While colour film is more expensive than monochrome to process, it is likely to be interpreted faster and with greater accuracy.

Colour photography has the advantage of providing useful information about the vegetation present, e.g. its suitability for burning and other species present in the area. Variation in colour between prints may result from such factors as the angle of the sun, processing materials and techniques, but this variation can be reduced using 'colour balance' methods (W.R. Stuchbery, pers. comm.).

Colour-infrared photography (CIR), using standard film sensitive to infrared radiation (at 0.9 micrometres) is also subject to tonal variation (G.J.E. Hill and G.D. Kelly, pers. comm.), though it is not greatly affected by atmospheric haze. Different plant species and diseased or dying vegetation appear as different tones of red. Changes in the infrared reflectance of vegetation brought about by tissue damage occur before they are visible to the naked eye. CIR photography has been used for early prediction of the mortality of plants due to herbicide application with 90% accuracy (Young and Evans 1972), and to evaluate the biological control of submersed aquatic weeds by grass carp (Martyn *et al.* 1986). Barrett and Leggett (1979) found that reliable results could be achieved with aerial CIR at scales up to 1 : 85 000, in cloud-free conditions, to identify the severity of *Echinochloa* infestations in individual paddocks.

This method could possibly be used to map and quickly assess the effectiveness of herbicidal or biological control measures on mimosa. Initial results obtained with aerial CIR on mimosa in the Northern Territory were promising. In December 1984 (early wet season), colour and colour-infrared photography was taken of vegetation containing mimosa, from approximately 20 m altitude in a helicopter. With CIR, it was possible to discern the mimosa from the other species more effectively than with colour photography. Similar results have been obtained at much higher altitudes. In late April 1985 (end of the wet season) CIR aerial photography at 1 : 18 000 clearly revealed areas of mimosa on the Adelaide River floodplain (Figure 3).

Further investigation of CIR aerial photography should be aimed at investigating choices of scales, filters and the time of year when mimosa is most easily identified. It is important to know whether mimosa has a characteristic 'signature' as distinct from other wetland species and, if so, at what scale and season this signature is most pronounced.

Most of the problems associated with the use of aerial photography for locating target species are related to interpretation of the data. Traditionally, photographic prints have been interpreted by eye based on such elements as size, shape, shadow, tone, colour, texture, pattern, location, association and resolution. This form of analysis is subjective, time consuming and expensive, and may not be suitable for a large-scale survey.

To keep costs to a minimum, it is necessary to find an efficient method of analysing large amounts of data. This may be achieved through computer-assisted interpretation of digitized aerial photography, although differences in tone between prints may present difficulties. Briefly, this method involves the scanning of photo prints by a microdensitometer which enables separation of units according to variation in their reflection of energy. A computer is used to compare and recognize areas of similarity and to develop a classification according to the requirements of the study. Scarpace *et al.* (1981) found that digital analysis of aerial imagery provided high resolution information (with approximately 90% accuracy) for monitoring and mapping large areas of wetlands. This method was also used by Everitt and Villarreal (1987), who found that computer analysis of conventional colour and CIR film transparencies can be used to quantify mature huisache (*Acacia farnesiana*) and Mexican palo-verde (*Parkinsonia aculeata*) infestations on rangelands. A disadvantage in using this method for widespread rangeland weeds is the large number of photographs requiring analysis.

Multiband scanners. Multiband or Multi-Spectral Scanners (MSS) are equipped with sensors capable of detecting radiation at different wavelengths and may be fitted to aircraft or satellites. These systems operate by absorbing reflected radiation from the earth's surface and quantifying the energy within specific areas of the electromagnetic spectrum (Bauer 1975). Data are collected in digital form on magnetic tapes which may be translated into pictorial representations of the scene for visual analysis, or analysis may be automated by using computers.

MSS imagery has been recorded by a series of Landsat satellites which commenced operation in 1972 (Anon. 1982). Landsat data is collected by receiving stations in Australia, Thailand and other countries, and is usually available for retrospective over-passes from which comparisons can be made with recent data. The current satellite (LANDSAT 5) circles the earth in a sun-synchronous, near-polar orbit which provides coverage of the same spot every 16 days (Creevey 1985). A Landsat MSS image covers an area of 185 km x 185 km and is made up of 7.5 million picture elements or pixels, each representing just under 80 metres square or 0.6 ha (Anon. 1982). Multiband scanners in Landsat satellites convert the radiation into a range of tonal values in each of four selected wavelength bands, green (0.5 – 0.6 micrometres), red (0.6 – 0.7), near infrared (0.7 – 0.8) and infrared (0.8 – 1.1) (Anon. 1982; Cuthbertson 1978; Myers *et al.* 1985).

LANDSAT 4 and 5 have another sensor, called a Thematic Mapper (TM), which has a resolution of 30 x 30 m and seven spectral channels within the range 0.45 to 12.5 micrometres (van den Brink *et al.* 1986). Not only is the resolution of the TM better, but the positional accuracy is ±28 m as opposed to ±200 m for a standard LANDSAT 5 MSS product. Unfortunately, the cost of TM data is significantly greater than that of MSS data — some six times more for the same area covered.

Multiband images have three advantages over the single broad-band images of conventional photographs. They increase the dynamic range of intensity captured as compared to the film system, have a capacity for combining bands to enhance given surface resources and can present information in wavelength intervals that are suitable for observing particular surface phenomena (Anon. 1982).

While traditional photo-interpretation techniques may be used for MSS data, computer analysis provides a more efficient and accurate alternative. Statistically calculated decision boundaries are developed to identify chosen 'signatures' within the range of natural variation. This range may be improved by accepting temporal and spatial variations (Cuthbertson 1978), i.e. variation of the signature over time and/or location. This is of particular importance for vegetation studies, due to the large variation in reflectance that may occur seasonally or between sites.

Computer hardware and software packages have been developed for analysis of digital data. For example, the BRIAN (Barrier Reef Image Analysis) system permits the user to develop a sensible, ecological interpretation (Jupp *et al.* 1985; Myers *et al.* 1985). BRIAN software has been transferred for use on microcomputers to make it more accessible and is now commercially available as micro-BRIAN. Most 16-bit microcomputers with a hard disc could use micro-BRIAN, although a separate colour display unit is required (P. Martin, pers. comm.). Rectified imagery can be produced to overlay on published maps, charts and other images needed for field analysis (Myers *et al.* 1985).

Although the spatial resolution of Landsat MSS imagery is quite coarse (areas of 0.6 ha or less may not be detected), it has been suggested as a method to monitor the distribution of weeds (Cuthbertson 1978; Auld 1984). It would be particularly useful for large target areas where the use of other remotely sensed data is too expensive.

In the Northern Territory, large thickets (0.5 km^2) have been identified by Landsat MSS imagery at scales of 1 : 250 000 and 1 : 500 000 (A. Press, pers. comm.). In north Queensland, it has already been used

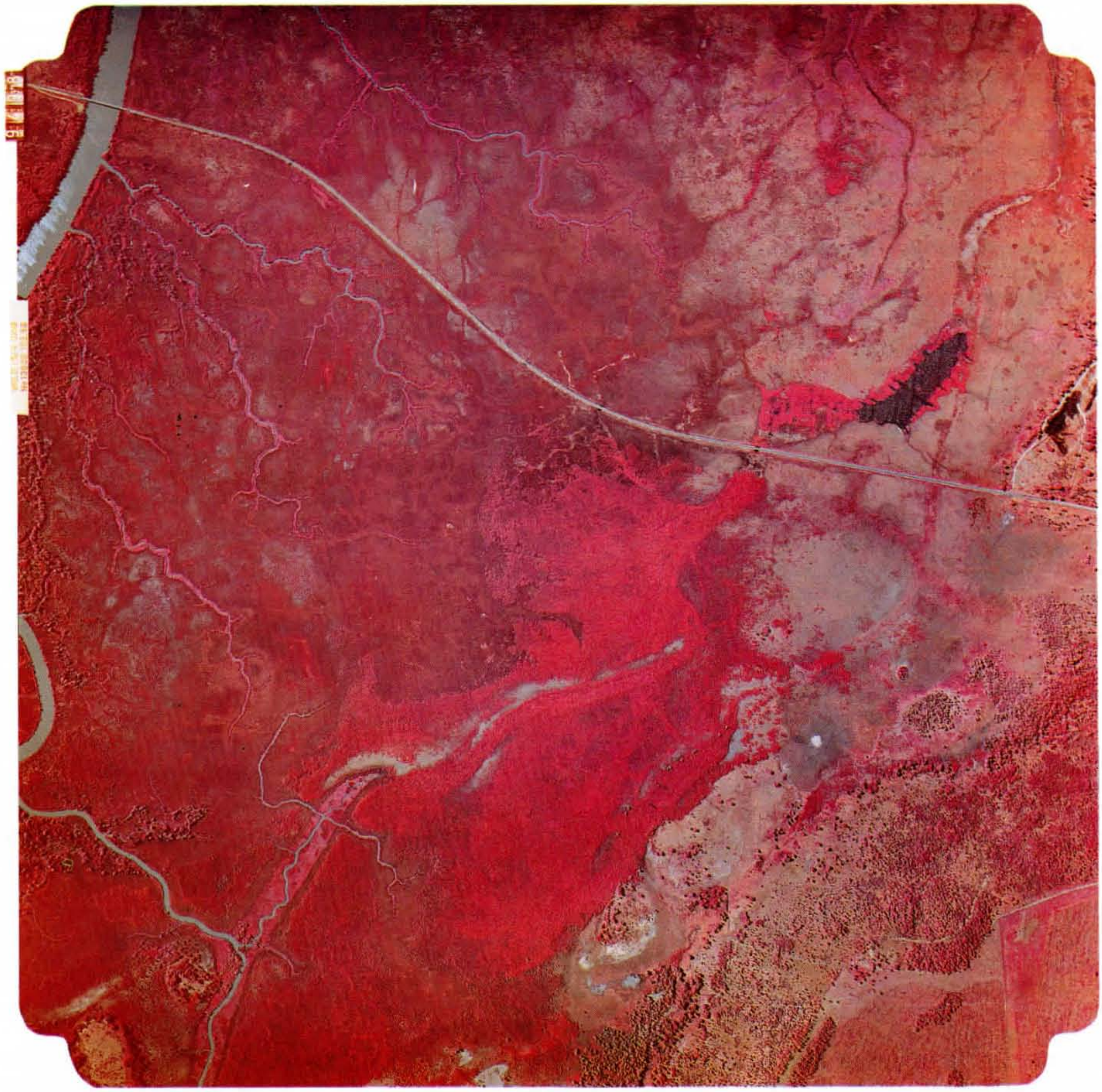

Figure 3 Colour-infrared photography of *Mimosa pigra* on the Adelaide River floodplain at 1 : 18 000, April 1985. Mimosa appears bright red near the centre of the photograph. The dark patch on the top right-hand side was previously aerially sprayed with Banvel 200 (dicamba) at 1.2 kg a.i. ha^{-1}.

to assist in the mapping of another woody legume, *Acacia nilotica* (M.P. Bolton and L.M. Kirchner, pers. comms). In Thailand, computer-analysed data of Kiu Lom reservoir showed the usefulness of Landsat MSS to survey changes in mimosa infestations (Shibayama *et al.* 1983).

A recent investigation into mapping mimosa in the Northern Territory from Landsat TM data indicated the potential of this method for detecting the weed and distinguishing it from other shrub and woody vegetation (Fitzpatrick *et al.* 1988). Multispectral scanning from aircraft may also be useful for the detection of mimosa. It offers more wavelength bands and superior resolution compared to current satellite data, and the same computer-assisted analysis methods as those used for Landsat digital data. Costs, however, may restrict the opportunities for using this method.

The French satellite SPOT (Systeme Probatoire d'Observation de la Terre) which was launched in February 1986 has better resolution and coverage than Landsat. SPOT data have a 20-m colour or 10-m broad-band (black and white) resolution, more frequent sampling of specific target scenes, and provision for stereo coverage of important areas (Chevrel *et al.* 1981). The data are available in Australia and could prove very useful for weed surveys, but are considerably more expensive than Landsat MSS data.

In some situations, a choice must be made between satellite imagery and aerial photography as a primary data source. The expense, time and difficulty in obtaining and analysing large amounts of aerial photography are the main disadvantages of using this method, although the inferior resolution of satellite data may undermine its economic advantages. A study of an estuarine environment in Western Australia by Hick (1979) indicated that, while the spatial resolution of Landsat data was barely adequate, repetitive aerial photography would require funds possibly out of proportion to the results. In general, Landsat MSS imagery is favoured where suitable, owing to its lower cost per unit area — about a tenth of that of infrared aerial photography (Creevey 1985).

Satellite imagery must be supplemented, by traditional data-gathering methods which may result in increased costs in the short term. However, it has the advantages of obtaining repetitive measurements and it ignores political and administrative boundaries (Creevey 1985).

Radar imagery. In comparison to other remote-sensing techniques, radar has some unique characteristics. It is an active, single-frequency system which depends on the relative intensity of reflected energy pulses to produce images (Cuthbertson 1978). Consequently, this method can be used day or night and is not affected by cloud cover or other environmental factors. It is useful for discriminating height variation of vegetation or topography.

The main disadvantages of this method are the coarse spatial resolution and the single-frequency image (Bauer 1975). Virtually all vegetation radar work is experimental and the resolution is such that it is unlikely to be of value for mapping mimosa. (G.J.E. Hill and G.D. Kelly, pers. comm.).

Video imagery. Recently, video imagery from aircraft has been investigated as another remote-sensing tool for range management. Everitt and Nixon (1985) have evaluated a multi-video system to assess several ecological rangeland ground conditions in southern Texas. They used narrow-band black and white imagery within the visible to near-infrared waveband of the electromagnetic spectrum to detect many variables including the presence of weeds. By selecting different filters, they were able to achieve better discrimination of the targets.

There are several advantages of using this method, the most important being the rapid data collection and analysis. Unfortunately, it does not have as sharp a resolution as photographic film and the use of this method for a large survey is restricted by technical and financial constraints, similar to those applying to aerial photography. It is unlikely therefore to be of greater use than conventional aerial photography or satellite imagery for detection of mimosa.

Conclusions

The survey method adopted for a weed will depend on the objective of the survey, the accuracy required and the resources available. The location of unknown infestations is the most difficult objective to achieve. With mimosa, its rapid seed production and longevity of seed make it desirable to detect and control individual plants in the field before they seed. Literature citations, herbarium records and questionnaires will not provide the necessary information from which control decisions can be made, or for the monitoring of control programs.

For the present it is necessary to continue developing a survey system based on the existing methods of field surveys from the ground and air, combined with increased public awareness of the mimosa problem to stimulate public reports. These methods should continue to be the major source of information for detecting new, isolated infestations and for mapping the expansion of mimosa in both countries. However, remote sensing methods should be used where applicable.

At present, Thailand is adequately covered by the Agricultural Extension network and the reporting of isolated infestations should improve as officers become more proficient in identifying the plant.

The Northern Territory is in a different position because of its low population density, the large area to be covered by survey teams and seasonal inaccessibility. Therefore remote-sensing techniques have more relevance in Australia, although they may be useful for assessing the success or failure of chemical and biological control in Thailand.

The only remote-sensing technique available with a resolution capable of detecting individual plants is large-scale aerial photography, which is far too expensive for a broadly based survey. Large infestations may be detected and monitored by small-scale aerial photography or by the satellite imagery currently available, but this requires further investigation. Certainly, as technology improves the resolution available from satellites will improve. Investigation of remote-sensing techniques is required to determine whether there is a particular spectral region in which mimosa may be discriminated from its background, whether there is a particular time of the year when spectral differences between target and background are at a maximum, the most suitable enhancement techniques available and the critical point where costs must be weighed against detail lost. Colour-infrared photography should be further investigated to ascertain optimal combinations of variables such as seasonal conditions, photographic scales and filters suitable for identifying and, if possible, emphasizing the presence of mimosa.

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