Advances in weed distribution mapping

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INTRODUCTION

Successful weed management calls for a co-ordinated systematic approach to all efforts directed either at eradication or control. In the one instance the desirability and feasibility of eradication depends to a large extent on the probability of reinfestation; in the other the locale dictates the control techniques employed. In both situations the whereabouts and extent of the infestation must be known as accurately as possible to provide the answer to the immediate problem.

Despite this requirement, there is little readily available, accurate, published information on the distribution of weeds in Australia. This is largely due to the time-consuming methods of data collection and collation previously available for dealing with the masses of information usually required. Currently, however, automatic data-processing techniques, able to digest large data sets rapidly, have done away with these tedious hand-sorting and mapping methods (Williams and Lamberts, 1960; Heath and Perring, 1975; Smith, 1975).

This paper looks at data collection methods and summarizes some of the advances made in vegetation data collection, processing and interpretation which may be useful in weed distribution studies.

DATA COLLECTION

Preparation of weed or vegetation maps comparable with others prepared previously or in the future, requires that the area in question be surveyed as thoroughly and evenly as possible. Thus distribution studies over an area the size of Australia provide some problems in using conventional methodology.

A number of techniques can be used with varying degrees of accuracy. They are literature review, herbarium samples, questionnaire, field surveys and remote sensing.

Literature reviews and Herbarium samples

Literature citings, Departmental records and herbarium samples are a useful start but they are rarely sufficient in themselves. Literature citings, other than floras, are often the results of collections in limited areas and herbarium samples are usually in a similar category; well known species, for example, are rarely forwarded for identification from what may be a new location.

Consider Figure 1, which depicts the distribution of Johnson grass (*Sorghum halepense*) and silver-leaf nightshade (*Solanum elaeagnifolium*) in New South Wales. The distribution of Johnson grass is based on information in "Contributions from the New South

Wales National Herbarium - Flora Series. No. 19, Pt. 1, 1961 pp 31-32" (Vickery, 1961). It is wrong on three counts! Considering the listed collection sites, the filled circles, then the indicated infested area, bearing in mind the weeds' aggressiveness, is probably insufficient. Secondly, a generalized statement of distribution says, '... naturalized in coastal and tableland districts and in irrigation districts elsewhere ...' (shown as the open circles), with the added rider '... chiefly in arable areas'. Thus, the correct interpretation for mapping purposes presupposes a prior knowledge of the distribution of arable lands, and the distribution depicted is in excess of actuality. Finally it makes no allowance for apparently non-reported infestations occurring in some of the naturally better watered areas of the Central Western Slopes readily observable by travellers in that area.

Questionnaires

Questionnaires can be used to provide a general idea of weed distribution in a relatively short period of time. Preparation of the data requires the co-operation of a large number of individuals. The accuracy of the resultant map, however, is a function of the number of answers received, and the ability of the co-ordinator to visit the non-answering areas and complete the survey forms required. Alex (1966) in his comment on such a survey states '... I visited several areas and completed forms for most of the municipalities from which information had not been received. However, a member of municipal units ... were not visited so survey information was not available ...'.

More information can be requested now than was the case when Alex conducted his survey because of computerization. But the major problem - lack of response - has not disappeared (Smith, 1975).

Field surveys

The best method of collecting weed distribution data presently available is the field survey. These are possibly only where sufficient workers, scattered over the survey area, belong to the one organization and can be directed to participate, or where several groups from different organizations are prepared to co-operate as was done in a recent silver-leaf nightshade survey in this country. In either event appropriate sampling systems must be evolved.

A stratified random sampling procedure used to select sampling sites, in which a goal of 1000 sites was set, is described by Thomas (1976). These 1000 sites were distributed over each of 41 Agricultural Extension Districts or strata. The number in each stratum was determined by the proportion of cultivated land in the District relative to the total cultivated acreage in the sampling area. This number of Township-range combinations was randomly chosen and, in turn, a section in each Township-range area and a quarter section (field) of each section, were also chosen at random. The quarter section became the sampling site. The sampling unit consisted of twenty 50 cm x 50 cm quadrats set down at 20 pace intervals from a set point in the field. The density of all weeds in each quadrat was recorded.

In a survey of arable weeds in Britain (Chancellor, 1977) volunteer workers were asked to record the presence or absence of forty named weed species in 2 km x 2 km squares or tetrads. The tetrads were positioned according to the Ordnance Survey Nation Grid lines. The choice of tetrad and the sampling procedure was left to the individual recorder on the assumption that each would have a knowledge of the local flora. A total of 668 tetrad reports out of a potential 65,000 were received. A similar system was employed in a survey of the South Australian distribution of silver-leaf nightshade (Smith, 1975). In this case the unit of area was the hundred, a statistical division in South Australia.

Until recently the practical limitations of hand-computation have restricted the amount of information sought in such surveys. Nowadays, although the personnel required for field work are still a limiting factor, the availability of automatic data-processing techniques, makes it desirable to record all possible information about the individual species. Individual Weed Record Cards (Figure 2) with space to record such items as abundance, altitude, aspect, habitat and soil and water relationship can be used to facilitate the handling of this type of data. By so doing the relationship between distribution and some or all of the environmental parameters may become apparent.

Remote sensing

More sophisticated techniques termed "remote sensing" are now being employed in the characterization of some agricultural phenomena. These techniques, which are broadly defined by Shepherd and Totterdell (1974) as '... the acquiring of information about ground conditions from an aerial platform by using techniques which record energy from within the electromagnetic spectrum', provide a permanent record of events less subject to bias errors in ground assessment data. Several variants of the concept including the use of satellites have been investigated (Colwell, 1956, 1964, 1973; Bauer, 1975).

The process is based on the ability of modern photographic film to detect, with the aid of appropriate filters, different bands of the electromagnetic spectrum. Thus it has been possible to record on film and identify vegetation stressed by disease or insect pest (Colwell, 1956; Wallen and Jackson, 1971). This application of remote sensing, including methodology, is succinctly reviewed by Chiang and Wallen (1977), who concluded that '... detection of insect and disease outbreaks and their assessment by aerial photography offers several advantages over conventional methods'.

The early detection of pest and disease stressed plants photographically relies on reflectance changes brought about by tissue damage. Collapse of the spongy mesophyll or a plugging of the tissue with fungal hyphae causes a significant reduction of reflectance in the infrared (0.72 to 0.9 μm) wavelengths: a change that usually occurs long before any reflectance change in the visible spectrum (Colwell, 1961). This early response to tissue damage was recently used to predict the effect of herbicide application. Colour infrared transparencies of green rabbit brush (*Chrysothamnus viscidiflorus*) were taken 2 to 4 weeks after spraying with 2,4-D. Comparative reflectance measurements allowed prediction of shrub mortality or partial mortality, with up to 90% accuracy nearly one year before field observation (Young and Evans, 1972). Satellite and high altitude infrared photography have also been used to identify and map pastoral land vegetation in Australia (Colwell, 1968), to identify emerged aquatic plants and to monitor changes in distribution of these, algal scums and rangeland brush vegetation as a result of ongoing control programs (Wrigley and Horne, 1974; McDaniel et al, 1975; Benton and Newman, 1976). Thus, since Bauer

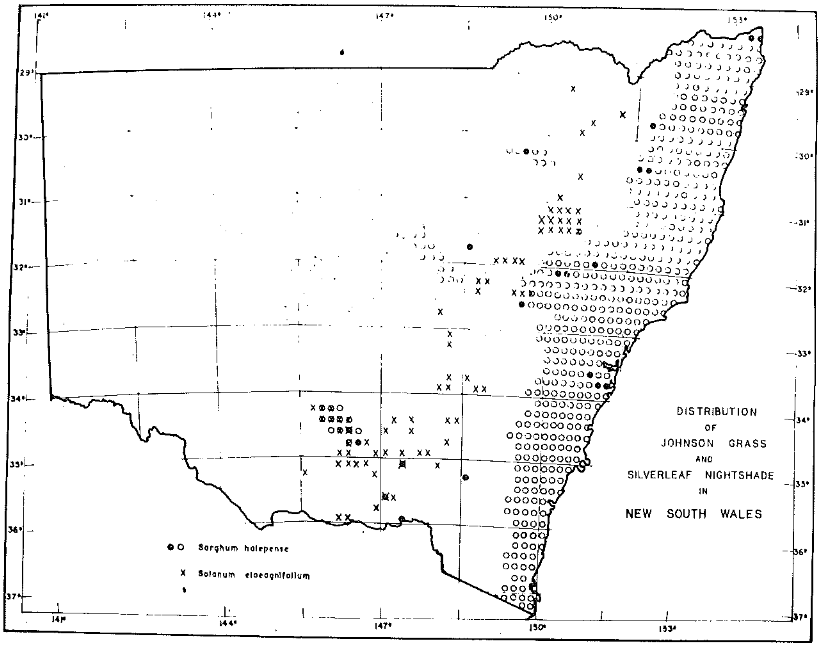

Figure 1 : Distribution of Johnson grass in New South Wales based on details given in printed flora (see text) and of silver-leaf nightshade based on field survey data.

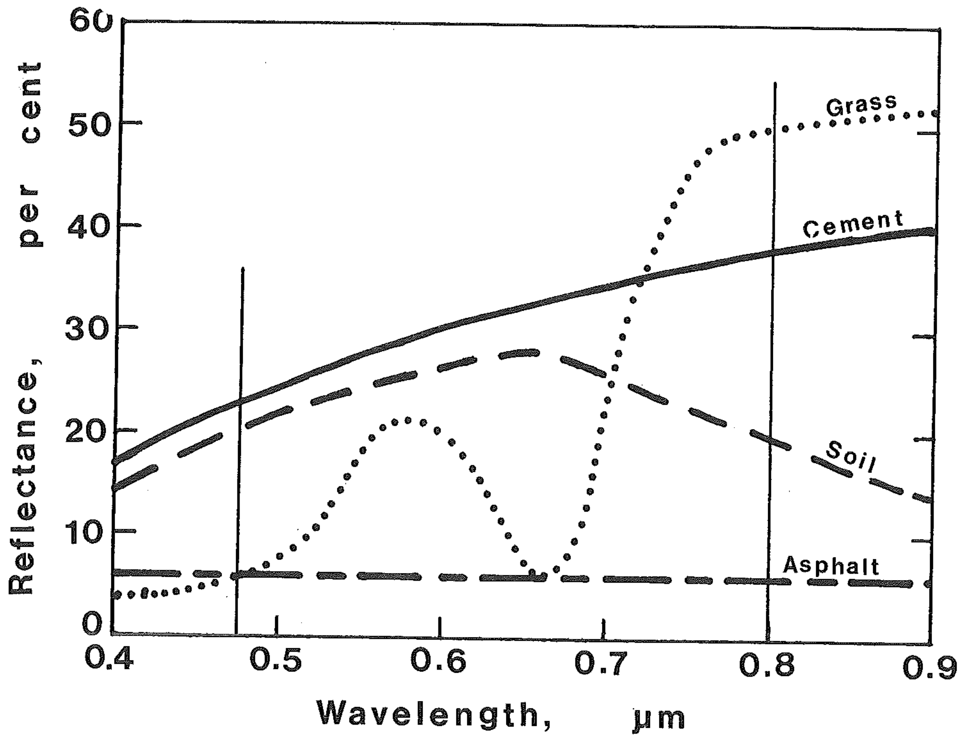

Figure 3 : Energy reflectance by different surfaces (Adapted from Colwell, 1961).

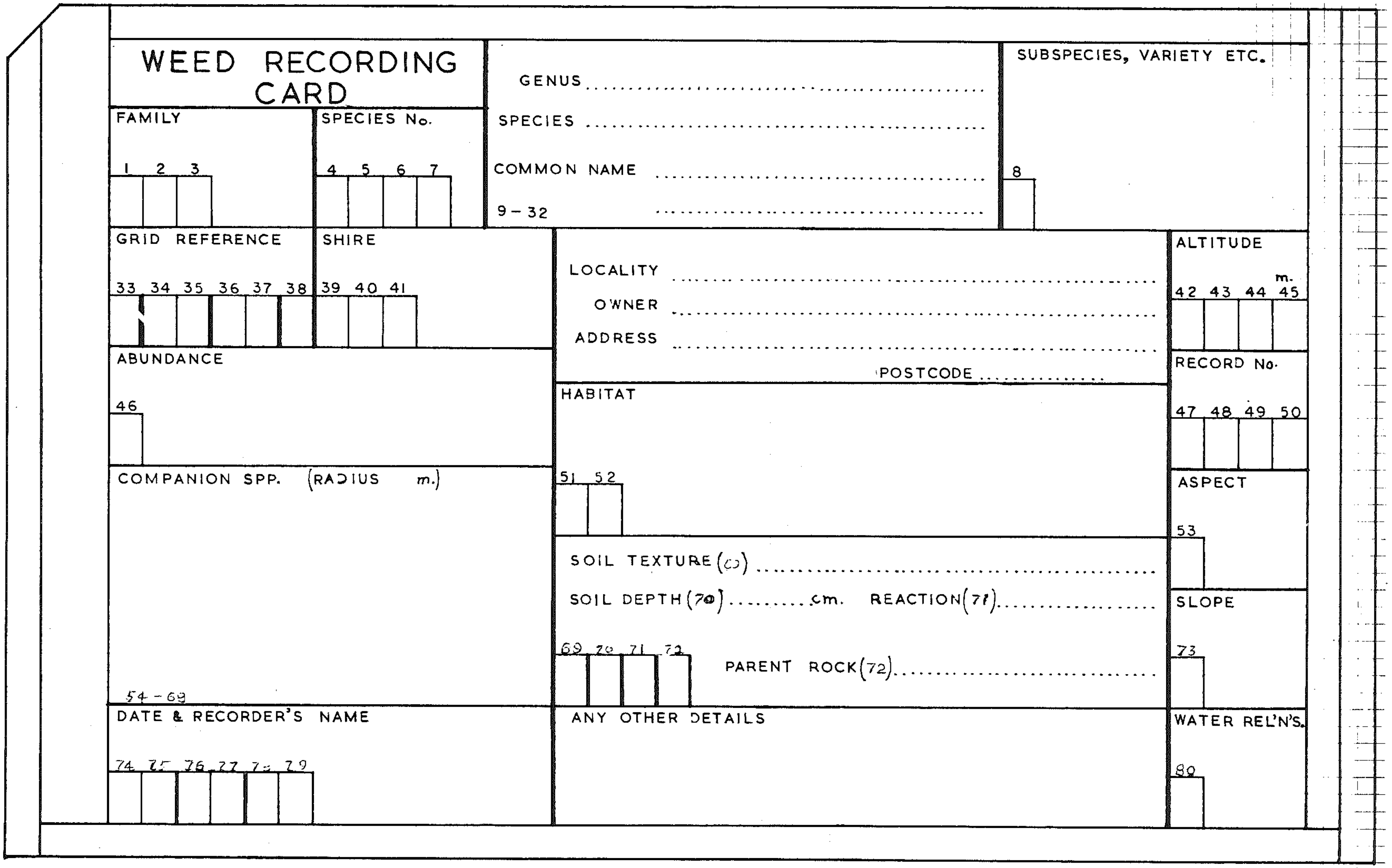

Figure 2 : Weed Record Card under test in New South Wales Department of Agriculture.

(1975) lists crop identification and area estimation, crop condition assessment, yield forecasting, rangeland surveys and soil mapping as promising agricultural applications of satellite imagery, I can see no reason why the same approach cannot be used to identify and map weed infestations.

Characterization

Basically, remote sensing records the electromagnetic energy reflected and emitted from the target area. Such radiation includes a wide range of wavelengths. Each feature, for example, rock, soil type, crop, has its own characteristic spectral composition exhibited as different brightness values in a series of multiband photographs. Theoretically, once identified, any feature can be recognized on multiband photographs of the appropriate wavelength. Feature identification, however, is usually improved by measuring and analysing the energy from a number of discrete wavelength bands rather than the whole spectrum (Bauer, 1975).

Energy sources

Except where active sensors like radar are employed the sun is the source of all outgoing energy from the earth's surface. The amount and spectral composition of the energy reaching the earth and, subsequently, the sensor, however, varies with sun angle and atmospheric transmissibility. Total radiation levels are affected by latitude, season and time of day. Visible spectrum levels are reduced as the number of haze, dust and smoke particles increase while infrared and ultraviolet wavelengths are absorbed as the concentration of water vapour, carbon dioxide and ozone increases. In practice, only those wavelengths between 0.3 µm and 100 cm which have high atmospheric transmission are used in remote sensing work (Bauer, 1975).

Of the radiant energy reaching the surface some is immediately reflected back into space. The remainder is absorbed but some is reradiated to space later as thermal infrared radiation, according to the Stefan Boltzman Law. Thus energy levels at the sensor are also affected by surface features, particularly the vegetation.

In the individual leaf, reflectance depends on the diffuse nature of the cell wall (Sinclair et al, 1973). It is low in the visible spectrum because of absorption by the chlorophylls. Conversely, it is relatively high in the near-infrared zone although water absorption reduces reflectance and emittance in some of these wavelengths. Reflectance also varies with plant age, water content and nutrition (Thomas et al, 1966; Sinclair et al, 1973; Al-Abbas et al, 1974).

Canopy reflectance and emittance is an even more complex process. As well as maturity differences due to species, seasonal growth pattern, soil type and water content, it also depends on leaf area, ground cover and a number of other variables. Bauer (1975) for example reports a linear increase of reflectance as leaf area index (L.A.I.) rises from 0.5 to 3.0. In addition, disease and pest incidence, wind flow, angle of solar incidence, rainfall pattern and soil salinity all play a part. (Colwell, 1956; Thomas et al, 1967; Hart and Ingle, 1969; Bauer, 1975). In a cropping situation these variables are intensified by maturity differences due to variety and planting dates, fertilization, planting direction and row width.

Sensors

Identification of the various objects in the target area is obtained by monitoring the reflected and emitted energy wtih two or more sensors. Each is adapted to record energy, usually photographically, in a specific wavelength band. Colwell (1961), for example, shows that soil, grass, cement and asphalt surfaces can be recognized by comparing tone differences on positive prints taken from Pan-Wratten 25A and Infrared - Wratten 89A film-filter combinations although the surfaces cannot be positively identified in either of the individual photographs (Table 1).

Table 1. Tone characteristics separating soil, grass, cement and asphalt surfaces in photographs taken with specific film-filter combinations (From Colwell, 1961)

Type of surface	Tone on positive prints	
	Pan - 25A	Infrared - 89A
Soil	light	dark
Grass	dark	light
Cement	light	light
Asphalt	dark	dark

Note the Pan-25A combination records in the 0.6 to 0.7 μm and the Infrared-89A combination in the 0.7 to 0.9 μm wavelength bands.

According to Bauer (1975) radiation in the visible, reflective-infrared, thermal-infrared and microwave portions of the electromagnetic spectrum has most potential in agricultural surveys. The more important sensors in these wavelengths are aerial photography, multispectral scanners and radar.

Aerial photography

The earliest used and best known remote sensing device, aerial photography, supplemented by appropriate on-the-ground observations, is still a valuable means of recording ground information. Its usefulness, however, depends on the quality of the image produced, a factor determined by environmental conditions, film, filter and camera.

Specifically designed multiple cameras are normally used but, because of the wide range of film types available (both black and white and colour), choice of film and filter depends on the particular objectives of the exercise. However, aerial panchromatic film becomes increasingly red sensitive and requires longer exposure as granularity decreases. Tonal contrast in photographs is not only affected by the reflectivity of the target surface but also by atmospheric absorption and scatter due to gas moleucles and other haze producing particles in the air. But, although light intensity is greatest and scatter least at noon, forenoon photography has been found to give better contrast resolution than noon or afternoon runs (Chiang et al, 1973). Image enhancement processes (Meyer and Chiang, 1971; Jackson et al, 1974) are important recent advances in aerial photography.

Multiband scanners

These are mechanical scanners in which an oscillating mirror reflects energy from a small part of the target surface through an optical system to a group of detectors sensitive to different bands of the spectrum. The detector outputs are recorded on magnetic tapes after suitable amplification. Multiband scanners of this type in Landsat satellites convert the radiation into 64 tonal values in each of four selected wavelength bands, 0.5 to 0.6, 0.6 to 0.7, 0.7 to 0.8, and 0.8 to 1.1 μm (Bauer, 1975; Bishop, 1977). The unit of data is the reflected energy from a 79 metre square instantaneous field of view, the numerical value of which in the range 0 to 63 provides the picture element or pixel (Bernstein and Stierhoff, 1976). This data is later transformed into black and white transparencies and is printed through colour filters to give simulated false-colour infrared images.

Radar

An active, single frequency remote sensing system, radar depends on the relative intensity of reflected energy pulses to produce images. The main advantages of radar are its day-and-night capability and its ability to penetrate cloud. Its disadvantages are a coarse spatial resolution and the single frequency image (Bauer, 1975).

Interpretation

The graphic images provided by all remote sensing systems can be interpreted manually. But, while this may be the best method in some circumstances, the overwhelming amount of data usually provided far outstrips the capabilities of the available manpower. As a result a computer based, numerical method of analysis has been developed.

Numerical analysis relies on the relative intensities of energy reflected in chosen wavelengths. The principal is summarized by Bauer (1975). Briefly, reflected intensities in two different wavelengths are compared as a two-dimentional feature. For example, grass, soil, cement and asphalt surfaces are separated by tonal differences in different wave bands (Table 1). In Figure 3, the reflection of these surfaces is graphed as a function of wavelength. By selecting two wavelengths and plotting the intensities recorded as a two-dimensional feature (Figure 4), the surfaces with different wavelength responses fall in different segments of the feature space. These points can be considered as their spectral signatures. Natural variation is accepted and statistically calculated decision boundaries are developed. Response-surface matrices using three wavelength bands are a logical extension of the two-dimentional signature. Classification can also be improved by temporal and spatial variations. Thus by using a detailed ground sampling of carefully chosen sites the computer can be programmed to identify surfaces with similar signatures on the overall image (Colwell, 1973). Vegetative and reproductive phenophases of plants vary. Consequently, where imagery is to be used in conjunction with weed control programs, the biological parameters of site, competition and plant age must be accounted for in the design of such computer programs (Young and Evans, 1972).

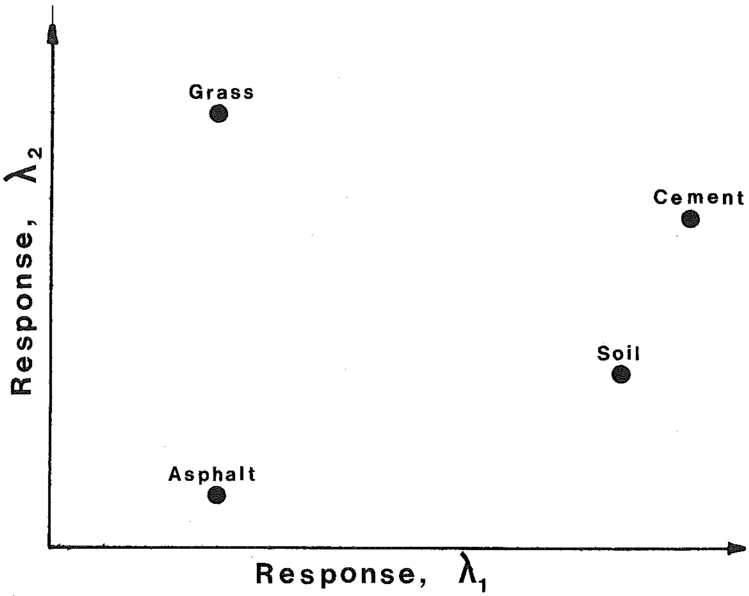

Figure 4 : Reflectance response of four surfaces relative to one another for two selected wavelengths. (Developed from data in Bauer, 1975 and Colwell, 1961).

	49	50	51	52	53	54	55	56	
SC						501 502			SC
				301 302	303 304 305 306	503 504			
SD				307 308	309 310 311 312	505 506			SD
				101 313 314	315 316 317 318	507 508			
			102 103	104 105 319 320	321 322 323 324	509 510	511		
			106 107	108 109 325 326	327 328 329 330	512 513	514		
SE			110 111 112	113 114 331 332	333 334 335 336	515 516 517 518	519 520		SE
			115 116 117	118 119 337 338	339 340 341 342	521 522 523 524	525 526		
			120 121 122	123 124 343 344	345 346 347 348	601 602 603 604	605 606		
		125	126 127 128 129	130 131 349 350	351 352 353 354	607 608 609 610	611 612 613		
SF		132 133 134 135	136 137 138 139	140 141 355 356	357 358 359 360	614 615 616 617	618 619 620 621		SF
		142 143 144 145	146 147 148 149	150 151 361 362	363 364 365 366	622 623 624 625	626 627 628 629	630	
	152	153 154 155 156	157 158 159 160	161 162 367 368	369 370 371 372	631 632 633 634	635 636 637 638	639	
	163	164 165 166 167	168 169 170 171	172 173 373 374	375 376 377 378	640 641 642 643	644 645 646 647	648 649	
SG	174	175 176 177 178	179 180 181 182	183 184 379 380	381 382 383 384	650 651 652 653	654 655 656 657	658 659 660	SG
	185	186 187 188 189	190 191 192 193	194 195 385 386	387 388 389 390	661 662 663 664	665 666 667 668	669 670 671	
	201	202 203 204 205	206 207 208 209	210 211 401 402	403 404 405 406	407 408 672 673	674 675 676 677	678 679 680	
	212	213 214 215 216	217 218 219 220	221 222 409 410	411 412 413 414	415 416 681 682	683 684 685 686	687 688 689	
SH	223	224 225 226 227	228 229 230 231	232 233 417 418	419 420 421 422	423 424 690 691	692 693 694 695	696 697 698	SH
		234 235 236 237	238 239 240 241	242 243 425 426	427 428 429 430	431 432 701 702	703 704 705 706	707 708 709	
		244 245 246 247	248 249 250 251	252 253 433 434	435 436 437 438	439 440 710 711	712 713 714 715	716 717 718	
		254 255 256 257	258 259 260 261	262 263 441 442	443 444 445 446	447 448 719 720	721 722 723 724	725 726 727	
SI		264 265 266	267 268 269 270	271 272	449 450 451 452	453 454 728 729	730 731 732 733	734 735	SI
		273 274 275 276	277 278 279		455 456 457	458 459 736 737	738 739 740 741	742 743	
		280 281 282 283	284 285		460 461	462 463 844 745	746 747 748 749	750	
		286 287			464 465	466 467 851 852	753 754 755 756	757	
SJ					468	469 470 858 859	860 861 862 763	764	SJ
						471 865 866	867 868 869 870	771	
						472 872 873	874 875 876		
							877 878		
SK							979 980 981		SK
							982 983 984		
							985 986 987		
							988 989 990		
	49	50	51	52	53	54	55	56	

Figure 5 : The D.D.H.G. major grid numbering system. The large grid superimposed over the map is that used by the Division of National Mapping for cataloguing the 1:250,000 survey maps (From Brook, 1976).

The simplest method of distribution mapping is the adoption of an appropriate grid i.e. noting the presence or absence within a grid-square area rather than at a co-ordinate point. The principal advantage of the grid system is that it is repeatable; each grid square is, in effect, a large quadrat. According to Brooke (1976), however, '... the fundamental problem in designing a national grid system is to balance two partly conflicting requirements: standardization which permits efficient flow of data, and flexibility, which allows requirements of the individual to be satisfied ... grid standardization with flexibility can be achieved with a series of standard grid sizes provided each is an exact multiple of the next smaller grid'.

In Britain the 10 km squares of the national grid are used, basically because they are marked on all Ordinance Survey Maps (Heath and Perring, 1975). This grid, the Universal Transverse Mercator (U.T.M.) is also being adopted elsewhere. In Australia, maps printed with the Australian Map Grid (A.M.G.), which is based on the U.T.M., covering all of the continent are unlikely to be available for some time. Further, since the continent needs to be divided into eight zones to preserve the rectangular nature of equal area grids, there are seven discontinuities at the zone boundaries. Such discontinuities provide problems in the production of type-writer "print-out" maps.

The Degree by Degree-and-a-half Grid (D.D.H.G.) system

Because of these problems Brook (1976) proposed a grid system based on geographic co-ordinates corresponding to latitude and longitude lines bordering the standard 1:250,000 topographical survey maps produced by the Division of National Mapping, Commonwealth Department of Minerals and Energy.

Briefly, each standard map sheet, which covers one degree of latitude and one and a half degrees of longitude is accepted as a major grid. Each major grid is identified by a three figure number. The first digit denotes the State (Figure 5) and the remaining two digits the approximate position within the State. Along winding State borders the first digit depends on which side of the border the record occurs.

Within each major grid are fifty four minor grids each 10 minutes of latitude by 10 minutes of longitude. They are identified by a series of two-digit numbers 01, 02, 03 ..., 54. Thus, five digits completely specify a minor grid. On this system the Wagga Agricultural Research Institute (A.R.I.) buildings would be recorded as 75503. They might be hard to locate as the reference only shows that they occur somewhere in a 10,000 ha area.

To give greater resolution each minor grid is divided into four quarters 5' x 5' in area. These quarter grids are numbered 1 to 4 and a sixth digit is added to the minor grid reference number. The location of the A.R.I. becomes 755031.

Considering even greater resolution was desirable in some weed surveys I divided the minor grid into 25 minigrid squares each 2' x 2' in area, numbered thus:

a	b	c	d	e
f	g	h	j	k
l	m	n	o	p
q	r	s	t	u
v	w	x	y	z

Note that the letter "i" is omitted. For coding the sixth digit of the quarter grid reference is replaced by the appropriate lower case letter. Thus the A.R.I. is defined as 75503f and, with only about 400 ha to search over, becomes easier to find.

Convenient mapping units defined by Brook (1976) are the nanogrid a 3 x 3 block of minor grids, and the supergrid a 3 x 2 block of major grids (3^0 x 3^0). Within each major grid the six nanogrids are specified by the upper case letters:

A	B	C
D	E	F

Each nonogrid is thus completely specified by three digits and a letter.

A major advantage of mapping on a grid system is that it provides an indication of the relative abundance of the species being studied. With geographic grids of the D.D.H.G. type, grid area varies from north to south, the grid size decreasing and the number increasing polewards. For Australian conditions, however, the relative ease of producing a wide variety of maps with an eighty-column typewriter (Brook, 1976) outweighs this disadvantage.

Shade printing

The absolute presence or absence of an individual weed species can be indicated solely by the typing of a single chosen symbol in the appropriate square of the map grid. Where it is desirable that additional information be provided, e.g. abundance, shade printing can be used. This is a method of creating a picture by computer printout (Figure 6). The technique, which consists of overstriking a set of characters is illustrated by Bernstein and Stierhoff (1976). Briefly, sixteen distinguishable shades of grey are obtained by overstriking these letters:

Strike 1	B	A	W	M	W	&	&	C	D	=	A	*	.	=	-	Blank
Strike 2	M	W	T	*	.	*	X	X	.	/						
Strike 3	-	-	-	-												
Strike 4	$	?														
	B	A	W	M	W	&	X	X	D	≠	A	*	.	=	-	
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Black															White

To produce the densest shade of black, first B is struck, then M, -, and $ in turn. The remaining shades are formed similarly.

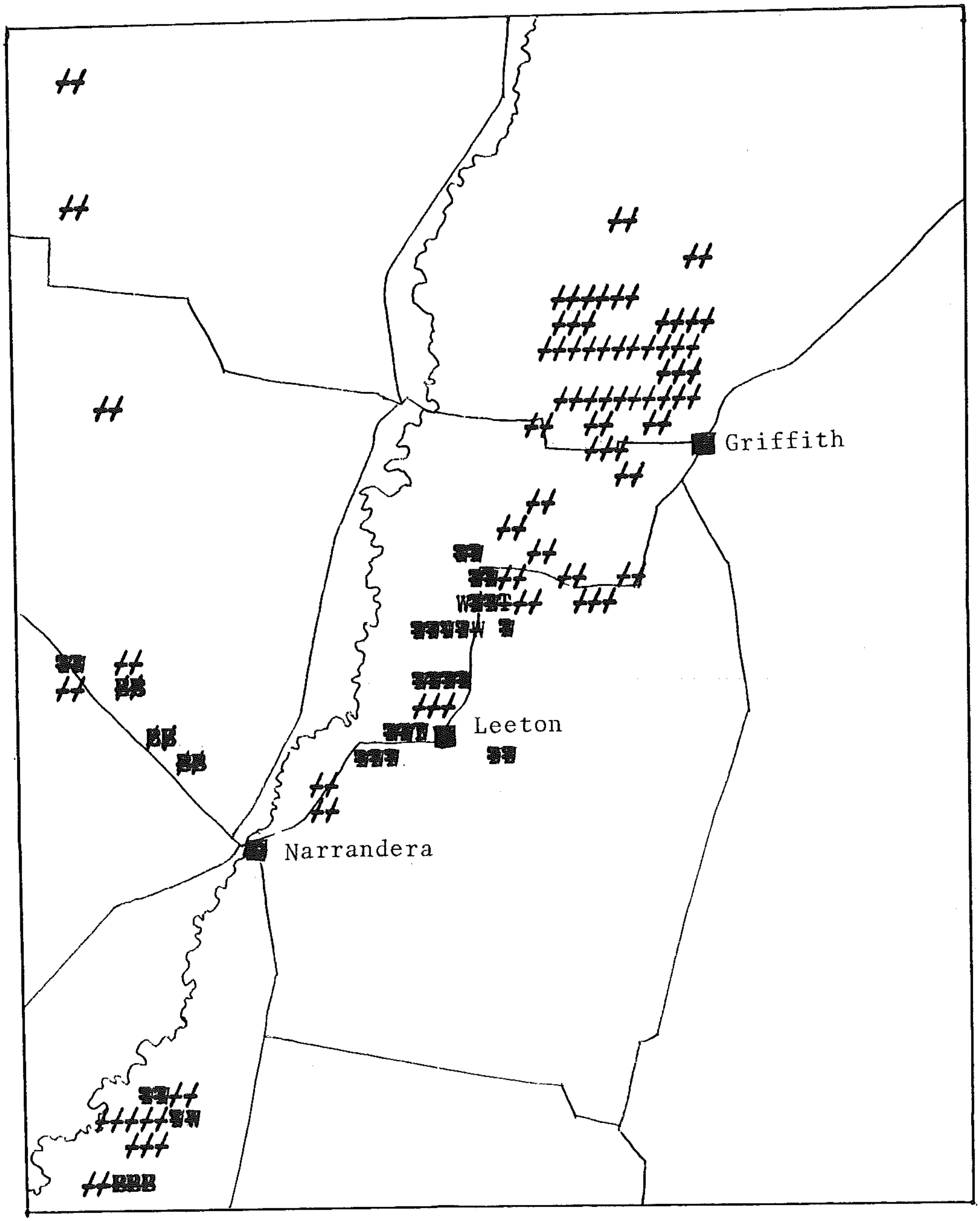

Figure 6 : Distribution of silver-leaf nightshade in the Murrumbidgee Irrigation Area. (/ Scattered plants only; W Scattered plants and colonies covering less than 1/20th of area; Ø Numerous plants covering ¼ to ½ of area).

Landsat Imagery

Each corrected Landsat image is essentially a map of an area 185 km square. According to Bernstein and Stierhoff (1976) when Landsat information is processed by computer, specific data can be extracted for specific applications. Thus there is a weed monitoring potential. Nominally the key to the process is to identify by field survey what the pixels in the satellite image of a small ground area represent vegetationally. These findings are then extrapolated by computer to the larger ground area.

In weed monitoring the early part of the process can be reversed. That is to determine which of the pixels comprising the small area image represent the known weed or weed complex infestation. With this information the computer can be used to analyse and highlight similar infestations on the large area image. The final stage as in all such operations is to check the accuracy of the computer image. This is done by a ground survey of some of the indicated sites on the large area image.

Recent advances suggest that distribution changes over short or long periods of time can be monitored with ease. Provided images have been corrected to conform geometrically to less than 0.5 pixel, the difference between intensity values of corresponding pixel pairs can be computed to show the changes which occurred in the period between recording (Bernstein and Stierhoff, 1976). The two scenes are 'differenced' digitally and the resultant or difference printed. Unchanged surfaces are shown almost in monotone, the changes as prominent "colours".

CONCLUSION

It is quite evident that considerable progress has been made in the process of collecting, collating and presenting information on weed distribution over the last quarter century. While it is unlikely that remote sensing procedures will detect individual weeds, there can be little doubt that weed aggregations will be recognized without difficulty. In summing up one can do little better than paraphrase Colwell (1961; 1973), "...Progress in remote sensing during the last decade has been the result of improvement in sensors, sensor platforms and data-processing. Thus, since further progress in these areas can be anticipated, it is quite probable that multiband spectral reconnaissance will become the primary means of detecting, analysing and presenting previously undetected weed infestations."

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