FULL COVERAGE AT LARGE SCALE

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Paper to be presented at the Symposium on Remote Sensing for Vegetation Damage Assessment.

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ABSTRACT

A major forest disease (<u>Phytophthora cinnamomi</u> Rands) in the jarrah (<u>Eucalyptus marginata</u> Sm) forests of Western Australia first shows symptoms in the understorey. The detection of these symptoms is best achieved with colour aerial photography, under cloud at a scale of 1:4,000.

A need to detect all sources of infection demanded a total coverage approach.

The paper describes a successful method of doing this using 70mm photography and sophisticated navigation equipment.

FULL COVERAGE AT LARGE SCALE

Large scale under-cloud 70mm colour aerial photography for detecting and mapping a disease in the forest understorey over extensive areas.

F.J. BRADSHAW & R.J. CHANDLER

Forests Department

Western Australia.

INTRODUCTION

Large scale aerial photography (1:3000 - 1:5000) is commonly used for small area intensive studies where the advantage of great image detail is not offset by limited area coverage.

The paper describes a case where both large scale photography and large area coverage were equally compelling requirements. The satisfaction of these conflicting requirements as well as peculiar photographic exposure constraints demonstrates that the traditional applications of aerial photography systems need not be inhibiting.

THE FOREST DISEASE

"Jarrah dieback", caused by the root rotting pathogen <u>Phytophthora cinnamomi</u> Rands (Podger, Doepel and Zentmyer

1965) is a disease which currently affects more than 10% of the jarrah (Eucalyptus marginata Sm.) forests of Western Australia. Unchecked it has the potential to infect and kill not only a large proportion of the jarrah overstorey within the forest but also a wide range of native understorey species (Podger 1972).

The potential effect on timber values, ecology and hydrological balance of the region is considerable.

The disease normally manifests itself a few years after infection with the death of bull banksia (Banksia grandis Willd) (a prominent understorey species), followed by the death of other species of the understorey, principally zamia palm (Macrozamia reidlei C.A. Gardn) and blackboy (Xanthorrhoea Preissii Endl). Dieback disease usually proceeds on a front from the intial infection and it may be several years before the jarrah becomes thin crowned and eventually dies. Presence of the disease in the early stages is normally determined by these symptoms among the understorey. Although soil baiting techniques are possible (Chee & Newhook 1965, Marks & Kassaby 1974) it has the disadvantage that a negative result can only be regarded as inconclusive.

P. cinnamomi is a water-borne fungus which, left undisturbed, spreads rapidly downhill and beside streams but only slowly uphill. It is spread artificially by the transportation of infected soil, particularly by earth moving and logging machinery in the winter months. The primary control measure is therefore the prevention of the movement of infected soil to healthy areas (Batini & Hopkins 1972).

FOREST QUARANTINE

In 1975 the Government of Western Australia quarantined, for a minimum of three years, 500 000 ha (increased to 750 000 ha in late 1977) of mostly healthy forest, prohibiting all vehicular movement in the area except by permit for essential services. The prime purpose of quarantine is to allow time for existing infections to manifest themselves so that all disease areas can be mapped to enable future operations to be carried out with full knowledge of the presence of all infections and thereby reduce the unwitting spread of the disease.

The task therefore was to design a system for the accurate detection and mapping of all areas of P. cinnamomi infections within the quarantine area at a cost and efficiency superior to the alternative technique of detailed ground survey.

CHOICE OF DIEBACK DETECTION AND MAPPING SYSTEM

There are five main requirements to be met by any technique selected for the detection and mapping of jarrah dieback in the context of quarantine :

- Detection of all sources of dieback infection in the quarantine area;
- Detection of dead and dying indicator plants;
- Detection of symptoms of small dimensions;
- Detection of symptoms beneath the forest canopy;
- Concentration of detection effort when the disease symptoms are most numerous.

A knowledge of the disease and previous experimental evidence indicated that these requirements could be best met by means of full coverage large-scale (1:4000) aerial colour photography taken under full cloud cover during autumn.

Bradshaw (1974) had shown that some of these specifications could be satisfied with 70 mm photography but its application to total coverage with its inherent problems of many precisely placed flight lines was a severe limitation. A further limitation was the large area requirement and the fact that suitable cloud above 500m was expected to occur on only 10 - 15 days during autumn.

Because of these limitations consideration was given to the use of survey cameras with a 230 x 230 mm format. However, this format with the 150 mm and 300 mm lenses which were available to us do not meet the specifications, primarily because the combination of slow lens (f5.6), colour film and low light levels would not permit the use of a sufficiently fast shutter speed to avoid unacceptable image motion.

While the recently developed Wild 300 mm f4 lens in combination with the faster Ektachrome EF film should allow sufficient exposure, the long focal length lens requires a cloud base of 1200 - 1500 m above ground level to achieve the desired scale and such conditions are estimated to occur on only 3 - 4 days each autumn. The restriction of so few suitable days imposes an unacceptable risk of failure on any substantial photography program.

For this reason the authors were prompted to pursue the proven 70 mm approach and concentrate on the navigational aspects of using small format for total coverage. Investigations are continuing into the feasibility of using a 300 mm (f4) survey camera to complement the 70 mm system on days of high altitude cloud.

THE 70 mm AERIAL PHOTOGRAPHIC SYSTEM

A series of investigations and trials over the past three years have led to the adoption of the system which is summarised in Table 1.

TABLE 1 NEAR HERE

The choice of many of the basic items was resolved at an early stage.

The 70 mm reconnaissance camera was selected for the focal length, angle and speed of it's lens. Additional functions such as cycling rate, magazine capacity, control features and construction were also considered.

Film type and processing product were chosen after trials of colour prints and transparencies, colour infra-red and multi spectral analysis. With normal processing the colour transparencies used cannot be adequately exposed under dense cloud but this is now compensated for by push processing two stops.

The aircraft contracted is ideally suited for this type of photography, being stable at slow speeds and providing adequate cabin space. The crew consists of pilot, mission controller, navigator, cameraman and magazine loader.

Dieback photography trials had shown that these components of the system were satisfactory, however accurate navigation still remained a problem.

Total photographic coverage with 70mm format at a scale of 1:4000 requires 200m spacing between flight lines allowing for 20% side lap with very little margin for navigation error. The maintenance of parallel flight lines within such narrow limits is beyond the scope of conventional navigation systems usually employed in aerial photography. A two-station microwave transponder navigation system (PACNAV) developed by a local geophysical survey company resolved this problem.

The PACNAV system incorporates an aircraft-mounted transponder which triggers two similar ground stationed transponders (Beacons). The aircraft range-monitor interrogates each of the two beacons in rapid succession and calculates the exact distance of the aircraft from each point. A computer compares these distances with the programmed flight-line and indicates track corrections to the pilot through a panel of lights. The flight pattern from any two beacons is established by locating a reference flight line above two suitably positioned ground features. These reference points are overflown and keyed into the computer. The only additional visual control required is the start and finish of filming on each run. This is easily performed with the aid of small-scale survey photographs and maps.

The system provides for flexibility of the spacing and sequence of flight lines, and the co-ordinates of individual lines can be recorded and relocated (from the same beacons) at any time.

To attain the most productive coverage pattern the flight lines are run approximately parallel to the axis between the two beacons. The only significant limitation is a corridor between the beacons which will not provide reliable aircraft guidance when the angle of intersection of the two signals exceeds 165^{o}. Transponder beacons are placed on high ground in the most suitable position to command the project area. The beacon aerials are broadly directional (120^{o}) to gain additional range and therefore need to be orientated for each photography area. A reliable range of 40 km is achieved in the forward zone of each beacon. Although the aircraft monitor is designed to measure the distance to each beacon to within one metre, the factor governing flight line accuracy is the control limitation of the aircraft itself.

SYSTEM TRIALS

Trials in 1976 and 1977 were designed to test the proposed system under operational conditions.

The elements of the system which were tested and evalutated were :

- Photograph acquisition;
- Performance of navigation equipment;
- Detection and interpretation of dieback;
- Film handling, and mapping.

PHOTOGRAPH ACQUISITION

The disadvantage of full coverage 70 mm photography is the small area coverage of each photograph and the large number of flight lines required, compared with larger formats. With a total (750 000 ha) area objective and an estimated 10 - 15 days per year available for photography it is essential that the highest possible proportion of the time available is spent on productive photography.

Apart from ensuring that both crew and equipment operate with maximum efficiency, the key factors affecting photography time are aircraft endurance and flight line patterns.

With a maximum of six hours photography time available per day the standard aircraft endurance of 4 hours results in time lost refuelling. It is proposed to increase the endurance to 6 hours by the installation of pod fuel tanks.

The flight pattern efficiency will be maximised by ensuring that flight lines are as longas possible, and that turns at the end of runs are executed as quickly as possible. With an average turning and approach time of three minutes, time lost in turning is significant being 50% of the time for 10 km lines and 30% for 20 km flight lines. To facilitate the planning of long, efficient flight lines the annual photography areas have been aggregated into elongated blocks and it is expected that most runs will exceed 20 km in length.

To obviate time lost in changing film magazines, a second camera will be installed. This will permit immediate change-over and also allow for continued operations should a camera fault develop in flight.

The aircrew needs to be well trained in all aspects of the job and be able to work continuously for six hours. Long periods of instrument flying makes the pilots task very demanding.

Some 200 hours of flying time in the 1976 and 1977 trials indicated that on an ideal day with the most efficient flight pattern and flight performance 16 000 ha of forest could be photographed.

NAVIGATION

Though the main components of the PACNAV system are stock items, the characterising feature is the way they have been modified and programmed to guide the pilot on specific flight patterns. The contracting company had successfully used the system for geophysical survey work in relatively flat terrain in outback Australia. Its application to the somewhat different terrain of the forest area required proving. A variety of sites were selected to evaluate its performance and arrive at the accuracy, range and reception pattern.

In an operational-style test the system performed satisfactorily over twenty parallel lines. Approximately 70% of any photography run was within 20m of the intended track with the reamining 30% no greater than 50m from the track.

The reception range of four transponders in different locations was tested. Forty kilometres was found to be the reliable maximum in the forward reflected zone from the aerial, rearward reception varied from 20 - 30 km. Hills intercepting the line of sight between aircraft and beacon cause reception failures.

With the two beacons at optimum separation (approximately 32 km), the common area swept by their 40 km signal range provides a photography zone with a maximum regular shape of 35 km x 15 km.

Some aspects of the navigation system can be improved. Mechanical reliability of the system to date has been poor due to installation problems and electronic component failure. These are inevitable consequences of using a system not fully developed, and it is expected that these can be overcome as problems are located and rectified and by implementation of more frequent preoperation testing. The present beacons are broadly directional but many of the beacon sites can serve two photography areas if suitably orientated. To improve flexibility of job choice on a particular day it will be necessary to convert these transponders to omnidirectional or incorporate a facility to alter their direction by remote control from the aircraft.

DETECTION AND INTERPRETATION

It is important to differentiate between detection of symptoms and the interpretation of those symptoms. The photographic system is aimed at detecting the presence and health of individual specimens of three susceptible "indicator" species in the understorey (Banksia, Macrozamia and Xanthorrhoea). These targets range in diameter from 0.15 m for the centre of the Xanthorrhoea crown to 3 m for the Banksia. Whether or not their death is indicative of the presence of P. cinnamomi is a matter for interpretation based on an understanding of the disease symptoms. In this sense the difficulties and uncertainties facing the photo interpreter are similar to those facing the ground interpreter.

Detection

Earlier work indicated that reliable detection of dying indicator plants was possible using colour transparencies which had been exposed under cloud at a scale of 1:3000 at the time when most of the affected plants were dying. Further experience has confirmed the critical importance of shadowless illumination obtained under cloud for understorey detection, and has also shown that satisfactory detection can be achieved with a base scale of 1:4000, allowing for topographic variation producing scales to 1:5000. Peripheral resolution of the lens of the reconnaissance camera is poorer than that normally obtained with survey cameras and for this reason the use of higher magnifications (with a Zoom stereoscope) to improve detection performance has only limited application.

Nevertheless the system provides the means of detecting symptoms with a high standard of accuracy, superior to all but the most intensive ground survey.

Interpretation

Interpretation of the cause of death of the susceptible understorey species is much more difficult. As understorey plant deaths occur for reasons other than P. cinnamomi infection, such as old age, fire, mechanical damage and drought, the interpreter must be able to detect not only the death of susceptible species, but also decide whether the deaths are symptomatic of P. cinnamomi.

The disease symptoms themselves also exhibit a wide variation as a result of the natural heterogeneity of the understorey, variations in site susceptibility, the intensity and age of the infection, and management history. It is therefore necessary for the interpreter to have a sound understanding of these possible variations and must examine each frame thoroughly and evaluate the significance of apparently minor indicators.

The classical situation where a front or patch of susceptible understorey, (several individuals of one species or individuals of more than one species) is dying, is easily and reliably interpreted as dieback.

However, variations in this general pattern can cause considerable difficulty in interpretation. Perhaps the most common situation is the absence or below average incidence of susceptible species, which may be either a natural variation or an indication of earlier P. cinnamomi activity. Here the interpreter must rely on minor indicators, or seek more positive evidence at the disease front which may be some distance from the area in question.

Interpretation difficulties also arise because patches of shallow-soiled or exposed forest are likely to die suddenly in autumn as a result of drought. The interpreter can often distinguish the drought patch from the dieback patch by the pattern and the rapid progress of death of the whole profile.

By far the most difficult situation to interpret is that where scattered and apparently unrelated deaths of individual understorey specimens have occurred. Whilst the majority of these deaths are due to natural causes, a proportion have been shown by soil baiting to be early indications of P. cinnamomi infection. In the absence of any other evidence the interpreter can only record the areas as possible sites of P. cinnamomi infection.

Despite the problems of determining "ground truth" for the disease, particularly over extensive areas, a quantitative measure of reliability was necessary. A trial area of 6000 ha was interpreted and two tests were performed.

The first involved the selection of 125 sites which the interpreter considered difficult to classify as either infected or healthy. These sites were precisely located in the field, and after careful study of the visible symptoms they were classified on the basis of the joint decision of three observers, two of whom were independent of the photo-interpretation. The results are shown in Table 2.

TABLE 2 NEAR HERE

Because the sites were not randomly chosen but were areas of uncertainty, this study provides a stringent test of interpretation. The types of error were also classified, and it was found that the four errors of commission were all boundary problems and therfore of little significance. Of the ten errors of omission, two were marginal boundary errors, five were revealed by the ground study to be only suspect, one was clearly an error of interpretation, and two were in fact photogaps, the sites being located during the field inspection.

A second test consisted of two detailed ground surveys carried out by two field interpreters working independently of each other on 100 m transects within a 1700 ha subsample of the trial area. Their maps were compared with the map prepared from photo interpretation, and within the areas where differences occurred, sixty sites were chosen for joint inspection and decision by all three interpreters. Results are shown in Table 3.

TABLE 3 NEAR HERE

An examination of the causes of the errors serves to illustrate some of the problems generally associated with ground surveys, including the inability of the ground interpreter firstly to gain an overall view of the pattern of symptoms and secondly to readily compare and contrast doubtful situations. These difficulties, compounded by the often inconclusive nature of the visible symptoms, lead to a diversity of opinion among ground interpreters, but may be largely overcome by photointerpretation, where pattern recognition is improved and referral to doubtful sites is convenient, and where the need for fewer interpreters results in more consistent standards.

The disadvantage of photography, however, is that it relies far more heavily than ground survey work on the presence of plants which have only recently died; leafless banksia stags, for example, cannot be reliably detected.

FILM HANDLING AND MAPPING

The handling of large numbers of 70mm transparencies might appear to be a daunting prospect. However, they can be handled with reasonable efficiency when retained in rolls of 450 frames each and viewed using a conventional x 2, x 4 magnification lens stereoscope, eyebase being compatible with the image separation on the film. For viewing in the field, battery powered portable light tables are used.

The exact locations of film runs and individual frames within the trial area were plotted by hand on 1:40 000 black and white (survey) aerial photographs. Whilst this method is obviously inadequate for large amounts of film, the problem can be overcome by a plotting system which records the exact transponder ranges at the moment each photograph is exposed. Magnetic tape recording of the distance from the two ground transponder stations would allow a suitably programmed plotter to print the nadir of every photograph on to an appropriate map, which would form the base for recording the interpreter's findings.

COSTS

Aerial photography is often considered a relatively inexpensive method of gathering a maximum amount of information about a tract of country. However, large scale aerial photography over an area as extensive as 750 000 ha sustains a rather high unit area cost.

The requirements of this particular job included a long contract period but relatively few flying hours, continuous commitment of the aircrew, a fairly large aircraft and specialised navigation equipment. The cost of this type of operation bears little comparison with that of mid-altitude and high-altitude survey photography.

Capital costs amount to some $A40,000 - $A50,000 for items such as cameras, transponder installations and long range fuel tanks. Excluding capital costs, the cost of the mapping program is expected to be 60¢ per hectare as follows:

Aircraft hire	:	20¢ per ha
Film & Processing	:	15¢ per ha
Interpretation, field checking, mapping.	:	25¢ per ha

These figures are based on the following costs and estimated production rates :

Aircraft hire	:	$147 per hour (150 hours)
Navigation	:	$800 per week (15 weeks) *
Aircrew	:	$160 per flying day
Film & Processing	:	$165 per roll (1,000 ha)
Interpretation, field checking, mapping	:	800 ha per man day

* The authors believe that the hire rate is lower than other similarly based but less accurate equipment. This is partly due to an involvement with a developing system.

A valid comparison of the costs of photointerpretation and ground surveys is not possible because of the difficulties of attaining equivalent levels of accuracy; however, the costs of producing a map to the standard indicated in Table 3 was 70¢/ha.

OPERATIONAL FEASIBILITY

The recent trials have confirmed that it is technically possible to detect and map jarrah dieback in its early stages over a large area using the system described. Furthermore it can be accomplished more accurately and at a cost similar to intensive ground surveys.

The remaining question is whether a system operating within such tight constraints is operationally feasible for a sufficiently large annual program.

The expected capacity of 150,000 ha per year from one aircraft unit has been adopted as the maximum operational target and the coverage of the quarantined area has been planned on this basis. It is expected to take six years to photograph the entire quarantine area. This annual program is regarded as sufficient for the re-instatement of forest management practices including prescribed burning for forest protection and the resumption of controlled timber harvesting operations.

FIGURE 1 NEAR HERE

The semi-operational trials carried out in 1977 have confirmed the authors' belief that this target is feasible provided every phase of the operation is performed with optimum efficiency. It is important to pre-plan jobs and site navigation beacons for maximum coverage and flexibility to allow the maximum ratio of photography time to flying time. The formation of photography areas into elongated blocks is the prime concern as this provides for efficient flight patterns. Other operational considerations include improving cloud forecasting and observation networks throughout the project area; having a well trained aircrew available throughout autumn; reducing downtime due to equipment failure by initiating an intensive program of preventive maintenance and by providing rapid repair facilities.

The interpretation phase will require the further selection and training of a small group of people who can combine their skill of photointerpretation with a thorough understanding of the disease itself.

It is planned to photograph and map 60 000 ha on a fully operational basis in autumn 1978, before the commencement of the major program in 1979.

CONCLUSION

Total coverage with small format large scale aerial photography over extensive areas has been shown to be practicable, even under these limitations of time and weather. While the cost is high compared with conventional photography, the cost in this case is acceptable and may be in other comparable cases where the problem demands detailed analysis over large tracts of forest.

The jarrah forest of Western Australia is not only the State's most important source of timber but is also the catchment of the water supply of its most densely populated region. Widespread P. cinnamomi infection has the potential to severely impair these values. In this context the cost of this phase of the forest hygiene program is amply justified.

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TABLE 1 COMPONENTS OF 70mm PHOTOGRAPHY SYSTEM

CAMERA :

2 Vinten 492 Reconnaissance Cameras
Remote control 101mm f2.0 lens
Shutter speed - 1/500 sec.
Film capacity 30m, 500 frames
Control & Cycling - custom built intervalometer.

FILM :

Ektachrome M.S. 2448
- colour transparency
- reversal processing to positive

Push processed 2 stops
Exposure - external meter (Sekonic).

AIRCRAFT :

Britten Norman Islander BN/2A
High wing twin, 5 seats
Long range tanks - 6 hour endurance
100 knots photography speed.

NAVIGATION :

Microwave Transponder system (Company designation "PACNAV")
Airborne ranger, computer, pilots tracking system
Navigators track input keyboard
2 ground stations
Very high frequency transmission (3050 Mhz)

TABLE 2 COMPARISON OF PHOTO INTERPRETATION AND GROUND TRUTH FROM 125 TEST SITES

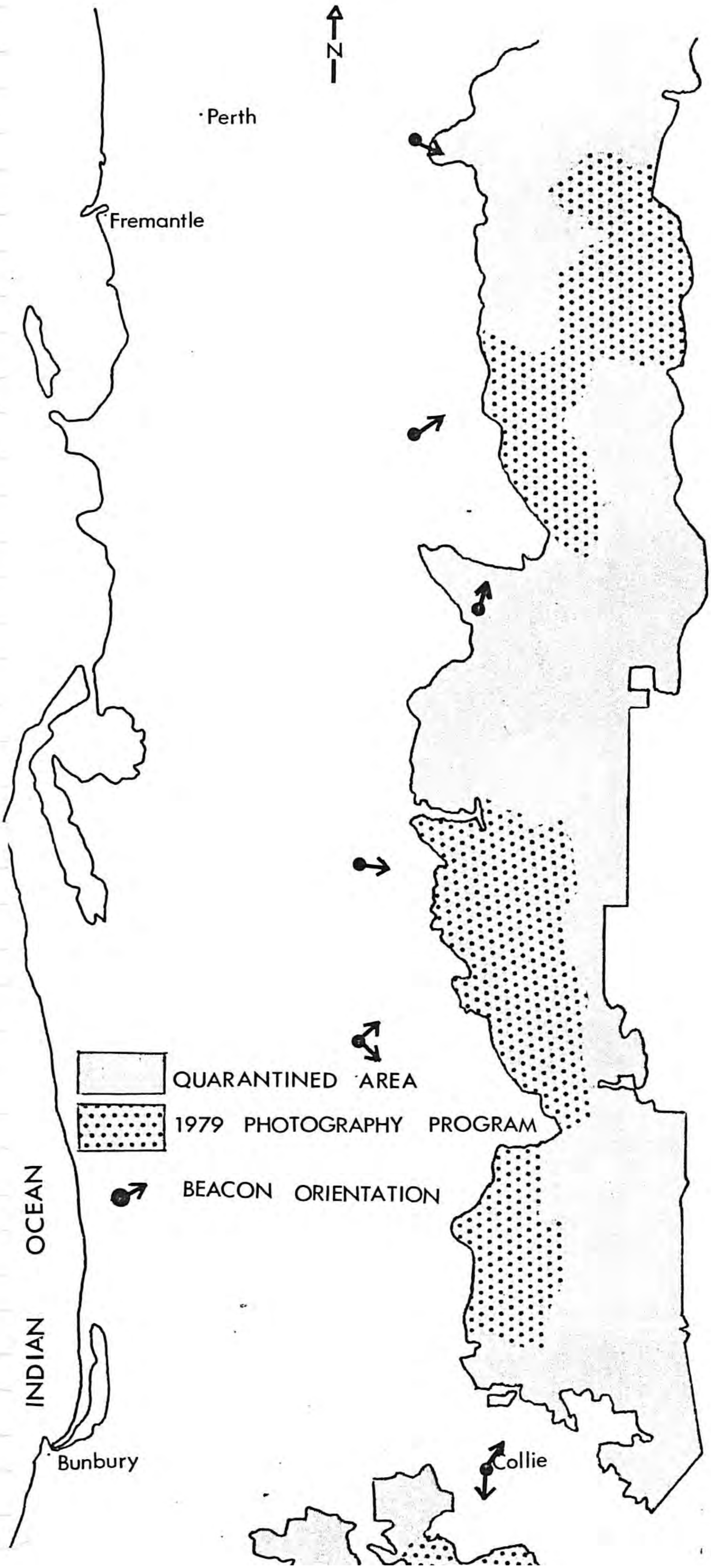
PHOTO INTERPRETATION	Total	GROUND TRUTH Dieback or Suspect	Healthy
Interpreted Dieback or Suspect	97	93	4
Interpreted Healthy	28	10	18

TABLE 3 COMPARISON OF PHOTO INTERPRETATION & GROUND SURVEY

SOURCE	RESULTS FROM 60 TEST SITES			TOTAL DIEBACK MAPPED (TEST AREA 1700ha)	
	Correct	Errors of Omission	Errors of Commission	Area ha	Percent of total area
'hoto Interpretation	53 (88%)	4 (7%)	3 (5%)	395	23
:round Survey A	30 (50%)	27 (45%)	3 (5%)	185	11
Ground Survey B	24 (40%)	32 (54%)	4 (6%)	115	7

CAPTION FOR FIGURE 1 (FIGURE AT TWICE FINAL SIZE)

Fig. 1. The northern portion (390,000 ha) of the quarantined area showing the siting and orientation of the beacons for the first year's program.


N
Perth
Fremantle
QUARANTINED AREA
1979 PHOTOGRAPHY PROGRAM
BEACON ORIENTATION
INDIAN OCEAN
Bunbury
Collie