Forest-type mapping by photo-interpretation: A multi-purpose base for Tasmania's forest management

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Abstract

Techniques to classify and map Tasmania's native forests by stereoscopic interpretation of aerial photographs were developed in the late 1940s to facilitate systematic forest management. Completion of statewide map coverage was achieved in 1996 after considerable evolution of interpretation and mapping methods. Current photo-interpretation (PI) typing procedures and coding standards are described. Because of its structural focus, with comprehensive and consistent coverage of all forests and tenures, PI-typing has become a fundamental information source for Tasmania's forest management. Typing has been widely used to assist wood inventory stratification, operational planning, vegetation and disturbance mapping, and site productivity assessment.

Introduction

That 'what cannot be measured cannot be managed' is as arguable in forestry as in any other field of business or resource management. The quest towards sustainable management of Tasmania's public native forests has therefore been closely linked to their progressive mapping and inventory.

From the earliest days of the Tasmanian Forestry Department in the 1920s, detailed forest mapping was seen as an important priority, motivated by three principal objectives:

- The *Forestry Act 1920* required the 'classification of the forest lands of the State…for the purpose of determining which…are suitable to be permanently dedicated as State forests or…as timber reserves'.
- The application of the principle of sustained yield to regulate the hitherto uncontrolled timber industry required a comprehensive, reliable and ongoing inventory of the forest resource. This need became progressively more urgent in the post-war building boom, and dominated the policies of the Forestry Commission following its establishment in 1947 (Carron 1985).
- Forest roading, harvest planning and operational management required the ready availability of topographic and forest-type maps.

The first attempts to document the nature and extent of the forests were by exploratory sketch mapping. From the 1920s, systematic parallel stripline surveys were undertaken. This method provided significantly better information but was extremely slow and expensive, especially in more remote areas (Cubit 1996).

The possible use of aerial photography for more efficient forest surveys had been discussed elsewhere but its first Australian application over 900 square kilometres of north-western Tasmania was initiated by the Forestry Department in April 1930 (Carron 1985). Whilst the resultant photographs were poor and yielded only limited information, a further trial was undertaken in 1936 over the north-east, this time combined with ground

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surveys to ascertain the possible value of detailed photo-interpretation. The outcomes were again disappointing but inspired some confidence that further research could unlock more detail (Hemmings 1949).

World War II interrupted ongoing experimentation but fortuitously accelerated the development of equipment and techniques for the interpretation of aerial photographs for military intelligence (Hemmings 1949). Even during the war, the newly created Forest Demarcation Branch began to use military photographs to assist in the identification of areas suitable to be dedicated as State forest (Carron 1985).

In 1946, a Photo-Interpretation Section was formed. This was the first of its type in an Australian forestry agency and was headed by W. Dudley Hemmings who had been trained in photo-interpretation during war service in air intelligence (Cubit 1996). Using military photogrammetric methods, emerging techniques reported in American forestry literature, and extensive local field research, the section made dramatic progress. By the end of 1946, different forest types and growth stages could be identified and, within two years, eucalypt stands could be subdivided into height and crown-density classes (*ibid*; Hemmings 1949). Based on the success of this rapid developmental phase, the Commission's focus then swung towards practical application of the new techniques to obtain full map coverage of the State's Crown native forests.

Technical development

The classification system adopted for Tasmanian forest-type mapping was primarily structural, and was partly a reflection of what was possible and partly a reflection of its purpose. Whereas the photo-interpretation of tropical rainforest is relatively inefficient due to its close intermixture of many species and closed canopy, Tasmanian forests could be readily separated into broad community and growth-stage types, and were open enough to allow reliable photogrammetric measurements of height and density (Hemmings 1949; Lawrence and Walker 1954). Direct recognition of individual eucalypt species was not possible, but this was not regarded as an important deficiency, since all the main timber species had similar commercial uses and value (*ibid*). Elsewhere, such as in New South Wales, the desire to achieve a more floristic basis for typing (down to the species-association level) has required a high degree of field survey and ground-truthing (Rod Squire, pers. comm.). This approach was consciously rejected in Tasmania, since typing based solely on photo-interpretation is more efficient and ensures greater consistency within project areas, thereby maximising the statistical validity of the use of PI-types as the basis for stratified inventory sampling (Lawrence and Walker 1954).

The ongoing development of Tasmanian typing specifications has reflected changes in forest management focus. The earliest priority was for information about the resource on which the industry of the day was dependent: mature eucalypts. Their total heights and stand densities were recognised early as being readily measurable and significantly related to timber volumes (Lawrence 1957). However, interpreters found that direct assessment of merchantable heights was obscured by canopies, and fire damage and over-maturity caused tree crown diameters to be poorly correlated with stem diameters (*ibid*). Stand density classes were originally based on a count of tree crowns per acre, but individual crowns were not readily distinguishable in multi-aged forest, so percentage crown cover was adopted as the measure (Lawrence and Walker 1954); stem counts are now used only for dead trees. The four original height classes, which were consistent with National Forest Inventory standards for that era (Forestry and Timber Bureau 1951), also evolved with experience. The tallest original class (E1, height > 180 feet), proved inadequate to describe the grandeur of trees which reached over 300 feet, requiring the institution of the E1* class for heights above 250 feet. More significantly, the original E3 class (90–135 feet) was found to encompass unacceptably wide variation in sawlog volumes and to span the critical ecological division between dry and wet sclerophyll forest, which roughly coincided with a total height of 110 feet. The E-3 and E+3 classes now encapsulate this distinction.

As interest in the eucalypt regrowth forests grew during the 1950s, more detail was required in their classification. Early typing simply distinguished saplings from poles, but height classes and percentage crown cover classes were quickly adopted, though using standards different from those applied to mature stands. Where regrowth did not co-exist with older eucalypts, the height-class of dead standing or fallen mature trees was also recorded as an effective indicator of the site quality or growth potential of the regrowth (Lawrence 1957).

During the 1970s, attention turned to the assessment of cool temperate rainforest, particularly the dominant myrtle (*Nothofagus cunninghamii* (Hook.) Oerst.). Rainforest was originally broadly identified as myrtle forest and coded as MM. From 1952, typing had distinguished myrtle from other tall species and scrub (i.e. M, T, S), and height classes were introduced in 1964 (Walker and Candy 1982). For over a decade from 1974, interpreters attempted to subdivide myrtle and blackwood (*Acacia melonoxolyn* R.Br.) by growth stage, height, and density classes, as well as identifying individual associated species. However, despite trials of alternative photographic films and scales, extensive field assessment proved that little of the additional detail could be consistently correlated with timber volumes (*ibid*). The only significant differences were between rainforest on fertile and poor sites, generally distinguishable by the crown diameter and height of the dominant myrtles. Thus, the codes M+ and M- were adopted from 1986 to represent rainforest communities (Hickey *et al.* 1993), eclipsing most of the previous stand detail, though two height classes of myrtle regrowth were retained. Use of the code T is now generally confined to specific identifiable species, particularly in non-rainforest communities (Brouder 1988).

The last two decades have also seen developments in the coding of logged and regenerated stands. Single-aged regeneration resulting from wildfires or clearfall silviculture was originally coded simply with its year and method of seeding. Over time, however, the distinction between regeneration and regrowth has become blurred. Establishment years have been coded against many natural regrowth stands, whilst heights and densities have been interpreted for advanced regeneration, particularly to identify stands potentially suitable for silvicultural thinning (Davis and Stone 1997). Meanwhile, partial or selective logging treatments have become the prevalent silviculture in the multi-aged stands of the dry and highland forests, and each resultant mix of retained and regenerated trees is now simply coded as a combination of mature, regrowth, and regeneration elements, listed in order of their significance. Most recently, the expansion of native forest thinning operations has prompted consideration of including other stand treatment information (e.g. thinning prescriptions) into PI-type codes. However, this has been rejected as being incompatible with the remotely sensed nature of PI-typing and as being likely to cause the code structures to become unduly complex. Accordingly, operational treatment information is being stored in separate databases.

As typing specifications evolved, the overall level of detail coded for each patch increased steadily. At their most complex, in the 1970s, individual rainforest species were being identified, two or three height classes could be recorded against a single mature eucalypt stand, density classes could be qualified with + or -, stands could be coded with multiple condition classes, and PI-types with four or more constituent elements were not uncommon. However, whilst this information was usually accurate, its value was questionable. The additional detail required additional interpretation effort, cluttered maps, and was generally counter-productive for inventory stratification. As a result, current PI-types have been simplified, rarely recording more than the three most significant stand elements, each with no more than one height, density and condition class (Brouder 1988).

In parallel with this maturation of the interpretation standards, major changes have also occurred in the associated mapping processes. Colour photography replaced the use of black and white prints from the late 1970s. Dependence on Forestry Department triangulation surveys to provide geodetic control diminished progressively as more reliable military and Lands Department base-mapping became available; since 1980, the majority of Tasmania has been covered by the *Tasmap* 1:25 000 topographic series. Rectification and transfer of the distorted photographic line-work onto cartographically consistent maps was initially based on radial-line plotting, at first hand-drawn and then using slotted templates (Cubit 1996). From the mid 1950s, photogrammetric plotters made this task faster and more reliable and allowed efficient scale changes until, in 1993, the process was automated using geographic information system (GIS) software and digital map data. GIS technology now allows map products to be printed in colour direct from the computer database, replacing decades of reliance on reprographic compilation and dye-line printing methods. Storage of the PI-type map data on GIS databases also enables their rapid and detailed spatial analysis for resource inventory and planning purposes.

Mapping progress

Complete mapping coverage of Tasmania's forests was finally achieved in 1996, fifty years after the establishment of the Photo-Interpretation Section. Figure 1 summarises the gradual progress towards this achievement. Whilst the 1:25 000 series mapping since 1980 has systematically covered the State via a sequence of major regional project areas (following the progress of *Tasmap* base-mapping), earlier work was fragmented, reflecting the availability of Lands Department photography and the shifting forest management priorities of the times.

- The Southern Forests were an early focus, though re-typing was necessary by the mid 1950s to provide greater detail on regrowth stands. Other pulpwood concession areas in the Derwent Valley and Burnie areas also received attention in the first decade. Generally, the higher quality sawlog-rich forests were of most immediate interest. Mapping of the poorer dry forests of the east coast and central highlands did not occur until commencement of the export woodchip industry in the 1970s.
- Diversion of PI-typing effort onto urgent special projects was common. These included mapping of hydro-electric dam floodplains to inform prior timber salvage (e.g. Gordon, Henty–Anthony); assessment of the impact of major wildfires (e.g. Hobart 1967); mapping of forests proposed for reservation into National Parks (e.g. South-West, Precipitous Bluff); and assessments of special species timbers (e.g. blackwood swamps of the north-west).
- The need to conduct resource reviews over large areas of as-yet incompletely mapped forest prompted several projects to use photo-point sampling, whereby sample points were located on photographs and the PI-type at each was interpreted and deemed to represent a larger area. This approach was used extensively for inventory reported at the 1974 Forest and Wood-based Industries Development (FORWOOD) Conference, based on grid points 0.25 miles apart, and as the primary level of multi-stage sampling for the 1982 Private Forest Assessment (Forestry Commission 1984).
- Private property was not specifically targeted for mapping until 1975, shortly before the Board of Inquiry into Private Forestry Development in Tasmania. Until then, coverage rarely extended beyond

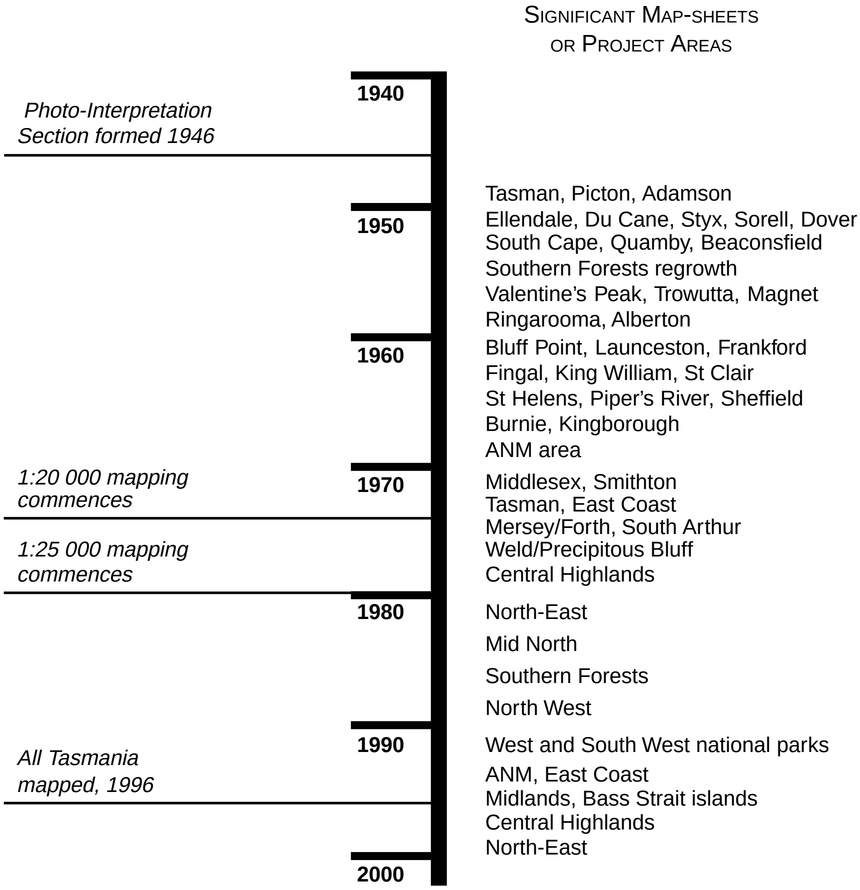

Figure 1. Timeline: mapping of Tasmania's forests.

map sheets containing existing or potential State forest. The remaining large areas of private property were mapped in the mid 1990s to enable an inventory and review of the private forest resource as required by the 1991 Forests and Forest Industry Strategy (Forestry Tasmania 1995).

- The requirement to complete PI-typing across all tenures of the whole State was a consequence of the emerging State and national objective of establishing 'comprehensive, adequate, and representative reserves' of each forest type, (Public Land Use Commission 1996a). This prompted mapping during the 1990s of the west and south-west, much of which was National Park, and finally the Bass Strait and other offshore islands.

Current typing procedures

The production of forest-type maps is today based around five principal activities.

1. Aerial photography

Forests are photographed from fixed-wing aircraft along parallel east–west flight lines. To minimise the adverse effects of shadow, photography is restricted to the hours around midday during summer months; the sun-angle must exceed 40°. Large format, mapping-quality cameras are used to shoot vertical photographs that overlap by 60% along the flight line and by 27.5% with adjacent lines. Based on a flying height of 6800 m above ground and a camera focal length of 305 mm, the resultant 23 cm x 23 cm colour contact prints are at a scale of

Figure 2. Interpreted aerial photography (1:20 000 scale).

approximately 1:20 000. (In order to obtain efficient coverage of conservation reserves and private property, recent use has also been made of 1:42 000 scale photography, both in colour and monochrome, but this does not allow adequately detailed interpretation for State forest management purposes.)

2. Photo-interpretation

Using a stereoscope to view overlapping pairs of photographs, interpreters divide the vegetation into patches which appear to be visually homogeneous and boundaries are drawn where the canopy structure or species composition changes significantly (Sulikowski 1995). Once delineated, each patch is scrutinised separately and described in terms of detailed stand attributes. These are encoded as a PI-type, following the syntax outlined below (*ibid*). Boundaries and PI-type codes are inked directly onto one photograph of each stereoscopic pair (Figure 2).

Figure 3. Native forest series mapping (1:25 000 scale).

The spatial resolution at which the forest is typed varies according to the scale of aerial photography being used: 1:20 000 scale photography is typed down to a minimum patch size of 3 ha, and 1:42 000 scale photography is typed to a minimum patch size of 10 ha. Smaller patches may be mapped if they are highly distinct from their surrounds. Because natural forest is rarely uniform in its structure and distribution, each PI-type code is understood to be a subjective generalisation of the patch of forest which it describes.

Interpretation of percentage crown cover is based on comparison with standard printed density scales. Representative tree heights are measured photogrammetrically using a parallax bar, allowing accuracies of ± 5 m to be maintained as long as ground-level is apparent.

Interpreters visit the field during each project, initially to familiarise themselves with the nature of the vegetation and topography, and subsequently to verify the accuracy of their work and to resolve uncertainties prior to mapping. Field measurement data from these visits are used only as a reference to assist the consistency and accuracy of interpretation, since PI-typing is fundamentally based on remote-sensing rather than ground-truthed survey.

3. *Digitisation and rectification*

Following interpretation, the forest patch boundaries and the location of key spatial reference points (such as stream or road junctions) are captured digitally from the photographs onto Forestry Tasmania's ARC / INFO GIS. These are then mathematically adjusted against a digital terrain model using the PHOTOGIS software to eliminate photographic distortions caused by topography and aerial camera tilt. The resultant digital linework is estimated as having a horizontal positional accuracy of ± 25 m, based on the claimed ± 12 m accuracy of the 1:25 000 *Tasmap* topographic mapping which is used for geodetic control.

A PI-type code is also entered onto the GIS for each patch. The codes are edited to ensure validity and are used to calculate a range of derived attributes which facilitate computerised analysis and reporting of the PI-type map database. Codes are discussed in detail below.

4. *Map production*

Once digitised, PI-type boundaries and codes are stored as a separate layer within the GIS, which can be queried, overlaid with other thematic spatial information, or printed in a wide range of physical map formats.

The most widely used output product is the Native Forest Series map (Figure 3) which shows PI-types printed against land tenure and topographic information derived from *Tasmap* 1:25 000 base-mapping. Segments of PI-type mapping are frequently used at a scale of 1:10 000 to support field forestry operations, but the recommended scale for usage is 1:25 000, in recognition of the original capture scales of the PI-type photography and topographic base-mapping. A wavy line is used as the standard map symbol for PI-type patch boundaries, reflecting both its relative spatial accuracy and its subjectively interpreted nature.

5. *Updating*

PI-typing provides a static view of a dynamic natural resource, and requires comprehensive updating and periodic re-mapping to be of maximum use for forest management. PI-types are currently re-mapped over regional project areas around Tasmania on a rolling cycle averaging about 20 years. This interval reflects a balance between the relative stability of native forest structure and the high cost of PI mapping on the one hand, and the need to keep pace with changes in actively growing regrowth and the cumulative impact of minor wildfires and other dynamic changes.

PI-type information for State forest is also updated at least annually to incorporate changes due to forestry operations such as logging, roading, regeneration and plantation establishment. The boundaries of these changes are captured using spot aerial photography or Global Positioning System (GPS) receivers, with attribute information being advised by field staff. Equivalent updating of private property forests is less regular. Private Forests Tasmania currently plans to co-ordinate a five-yearly inventory, and some larger industrial forest-owners maintain their own comprehensive records.

Mapping may also be updated on an occasional basis for special purposes, such as to monitor the height and stocking of young eucalypt regeneration in order to identify stands suitable for thinning. New aerial photography is acquired every 10 years, both to enable such occasional PI-typing projects and also to provide recent prints for operational reference by field foresters.

PI-type codes

A PI-type code is composed of a series of stand elements, each delimited with a full-stop, and representing a single species-group / age-class component of the stand being described. The order in which the elements are listed reflects their relative significance (i.e. the element which is most abundant or likely to determine the current management of the stand is listed first). PI-type codes usually comprise between one and three elements. Any fourth or subsequent elements are rarely significant enough to record except for research purposes.

Different vegetation elements are coded at different levels of detail. Eucalypts are not distinguishable from photographs at the species or association level but are subdivided according to growth stage, each with stand height and percentage crown cover estimates where possible. Myrtle-dominated rainforest is separated by growth stage and crown size, with height class recorded against regrowth. Its constituent species are generally not separately coded other than for research purposes.

Other native forest species are generally grouped as *other species* (if taller than 15 m) or *scrub*. However, particular species which are locally important (e.g. wattle, *Acacia dealbata* Link, in the north-east or blackwood in the north-west) are coded as separate elements.

Intensively managed plantations are coded as either hardwood or softwood, and their planting years are recorded where known. A range of native and non-native ground-cover vegetation elements are also distinguished, as are bare rock, 'wasteland' and inland waterbodies.

Where apparent from the photography, PI-types (or elements within them) may be preceded by a condition-class code, indicating that the stand is dead, severely fire-damaged, over-mature, thinned, or cut-over in past selective logging.

Whenever a forest patch does not contain a mature eucalypt element, evidence of the height of any previous mature eucalypts on the site is recorded as an indication of the growth potential of current and future eucalypt regrowth stands. The height-potential class may be measured from isolated mature trees, dead stags or fallen trees. In the case of stands regenerated after clearfelling, height-potential boundaries are transferred from older maps or from photographs of the original forest.

Whilst PI-typed data are primarily remotely sensed from photographs, some coded information about silviculturally treated stands is derived from ground observation. Such parameters include the year and method of establishment of regeneration, the identification of thinned stands, and the composition of elements remaining after selective harvesting. These details are provided by field foresters in order to update PI-type mapping to reflect ongoing operations on State forest. When such stands are subsequently re-mapped, the forest structure will be re-interpreted from photography, but details such as establishment years are copied through from the previous mapping.

A listing of PI-type code descriptor values is presented in the Appendix. Some indicative examples of PI-type coding are shown in Table 1.

Derived codes

Because PI-type codes are highly irregular in length and content, they are not readily analysed in computer database applications. Accordingly, a wide variety of derived codes are calculated from each basic PI-type to enable database analysis and standardised reporting. This processing is carried out by the PI Decoder Library (PIDL) programs, which also check the syntax of the original PI-type. Some of the most significant derived codes are:

- **Concise PI**. This is a 20-character 'regularised' format in which each character records a predetermined attribute of the original PI-type (e.g. character 4 holds the mature eucalypt height-class, if any). Only the main (most-used) attributes are stored. This code is designed to allow easy analysis of PI-type information on databases. The first character, **Standtype**, gives a useful overview description of what general type of forest is in the PI-type.

- **Forest group.** This is a three-letter code which classifies a PI-type into one of seven broad reporting groups: Hardwood or Softwood Plantation, Tall or Low Native Eucalypt Forest, Rainforest, Other Native Forest, or Non-Forest.
- **Forest class.** This two-digit code is used to stratify forest types into classes which have broadly similar timber volumes and growth characteristics. These strata are therefore useful for timber inventory and yield planning applications.
- **Expanded PI.** This is a 'regularised' format, in which every possible attribute of a PI-type is re-coded into a predetermined character position. (Thus, it is similar in concept to Concise PI but is comprehensive, requiring 196 characters.) It is used internally within PIDL as the basis to extract/calculate the other derived/summary codes described above. However, it can be returned to an application program if required for analysis of attributes which are not contained or summarised in Concise PI.

The PI-type database

PI-type information is stored digitally on Forestry Tasmania’s GIS database in three conceptually separate 'layers':

- The 'base' layer stores the PI-types as originally interpreted from the most recent regional re-mapping photography. It is not updated and is retained to provide an archival snapshot for purposes such as monitoring stand history and derivation of site potential.
- The 'changes' layer stores the details of stands whose PI-type codes have been updated as a result of forestry operations since the most recent base-mapping. Increasingly, the spatial accuracy of this layer differs from the base-mapping because of the use of GPS.
- The 'live' layer is an automated combination of the base and changes layers, providing the up-to-date working map required for most mapping and analysis functions.

Clearly, PI-type is only one 'view' of Tasmania’s forests. It is remotely sensed in origin and is mainly used for the extensive management of native forests. Intensive forest management, particularly of plantations, requires both higher levels of spatial resolution and the recording of numerous ground-measured stand treatment parameters. Accordingly, this information is stored in a separate Plantation Area System (PAS), mapped primarily from GPS and ground-survey. The PI-type database is periodically reconciled with PAS to ensure conformity.

Some statistics from the current PI-type database are summarised in Table 2.

Uses of PI-type information

Whilst the original objectives which prompted Tasmania’s PI-type mapping programme have reflected an ongoing core of technical need, its uses have been extended to a wide range of activities.

Demarcation of State forest

The progressive dedication of 856 000 ha of Crown land as State forest between 1946 and 1991 has been informed primarily by PI-type mapping. Forest types were used to stratify land according to its likely current timber volumes or future growth potential (based on eucalypt height class). In most instances, no on-ground inventory was measured, with volumes or values being inferred based on experience. Generally, State forest boundaries were defined in terms of topographic features or pre-existing cadastral surveys but, in

Table 1. PI-type elements and codes.

Element	Details which may be coded	Examples
Mature eucalypt	Height class, per cent crown-cover class [1]	E+3b.
Unaged regrowth eucalypt	Height class, per cent crown-cover class [1, 2]	ER5c / 2. ER2b.
Aged regeneration	Species, establishment year(s), establishment method, height class, per cent crown-cover class [1, 2]	E(75)A / 2. E(72:93)2c / 1. M(78)N / M+.
Non-eucalypt	Height class [1, 2]	Tw. M+. S.
Plantation	Planting year	Ps(69).
Non-forest	[2]	Wg. Water. Sea.
Unstocked forest	[2]	U / +3. Z / S.

Some example PI-type codes

co E2c.Tw.S.	A previously cut-over stand of tall mature eucalypt of moderate density, over wattle and scrub.
ER1b.fd E-3f.	Dense short eucalypt regrowth, with sparse fire-damaged remnant mature eucalypts of medium height.
M+.Tb.	Large-crowned myrtle rainforest, with blackwood.
E(76)A / 1.T.	Eucalypt regeneration, artificially seeded in 1976, on an excellent site, with other unspecified species.
th E(34)4a / 2.	Tall fully stocked eucalypt regrowth which has been thinned, on a good site.
Wg.E4d(P).	Buttongrass moorland, with patches of low-density, short mature eucalypts.
Vz / +3.	Pasture, with evidence that the site once had medium height eucalypts on it.

[1] May be preceded by a condition class.

[2] May be accompanied by a height-potential code.

Table 2. PI-type database statistics.

Total area of Tasmania mapped:	6 802 670 ha
Total number of mapped forest / land patches:	178 300
Average area of forest patches:	37 ha
Average perimeter of forest patches:	3183 m
Number of unique PI-type codes currently in use:	10 400

north-western Tasmania, over 250 km of boundary was actually gazetted in terms of the mapped forest / moorland edge.

As the proportion of unallocated Crown land diminished, with simultaneous pressure for private subdivision and declaration of conservation reserves, the dedication and retention of land as State forest became more contested. Noteworthy examples include the 1970s debate over blackwood swamps near Smithton, the 1976 Precipitous Bluff / Hartz National Park swap, and the 1987 Helsham Inquiry into Lemonthyme and Southern Forests. In this environment, land-use decisions required increasing quantitative argument based on ground inventory and economic analysis, but such information has in each case been built upon a foundation of forest-type mapping.

Wood inventory and yield modelling

The primarily structural focus of Tasmanian PI-typing has provided a strong basis for resource stratification for timber inventory. Major efficiencies have been gained by excluding non-target forest types from assessment and by use of stratified sampling in inventory designs, based on strong correlations between timber volume and stand height and density (Lawrence 1957; Snowden and Thompson 1992). Techniques have included low intensity, subjectively located stripline assessments to explore new tracts, high intensity systematic striplines for operational-level surveys, and stratified random sampling for resource-level Continuous Forest Inventory (Lawrence 1978). Where continuous PI-type mapping had not been completed, multi-stage sampling designs have been based on systematic grids of photo-points whose immediate surrounds were photo-interpreted to normal PI-type specifications (e.g. Forestry Commission 1984). Whilst such inventory has generally targeted the eucalypt timber on which local industry is overwhelmingly dependent, equivalent techniques have been used to delineate and stratify other forest types such as blackwood, wattle and rainforest (Walker and Candy 1982).

As well as assisting the estimation of standing timber volumes, PI-types are central to the calculation of sustainable yields for Tasmania's eucalypt forests. This is based on the use of mature eucalypt height potential as a second dimension in stratification, since height potential is broadly correlated with site index and therefore predicts future growth rates (Lawrence 1957). For regeneration, whose year of origin is coded into each PI-type, stand age provides a further significant dimension on which to stratify for yield modelling. The 88 Forest Class strata, into which the 10 000+ unique PI-type codes are currently grouped for strategic inventory and yield calculation, reflect these three dimensions (Forestry Tasmania 1996).

With few exceptions, significant native forest inventory measurement in Tasmania has been confined to State forest, and current growth models are also derived from State forest data. However, the consistent mapping of PI-types across all tenures to cover the whole State has provided a basis to extrapolate timber volume and sustainable yield estimates from State forest to equivalent forest strata on other land tenures, particularly private property (Forestry Commission 1984; Forestry Tasmania 1995). This capability is unique in Australia (Public Land Use Commission 1996b).

Operational mapping and land management

Prior to the 1980s, when publication of *Tasmap* 1:25 000 mapping commenced, Forestry Commission PI-type maps were often the only available working-scale (generally 1:15 840) maps for planning and recording of harvesting, regeneration, fire-fighting, and roading operations. Accordingly, photo-interpreters were careful also to delineate creeks, roadlines, and even patches of distinctive vegetation, which could serve as navigational aids for field foresters (Brouder 1988). Today, whilst *Tasmap* data are used as the topographic base for new forest maps, PI-type boundaries are still regarded as vital information to orient field operations.

Vegetation community mapping

Though primarily structural in focus, Tasmania's PI-typing does provide a valuable floristic summary of vegetation cover at the formation level (Sun *et al.* 1997). It has been used for many years to provide overview descriptions of the composition of Tasmania's forest (e.g. Forestry Commission 1994), to assist lower-resolution statewide floristic mapping (e.g. Kirkpatrick and Dickinson 1984), to assess the reservation status of tall forests (Hickey 1987), to assist detailed vegetation mapping of the Tasmanian World Heritage Area, and as the basis for establishment of representative conservation reserves of rainforest and wet and dry sclerophyll eucalypt forests (Hickey and Brown 1989).

The recent compilation of statewide 1:100 000 scale vegetation forest-type mapping to enable biodiversity reservation analysis during the Tasmanian Regional Forest Agreement (RFA) process was highly dependent on PI-type information. Mapped patch boundaries were used to provide its underlying spatial framework, and photo-interpreted community and structural data were used in combination with detailed ground and aerial survey, botanical site records, and expert knowledge to identify the extent of forest communities (Public Land Use Commission 1996a).

Disturbance and oldgrowth mapping

PI-type coding contains significant explicit and implicit information about the degree to which the biophysical naturalness of forest has been reduced by processes such as wildfire, clearing and timber harvesting. Indices of disturbance / naturalness have been used in methodologies to determine wilderness quality, river wildness and oldgrowth values. PI-type data were therefore used extensively to map disturbance as part of the assessment of these values for the RFA (*ibid*). Mapping of crown senescence, used as the primary indicator of stand maturity in the RFA oldgrowth study, was also greatly facilitated by PI-type information. The textural homogeneity of PI-type patches was found to be useful to delineate patterns of eucalypt crown senescence, allowing the patch boundaries to be adopted as the spatial framework for the mapping; a single senescence estimate was simply attributed to each patch. PI-type information was further used to target senescence interpretation towards forest types and growth stages which contained older trees (*ibid*).

Site productivity assessment

In the absence of detailed physiological growth models, environmental datasets, and particularly soil maps, PI-type data have provided useful empirical indications about the likely productivity of sites being considered for plantation development and other intensive forestry (Forestry Commission 1990). Eucalypt height potential has been used both in formal guidelines for evaluation of individual sites and for strategic analyses of the extent and distribution of potentially plantable land (Public Land Use Commission 1996b).

National Forest Inventory

Since the initiation of the National Forest Inventory (NFI) programme in 1988, PI-type mapping has been used as the basis of data contributed to describe Tasmanian forests at a national level, initially at continental scale (1:1 000 000) and subsequently at regional scale (1:100 000). Grouping of PI-type data to these resolutions has involved translation of forest-type attribute codes into the closest equivalent NFI classes, but without spatial generalisation, thus maintaining consistency between scales. Similar methods have been used to provide Tasmanian forest statistics for other national-level summaries, such as the State of the Forests Report and Montreal First Approximation Report.

Indirect benefits

The PI-type mapping programme has had a number of valuable side-effects. The maintenance of a unit of trained photo-interpreters has allowed their technical skills and forestry knowledge to be applied to a variety of specialised tasks including the sketching of ground contour details to assist the planning of cable-logging operations, stratification of plantation stocking, evaluation of alternative photographic media and scales for rainforest assessment (Walker and Candy 1982), and assessment of the extent and severity of eucalypt regrowth dieback (Myers 1980). Ready availability of aerial photography and stereoscopes, and awareness of their value and efficiency, has also resulted in their widespread use for operational planning by field foresters.

Other uses to which PI-type information has been put, or which are being investigated, include fire-age mapping, forest valuation, and research into leaf-beetle infestation patterns and eagle habitat. In combination with wood volume plot measurements, PI-typing has been used to calculate biomass estimates as a basis to derive forest carbon stocks and fluxes for national greenhouse gas inventories (Lucas *et al.* 1997). PI-types are used to estimate fuel types and fuel loads for fire management planning. One current project is attempting to use PI-type data as the map base for a computerised landscape visualisation system.

Discussion

The PI-type mapping programme has not only achieved its original objectives but has delivered a valuable basis to address many new forest management issues which have emerged during its 50-year history. The statewide PI-type dataset now constitutes a core element of the spatial information infrastructure on which Tasmania's native forest management systems are dependent. This has been clearly demonstrated during the recent RFA process.

Despite its accepted value, external developments continue to require ongoing review of the rationale and scope of PI-type mapping. In contrast to 1946, reliable topographic base-mapping is now readily available, the dedication of the State forest estate is essentially complete, and forest-type map coverage of the whole State has been accomplished.

Although use of remotely sensed imagery from satellites and airborne scanners has been widely suggested as a panacea for forest mapping and inventory which will eclipse the need for aerial photo-interpretation, its promise is as-yet unproven in Tasmania. Attempts to use Landsat data to classify Tasmanian forests have achieved only broad and unreliable results. Problems have included cloud-cover, rough terrain and the relative openness of eucalypt forest canopies (Ahmad 1987; Elton *et al.* 1990). Despite these poor results to date, remote-sensing technology continues to develop rapidly, so that cheap, fast, accurate, and direct forest measurement remains a tantalising possibility. Broad classification is undoubtedly useful in simple landscapes, or where more detailed mapping is unavailable or not cost-justifiable, but Tasmania's forests are spatially and structurally complex, commercially valuable, and are already covered by detailed maps. It is therefore arguable that PI-type mapping will continue to provide an important view of Tasmania's forests for many years to come, both in its own right and also to train, validate, and complement digital imagery and analysis.

Another potential challenge to current PI-typing methods is the call for uniform national vegetation classification standards (Sun *et al.* 1997). Given the diversity of approaches currently evident across Australia and the growing need to report on key forest parameters at national and international levels, this goal appears highly desirable and is probably attainable at the level of field site survey measurements. However, the nature of remotely sensed mapping classifications is that the scope of each is limited to what a particular technology can reliably detect. In any case, the economic and methodological investment by land managers in current mapping systems acts as a strong inertia against change. Systems such as Tasmania's PI-typing have evolved to reflect local forest characteristics and regional management objectives, have taken many years and significant cost to implement, and have become closely integrated with associated applications such as field inventory. It is also doubtful that any single national classification framework can either simultaneously meet the needs of all potential users or remain stable over time. In this context, it is notable that Tasmania's current PI-type standards remain consistent with the prescriptions jointly agreed by all States and the Commonwealth in 1951 for National Forest Inventory purposes (Forestry and Timber Bureau 1951).

Other contemporary changes also pose questions for the future of PI-type mapping. Following the corporatisation of Forestry

Tasmania, Private Forests Tasmania has continued to fund the routine re-mapping of private land in conjunction with the State forest re-mapping programme. However, ongoing support for periodic update of PI-typing to reflect the natural and other change processes on Crown reserves is unresolved. In the commercial environment of the 1990s, continuing efficiency improvements will be required to offset the slow, labour-intensive nature of photo-interpretation. At the same time, the number of photo-interpreters must be kept above the critical mass required to maintain a viable specialist unit. In drier forests, changes in silvicultural practices towards selective harvesting systems are creating sub-stands which are of interest to field managers but frequently smaller than the minimum patches mapped to date.

Notwithstanding these issues, overall usage of PI-type mapping is likely to increase. Traditional usages, such as for inventory and resource planning, are being greatly facilitated by advances in GIS technology which are improving analytical capabilities and accessibility, and providing automated mapping which can be customised. Widening interest in the study and management of native vegetation by local government, smaller landowners and community groups will broaden the usage of forest typing beyond State government agencies. As shown during the RFA assessments, PI-typing has been under-utilised to date as an information source for environmental and ecological studies, particularly at a landscape level. Its focus on stand structure and growth stage promises to provide useful descriptors of habitat. Major modelling synergies are also probable from the combination of PI-type data with digital imagery, site survey records, and environmental thematic datasets such as climate, topography and soils. As well, each 20-year re-mapping cycle will increase the value of the PI-typing programme in providing baseline datasets and periodic monitoring of long-term forest change at stand, landscape and regional scales. To this end, all mapping is routinely archived on microfilm or digital media.

Whatever its future, Tasmania's forest PI-type mapping has already proven itself as a highly successful, efficient, and versatile classification system. Fifty years on, it continues to be the primary thematic map used to inform the management of State forest. Uniquely in Australia, it also provides consistent and complete coverage of all forests across all tenures, providing full regional context for consideration of issues ranging from national policy down to individual coupe plans. Its spatial structure, resolution, and classification system support and integrate a wide variety of functions at both strategic and operational levels for both wood and non-wood values. It has become, and remains, a multi-purpose information base for the multiple-use management of Tasmania's native forests.

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Appendix. PI-type code legend.

PI-types are coded descriptions of forest vegetation, derived by stereoscopic interpretation from aerial photographs. Each PI-type code is composed of a series of stand elements, each ending with a full-stop, and representing a single species/age-class component of the stand being described. They are listed in order of their relative significance.

CONDITION CLASSES

co	cut-over	**fd**	severely fire-damaged	**th**	thinned
dd	dead	**om**	over-mature		

MATURE EUCALYPT

E1*	average height > 76 m	**E+3**	average height 34–41 m	**E4**	average height 15–27 m
E1	average height 55–76 m	**E-3**	average height 27–34 m	**E5**	average height < 15 m
E2	average height 41–55 m	**E3**	average height 27–41m		

Live crown density-classes

a	70–100% crown cover	**c**	20–40% crown cover	**f**	< 5% crown cover
b	40–70% crown cover	**d**	5–20% crown cover	**(P)**	Patches or scattered

Dead stem-count classes

A*	> 60 stems/ha	**B**	25–39 stems/ha	**D**	2–14 stems/ha
A	40–60 stems/ha	**C**	15–24 stems/ha	**F**	< 2 stems/ha

REGROWTH EUCALYPT

ER1	average height < 15 m	**ER3**	average height 27–37 m	**ER5**	average height 44–50 m
ER2	average height 15–27 m	**ER4**	average height 37–44 m	**ER6**	average height > 50 m

Density-classes

a	90–100% crown cover	**c**	50–70% crown cover	**f**	1 – 10% crown cover
b	70–90% crown cover	**d**	10–50% crown cover	**(P)**	Patches or scattered

Mature height potentials

/1*, /1, /2, /3, /+3, /-3, /4, /5 as per eucalypt mature height classes

AGED REGENERATION

E(yy)m	Eucalypt regeneration, where **yy** is year(s) of regeneration, **m** is method. Height-class, density-class, and height-potential codes as for unaged regrowth eucalypts; (unknown height-potential = /**X**)
M(yy)m	Myrtle rainforest regeneration
B(yy)m	Blackwood regeneration
C(yy)m	Celery-top pine regeneration

Regeneration-method codes

A	Artificially seeded	**P**	Planted (not for intensive plantation)
N	Natural seeded	**W**	Wildfire-induced natural seeding

Appendix. Continued.

NON-EUCALYPT SPECIES

M	Myrtle (old type)	**S**	Scrub (< 15 m tall)	**Tb**	Blackwood
M+	Tall myrtle rainforest	**T**	Secondary species (> 15 m tall)	**Tw**	Wattle
M-	Low myrtle rainforest	**Tr**	Radiata pine (wild)		
MR	Myrtle regrowth (old type)				
Mr1	Myrtle rainforest regrowth < 15 m tall				
Mr2	Myrtle rainforest regrowth > 15 m tall				

Rainforest site potential

/M+	Fertile rainforest site	**/M-**	Poor rainforest site

Other codes (for specialised projects)

Sb	Bauera scrub	**Tc**	Celery-top pine	**Tl**	Leatherwood
Sh	Horizontal scrub	**Th**	Huon pine	**Ts**	Sassafrass
St	Tea-tree scrub	**Tk**	King Billy pine	**Tt**	Tea-tree

PLANTATION

Ph(yy)	Hardwood plantation (with planting year yy)
Ps(96)	Softwood plantation (planted 1996)

NON-FOREST

K	Bracken	**Vo**	Orchard	**Wg**	Buttongrass
Not Typed	Untyped	**Vp**	Pasture	**Wm**	Mountain moor
Sea	Ocean, sea	**Vz**	Rough grazing	**Wr**	Rock
V	Grazing	**W**	Waste, bare ground	**Wu**	Urban
Vc	Cultivated land	**Water**	Inland water		

UNSTOCKED FOREST SITE

U/p	Un-regenerated forest site (with eucalypt potential p)
Z/S	Un-regenerated former scrub site
Z/W	Un-regenerated former waste site