COLOURATION AND VISIBILITY OF TRACK MARKERS

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BACKGROUND

This report is restricted to discussing the visibility and identification of forest track markers and analysing some of the associated factors.

Forest track markers present a number of peculiar problems:

They must be visible under a wide range of illumination conditions and against an equally wide range of background brightnesses and colours.

Their positioning on established trees provides an additional problem as the available tree may not be ideally located or have an appropriate trunk configuration for convenient marker placement.

There are also a number of human related factors which influence marker visibility:

Sunglasses distort the colour value of the marker and influence both apparent colouration and visibility.

Eight percent of males and ½ percent of females have a clinically significant inherited colour vision deficit which affects their colour perception of most spectral hues.

A significant number of people have inadequately focussed vision. This blurs the retinal image and so reduces colour contrast and brightness differences.

Older people have an advancing condition which is age related called acquired tritanopia. This affects primarily their perception of blue hues which lose some saturation due to pre-retinal absorption, particularly by the crystalline lens and macular pigmentation.

The visual; search required to locate a track marker is a complex task relying upon a multitude of cues. Specifically, these are the discriminative cues of: shape, colour, brightness and contrast.

it is not always appreciated that the visual system is only sensitive to shape,colour, contrast and detail if you are **looking directly at the object** using foveal vision. In other words, this is often after you have located it and are then confirming its identification.

Foveal vision encompasses only a very small area of the retina which projects to a visual field size of about $1\frac{1}{2}^{o}$ (equivalent to a 3/4m diameter area at 30m distance). Reliance upon foveal mechanisms in search tasks is therefore time consuming and risky.

Peripheral visual mechanisms however are more finely tuned for the detection of movement and brightness differences (de Groot, Dodge and Smith, 1952, see Appendix A). Brightness difference is a logical cue to emphasise in marker design.

Some means of enhancing marker visibility are:

* Enlarge target area
* Increase material reflectance
* Higher visibility colour

* Utilise pattern or a unique shape
* Enhance contrast

The principal thrust of this report is to outline why the use of colour as the primal cue is doomed without jointly considering the other factors involved in visibility enhancement.

REPLY TO THE DEPARTMENTS ENQUIRY

(Communication from Paul Wilson, Visitor Services Division, Southland Conservancy, November 10,1993)

1 **ARE THE LARGE ORANGE TRACK MARKERS THE BEST COLOUR OPTION FOR VISIBILITY GIVEN THEIR USE IN FOREST SITUATIONS THROUGHOUT NEW-ZEALAND?**

The large orange track markers have a dominant wavelength approaching 590nm which positions them chromatically on the yellow side of pure orange(600nm). They have a relatively high purity at 86% and approach the specifications of the AS 2156-1978(Appendix B) Colour 557: 593nm, 83% purity.

Figure 1 describes the visual system's luminous efficiency to the spectrum. It highlights some of the disadvantages of this wavelength band which evokes the perception of orange.

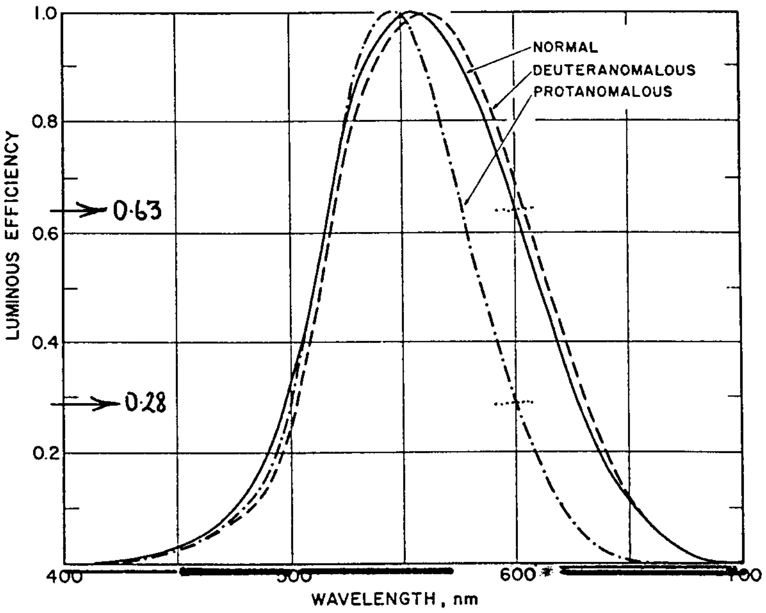

Fig. 1 **Mean luminous efficiency curves for the normal trichromat, the protanomalous and the deuteranomalous observer (from Wright, 1946).**

The eye is about 37% less effective to the orange wavelength band than to peak sensitivity 555nm, green-yellow. This responsiveness declines systematically and dramatically as illumination is reduced. Eventually, under night conditions the eye is 96% less efficient at 600nm than to 505nm, blue-green (see Figure 2).

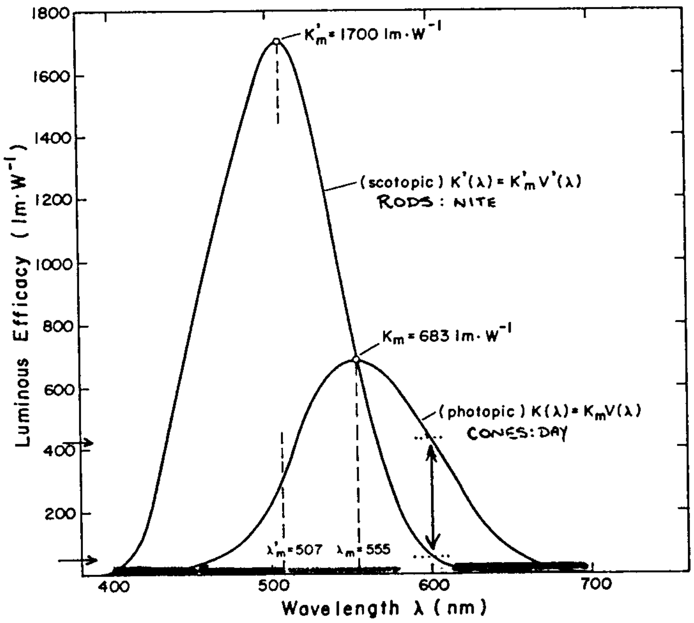

Fig. 2 Spectral luminous efficacy functions $K(\lambda)$ and $K'(\lambda)$ for photopic and scotopic vision, respectively.

Protan colour defectives (people with an abnormal or absent long wavelength cone response) are severely disadvantaged in this wavelength band. Their efficiency is some 35% less than normal (Figure 1). This is to say the marker would need to have 35% greater luminance to be seen by these people, under the same conditions.

The forest canopy selectively absorbs the shorter wavelengths so as the seasonal foliage cover increases this reduces the amount of light which penetrates to the trunk area(K.Egle cited in Geiger.R,1966). Figure 3 presents Egle's data in graphed form.

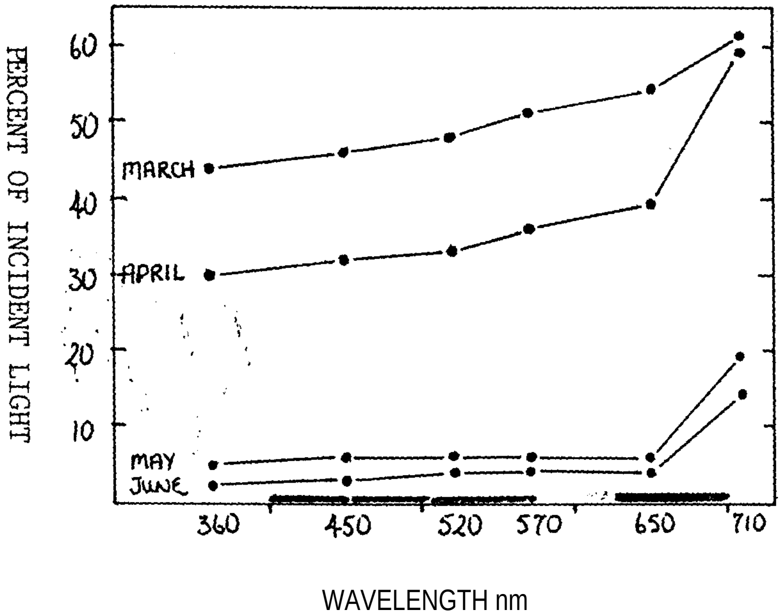

Fig. 3 Percent incident light to reach the trunk area ,for northern hemisphere forest (Egle, see Geiger, 1966).

Refer also to the selective absorption figures cited by Evans on page 11 of this report.

2 IF NOT WHAT COLOUR WOULD BE THE MOST VISIBLE COLOUR?

As mentioned in the BACKGROUND notes there are a large number of physical variables which enhance object visibility. An analysis of the present marker may help to appreciate the interactive role of these variables.

Marker Size:

The **larger** marker measures 72mm (across the base) by 110m (high) which equates to an area of $3960mm^2$. This is 10% smaller than the AS 2158-1978 which specifies 80mm base x 110mm high with an area of $4400mm^2$.

There is a direct relationship between area and visibility, larger is easier to see. Marker size is a crucial variable. For targets of these dimensions Ricco's law is valid for distances beyond 10m.

TARGET AREA X LUMINANCE = CONSTANT

This says that if you double the area you obtain the same improvement in visibility as if you had doubled the luminance, or reflectance (or vice versa). For example, the larger orange marker has 57% greater area than the smaller marker, meaning it is 57% more visible and would be seen at $1\frac{1}{2}$ times the distance.

Marker Shape:

If we calculate the diameter of a circular disk (71mm) of equivalent area ($3960mm^2$) it is possible to estimate some thresholds.

At 30m the circular disc equivalent subtends 0.13^{o} or 7.7 min. arc. In visibility terms this is a very small target. At these dimensions it becomes difficult to distinguish shape, colour discrimination becomes unreliable, while contrast interactive effects play tricks on apparent colour and brightness. Heinz and Lippay (1928) demonstrated that to achieve 100% visibility for a centrally viewed 11 min. arc circular target its relative luminance needed to be 17.6% greater than the field. (Refer Graham, 1966, p211). It should also be noted that in astronomical terms 7.7min. arc represents an object which approximates 1/4 of the moon's diameter.

Aulhorn (cited in Moses, 1970, p574) records that a 7.7min. arc disc needed only 0.64cd/m^2 above the background for luminance discrimination, and 3cd/m^2 for normal(6/6) letter recognition. Shape recognition threshold lies between these two limits which exceed the luminance levels of the daylite forest.

At the time of compiling this report a definitive study addressing the relative visibility of geometric shapes has not been located. Absolute threshold visibility studies by Hochberg et al (1948, see Kling & Riggs,1972, p443) proposed the threshold should increase with the ratio of figure perimeter to its area. This would rank order circle as the most sensitive, followed by square, diamond, equilateral triangle then narrow triangle (track marker). My initial observations would suggest the **reverse** order for the colour/brightness discrimination involved in locating and recognising the markers. This is supported by Butler, 1964 who demonstrated that, using the same range of shapes the reaction time for discrimination between paired approx. 2^{o} targets was least between the circle and triangle and greatest between the triangle and diamond.

Material Reflectance:

The injection moulded high density polyethylene has a minimally textured diffusely reflectant front surface which would aid its detection.

Measurements with a Spectra Pritchard Telephotometer Model. 1980A using a 1 ^{o} aperture under indirect daylight reveal the following reflectances for the front surface

TRACK MARKER	REFLECTANCE
Large orange	0.415
Small orange	0.356
Small blue	0.322
Small yellow	0.877

The large orange marker reflects less than half the light (41.5%) which is incident upon it. To put this in perspective some representative graphs are included in Figure 4.

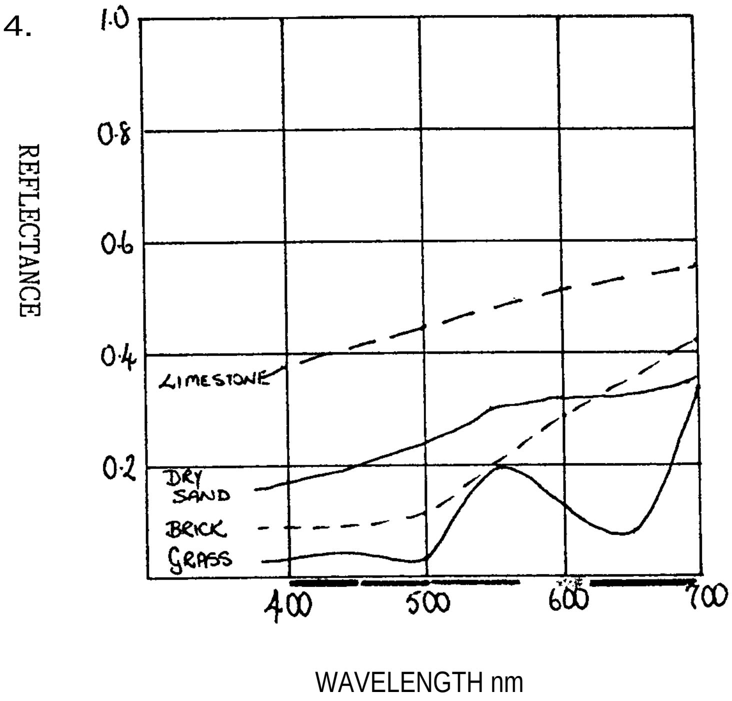

Figure 4. Spectral reflectance curves (Krinov,1947) Refer Wyszecki & Stiles, 1982, p62.

Natural objects have a large range of reflectances, however forest foliage, soil, rock and bark seldom reach very high values. With the exception of the small yellow marker the other markers do not consistently exceed that of the background. This problem highlights the initial comment that a brightness difference must be established in the marker's design protocol.

Intensity Discrimination:

We are very sensitive to intensity differences. The meteorologists adopted daylight standard is 2%. A mountain mass of 2% lower luminance than the sky background would be deemed visible.

Under daylight conditions (above $1 cd/m^2$) this standard would be realistic, but understandably it reduces quickly with dim illumination conditions. However, even under moonlight ($10^{-3} cd/m^2$) the discernible difference is still better than 20%, although colour perception is totally absent under these conditions.

Forest Illumination:

The penetration of forest illumination can be extremely variable dependent upon weather conditions as well as canopy cover. Fortunately the human visual system can adjust to these extreme changeable conditions although this process does take time. Richards (1952) presents the following intensities as a percentage of the incident light on tropical rain forest and comments that it seldom exceeds 5% at the forest floor.

	UPPER CROWN	SMALL TREE TOPS	TRUNK SPACE	FLOOR
Height m	25	18 - 12	9 - 6	0
Light %	25	6	5	1

Table: Richards (1952) Solar luminance in rain forest.

Full exposed daylight luminance approximates 10^4 cd/m^2, which after absorption through foliage represents a maximum luminance level of about $100cd/m^2$, still a very comfortable reading illumination range. As mentioned earlier this light is biased toward the red end of the spectrum. Evans (cited in Geiger, 1966) notes that of the available light above the canopy only 8% of light up to 500nm, 22% from 470-590nm and 45% above 600nm reaches the forest floor.

Which Colour?:

Hopefully, by this stage it will be appreciated that colour per se is not the only problem and unfortunately there is not a magic colour which will solve the dilemna.

My immediate response would be to consider as many variables as possible:

- move toward yellow to increase reflectance and visual responsiveness.
- increase size.
- consider a different surface texture
- (cameo pyramidal impression?).
- reconsider shape?
- evaluate pattern/contrast options as is planned for river crossings.

4 TO WHAT DEGREE ARE THE ORANGE MARKERS UNABLE TO BE SEEN BY COLOUR BLIND PEOPLE?

There is an extremely rare condition where people are blind to colour. They generally also suffer from albinism, photo-phobia and poor vision.

All other colour defectives people see colours, but their apearance is different from that of a normal observer. There is also a high probability that they will confuse colours.

There are two principal forms of colour defective (Figure 1) expressed in two degrees of severity. **Protan** is the 'red weak' form who have a poor or absent long wavelength cone response. The **Deutan** is the 'green weak' form and they have a weakened or absent middle wavelength cone response.

The mild condition resembles the effect of reducing the colour content on your TV set. However, the severe form is more dramatic because all the colours the normal appreciates from blue-green through yellow to red are to them a single hue, increasing in saturation to the normal's yellow and then reducing in brightness as they approach the normal's red. Which is to say, a lemon gets more saturated in colour as it ripens from the normal's green to yellow. While the colour of a tamarillo gets darker as it ripens from the normal's dark green to dark red.

Because there is a response bias in the cone colour encoding system confusions between different colours are very common. In fact there is no region of the spectrum or in the extra-spectral purples which is not prone to confusion except perhaps blue which retains its appearance. Figure 5 shows the confusion loci of the more common colour defectives. What it essentially says is that you can not select a colour which will avoid the colour defectives problem of colour confusion.

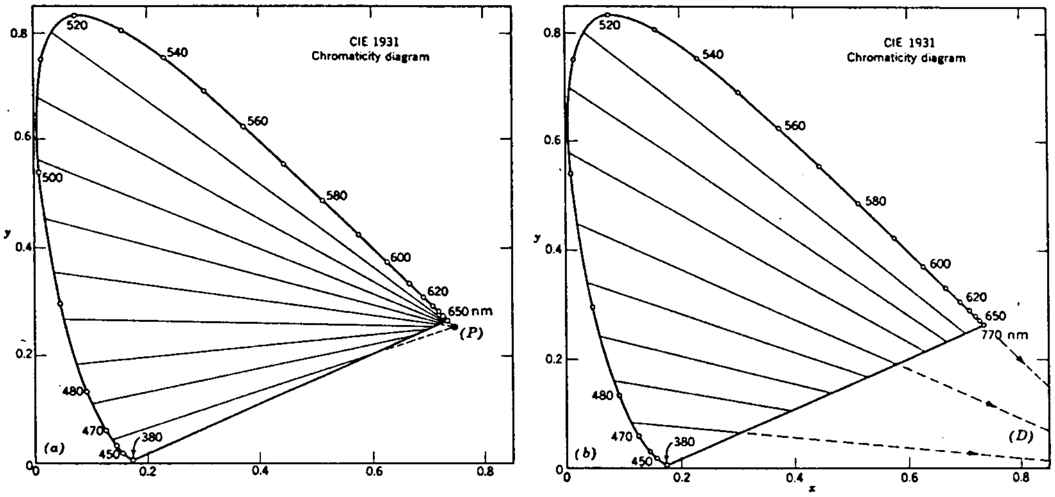

Fig. 5 **Lines of constant dichromatic chromaticity drawn in the normal trichromat's chromaticity diagram**

Blue's Unique Problems:

Unfortunately, the colour defective's problem can not be solved simply by using blue, given the earlier comment of low blue radiation on the forest floor.

1. Small Field Tritanopia:

For targets smaller than 20min arc there is no reliable perception that the object colour is blue. If the observer could identify its shape as being the marker they would "colour it blue" mentally, if that was what they expected. But without that additional cue its colour, blue, would not be a primary aid to its location.

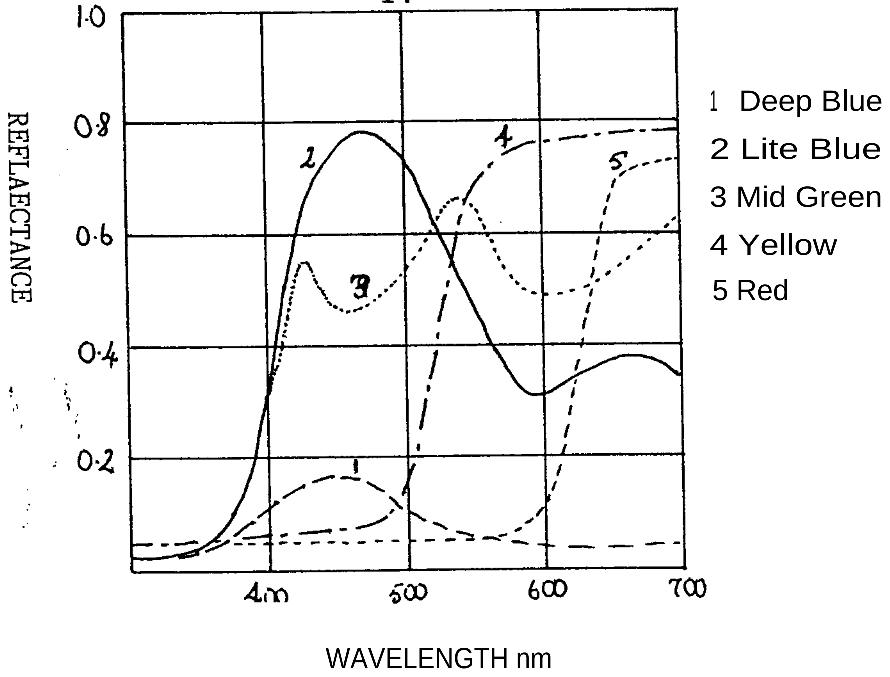

Fig. 6 Spectral reflectance plots for 5 enamel paints.

2 Spectral Reflectant Properties of Dyes and Pigments are not Uniform:

Long wavelength reflecting pigments (Y,0 & R) tend to reflect very little middle (G) or short (B) wavelength and so avoid desaturation (or reducing the amount of colour) of the primal hue. In this spectral region only the red and green evoking cones are stimulated so the colours seen have high purity. These 2 effects are illustrated in Figures 6 & 7 respectively.

However, it is very difficult to achieve fully visually saturated reflectant blue-greens (Figure 6). Blue and green pigments have secondary components which desaturate the primary colour or reduce it by complementary subtraction.

Adding to this dilemna are the natural quirks of the visual cone system. Firstly, the short wavelength cone ("blue cone") has a comparatively weak response function(Figure 7). Secondly, their response is desaturated by the red and green cone inputs. So even if the dyes had sharp reflectance cut-offs blue is not an ideal colour for accurate identification of small targets.

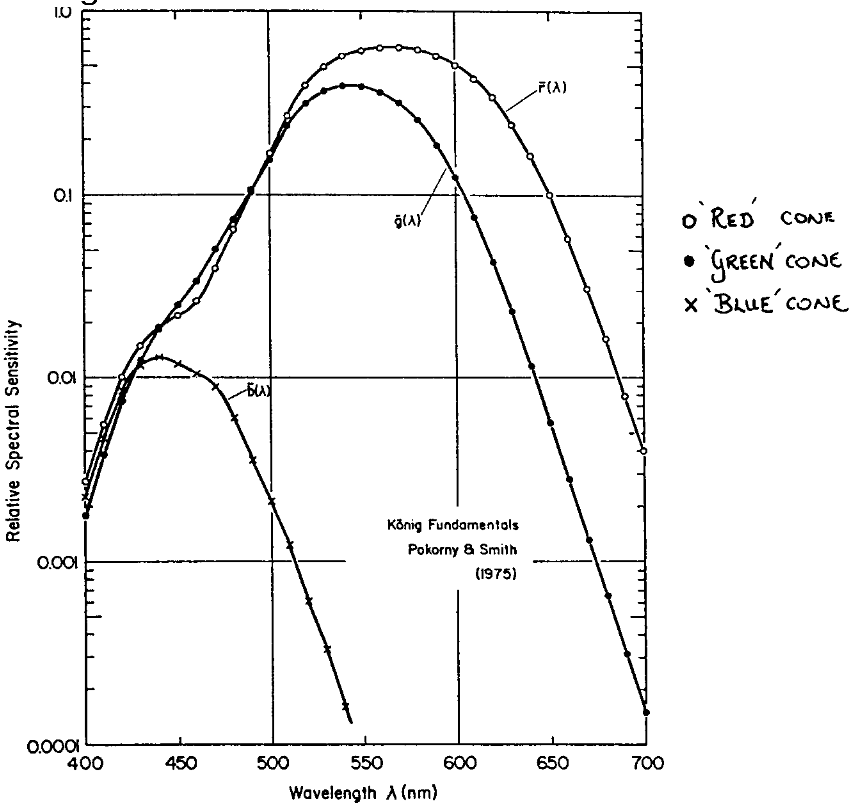

Fig. 7 **Relative spectral sensitivities of Konig-type fundamentals derived by Smith and Pokorny (1975).**

How Visible are the Orange Markers to a Colour Defective?:

The preamble has demonstrated that the colour defective response to colour is complicated and influenced by many physical(more reliable if lustrous colours of large area), psychophysical(prefer steady state adaptation) as well as physiological factors(degree of photopigment dysfunction).

The Dichromat(cone pigment absent condition) judges all colours from green through red on the basis of brightness and saturation only. Until they identify the marker by its shape or brightness difference the orange colouration (based on its low reflectance and and location on a principal confusion locus) will only act as a minor secondary cue under most forest conditions. Figure 8 demonstrates their inability to distinguish between hues at these longer wavelengths.

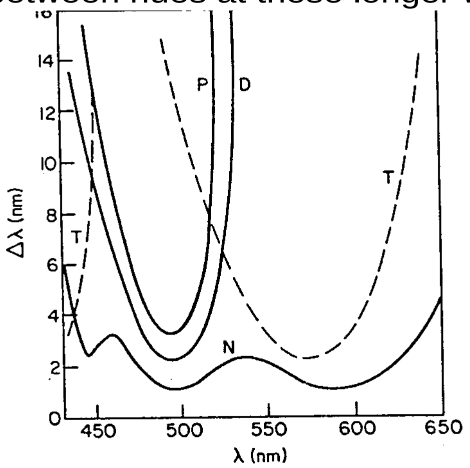

Fig. 8 **Wavelength discrimination curves for protanope, deuteranope, and tritanope' and normal observer. (Le Grand, 1957).**

The Anomalous Trichromat (cone pigment present but abnormal) has a weakened cone response. To the 'red weak' Protan the 'orange' is seen darker than for the normal observer. The orange colouration alone would not be a major cue. The Deutan ('green weak') observers would fare better than the other colour defective groups. However they are predisposed to a wider range of colour confusions and so lose some of their apparent advantage.

Overall the orange markers are not very visible to most colour defectives.

4 IS IT POSSIBLE TO GIVE AN INDICATION OF THE PERCENTAGE OF THE POPULATION THAT WOULD BE UNABLE TO SEE THE MARKERS IN A NORMAL FOREST SITUATION?

Walking Track Markers Installation:

Quotes from the specification -

"Markers should be spaced so that they can be viewable in both directions of travel."

This implies that the walker will seldom have a marker aligned so they are looking directly at it. Which means it presents an even smaller area to locate.

"The upcoming marker must be visible from the preceding marker (generally 30m in forested areas)". As mentioned earlier the markers are visually very small from a 30m distance, even when seen face on.

There are 3 groups of people who would have difficulty seeing the markers.

1. The colour defectives and poor colour discriminators.

About 8% of males and ½% of females are colour defective. There is a small group of people (about 1%) who have reduced colour discrimination.

2. People with reduced vision.

A reasonable proportion of the population do not meet the normal visual criteria. In most cases this could be optically corrected while for others it accompanies ocular disease and is not remedial. This is a difficult group to quantify but perhaps 4-5% of the active public would fall into this category. Their image is out-of-focus, so it is difficult to distinguish shape, contrast is reduced and colours are desaturated.

3. The older age group.

again this is a difficult group to quantify, by proportion or against the number who 'go bush'. Their principal difficulties are greater problems with glare, slower recovery of visual sensitivity going from light to dark, visual acuity can be reduced due to natural aging processes and their colour perception can be desaturated as well as showing the blue deficit mentioned earlier. Conservatively, could include less than ½% of your trampers. The Department may have demographic information regarding the age distribution and may be able to assess this group's importance more accurately.

Conclusions:

From my consideration of these markers I would imagine that about 10% of the population would be unable to see the markers easily: from the distance expected under the variable, but normal forest situation.

About 1/3 of this group could be anticipated to have considerable difficulty, which would be exaggerated if the cues were unnecessarily restricted. For example

- marker located on an equally reflectant tree trunk.
- low lighting.

- shadows and snowflake lighting.
- oblique marker alignment.
- viewed against bright background, eg for example the sky behind the foliage.

REPORT SUMMARY

The current track marker is criticised on the following grounds

1. It is smaller than the AS 2158-1978 recommends, especially across the base dimension.
2. The surface reflectance is not significantly greater than the forest 'background'.
3. The colour is not easily seen in a forest situation by a significant proportion of people.

It is considered that the markers shape is reasonably visible, particularly in the forest setting where it presents a novel configuration, enhancing its location.

It is suggested that a range of field studies be undertaken to assess the relative importance of the variables discussed and to provide a basis for presenting informed, supportable recommendations.

APPENDIX A

Figure 9 presents the threshold functions for a 10.5 min.arc white circular patch exposed for 2 seconds along the horizontal and vertical primary meridians (cited by Graham, 1966, 169).

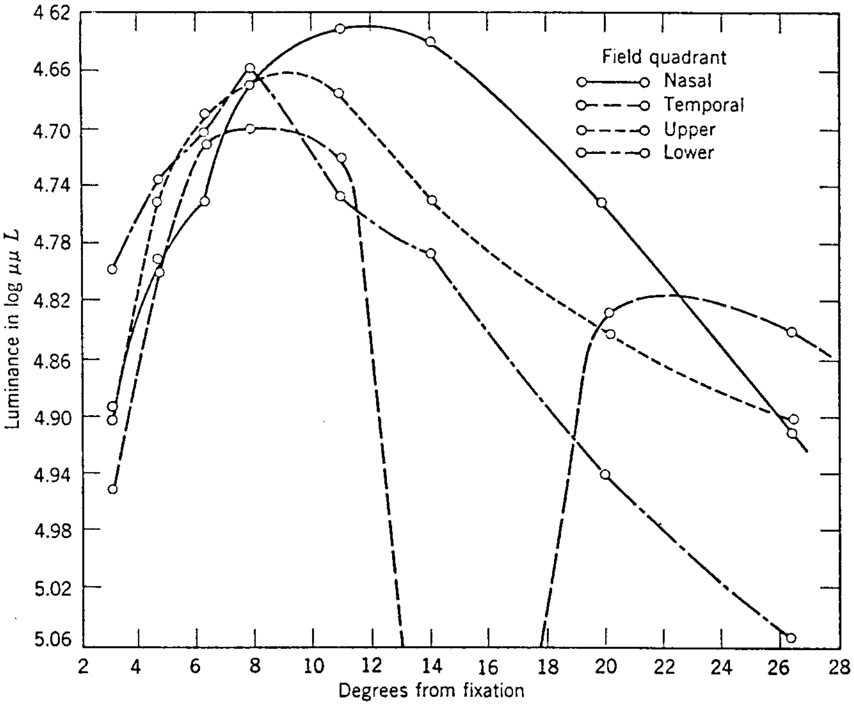

Fig. 9 Mean thresholds, in log micro-microlamberts, for three subjects for each field quadrant at various degrees from fixation. (From deGroot, Dodge and Smith, 1952.)

APPENDIX B

Track Marker Colourimetric Data:

A.S. 2158-1978

Colour		Munsell notation	C.I.E. coords. x	C.I.E. coords. y	Luminance factor
Blue	108	7.5 PB 2.5/10	0.1944	0.1397	0.045
Yellow	356	10 Y 7.5/12	0.4381	0.5076	0.510
Orange	557	2.5 YR 6/14	0.5488	0.3947	0.300

N.Z. Dept. of Conservation track markers

Blue		5 B 6/12	0.1685	0.2339	0.288
Yellow		5 GY 8/12	0.3924	0.5199	0.511
Orange	small	5 YR 6/10	0.4921	0.4022	0.255
	large	5 YR 6/14	0.5423	0.4188	0.278

These C.I.E. coordinates are graphed on page 22 to present their principal wavelength and colour purity. For the purposes of illustrating these relative and approximate values a daylite colour temperature of 5500^{o} K, C.I.E. illuminant D_{55} was selected (x=0.335, y=0.347).

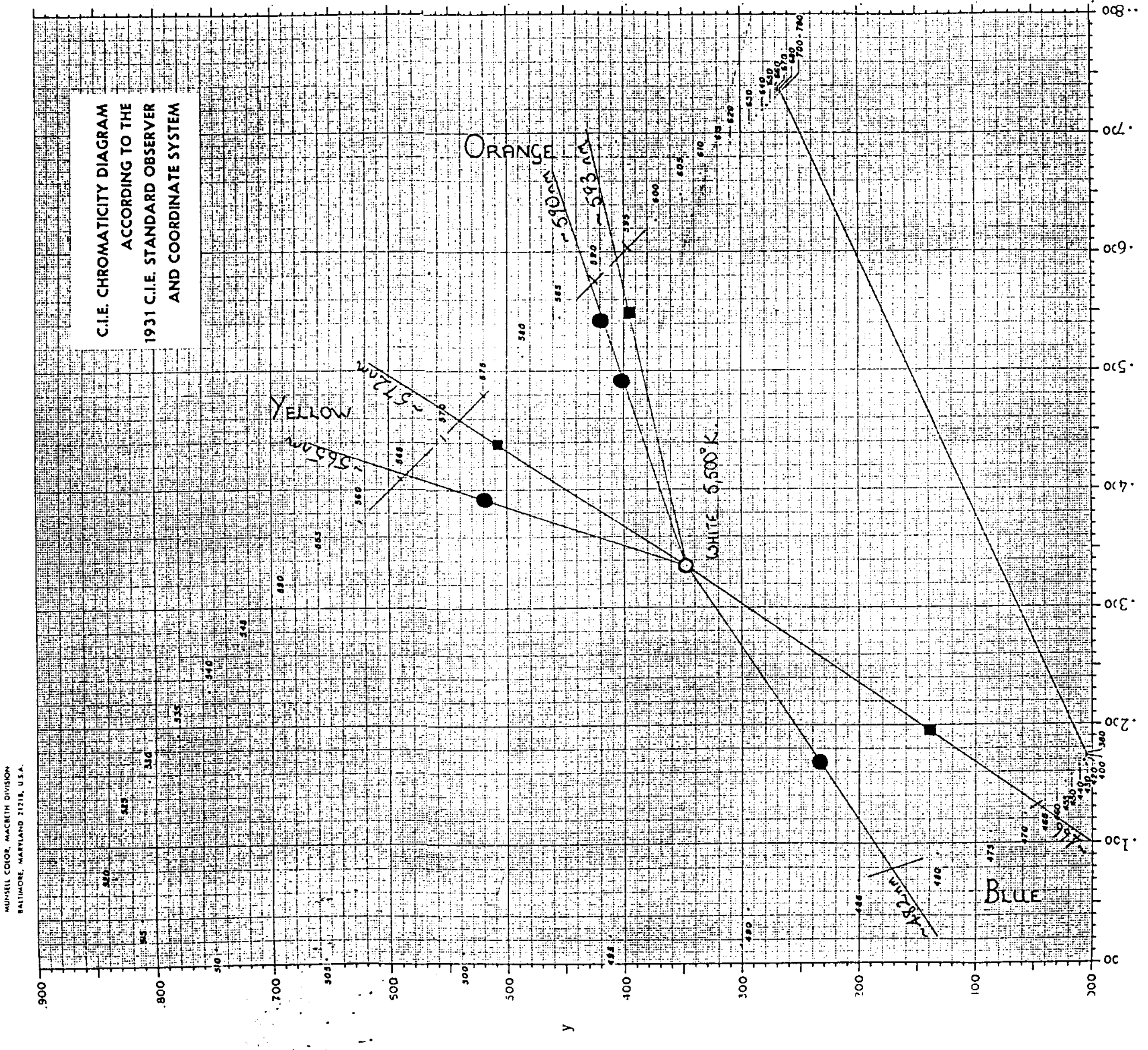

Fig. 10 C.I.E. plots of the A.S. 2158-1978 colours(■) and the NZ Department of Conservation track markers (●), referenced to 5500°K white(○). The dominant wavelength is specified while colour purity is indicated by the distance of the colour from the 'white' reference.

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