THE EFFECT OF HEDGING ON WOOD CHARACTERISTICS OF *PINUS RADIATA*

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ABSTRACT

Eleven **Pinus radiata** trees grown from seed in the Australian Capital Territory were kept as a hedge two metres high from age five years by removing all long-shoot buds in the autumn of successive years. Wood specimens from these and 11 normal trees growing nearby were examined. The hedged trees exhibited reduced radial growth rate, larger spiral grain angles, shorter tracheids and reduced density values compared to normal trees. The wood of ramets derived from the hedged trees at age eight years was not different from that of ramets propagated from normal trees grown from seed.

INTRODUCTION

Techniques are available for the economic large-scale production of rooted cuttings of *Pinus radiata* (Thulin and Faulds, 1968). The use of clonal plantations is therefore a possible and attractive procedure in tree improvement work for this species (Fielding, 1964; Thulin and Faulds, 1968).

General experience has shown that both the rooting ability and quality of the rooted cuttings decrease with increasing age of the ortet (Fielding, 1964; Libby and Conkle, 1966; Thulin and Faulds, 1968). However cuttings from mature ortets retain the adult morphological stage of development and avoid the defects in stem form and branching associated with juvenility and adolescence. In addition, the wood of these ramets is less dense, has larger spiral grain angles and longer tracheids than the wood of the associated ortets at the same age (Nicholls and Brown, 1971).

There is evidence (Fielding, 1954; Pawsey, 1971) that "juvenility" with respect to rooting ability can be preserved by re-propagating from a succession of young ramets rather than from the original ortet. The wood of young second-stage ramets tends to be of the same density, have larger spiral grain angles and form mature tracheids at an earlier age than that of the associated first-stage ramets (Nicholls *et al.*, 1976).

It has also been observed (Matthews, 1952; Fielding, 1954) that rooting ability can be maintained by using cuttings from seed-grown *P. radiata* trees whose height growth has been repeatedly restricted by training them as hedges. From a study of such material,

FIG. 1—**Pinus radiata** trees growing at Halls Block in November 1975. In the foreground is a normal tree-form stem. The several small trees are of the same age as the normal tree, but from age 5 years they have been kept to a 2 m high hedge. An older plantation in the far background is separated from the experimental block by a 20 m wide road.

Libby *et al.* *(1972)* concluded that the hedging treatment arrests the decline in rooting percentage and quality normally associated with maturation of a clone.

It is of interest to ascertain the effect of hedging on wood characteristics of both the hedged trees and their asexually-derived progeny. Therefore values of average tracheid length, spiral grain angle and densitometric parameters in successive growth rings from the pith from hedged trees were compared with those from normal tree-form trees of the same age growing nearby. The wood characteristics of the hedged trees were also compared with those of their associated ramets and ramets from normal tree-form trees.

MATERIAL

The hedged and adjacent untreated trees were growing in compartment 166, Halls Block, Uriarra Forest, about 23 km WSW of Canberra at an elevation of 700 m. Mean annual rainfall is about 1000 mm and the soil is derived from Paddys River Volcanics (dacite, acid tuff, lenses of limestone, calcareous shale and phyllite).

All of these trees had grown from naturally-regenerated seedlings on a site which sloped down gently to the WNW. In 1963, it was estimated that they were 5 years old from seed. In the autumn of 1964 and of each subsequent year, cuttings were taken from each of the 11 hedged trees, and then the ends of all remaining long shoots were removed. The height of the trees was thus maintained at about 2 m (Fig. 1). After 1964 virtually all new shoots originated from fascicle meristems.

All the trees were irregularly and rather widely spaced in an area 30 m by 30 m. The relatively large size of the normal trees (mean height 14.4 m, mean d.o.b. 20.6 cm at 30 cm height) together with the presence of unsampled stems, produced a higher stand density for them than for the hedged trees (mean height 2.0 m mean d.o.b. 15.3 at 30 cm height in 1975).

In 1966 shoots were collected from 6 of the hedged trees and planted in 1967 as rooted cuttings in a field trial at Gibraltar Creek, about 45 km SSW of Canberra at an elevation of 700 m. A seventh treatment derived from 4 year-old normal seedlings from the Blue Range Plantation (Uriarra Forest) was also represented. Mean annual rainfall is 845 mm and the geological parent material is granodiorite on the Murrumbidgee batholith.

The 56-tree clone plot, situated on a gently sloping site, measured approximately 14 × 30 m and the ramets were spaced at 2.1 m × 2.7 m in a random pair design. At the time of sampling the ramets had a mean height of 10.5 m and a mean d.o.b. at 1 m height of 15.6 cm. During 1974 the ramets were pruned to a height of 2 m above ground level.

EXPERIMENTAL PROCEDURE

In July-August 1975, the 11 hedged trees and an equal number of the normal trees were sampled by taking wood specimens at a height of 30 to 40 cm. In late September 1975, 2 ramets from each of the 6 clones derived from the hedged ortets and 3 ramets from the normal treatment were sampled and wood specimens collected at a height of about 1 m.

Specimens were sawn pieces measuring 4 cm × 4 cm, extending from bark to bark including the pith and located between branch whorls. Sampling heights were adjusted to show 13 complete growth rings for the specimens from the hedged and normal trees and 6 rings for the ramets. Before removal from the tree, the ends of each specimen were marked to show the direction of the tree axis. Bark thickness was determined at a height of 0.6 m for both the hedged and control trees.

Determinations of spiral grain angles, average tracheid length and the collection of densitometric data were carried out according to procedures described elsewhere (Nicholls and Phillips, 1970; Nicholls, 1971). Angles of grain deviation for individual growth rings in each specimen were expressed as the mean of values for both radii. Material from the growth ring adjacent to the pith was not examined because this ring may be incomplete and non-representative.

From selected growth rings in four of the hedged trees, transverse sections 15 μm thick were examined using a projection microscope. The number of tracheids in each growth ring were counted. In each ring 100 tracheids at the position of maximum or minimum density were measured at 400× magnification, and lumen diameter and double wall thickness in the tangential and radial directions were determined (Table 1).

The data for the 11 hedged trees, the 11 normal trees, the 12 ramets from the 6 hedged ortets and the 3 ramets from the normal ortets were grouped separately on the basis of ring number from the pith and means were calculated for each characteristic. The variation in the means through successive growth rings from the pith for the hedged and normal trees are shown in Fig. 2. Mean values for the two sets of ramets and the hedged ortets are set out in Table 2.

RESULTS AND DISCUSSION

Hedged and Normal Trees

Ring Width

Initial differences at growth rings 2 and 3 (Fig. 2) probably reflects the greater competition from weeds experienced by the normal trees.

For both means localised decreases in ring width are apparent at rings 4 and 7 corresponding to the 1964/65 and 1967/68 growing seasons which had below-average rainfall.

The two means are significantly different from ring 5 to ring 13 despite the greater stand density of the normal trees compared to the hedged trees. If the means were adjusted to equality in the pretreatment period they may have exhibited a significant difference at ring 4. It is unlikely that the larger decrease in ring width by the hedged trees at ring 4 is due to a greater response to water stress than that of the normal trees, as there is no evidence of this at ring 7.

A significant correlation based on samples from hedged and normal trees was found for ring width and the number of cells across the ring ($r = 0.93^{**}$). The narrower rings of the hedged trees are therefore mainly due to fewer cells rather than a smaller average cell size.

It is very clear (Fig. 1) that the hedging treatment has caused a major reduction

TABLE 1—Means of cell cross-sectional dimensions and density data at the positions of minimum and maximum density in selected growth rings from hedged and normal **P. radiata** trees

Measuring position	Minimum density						Maximum density					
Tree type	Hedged			Normal			Hedged			Normal		
Growth ring number from pith	2	6	12	2	6	12	2	6	12	2	6	12
Radial cell diameter (μm)	42	34	32	32	41	39	16	12	16	11	12	20
Radial cell-wall thickness (μm)	4.1	2.9	3.3	2.9	3.8	5.5	3.8	2.9	4.1	3.1	3.9	5.9
Tangential cell diameter (μm)	26	28	31	27	31	36	27	31	35	23	26	37
Tangential cell-wall thickness (μm)	3.5	3.0	3.7	3.1	3.7	5.0	6.2	4.9	6.0	5.6	5.5	8.1

TABLE 2—The means of wood characteristics through successive growth rings from the pith for 11 hedged ortets, 12 derived ramets and 3 ramets from normal or tree-form ortets

Growth ring no. from pith	Ring width (mm)			Spiral grain angle (deg)			Av. tracheid length (mm)			Max. density (kg/m³)			Min. density (kg/m³)			Latewood ratio %			Av. density (kg/m³)		
	H.O.	R.H.	R.N.	H.O.	R.H.	R.N.	H.O.	R.H.	R.N.	H.O.	R.H.	R.N.	H.O.	R.H.	R.N.	H.O.	R.H.	R.N.	H.O.	R.H.	R.N.
2	7.7	16.2	15.2	–7.1	–7.4	–7.9	1.63	2.00	2.01	592	594	570	357	228	223	0.39	0.34	0.37	452	349	353
3	7.8	12.7	12.0	–6.1	–6.1	–7.7	1.91	2.33	2.28	589	730	708	319	288	277	0.39	0.22	0.21	422	383	367
4	5.2	8.8	8.6	–4.7	–5.5	–6.8	2.07	2.75	2.68	677	691	690	314	312	320	0.32	0.28	0.25	429	418	412
5	4.7	10.7	12.1	–3.6	–4.7	–4.7	2.24	3.02	2.91	551	660	613	297	285	260	0.31	0.28	0.32	377	387	373
6	5.2	7.3	7.3	–3.1	–3.6	–3.7	2.35	3.17	3.12	561	809	832	289	322	293	0.35	0.23	0.23	386	431	418

H.O. — Hedged ortets

R.H. — Ramets derived from hedged ortets

R.N. — Ramets derived from normal ortets in the photosynthetic capacity of the tree with a concomitant reduction in annual radial increment.

Bark Thickness

At a height of 0.6 m the bark thickness for the hedged trees is 17.5 mm and 16.4 mm for the normal trees. There is no significant difference between the two means.

Spiral Grain

The pattern of variation for the normal trees (Fig. 2) is typical of *P. radiata* grown in Australia, viz. initial "left-hand" spiral angles which decrease with age through zero to a "right-hand" spiral (Fielding, 1967). That for the hedged trees is similar, with pre-treatment values almost the same, but with a less rapid decrease in grain angles with increasing age. However the two means are significantly different only at rings 10 and 11.

Investigations of spiral grain in *P. radiata* (Nicholls and Fielding, 1965; Fielding, 1967) have indicated that grain angles are not affected significantly by site quality or by environmental variation between trees as expressed by differing growth rates. The observed differences are unlikely therefore to have any association with environmental factors across the block.

In a series of experiments dealing with grain alignment in the corewood of this species Harris (1969) removed all vegetative buds at fortnightly intervals throughout the growing season. It was hoped to curtail the main sources of auxin to the stem but the procedure resulted in a profusion of short shoots which partially defeated the objective. Nevertheless, there were indications that the treatment produced smaller grain angles. The present results indicate a tendency to larger negative grain angles in the treated trees.

Average Tracheid Length

The means for both the normal and hedged trees (Fig. 2) follow the generally observed pattern of increase from the pith outwards (1.65 mm for both means at ring 2). Following treatment, the rate of increase reduces progressively for the hedged trees to some 15-16 percent at rings 11 and 13. The mean is highly significantly less than that for the normal trees from growth ring 7 onwards.

Examination of individual trees indicated that there was no relationship between tracheid length and tree spacing.

Most variation in tracheid length is traceable to the cambial initials from which the tracheids were derived (Larson, 1963). Tip growth of the derivatives is rarely larger than 20 percent (Bailey, 1920) and is greater in the latewood than in the early-wood (Chalk and Ortiz, 1961). However, differential intrusive growth of the maturing tracheids could explain the observed differences in the present study especially as sampling was carried out in the last-formed latewood.

On the other hand, tracheid length is highly dependent on the frequency of anticlinal or pseudotransverse divisions occurring in cambial cell multiplication. Such divisions give rise to daughter cells about one half the length of the cambial initials. It is unlikely that the shorter tracheids of the hedged trees are due to a greater number of anticlinal divisions because these trees grew more slowly and at a given age would have smaller circumferences and hence require fewer radial files of the same size cells as the normal trees. As the distribution of these divisions may vary throughout the

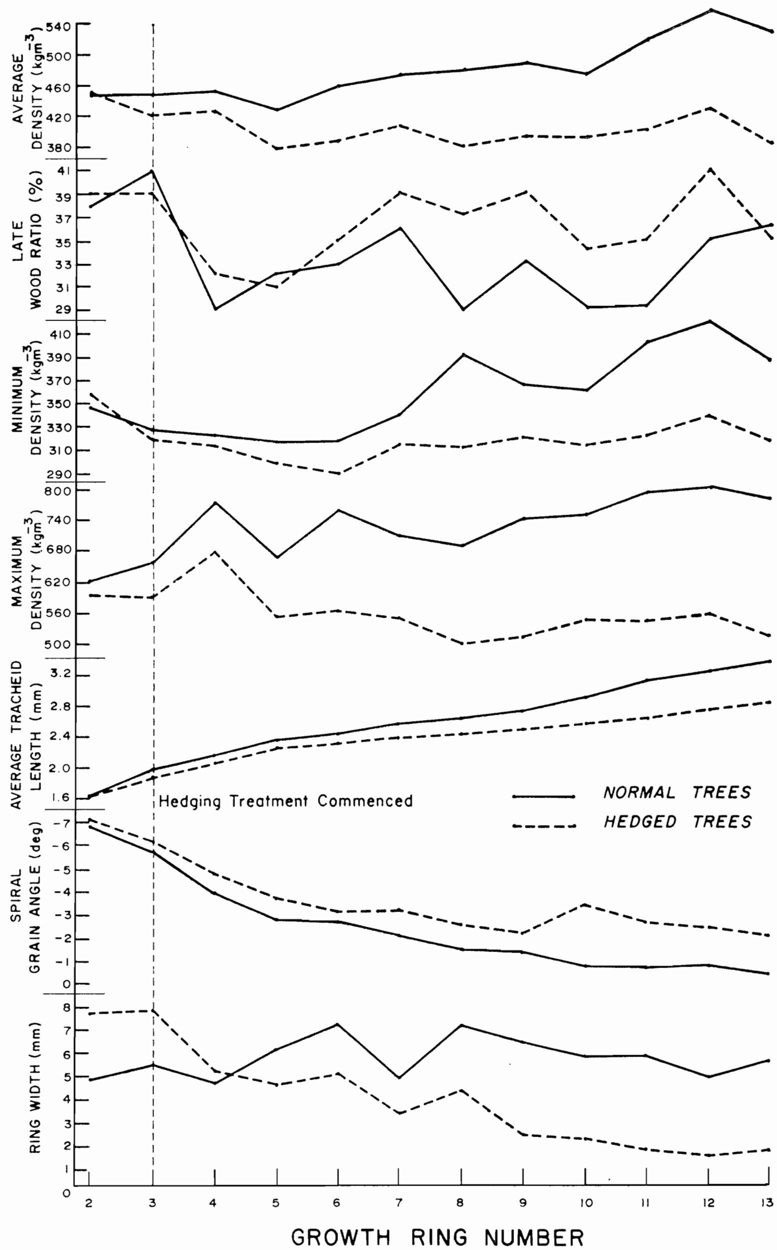

FIG. 2—Variation through successive growth rings from the pith of the means of ring width , spiral grain angle, average tracheid length, maximum and minimum density, late wood ratio and average density for the wood of hedged and normal **P. radiata** trees.

growing season (Bannan, 1968) it is possible that the observed differences are the result of the sampling position. However, tracheid lengths in serial sections across growth rings of the same width and at the same ring number from the pith, in hedged and normal trees, showed similar values at the selected sampling point.

There may be no clear cut explanation, as Bannan (*see,* for example, 1960 reference) has stressed that tracheid length variation may be the result of the combined effect of several independent cambial processes. The increasing differences in tracheid length between the hedged and control trees, together with the increasing height differential, suggests that the apical meristem may be involved, and Richardson (1964) has emphasised the importance of this in explaining tracheid length variation.

Maximum Density

The mean for the normal trees (Fig. 2) increases steadily from ring 2. This pattern is similar to that recorded for other young *P. radiata* material from the Canberra area (Nicholls *et al., 1974).* The mean for the hedged trees decreases from ring 2 outwards and is highly significantly less than that for the normal trees for rings 3 to 13. However, if the two means were adjusted to equality in the pretreatment period it is unlikely that significant differences would have been recorded until rings 5 or 6.

There is a localised increase in maximum density for both means at ring 4 corresponding to the autumn of 1965, but not attributable to meteorological factors (Nicholls and Wright, 1976).

Previous work (Nicholls, 1971) has shown that maximum density is not affected by thinning and therefore the observed differences are unlikely to be due to differences in spacing.

Maximum density in this species is generally recorded in the last-formed latewood of the growth ring at the position where cell-wall thickness is a maximum and tracheid radial diameter is minimal. Table 1 shows that cell-wall thickness accounts for the majority of the differences in maximum density between the material from the normal and hedged trees.

Maximum density may be an index of the period in the growing season of greatest photosynthate import to the developing xylem. The amount will depend not only on the total quantity available for distribution but also on the net allocation after competition with other metabolic sinks within the tree. The amount of foliage carried by the hedged trees is much less than that of the normal trees and there is an even greater disproportion for photosynthetic production since conditions are more favourable for the formation of assimilates in the upper crown (Fig. 1). It will also be noted from Fig. 2 that the difference in maximum density increases with age; as does the amount of foliage available for the production of photosynthates.

Minimum Density

The variation displayed by both means (Fig. 2) is one of initial decrease from ring 2 to 6 followed by an increase. This pattern has been recorded previously for *P. radiata* material from the Canberra plantations (Nicholls *et al.,* 1974). Differences between the two means are significant at ring 6, and highly significant for rings 8 to 13.

Minimum density also has been shown to be unaffected by thinning (Nicholls, 1971) and therefore the observed differences are unlikely to be due to differences in spacing.

Minimum density for this species occurs in the earlywood where tracheid diameter is at or near maximal and wall thickness is minimal. However, because minimum density is sensitive to small changes in wall thickness, the position of minimum density is not always as clear or as constant as that for maximum density. Nevertheless, as tracheid diameter is determined to a large degree by the amount of auxin reaching a developing tracheid, minimum density should be an index of the period in the growing season when shoot and needle production are most vigorous, as these appear to be the principal source of auxin for tracheid enlargement (Larson, 1969). It may be seen from Table 1 that variation in cell-wall thickness accounts for most of the differences in minimum density between the normal and hedged trees with differences in tracheid diameter playing a minor role.

It would appear that the reduction in wall thickness in the hedged trees is attributable to the marked reduction in available photosynthates brought about by a reduction in foliage as a result of the hedging treatment. Removal of the long shoot buds has suppressed terminal growth and this should result in the observed reduction in tracheid diameter (Larson, 1969).

Latewood Ratio

This is the proportion of latewood in a growth ring assuming the earlywood/latewood boundary at the mid-density point (Nicholls and Brown, 1971). The pattern (Fig. 2) is similar to that observed previously in material of comparable age from this area (Nicholls and Brown, 1974). Values for the hedged trees are larger from rings 6 to 12, but the two means are only significantly different at rings 8 and 11. The annual variation exhibited by both means is an indication of the influence of seasonal factors on this parameter.

An increase in latewood ratio may be the result of an increase in the amount of wood formed in autumn, or a decrease in the production of wood resulting from growth in spring and early summer. The reduction in ring width for the hedged trees indicates that the latter is the more probable, as the hedging treatment carried out in autumn removes material which not only is a potential producer of photosynthates, but also is a source of stored food reserve for spring growth. Experimental reduction of crown size in longleaf pine by Marts (1951) likewise resulted in a curtailment of overall annual radial growth, and in particular, a loss of spring-formed wood.

Average Density

This characteristic is related to the other densitometric parameters as follows:

$$\text{Average density} = \text{latewood ratio (maximum density} - \text{minimum density)} + \text{minimum density.}$$

Both means decrease from ring 2 to ring 5 and then increase (Fig. 2). The rate of increase of the normal trees is much faster than that of the irregular trend of the hedged trees so that the two means are highly significantly different from rings 5 to 13. Detailed variation in the means for the component parameters (maximum, minimum density, etc.) is clearly evident in the means for average density.

Average density is influenced mainly by cell wall thickness; the observed differences are therefore due to a reduced total photosynthetic output through reduction in crown size by the hedging treatment.

Ramets

Ring Width

Growth rate recorded at the ramet plot is markedly greater than that for the hedged trees prior to treatment (Table 2). The better growth is attributable to cultural differences between the two sites which is expressed particularly in the early years. There are only slight differences in ring width between the ramets derived from the hedged trees and those from the normal trees.

Spiral Grain

There are no differences in grain angles between the ortets and the derived ramets or between the two sets of ramets (Table 2). The general pattern of variation is one of decreasing magnitude from a maximum at growth ring 2.

Other work indicated that the wood of the ramets might show larger grain angles than the ortets (Nicholls and Brown, 1971; Nicholls *et al.,* 1974). However, a comparison involving a minimal age difference between ramets and ortets such as in the present case, revealed that grain angles were essentially the same (Nicholls *et al.,* 1976).

Average Tracheid Length

For each mean there is an increase from the pith outwards (Table 2). There is no essential difference in tracheid length between the two sets of ramets, but the ramets derived from the hedged ortets have tracheids which are significantly longer in all growth rings than those for the hedged ortets, or for the 11 normal trees. In other words, it is not a reflection of the hedging treatment.

The longer tracheids of the ramets compared to the ortets support the findings of previous studies (Nicholls and Brown, 1971; Nicholls *et al.,* 1974). Thus it is unlikely that the observed differences are the result of cultural or edaphic factors between the two sites nor to differences in climate during the two periods when the wood undergoing comparison was being formed. However the present observations conflict with those when there was a minimal age difference between the ramets and ortets (Nicholls *et al.,* 1976).

Maximum Density

There are no significant differences in maximum density between the two sets of ramets but values for the ortets are highly significantly less than those for the ramets from the hedged ortets at growth rings 3, 5 and 6. On the other hand there is no significant difference at growth rings 5 and 6 for the mean of the ramets from the hedged ortets and that for the 11 normal trees, suggesting that the observed differences are due to the hedging treatment and not the result of the method of propagation.

Minimum Density

The mean for the ortets is highly significantly different from that for the derived ramets at growth rings 2, 3 and 6 but there are no significant differences between the means for the two sets of ramets. There is no significant difference at growth ring 6 for the mean for the ramets from the hedged ortets and the 11 normal trees so that the observed differences are the result of the hedging treatment.

Latewood Ratio

There are no significant differences in latewood ratio between the means for the two sets of ramets but the mean for the hedged ortets is highly significantly different at rings 3 and 6 than that for the derived ramets. The mean for the ramets is significantly different at ring 6 by comparison with that for the 11 normal trees.

Average Density

Because of the relation between average density and the component parameters, it is not unexpected to find that there is no significant difference between the means for the two sets of ramets. There are significant differences between the means for the hedged ortets and derived ramets at rings 2, 3 and 6. However the mean for the ramets is not significantly different from that for the 11 normal trees at ring 6 indicating that the observed difference is due to the hedging treatment.

The results for the density parameters support the previous work (Nicholls *et al.*, 1976) involving a comparison of wood characteristics between ramets and juvenile ortets (less than *ca.* 8 years old).

CONCLUSIONS

The treatment given to the hedged trees has resulted in reduced ring width, increased spiral grain angles, decreased average tracheid length and reduced density values. These are characteristics associated with juvenile wood, but it is not suggested that hedging results in juvenile wood formation.

The most marked effect of the hedging treatment is the loss of foliage which directly reduces the photosynthetic capacity of the tree. This limits the production of wood formed in spring and this in turn is reflected in an overall loss in annual radial increment. A reduction in total photosynthate results also in reduced cell-wall thickness and thus the formation of less dense wood.

The interference with the balance of growth regulating substances apparently does not result in severe changes in wood characteristics. Endogenous supplies of these are evidently sufficient for the physiological needs of the tree, especially taking into account the reduced size.

It is gratifying to find that the hedging treatment does not affect wood characteristics in trees which are vegetatively propagated from them. Full advantage may therefore be taken of the hedging treatment as a source of scion material. However, for long-term use of hedged material (as would be required to produce cuttings of proven genotypes for aforestation) it remains to be shown that hedged trees do not lose juvenility beyond the age of those used for the present study (eight years). Except for average tracheid length the similarity in wood characteristics of the ortets and ramets support other work which also involved material derived from juvenile ortets.

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