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Seasonal Variation in Root Growth Capacity during Cultivation of Container Grown *Pinus sylvestris* Seedlings

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Root growth capacity (RGC) in Scots pine seedlings was studied from the time of sowing and during the following two growing seasons. The method used for measuring RGC is also described. In the first growing season root growth was intense during the period mid-July to mid-September with an earlier peak for early sowing dates. After a period of low growth activity during winter, RGC rose sharply in early spring. During periods of intensive shoot elongation in May and June root growth was depressed. After shoot elongation was completed, RGC rose again before declining during the autumn. During winter and the second growing season, higher RGC levels were obtained for seedlings sown in June compared to the ones sown in April. This result is discussed with regard to differences in cultivation regimes. *Key words: Pinus sylvestris, containerized seedlings, root growth capacity, shoot elongation, seasonal variation.*

INTRODUCTION

Rapid root egress after outplanting is of vital importance for seedling establishment. To attain growing regimes with a maximum in capacity for root growth at the time of planting, better knowledge of the dynamics in root growth during cultivation at the nursery is needed.

In a number of studies, levels of root growth have been determined for forest tree seedlings, e.g. at the time of lifting (Stone et al., 1962; Day & MacGillivray, 1975; Jenkinson, 1980) or before or after cold storage at the nursery (Webb, 1976*a*; Rhea, 1977). Seasonal patterns in root growth for one-year-old or older seedlings have also been identified in several studies (for references, see e.g. Lyr & Hoffmann, 1967; Riedacker, 1976; Ritchie & Dunlap, 1980).

Most studies within this field have been made with North American species and mostly with bareroot seedlings. For European species these types of investigations are more rarely found (cf. Hoffmann, 1972; Hoffmann & Lyr, 1973; Lüpke, 1976). Furthermore, very few investigations have been published where seasonal variation in root growth of coniferous forest tree seedlings have been studied from the time of sowing (cf. Hoffmann, 1973; Nakvasina, 1982).

In the present study a method for measuring root growth is described. The general principles were originally outlined for bareroot seedlings by Stone & Jenkinson (1971), but here they have been adapted to containerized seedlings and the equipment designed to conform to operational demands from Swedish nurseries. The method described has then been used to determine seasonal root growth patterns in Scots pine (*Pinus sylvestris* L.) seedlings from the time of sowing and during the following two growing seasons in the nursery. Throughout this period root–shoot interactions have also been studied.

When measuring root growth, terminology has varied between different studies. "Root regenerating potential" (RRP) has been used by, e.g. Stone (1955), Stone et al. (1962, 1963), Krugman & Stone (1966), Zaerr (1967), and Rhea (1977), "Root growth potential" (RGP) has been used by, e.g. Ritchie & Dunlap (1980), and Ritchie et al. (1985). The expression "Root growth capacity" (RGC) has been used by several authors, e.g. Stone (1970), Stone & Jenkinson (1970), Burdett (1979), Jenkinson (1980), and Sutton (1980*a*). Since "root regenerating" is commonly used in the rooting and tissue culture literature with an entirely different meaning and since the term "potential" is frequently used in water relation terminology, the expression "Root growth capacity" (RGC) will henceforth be used in this study.

MATERIALS AND METHODS

Seedling cultivation was carried out at a commercial nursery in Nässja (lat. 60°15′ N, long. 16°50′ E) about 150 km NW of Stockholm. The plant material consisted of Scots pine (*Pinus sylvestris* L.) seedlings grown from seeds collected in a seed orchard (lat. 60°20′ N, long. 17°05′E, alt. 0–100 m) and originated from grafted trees from latitudes between 58°03′ and 61°37′ and altitudes between 70–170 m. Sowing took place on April 15 and June 15, 1981, in Paperpot Fh 408 containers (Lännen Tehtaat OY, Finland, 1 060 seedl. m^{-2}). The growing medium used was peat chips (Hasselfors K 11, pH 5.0, Sweden) mixed with two kilograms of dolomite lime per cubic metre.

The seeds were germinated and grown on pallets 20 cm above the ground in a plastic greenhouse until June 23 (April sown) and October 29 (June sown) after which the seedlings were moved outdoors together with the pallets. By growing the seedlings on raised pallets the roots were air pruned at the bottom of the container. During winter the seedling trays were stored close together on the ground without any form of snow fence, snow guard or shade cloth in spring. After completion of winter storage the trays were lifted from the ground and placed on the pallets for the rest of the growing season.

The seedlings were irrigated and fertilized in accordance with the nursery's standard routines. The fertilizer was dissolved in the irrigation water and consisted of a complete mineral nutrient solution (Ingestad, 1979) without magnesium or calcium. Fertilization started two weeks after sowing and continued for 12 weeks. The total nitrogen supply during the first growing season varied between 35 and 38 g m^{-2} for the two sowing dates. During the second growing season the seedlings were fertilized once every week from May until the middle of September. The total nitrogen supply was equivalent to 45 g m^{-2}.

The physiological state of a seedling is intimately dependent on plant growth regulators as well as on nutrition, internal water status and carbohydrate reserves (Sutton, 1980*b*). RGC can simply be described as one expression of this physiological state measured as the capacity of a seedling to increase the size of its root system at a certain time and in a controlled test environment through the elongation of roots already present and/or the initiation of new roots and their elongation.

In this study, RGC is measured as the total length of new roots after a certain period of growth. Determination of the total root length combines root growth by initiation or elongation in the same measurement, although root initiation and root elongation are different processes mediated by different factors (Street, 1969; Lavender & Hermann, 1970; Larson, 1975; Torrey, 1976).

RGC in seedlings was studied at two (1981) or four (1982) week intervals starting four weeks after sowing. The measurements were continuously repeated until the end of August, the second growing season after sowing. On each occasion 30 seedlings were

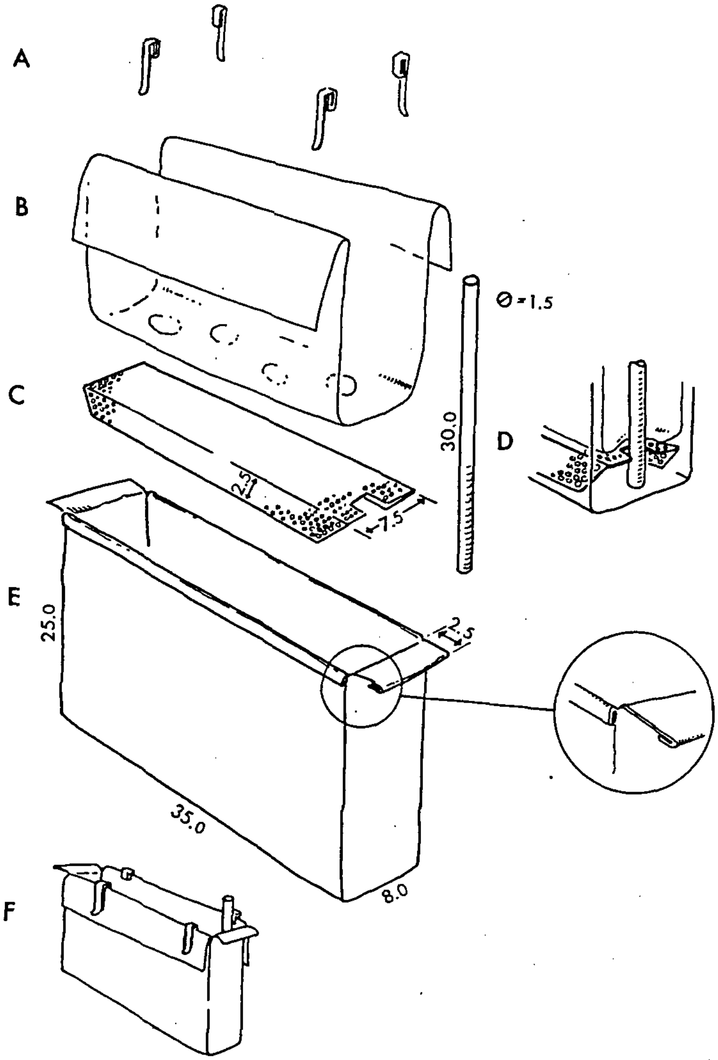

Fig. 1 Design of the RGC tray. The tray is made of 0.1 cm stainless steel plate. All measurements in cm. A=clips for attaching the plastic film to the RGC tray, B=plastic film (80×35 cm, thickness 0.02 cm) with holes for drainage, C=perforated stainless "floor" through which excess water can drain and be collected in the bottom of the RGC tray, D=drain-pipe used for sucking out excess water by connecting the pipe to a pump, E=RGC tray with flaps for attaching the tray to the water bath (cf. Fig. 2), F=assembled RGC tray where the plastic film must extend at least 10 cm outside the tray so that the soilmix and the seedlings can be pulled out of the tray after the test period by using the protruding plastic film.

randomly sampled from each sowing date. As the seedlings were air pruned during cultivation, no roots had developed outside the containers. The seedlings were then planted and treated according to a standardized RGC technique which is described below.

Sampled seedlings were planted in stainless trays (Fig. 1) in a growing medium of equal volumes of peat (Hasselfors, K 11, Sweden) and sand (Silversand 95, Ahlsell, Sweden). The trays were water-tight and designed so that excess water could be sucked out by a pump.

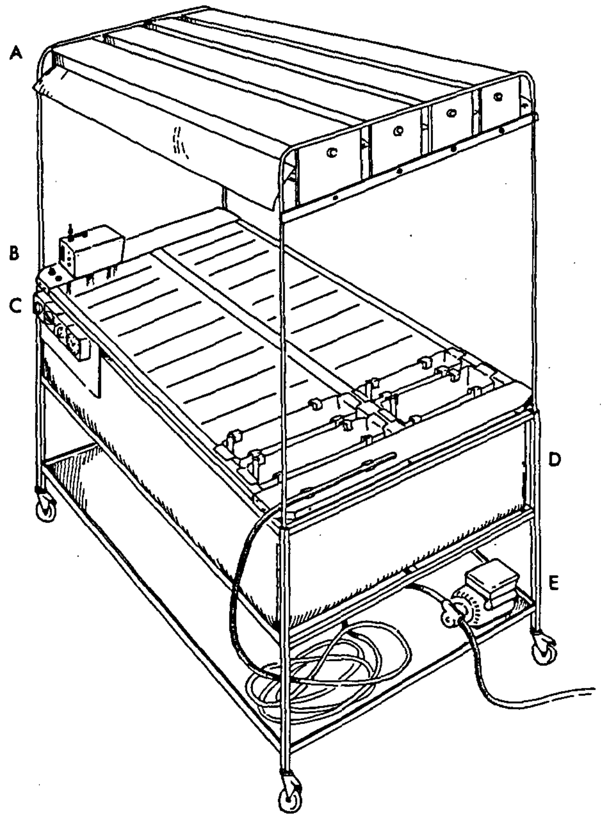

Fig. 2. Carriage with water bath and RGC trays. A=light equipment adjustable in height for different seedling sizes, B=immersion heater for temperature control of the water bath, C=control panel including time clock for adjusting the photoperiod, D=water bath, E=water pump and hose for sucking out excess water in RGC trays through the drainpipes (cf. Fig. 1).

After planting, the trays were immersed in a stainless water bath (24 trays in each bath) attached to a carriage with light equipment (Fig. 2). The temperature in the water bath was controlled by a thermostat-regulated immersion-heater. Light was provided by high-pressure sodium lamps (SON T 400 W, General Electric) giving a photon flux density at plant level of 325 μmol $m^{-2} s^{-1}$ when mounted one meter above the water bath. The trays, each containing five seedlings from the same treatment were arranged in the bath according to a completely randomized (CR) experimental design with six replications per treatment.

During the test period, which extended over 21 days, the water and air temperature were held at 20±1°C, relative humidity at 60±5% and the photoperiod was set to 18 hours at the irradiance given above. The seedlings were watered twice a week to keep the growing medium at the point of runoff. Excess water was sucked out from each tray about one hour after watering. No fertilizer was added during the test period.

After completion of cultivation all roots that had developed outside the containers were washed clean of peat and sand after which they were cut off. Total root length for each group of five seedlings was then registered by a "Root length scanner" (Comair Corp. Ltd., Australia). The "Scanner" is designed to provide a statistical measurement of the total length of a root sample randomly spread across a sample tray. Total length of plant roots is determined by detecting and counting root intersections that are in the spiral path of an optical scanner, using a line intersect principle suggested by Newman (1966). The instrument is capable of detecting roots down to 0.1 mm in diameter.

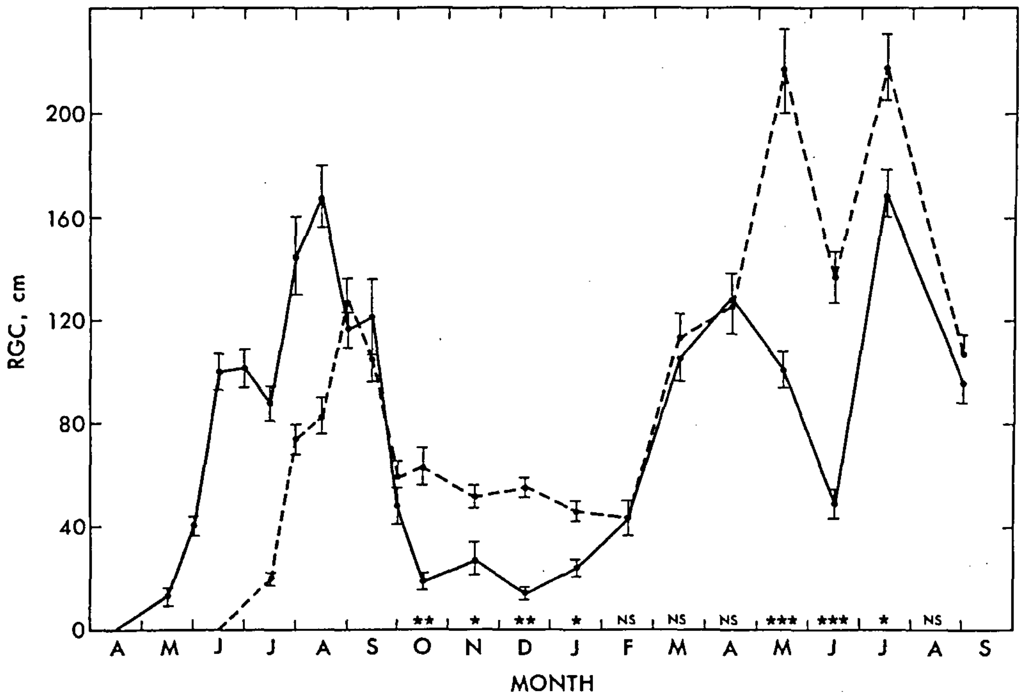

Fig. 3. Seasonal variation in Root Growth Capacity (cm per seedling) of Scots pine (*Pinus sylvestris* L.) seedlings during two growing seasons in the nursery. The results refer to seedlings sown on April 15 (—) and June 15 (---) respectively. The seedlings were cultivated in a greenhouse until June 23 (April sown) or October 29 (June sown) after which the seedlings were moved outdoors for the rest of the time presented in the figure. Vertical bars show ± standard error. Significant differences established by F-test (a=0.05*, 0.01**, 0.001***).

Statistical analyses of root lengths were made by Anova and significant differences in root growth between treatment means were established by F-tests.

RESULTS

Seasonal variation in RGC during two growing seasons following sowing are presented in Fig. 3. For seedlings sown in April the growth capacity during the first growing season peaked in the middle of August after which RGC rapidly decreased during the autumn. For seedlings sown in June the peak in root growth occurred in the beginning of September at a somewhat lower level than for seedlings sown in April. The RGC levels measured during the winter were low for seedlings from both sowing dates but with a constantly higher growth capacity for seedlings sown in June. During the second growing season, a rapid increase in RGC during March and April was followed by a depression in May and June. After this depression, RGC rose again in July after which root growth declined during the autumn. For the measurements in the middle of May, June, and July the levels of RGC were significantly higher for seedlings sown in June than for those sown in April.

Interactions between shoot and root growth during cultivation were studied in the first (Fig. 4) and second (Fig. 5) growing season. For seedlings sown in April, shoot elongation in the first year was approximately 1 cm every 14 days until the middle of July. During the period from mid-July to mid-August shoot elongation was intense, representing about 50%

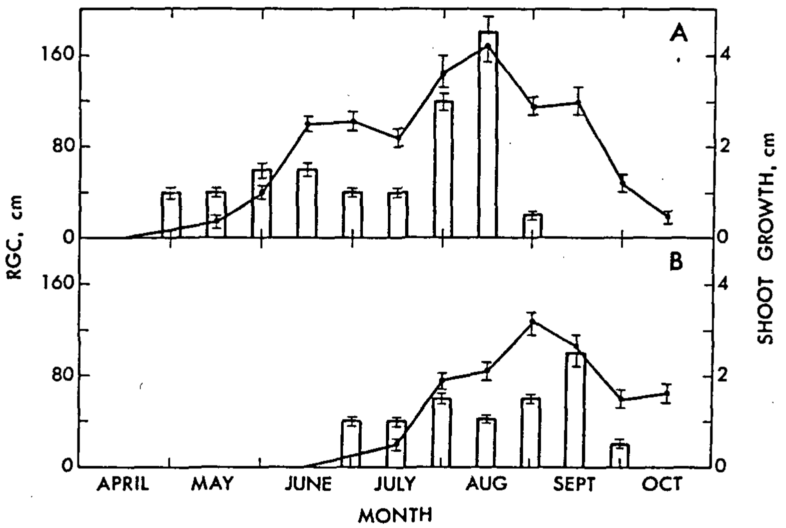

Fig. 4. RGC (—) and shoot growth (bars) of Scots pine (*Pinus sylvestris* L.) seedlings during the first growing season after sowing. The results refer to seedlings sown on April 15 (A) and June 15 (B) respectively. Vertical bars show ± standard error.

of the total height increment in 1981. For seedlings sown in June, intensity in shoot growth was low until the end of August after which a period of stronger shoot elongation could be registered until the middle of September.

Shoot elongation in the second growing season started in the beginning of May and was completed in the middle of July (Fig. 5). This applied to seedlings from both sowing dates. During intensive shoot growth in June root growth was depressed for both treatments.

DISCUSSION

Measurements during the first two growing seasons after sowing showed pronounced inherent seasonal patterns of RGC. Characteristic of the first growing season was the fact that RGC levels were high also during periods with intense shoot elongation. Several investigations have shown a relationship between shoot and root growth for one-year-old or older seedlings where periods with intense shoot growth have depressed root growth (e.g. Neuwirth, 1959; Schier, 1970; Etter & Carlson, 1973; Webb, 1975; Riedacker, 1976). This relationship has often been referred to as a competition within the plant for available carbohydrates (Eliasson, 1968, 1971; Riedacker, 1976; Webb, 1976*b*; Sandvik, 1981) where the comparative sink strength of root and shoot is essentially determined by their level of metabolic activity (Loach & Little, 1973; Glerum, 1980).

In this study, however, where activity patterns have been followed from the time of sowing, no such competition seems to be present during the first growing season. The strong growth activity for both root and shoot at equal periods indicates that the access to available photosynthate does not affect the priority between root and shoot growth capacity. The initial growth pattern of the primary root system emerging from a seed is therefore probably mostly related to an interacting complex of environmental factors where mainly soil factors as temperature, moisture, and oxygen are vital components in this process (cf. Sutton & Fayle, 1979; Sutton, 1980*b*).

The seasonal pattern in shoot growth during the first year can also be related to

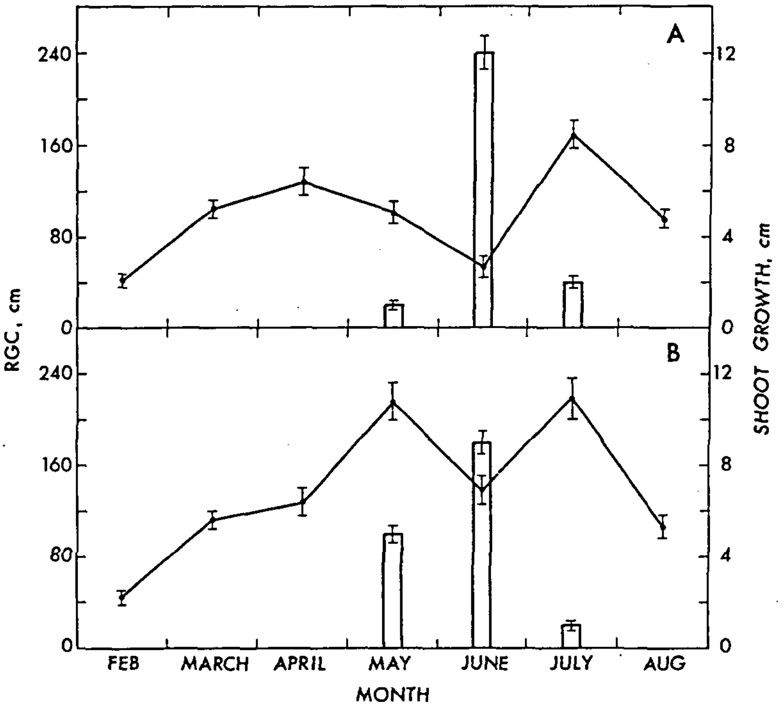

Fig. 5. RGC (—) and shoot growth (bars) of Scots pine (*Pinus sylvestris* L.) seedlings during the second growing season after sowing. The results refer to seedlings sown on April 15 (A) and June 15 (B) respectively. Vertical bars show ± standard error.

environmental factors where germination, *inter alia,* is dependent on moisture and temperature regimes (cf. Koller, 1972; Kaufmann & Eckard, 1977) and shoot elongation is affected by factors such as water potential and light intensity (cf. Logan, 1966; Kaufmann, 1968). The shortening photoperiod and decreasing temperatures during autumn are then factors of importance for the termination of shoot expansion and dormancy induction (cf. Downs & Borthwick, 1956; Aronsson, 1975; Cannell et al., 1976; Christersson, 1978; Ekberg et al., 1979).

During winter, root growth capacity was low. Although probably no internally controlled period of true dormancy is present in roots (cf. Stevens, 1931; Vogl & Kemmer, 1961) a longer period of quiescence (cf. Doorenbos, 1953) can be expected during winter in areas having low winter temperatures (Lyr & Hoffmann, 1967).

Root growth capacity rose sharply in early spring in the second growing season after sowing. Factors that affect root growth initiation in spring for one-year-old or older seedlings have been studied intensively (e.g. Hess, 1969; Street, 1969; Hartman & Kester, 1975; Torrey, 1976). From these investigations it is demonstrated that as the environmental conditions improve during spring, growth-regulating hormones such as, e.g. auxins or gibberellins increase leading to a gradual release of bud dormancy (Lavender & Wareing, 1972; Smith & Wareing, 1972). Apparently hormones are then transported from the shoot through the phloem to the root (Åberg, 1957; Burström 1957; Richardson, 1958; Leopold & Kriedemann, 1975; Torrey, 1976). The sharp increase in seedling root growth in early spring must therefore be interpreted as a response to more favourable growing conditions at the nursery in terms of, e.g. water supply, light intensity, and temperature affecting the root growth capacity in the way observed.

For seedlings from both sowing dates, RGC in the second growing season was depressed in May and June during which time shoot activity was intense (cf. Merritt, 1968; Smit-Spinks et al., 1985). During intense elongation the shoot can be considered as the major metabolic sink for currently assimilated carbohydrate resources limiting the possibilities for root expansion (cf. Gilmore, 1965; Etter & Carlson, 1973; Ericsson, 1978).

The resumption of root growth, after completion of shoot elongation, can be seen as a reverse sink strength relation favouring root growth under favourable environmental conditions. As these conditions deteriorate during autumn, root growth capacity will decline as an expression for a gradually increasing root hardiness induced by, *inter alia*, shortened daylength and lower soil temperatures (Pellet & White, 1969; Mityga & Lanphear, 1971; Johnson & Havis, 1977).

RGC in winter and during the second growing season was higher for seedlings sown in June. These differences are probably explained by the various environmental regimes during the autumn of the first year. Seedlings sown in April were moved outdoors in late June while seedlings sown in June were left in the heated greenhouse until the end of October. This must have been of significance for the potential formation of new root tips within the containers and also for the possibility of carbohydrate accumulation.

This paper has demonstrated distinct seasonal variation in root growth capacity for the seedlings studied. The limitation to one species and provenance, the container system used, and the growing routine described imply the need for further studies within this field. Better understanding of root growth patterns for forest tree seedlings, grown under different cultural practices, can be of decisive importance for the possibility of improving seedling establishment in the future.

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