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Root Studies in the Chilean Matorral

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Summary. The roots of matorral shrubs were excavated from an 18 m^2 site of a mixed matorral stand located on a 27° NE facing slope at 1000 m elevation 40 km NNW from Santiago de Chile. The climate in this area is similar to that of the Southern Californian chaparral. The main species present were *Lithraea caustica*, *Cryptocarya alba*, *Colliguaya odorifera*, *Mutisia retusa*, and *Satureja gilliesii*. After harvesting the above ground biomass, the soil was washed out in 20 cm layers down to a depth of 60 cm. The roots were harvested according to their position in the site, separated into species and root size classes. Soil analysis indicated a fertile and deep reaching, clayish soil. *L. caustica* was a deep rooting species with many thick roots growing deeper than 60 cm. This species had a massive burl of 67 kg dry weight in the excavation site. *Cryptocarya* was less deep rooting, and *C. odorifera* had a shallow root system. It is thought that the root:shoot biomass ratios of 4.9 and 1.4 for *L. caustica* and *C. alba* respectively are indicative of the forest character of this site in the past. This forest would have been destroyed by continuous charcoal manufacture. The bulk of the fine roots was found in the 20–40 cm soil layer. The average distance between fine roots was calculated as 1.9 cm. The results were compared with an earlier excavation in the Californian chaparral.

Introduction

Recent comparative studies of the Californian chaparral and the Central Chilean matorral have contributed substantially to our understanding of structure and primary production in these ecosystems (Kummerow and Fishbeck, 1977; Mooney, 1977). Nevertheless, it is evident that an adequate data base regarding the biological processes below ground is necessary for a more complete picture of the plant community dynamics.

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Initially, the structure of root systems of the main shrub species in the area should be analyzed. Some information in this respect is available from the Southern Californian chaparral. Hellmers et al. (1955) described the root systems of 18 shrub species with respect to their horizontal spread and depth penetration. Information was obtained from road cut observations and hydraulic excavations; rooting depths of 4 m and horizontal root extensions of 10 m were found. In the Israeli maquis, root depths of approximately 9 m were reported by Shachori et al. (1967). Recently, more quantitative information on chaparral roots has been added (Kummerow et al., 1977; Miller and Ng, 1977). In general, it can be concluded that horizontal root spread exceeds the extension of the shoot system by several times. With respect to rooting depth, chaparral species are very plastic and adapt to a wide variety of soil conditions.

Information on root systems in the Chilean matorral is scarce. Some mechanical excavations and road cut observations made by Giliberto and Estay (personal communication) have yielded results similar to those obtained by Hellmers et al. (1955) in California. The first hydraulic root excavations in Chile were reported by Miller and Ng (1977). The two species mentioned in this study, *Satureja gilliesii* and *Colliguaya odorifera*, were characterized by shallow fibrous and shallow wide spreading root systems, respectively. The root: shoot biomass ratio (R:S ratio) for both species was 0.7. This value is similar to the R:S ratios reported by Kummerow et al. (1977) from the chaparral in California. The root excavations in Chile and California were made on shallow soils in an open vegetation. It is therefore legitimate to ask what R:S ratios would be found if the analyses were made on a site with several competing species, a closed canopy, and a deeper soil.

The purpose of the present study is two-fold: First, to contribute quantitative data to the generally scarce knowledge of mediterranean scrub root systems; and second, to test the hypothesis that with higher soil fertility the fine root density increases.

Materials and Methods

The Root Excavation Site

The general area for the root excavations was located within the boundaries of the Fundo Santa Laura, 40 km NNW from Santiago de Chile (33° 4′ S latitude, 71°00′ W longitude) at an elevation of about 1000 m. A detailed description of climate and geography for this specific zone was recently published by Thrower and Bradbury (1977). Dry, warm summer months and mild, humid winters, averaging 350 mm precipitation per year, characterize this part of Central Chile as a typical mediterranean area (Aschman, 1973).

On a 27° northeast facing slope (north = equator facing), a 3 × 6 m site was chosen and marked with angle irons. This choice represented a compromise between logistics and the need for a site with a representative floristic composition and plant cover. A road only 50 m distant from the site, access to an electrical power line, water from a small creek, 50 m away and 15 m below the site, were the main practical advantages. Since the creek is usually dry during the summer, excavations were limited to winter and spring, July–October, 1976.

The Vegetation

The vegetation in the staked 18 m^2 site included a dense group of evergreen sclerophyllous shrubs, namely *Lithraea caustica* (Anacardiaceae), *Cryptocarya alba* (Lauraceae), and *Colliguaya odorifera*

(Euphorbiaceae). Several specimens of the climbing *Mutisia retusa* (Compositae), the less conspicuous subshrubs, *Satureja gilliesii* (Labiatae), and *Haplopappus* sp. (Compositae), and one specimen of a cactus (*Trichocereus chiloensis*) were also present. Below the canopy and between the shrubs an important herbaceous fraction of the vegetation, composed principally of grasses and geophytes, e.g. *Solenomelus* sp. (Iridaceae), *Trichocline* sp. (Compositae), and *Pasithea* sp. (Liliaceae) was found. However, roots of the herbaceous fraction were not considered in this study.

The Soil

The soil at the excavation site, originating from an igneous porphyritic rock, has moderate permeability and infiltration capacity. Abundant superficial stones were seen. Soil characteristics and results of chemical soil analysis are summarized in Tables 1 and 2. The chemical analysis of the soil samples was made by the Institute of Agricultural Sciences, Palmer Research Center, Palmer, Alaska, under the supervision of Dr. Jay McKendrick.

Table 1. Soil horizons and texture at the Fundo Santa Laura root excavation site, 18 m^2 in size

Soil horizon	Depth cm	Color[a]	pH[b]	Texture and observations
A	0–8	10 YR 5/4	6.8	Compact and hard, base humus layer under *Lithraea*
B	8–32	10 YR 3.5/3	6.8	Clayish, sandy, gravel, broken stones
C	32–46	7.5 YR 5/6	5.8	Indications for past fire. Clayish
D	46–63	5 YR 4/8	6.6	Clayish
	>63			Compact, hard. Rock completely decomposed

[a] Color from Munsell Soil Color Table (Munsell Color Company, Inc., Baltimore). Dry soil
[b] pH measured with creosolbromide blue

Table 2. N and P analysis in the root excavation site Fundo Santa Laura, Chile. The two series of samples represent data from two independent soil collections. I: soil collected November, late spring, 1976; II: March (Fall), 1977

Sample location		ppm-N NH_4	ppm-N NO_3	ppm-N total	% total N mainly organic	ppm-P from weak HCl solu.	% total P organic + nonexchang. mineral
0–20 cm depth	I	16.1	7.5	23.6	0.168	28.1	0.089
	II	15.2	6.9	22.1	0.137	27.0	0.092
20–40 cm depth	I	8.5	6.2	14.7	0.073	5.0	0.082
	II	10.9	4.0	14.9	0.090	6.5	0.083
40–60 cm depth	I	7.8	4.3	12.1	0.066	2.7	0.066
	II	8.7	4.4	13.1	0.065	4.4	0.077
surface, open ground	I	41.3	8.5	49.8	0.224	36.4	0.090
	II	17.8	14.4	32.2	0.211	56.1	0.099
surface, under *Lithraea*	I	27.3	6.3	33.6	0.433	49.7	0.100
	II	28.1	8.7	36.8	0.560	42.0	0.110
surface, under *Cryptocarya*	I	30.7	6.6	37.3	0.354	51.8	0.099
	II	10.9	7.4	18.3	0.425	80.7	0.119

Harvesting of the Above-Ground Plant Material

The excavation site was subdivided into 18 one-m^2 plots by means of wires strung between supporting angle irons at ground level. The stems and branches in each m^2 plot were carefully harvested and individually bagged. Subsequently the material from each plot was separated into species, oven-dried, and the dry weights were recorded. Subdivision of the aboveground material into stem size classes, leaves, etc. was not done since considerable information in this regard is already available (Giliberto et al., 1977).

Root Harvesting

Water for the hydraulic excavation was pumped (electric pump, 50 l/min) from the creek through a 3/4 garden hose with a spraying nozzle. The 27° slope permitted adequate water run-off. Thus, beginning with the lower boundary of the site, it was possible to wash out the upper soil layer to a depth of 20 cm square meter by square meter. Several large rocks, weighing up to about 75 kg, had to be removed during this phase.

The thinner roots (diam. <1.0 cm) that had been exposed during the first phase of excavation were harvested strictly according to the m^2 limits. In general, it was possible to assign the roots to their corresponding species, but errors in identification may have occurred. Major roots were collected after their position had been recorded by means of in-scale drawings. In the latter cases, specific identification of roots was possible, because, after tracing some of them to their respective crowns and burls, they could be recognized by their morphological features.

After harvesting the first 20 cm layer, the next two layers each 20 cm deep, were treated likewise. In the deeper layers, where fine root masses were fewer but thicker roots more frequent, crowbars were used to loosen the hard clay in order to increase the erosive action of the water necessary to move the clay down the slope. At 60 cm depth further excavation proved to be nearly impossible. At this depth fine roots were rare but considerable numbers of thicker roots, mostly from *Lithraea caustica*, were found penetrating the deeper soil layers. Root loss, resulting from the excavation technique, was estimated at 25 % for the fine root fractions and 5 % for the thicker size classes.

Root Processing

The root processing followed the method established earlier in California (Kummerow et al., 1977). The roots, identified and bagged in the field, were washed in the laboratory and subdivided into three diameter size classes: Class 1 = <2.5 mm, 2 = 2.6–10 mm 3 = >10 mm. Although the bulk of the fine root fraction (size Class 1) had root diameters <1.0 mm, it proved impractical to separate these mostly absorbing fine roots from the slightly thicker and mostly conducting roots. Finally, dry weights for each root fraction and species were measured and recorded.

Results

Aboveground Shrub Vegetation

The experimental site is heterogenous in its floristic composition considering only the number of perennial shrubs. Figure 1, illustrating a bird's eye perspective of the vegetation, emphasizes the dominant role of *Lithraea caustica* in this specific site. A profile drawing (Fig. 2) shows the height relations between the major shrub species and their main rooting patterns. *Mutisia retusa*, a foliated vine which grows profusely in the shrub canopy, presents a special case.

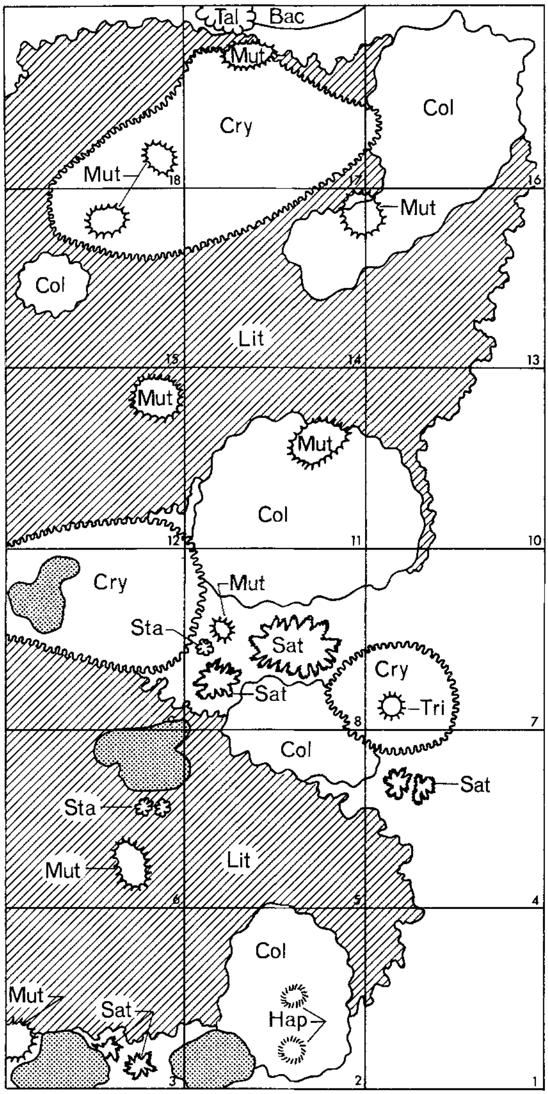

Fig. 1. Floristic composition and species distribution of the root excavation site from the bird's eye perspective. Each square represents one m^2. The *hatched area* indicates the canopy projection of *Lithraea caustica (Lit)* on the ground. *Cry = Cryptocarya alba; Col = Colliguaya odorifera; Mut = Mutisia retusa; Sat = Satureja gilliesii; Hap = Haplopappus* sp.; *Sta = Stachys* sp.; *Tal = Talguenea quinquenervia; Bac = Baccharis rosmarinifolia; Tri = Trichocereus chiloensis.* The *dotted areas* represent rocks

Above- and Below-Ground Biomass

The total root and shoot biomass recorded per species, without regard to the number of specimens in the excavation site, is summarized in Table 3. The calculated R:S ratio shows that approximately five times the shoot biomass of *Lithraea caustica* is found below ground. Even discounting the 71 kg of burl tissue of this species from the root weight, the R:S ratio would still be 2.9 and thus, much higher than other R:S ratios reported from the mediterranean areas in Chile and California (Miller and Ng, 1977; Kummerow et al., 1977). It should

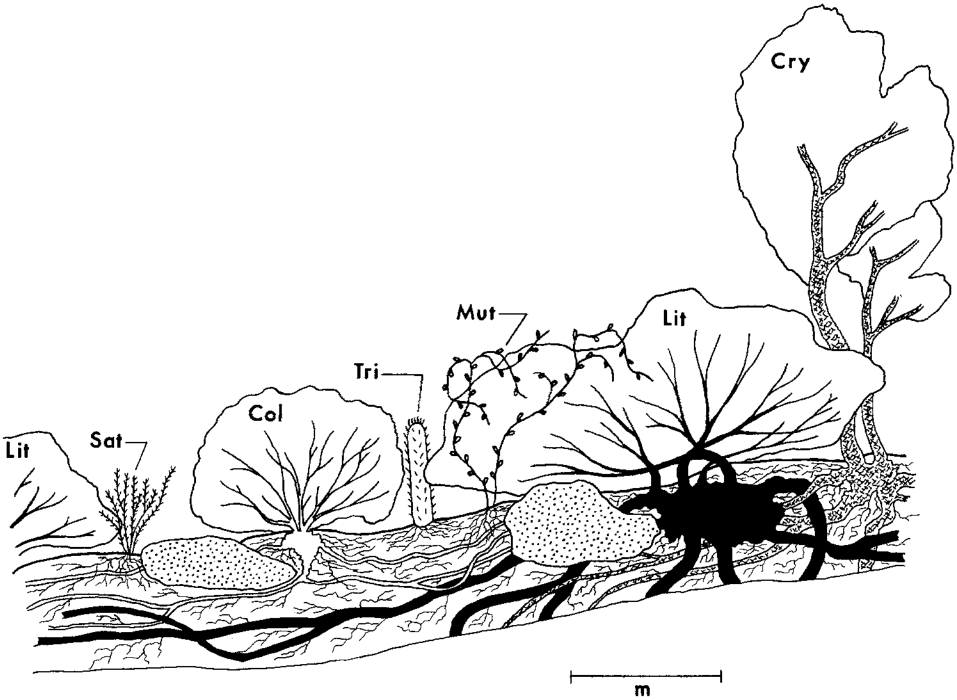

Fig. 2. Profile drawing through the root excavation site. Abbreviations are as in Figure 1. The *massive black structure* on the *right hand side* of the drawing is a burl with several thick roots emerging from it. *Cryptocarya*, here a small tree, is frequently seen in the area as a dense shrub from stump sprouts

Table 3. Root and shoot biomass from an 18 m^2 experimental site, Fundo Santa Laura, Chile

Species	Root biomass g dr.wt.	% of total	Shoot biomass g dr.wt.	% of total	Root:shoot biomass ratio
Lithraea caustica	173,054	85.3	34,855	64	4.9[a]
Cryptocarya alba	24,580	12.1	9,209	18	1.4
Colliguaya odorifera	3,916	1.9	6,094	11	0.6
Mutisia retusa	631	0.3	2,256	4	0.3
Satureja gilliesii	163	0.1	749	1	0.3
Stachys sp.	94	0.05	256	0.5	0.3
Baccharis rosmarinifolia	501	0.15	154	0.3	–[b]
Trichocereus chiloensis	60	0.03	104	0.2	0.5

[a] The R:S ratio includes the burls with 71 kg in the root system
[b] Some branches hanging into the experimental site. The root crown located beyond the site limits

also be considered that many thick *L. caustica* roots penetrated deeper into the soil than the excavated 60 cm, and that the dry weight of this deeper fraction may well equal that of the burls.

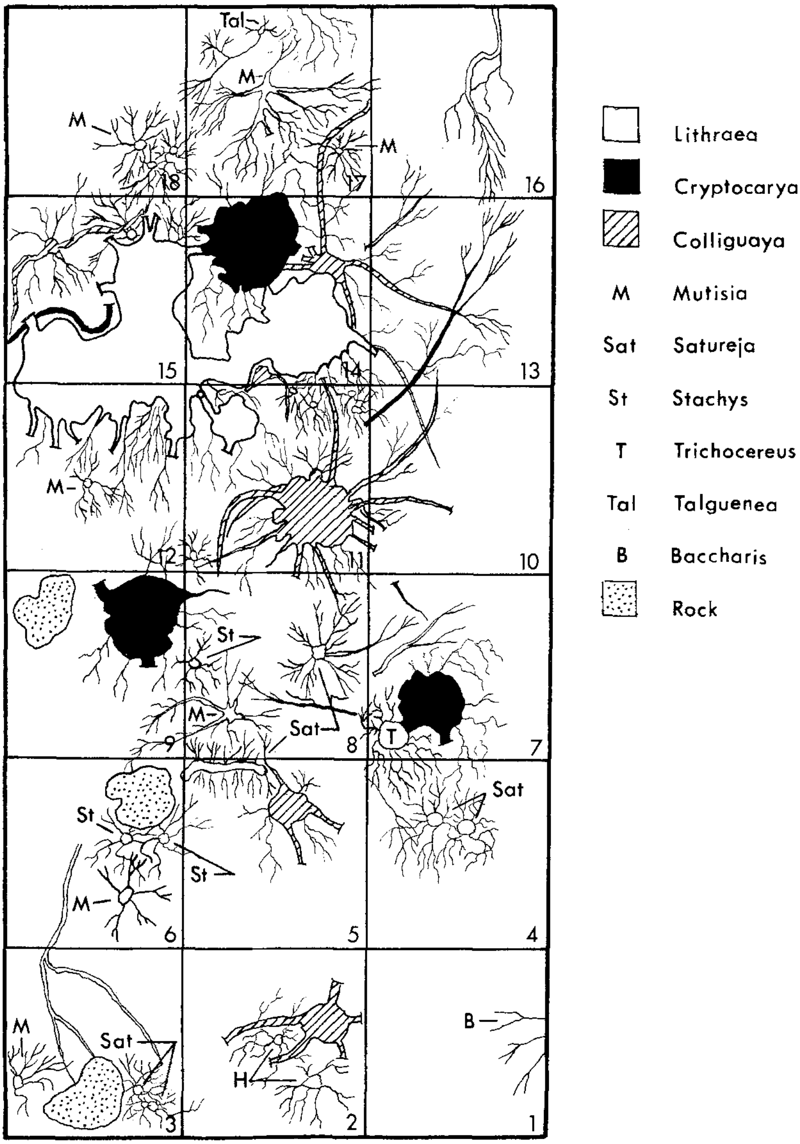

Fig. 3. Surface view of the excavation site after the removal of a 20 cm soil layer. *Grid squares* are the same as in Figure 1. Few bigger and many fine roots are visible. The *massive areas* in the figure, *open*, *black*, and *hatched*, represent burls. The *fine roots* are not drawn to scale; this root fraction forms dense mats around the burls.

Root Distribution

The general root distribution was recorded by means of scale drawings. The high root density forbade any attempt to project the major roots (diam. >1.0 cm) into a single plane. Therefore, drawings for each 20 cm of soil depth were prepared (Figs. 3–5). The larger conducting roots of *L. caustica* formed an

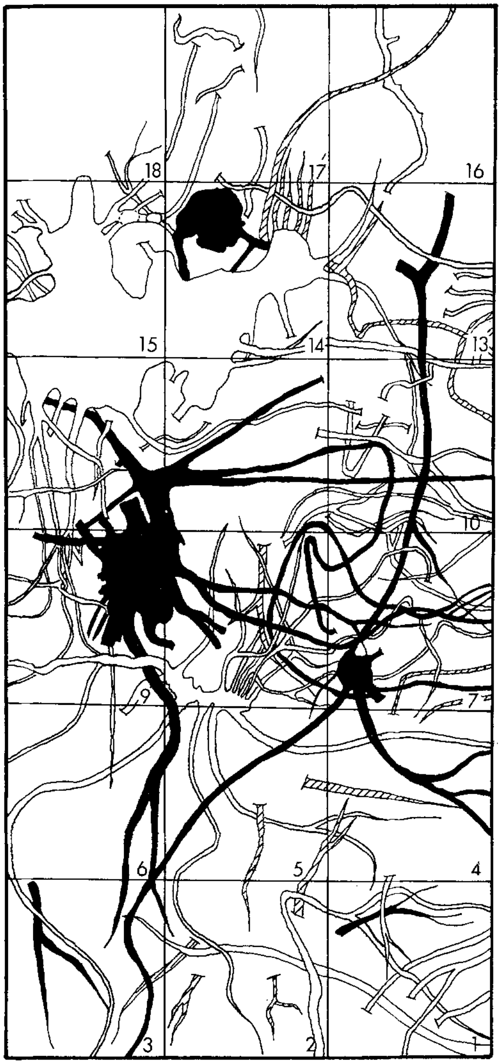

Fig. 4. The same view as in Figure 3 after harvest of the roots and removal of a second 20 cm soil layer. Only roots thicker than 1 cm were drawn to scale. Root species symbols are given in Figure 3

intricate meshwork, and grafts were frequently observed at crossings not only between roots of the same shrub but also between individuals growing several meters apart from each other, e.g. in Figure 5, plots 12 and 16.

Strong evidence for the existence of species-characteristic root depths in this experimental site is shown in Table 4. The total root biomass per species, recorded for three different depth levels and three root diameter classes is given. The fine roots of *L. caustica, C. alba, C. odorifera,* and *Haplopappus* sp. were most dense in the 20–40 cm soil level, whereas the fibrous root systems of *Mutisia retusa, Satureja gilliesii, Stachys* sp. and the cactus *Trichocereus chi-*

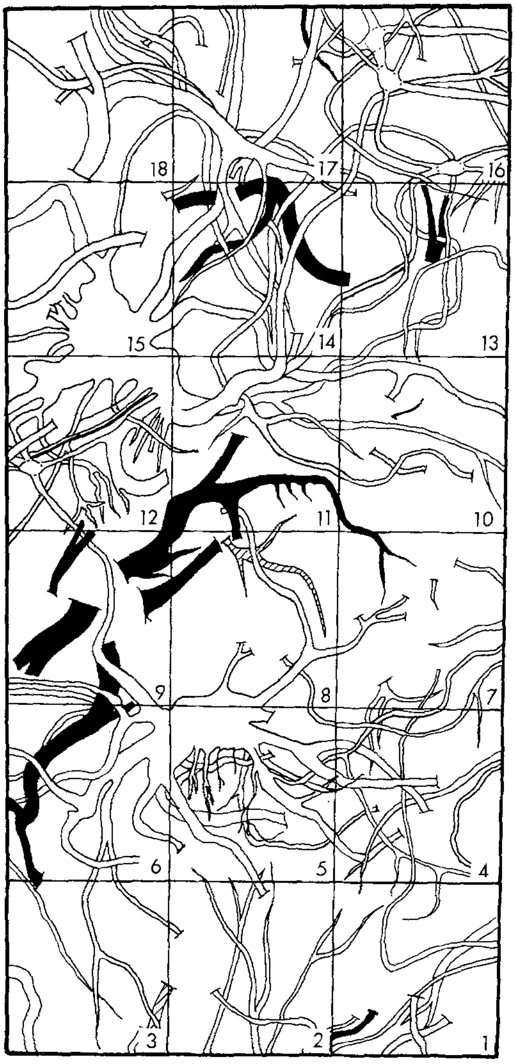

Fig. 5. The same view as in Figure 4 after harvest of the roots and removal of a third 20 cm soil layer. Details are given in Figure 4. Note the *root grafts* in squares No. *12* and *16*. The burls of *Lithraea* in squares No. *12* and *15* did not reach deeper down into the ground

loensis were concentrated in the upper 20 cm of the soil. *Talguenea quinquenervia*, a summer deciduous shrub, seems to be a member of the first group, but as more than half of the roots of this species grew outside the plot, the data may not be significant. The same reasoning is valid for *Baccharis rosmarinifolia*.

The deep rooting pattern of *L. caustica* is very obvious. Roots with diameters >2.5 mm are concentrated in the 40–60 cm level (Table 4 and Fig. 5). If the burl tissue, 67 kg dry weight alone for square meters 14 and 15, and located mostly in the 20–40 cm level (Table 4 and Fig. 4), were not added to that root fraction, the relative amount of roots in the 40–60 cm level would appear even greater.

Table 4. Total root biomass harvested from the $18\,m^2$ excavation site for each soil layer and separated into root diameter classes

Species	Soil depth level cm	Root diameter classes (mm) 0–2.5	2.6–10	> 10	Total root biomass g dr.wt.
Lithraea caustica	0–20	471	221	14,072	14,764
	20–40	1,438	4,812	51,391	57,641
	40–60	990	12,667	86,992	100,649
Cryptocarya alba	0–20	275	35	6,254	6,564
	20–40	804	1,665	11,457	13,926
	40–60	145	915	3,030	4.090
Colliguaya odorifera	0–20	302	1,081	448	1,831
	20–40	967	880	169	2,016
	40–60	1	68	–	60
Baccharis rosmarinifolia	0–20	–	–	–	–
	20–40	42	22	–	64
	40–60	–	266	171	237
Mutisia retusa	0–20	268	363	–	631
	20–40	–	–	–	–
	40–60	–	–	–	–
Haplopappus sp.	0–20	–	–	–	–
	20–40	13	–	–	13
	40–60	–	–	–	–
Satureja gilliesii	0–20	150	13	–	163
	20–40	–	–	–	–
	40–60	–	–	–	–
Talguenea quinquenervia	0–20	21	44	–	65
	20–40	57	195	–	252
	40–60	78	239	–	317
Stachys sp.	0–20	83	11	–	94
	20–40	–	–	–	–
	40–60	–	–	–	–
Trichocereus chiloensis	0–20	22	7	30	59
	20–40	–	2	–	2
	40–60	–	–	–	–

Cryptocarya alba is different: Most of the stronger roots were found in the 20–40 cm level (Table 4). Fewer roots grew down to the depth of 60 cm and deeper penetrating roots were observed only occasionally. *Colliguaya odorifera* is shallow rooting with most of the stronger roots growing in the upper 20 cm of the ground.

Discussion

In contrast with earlier root studies from Central Chile and Southern California, the root and shoot biomass values reported here came from a vegetation growing on a deep and fertile soil (Table 2). Unfortunately, it was impossible to proceed with the excavation to a depth greater than 60 cm. Not only was the toxicity of roots and shoots of *Lithraea*, comparable to the North American poison oak *(Toxicodendron diversilobum)*, a problem but also the hard clay in the deeper soil layers rendered the hydraulic excavation technique inefficient. Nevertheless, the information collected can be used for a comparison with Californian data.

With the exception of *Lithraea caustica* and, to a lesser degree, *Cryptocarya alba* (Table 3), the Chilean species show R:S ratios comparable to those reported from California (Miller and Ng, 1977; Kummerow et al., 1977). These values are below unity and confirm Barbour's (1973) statement that xerophytic plants need not have high R:S ratios.

L. caustica and *C. alba* with R:S ratios of 4.9 and 1.4 respectively, should be considered differently. Both these species are known to form trees when undisturbed. Their floristic importance was stressed by Oberdorfer (1960) who considered the *Lithraeo-Cryptocaryetea* association as the terminal stage in a succession of plant associations. Especially striking is the size of the Lithraea burl (Figs. 3–5). Since the volume of burls increases with age and repeated stem harvesting, the massive burls of both species are probably the result of many years of wood cutting for charcoal manufacture. Several charcoal ovens on the farm grounds are evidence for this activity, which continued until 1959 when the farm owner adopted a policy of vegetation protection (Aschmann and Bahre, 1977). Although an estimate of the age of larger burls is impossible, the high R:S ratios of these two species may be an indication of the original existence of a *Lithraea-Cryptocarya* grove. The fertile soil and adequate moisture supply have probably permitted maintenance of a root system suitable for a forest type vegetation with higher biomass values for the shoot system. The frequent root grafts in *L. caustica* may contribute to the success of this species in the research area. It is postulated that 50 years of undisturbed growth would reestablish this small *Lithraea-Cryptocarya* forest.

The earlier root excavations by Kummerow et al. (1977) and Miller and Ng, (1977) in California and Chile failed to show specific root depths for different shrubs. This was interpreted as resulting from a very shallow soil in which all the roots had to compete for the available resources in a limited space. The excavation reported here deals with a deep and fertile soil, and a clear cut vertical root distribution could be demonstrated (Table 4). Most of the major *Lithraea* roots were found in the deepest soil layer (40–60 cm) and many thick roots penetrating beyond the 60 cm excavation limit were observed. Most of the *Cryptocarya* roots were found in the 20–40 cm soil layer, while *Colliguaya* proves to be a shallow rooting species. It is interesting to observe that these three species concentrate their fine root mass very clearly in the 20–40 cm soil layer, a tendency much less pronounced in the Californian excavation site.

A comparison of the biomass values per m^2 obtained in Chile with those in California, using identical methods, is instructive (Table 5). It should be understood that this comparison refers to only two small excavation sites, both arbitrarily chosen, and not meant to represent matorral and chaparral but rather two different kinds of mediterranean scrub. The shoot biomass from the Chilean site was found to be about 1/3 and the root biomass 16 times greater

Table 5. Comparison of shoot and root biomass values per m² with Californian values (Kummerow et al., 1977), obtained with the same method

	California Echo Valley	Chile fundo Sta. Laura
Shoot biomass per m^2, g	2,040	2,988
Root biomass per m^2, g	685	11,314[a]
Fine root mass per m^3, g	110	567
Fine roots in % of total roots	9.6	3.0

[a] The value includes 4.4 $kg\,m^{-2}$ of burl tissue. It is estimated that a similar amount of roots was not colllected from soil layers deeper than 60 cm

Table 6. Average N and P values from the Chilean root excavation site and the Californian general research area. The values from Chile are averages from Table 2. The values from California represent averages of 50 independent analyses, from 5 sampling dates between spring and fall and 10 samples for each date. The ratios between the Chilean and Californian data show a higher availability of N and P for the Chilean root excavation site

	Chile Root excavation site	California Echo Valley	Ratio Chile: California
Total % N (mainly organic)	0.233	0.065	3.6:1
Available N, ppm ($NH_4^+ + NO_3^-$)	25.7	18.7	1.4:1
Total % P (org. + non-exchangeable mineral)	0.092	0.039	2.6:1
Available P, ppm (from weak HCl solution)	32.5	7.1	4.6:1

than the corresponding Californian values. Although the root biomass data for Chile include the burl weights, similar amounts of roots could not be extracted from soil layers below 60 cm, whereas in California root extraction was nearly complete, and thus the comparison may still be fair. A possible reason for this high R:S ratio in Chile has been discussed above. In addition, as shown in Table 6, average N and P concentrations for the Chilean and Californian excavation areas have been compiled. A much higher availability of nitrogen and phosphorous in the Chilean site is obvious and may also be significant in comparing the differing biomass values of the two areas.

Also noteworthy is the difference in fine root masses between the two sites (Table 5). Since these fine roots are concentrated in the upper 40 cm of the soil their density has to be much higher in the Chilean site. Root measurements from container grown matorral shrubs (average from 4 species, Kummerow, unpubl.) show that 1 g of fresh fine roots extended over 6.2 m. The equivalent for chaparral roots from field collections was 15 $m\,g^{-1}$, i.e. chaparral roots were significantly thinner. It is possible that field collected roots from the matorral are thinner than those from container grown plants. Further research is necessary to decide this question.

The root length data permit calculations of root length densities (RLD). For the matorral and the chaparral sites, 1650 and 3513 $m \cdot m^{-3}$ of soil, respectively, were calculated. The RLD can be converted into an average distance between roots because the reciprocal ($m^3 m^{-1}$) is the average cross sectional area of the cylinder of soil exploited for water and nutrients by the roots (Miller and Ng, 1977). The average distance between fine roots in the Chilean and Californian excavation sites was found to be 1.9 cm and 2.8 cm respectively. If it could be shown that field grown fine roots are thinner than those from container grown matorral shrubs, the average distances between roots will be smaller. This calculation is not considered definite, but it demonstrates clearly the relation between higher nutrient concentrations, shorter root distances, and greater shoot biomass values.

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