Fine Root Notes
Compiled by Rob Jackson
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Intro
From Hendrick and Pregitzer 1993: "Grier et al. (1981) estimated that 55% of total ecosystem NPP was allocated to fine roots in a 23-year-old Pacific silver fir (*Abies amabilis* (Dougl.) Forbes) stand in Washington, while the corresponding value from a 180-year-old site was nearly 69%. Fogel and Hunt (1979) estimated that about 73% of NPP is allocated to fine roots and mycorrhizae, and that fine root and mycorrhizal turnover was responsible for about 85% of all detrital inputs, in an Oregon Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) forest."

Boreal Forest

Perrson 1982; fine roots, 60% of wt < 1mm, 90% of length < 1 mm (avg diameter 0.5 mm) for all roots < 2mm in diameter. For fine roots (<2mm), **47% are live** (189 of 401 g m-2).

Persson et al. 1995, fine roots (<1mm) to 1 m. **27% of fine roots** (<1mm) are live (273 of 1001 g m-2).

Strong and LeRoi 1983, # roots to 130 cm, total roots

Strong and LeRoi 1985, # roots to 115 cm, total roots, but >95% were < 1mm.

Deserts

Barbour et al, total root mass, Larrea and other shrubs to 80 cm, g m-2 (no fine root data)

Branson, root density, total live plus dead roots (no fine root data)

Dobrowolski, # roots , (acceptable for fine root analysis, but no biomass)

Fernandez, roots against a plane, (acceptable for fine root analysis, but no biomass)

Freckman, total roots (no fine root data)

Jordan, cactus to 15 cm

Moorhead, fine roots (<2mm) to 70 cm (g m^{-2}, Larrea community)

Montana et al., # roots for various shrubs and grasses to 70 cm (no biomass)

Rundel and Nobel, total fresh roots to 12 m

Sturges, total root biomass density (not entirely clear; some indication in Methods that woody roots were removed)

Temperate Coniferous

Ares and Peinemann, 2mm, conifer plantations, good data! (<10% dead roots; I used 10%)

Farrish 1991 (2 sites, loblolly pine comprises 40-50% of stem numbers and basal areas) 945 g m-2 fine roots (<3mm); 8.24 x 10^4 m^2 ha^{-1} or 8.24 m^2 m^{-2}. So **SRL=?**
SA/Biomass = 8681 m^2 Mg^{-1} or 8.68 x 10-3 m^2 g^{-1} or 86.8 cm^2 g^{-1}

Gerhmann, fine roots to 80 cm (53% live roots; value given is live)

Harris et al: < 10mm (lowest division is <5mm)

Kelly and Joslin: total

Kochenderfer: # root endings

McClaugherty and Aber 1982 Leaf litter fall was 5.3 Mg ha^{-1} yr^{-1}. Fine roots (<0.5 and < 3mm).

Reynolds 1970, fig 3 for dead/live info. On average, 50% is live. Table 4: 7.69 km m^{-2} for all roots, 0.5 mm mean diameter for fine roots (cited in Kummerow et al. 1978). No fine root data.

Vogt et al. 1983 found 21.4, 13.2, 60.0, and 145.5 g m^{-2} in the upper 5 cm organic layer. **On average, 63% of fine roots were live (<2mm), but the variation was large. She also cites Persson 1980 for a 120-yr old Pinus sylvestris stand where 66% of fine root biomass was live; and Copeland (1952) with 18% dead fine root biomass at 40-yr old shortleaf pine.**

Temperate Deciduous Forest

Farrish 1991 - (**live** only) abstract: 9.9 Mg ha^{-1} (<3mm diameter) = 990 g m^{-2} fine roots to 90 cm, total surface area 1.48 x 10^5 m^2 ha^{-1} or 14.8 m^2 m^{-2}. (LAI=?)
SA/Biomass = 14941 m^2 Mg^{-1} or 14.941 x 10-3 m^2 g^{-1} or 149.4 cm^2 g^{-1}

Harris et al: < 5 mm

Kelly & Joslin 1989, no fine root data

Kochenderfer, root endings m^{-2} to 150 cm (no fine root biomass data)

McClaugherty et al. 1982 Leaf litter fall was 4.4 Mg ha^{-1} yr^{-1}. Fine roots (<0.5 and < 3mm) 610 and 510 g m-2 for a hardwood and pine plantation, respectively. Annual NPP is 540 and 410 by the "annual method", and 1140 and 1090 for the "less than monthly" method. Check other papers and see which seems most appropriate. For hardwoods, 58% of fine roots (<3mm) were live (610 out of 1050 g m-2); for conifer plantation, 56% of fine roots (510 out of 910 g m-2) were live (Table 1).

Sala et al., total (Nothofagus) no fine root data

Scully, # roots ft^{-2} to 91 cm (no fine root biomass data)

Ulrich, fine roots to 90 cm, beech plantation

Yin et al: % fine root biomass to 60 cm (<2mm)

Temperate Grassland (problem with live and dead!)

Dahlman and Kucera, live and dead, total roots to 90 cm

Fernandez and Paruelo, total root length for 2 shrubs

Lee and Lauenroth, % total root length with depth for 1 grass and 2 shrubs

Liang et al., live and dead!, all < 2mm, very high values, but good data for 3 shrub and 2 grass sites to 90 cm

McKell, total root biomass to 60 cm (but only valid for, but fertilized and all roots probably <2mm

Old, live and dead, to 100 cm

Sims and Singh, live and dead, total root biomass, to 60 cm

Singh and Coleman, 73.5% of roots in 0-20 cm were functional, 33.5% functional in 20-60 cm. On average, 62% of root biomass was functional from 0-60 cm. Data fine as is: functional root biomass to 60 cm (no biomass)

Weaver 1954, 1977, good for cumulative root fraction only (no biomass)

Topical Deciduous

Bang-Xing, total root biomass to 150 cm

Castellenos, fine root biomass (<5mm) to 80 cm

Lawson et al., fine root biomass (<2mm) to 50 cm

Tropical Evergreen

Arunachalam et al. 1996, 16-yr old forest, **720 g m-2** to 30 cm for live roots <2mm diameter (77% of total live + dead: 940 g m^{-2}). Of that 720 g m-2, 450 g m-2 or 63% is <1mm diameter.

Berish, fine roots (<2mm, in many classes) to 85 cm: Total length: **2.26 km m^{-2}**, 2.07 for <1mm (92% of total). **341.7 g m^{-2}** fine root biomass (60% of which is <1mm). RAI is **4.14 m^2 m^{-2}** (78% of which is <1mm). SRL **10.103 m g-1** for <1mm; **1.392** for 1-2mm; assumed all roots were the midpoint of the diameter class (0.5mm and 1.5 mm).

Gower, fine roots (<2mm, in many classes) to 50 cm. Dead fine roots had about 3-fold more biomass than live (187 vs 662; 125 vs 369 g m^{-2}). Cites Raich (1982) at 289 g m-2 in La Selva (<2mm) and Berish 527 g m-2 (< 5mm, 70 yrs old Costa Rica).

Greenland and Kowal, total roots only

Huttel, fine roots (<2mm, in many classes) to 130 cm

Klinge, fine roots (<2mm, in many classes) to 130 cm and 89 cm (length data; also see Table 2 for biomass). **0.22 and 0.55 km m-2** for two forests (data **incorrect** by a factor of 10?), with **92% and 98% of total length in fine roots (<2mm**); 82.5% and 93.8% of total length in roots <1mm diameter. For biomass, 21% and 20% of total root biomass is <2mm. For fine root biomass: 497.4, 345.6, and 843 g m-2 for <1mm, 1-2mm, and <2 mm respectively for the latosol; 364.8, 190.8, 555.6 g m-2 for <1mm, 1-2mm, and <2 mm respectively for the humus podsol.

Klinge and Herrera, total roots only

Mensah and Jenik, fine roots (<2mm, in many classes) to 50 cm

Nepstad et al, fine roots (<1mm) to 6 m

Vance and Nadkarni, fine roots (<2mm, in several classes) to 180 cm (values ranged from 300 to 1300 g m-2).

Tropical Grassland

Fiala and Herrera, fine root biomass to 50 cm in 3 communities (live/dead breakdown) Revisit this paper

Heitschmidt, # roots to 2 m (Prosopis?) (no biomass data, but ok for depth distribution)

Le Roux (2 size classes: <2mm, > 2mm).

Tundra

Dennis and Johnson, very high numbers, include rhizomes. See Table 5 for live/dead

Dennis et al., live root biomass to 25 cm

Hobbie and Chapin, Toolik Lake, root biomass to 50 cm

Ignatenko, live root biomass to 34 cm

Khodachek, live and dead root biomass

For leaf area index,
see Dennis et al.
Kummerow
Soriano

For the calculations of total fine root surface area, find at least one reference for each biome:

Fahey and Hughes, J Ecol 82:533-548: deciduous forest (only <1mm, with one important exception). Roots in organic layer tend to be finer than roots in mineral soil. Average root diameter = 0.33mm. NPP estimate from ingrowth cores: 254 g m-2 yr-1 for <1mm.

Hendrick and Pregitzer 1992 (Ecology) Fine root demography (<2mm diameter). Mean root diameters were 0.42 mm and 0.49 mm for <30 cm and >30 cm respectively. 80% of root numbers and 76% of root length were from roots <0.5 mm in the shallow layer. For deeper roots they were only 64% and 56%

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Hendrick and Pregitzer 1993 (Can J For Res) Based on Table 3, **807 g m-2** average fine root biomass (<2mm) at two sites and two times of the year. Roots <0.5mm comprised 72% of that total and 44% of the biomass of all roots <10mm. They estimate that >80% of all roots at their sites are <0.5 mm in diameter. Average fine root diameter (<1mm) is **0.44 mm**. See also Table 10 for 0.10 kg root m^{-2} leaf area (fine root production).

Berish 1982

Cavelier, 1992, on a biomass basis, 1.1g root for 1-2mm to 1 g 0-1mm. Assuming equivalent root tissue densities, and average diameters of 1.5mm and 0.5 mm, that means about 9 times as much SA <1mm than 1-2mm.

Clemensson-Lindell A, Hakån A 1995 Fine-root morphology and uptake of 32P and 35S in a Norway spruce (Picea abies (L.) Karst.) stand subjected to various nutrient and water supplies. Plant Soil 173:147-155.

Average ratio of live to dead roots in a spruce boreal forest was **86%** for <1mm and **82%** for 1-2mm. **Average SRL was 15.9 m g^{-1}** for <1mm. See **Table 2** for fine root biomass (not really useable, due to necessary conversion).

Eissenstat DM 1992 Costs and benefits of constructing roots of small diameter. J Plant Nutrition 15:763-782.

Roots in citrus rootstocks range from 0.4-1.5 mm, with 78% between 0.5 and 0.75 mm. SRL ranged from 13 to 23 m g-1, with an average SRL of **15.9± 1.6** (mean, se). Median fine root diameter approximately **0.6 mm**.

Hendriks & Bianchi 1995 Pure and mixed stands of Fagus sylvaticus and Pseudotsuga menziesii in the Netherlands (<2mm). Biomass for the 60-yr Doug-fir stand was **780 g m-2**, root length was **6.7 km m-2**, and SRL was **26.3 m g-1 for 0-1mm, 2.3 m g-1 for 1-2mm, and 20.7 m g-1 for 0-2mm**. For the beech stand, biomass was **960 g m-2**, root length was **18.4 km m-2**, and SRL was **11.0 m g-1 for 0-1mm, 2.0 m g-1 for 1-2mm, and 9.0 m g-1 for 0-2mm**. See Table 3 for good depth data to 90 cm.

Higgins et al. 1987; 85% of root length is <2mm roots (5.5 times the root length for Protea neriifolia

Jastrow JD, Miller RM 1993 Neighbor influences on root morphology and mycorrhizal fungus colonization in tallgrass prairie plants. Ecology 74:561-569.

Mean root diameter for Andropogon gerardii (0.365 mm), Coreopsis tripteris (0.376 mm), and Solidago altissima (0.373 mm) in a tallgrass prairie ecosystem.

Kummerow and Mangan 1981 p.184: Mean fine root diameter of **<1mm** roots was **0.397** mm *Quercus dumosa* (S.E. 0.176, n=90). Total length of live fine roots was **6 km m^{-2}** and the estimate of active surface area is **7.7 m^2 m^{-2}** (based on avg diameter of 0.4 mm). Consider the limitations of this with mycorrhizae, however. Fine root biomass: 133 g m-2. So **SRL: 45.1 m g-1 for roots <1mm**

Kummerow et al. 1977. Fine roots (**<2.5mm**). Estimates of **SRL** ranged from 8.4 to 20 m g^{-1}. Kummerow uses **15 m g^{-1}** as his mean.

Kummerow et al. 1978. (Oecologia) Total fine root length (**<1mm**) increased from 0.35 to **2.2 km m^{-2}** over the season for Adenostoma fasciculatum.

Kummerow et al. 1990. *Quercus coccifera*. Fine roots (**<1mm**) constituted 3% of total root biomass (216 g m^{-2}) but see Fig 4 (max 560 g m^{-2} in November). More than half the fine roots are dead (Fig 4). See also Table 1 for annual fine root production in different tree species (200-900 g m^{-2} yr^{-1}).

Martinez et al., unpub. Fine roots (<1.25mm). See Table 1 for a good fine root biomass distribution to 1 m. (total biomass 784.8 g m-2). See Table 2 for a good fine root length distribution to 1 m (total length: 7.742 km m^{-2}). Roots in the top layer on average 6.5 mm apart. So **SRL: 9.86 m g-1.**

Miller and Ng 1977. See Table 4 for different root diameter classes (length with depth in the soil) for 2 Chilean shrubs: *Satureja gilliesii* and *Colliguaya odorifera*. Median root diameter for Satureja is 0.5mm; for Colliguaya it's approximately 0.65 mm (no exact number given). Mean fine root diameter (<2mm) is .595mm for Satureja and 0.695 for Colliguaya (my spreadsheet calculation).

Reynolds, fig 3 for dead/live info. On average, 50% is live. Table 4: 7.69 km m^{-2} for all roots, 0.5 mm mean diameter for fine roots (cited in Kummerow et al. 1978)

Safford LO and S Bell 1972 Biomass of fine roots in a white spruce plantation. Can J For Res 2:169-172.
696 g m-2 of fine roots (<3mm) in the upper 45 cm of soil. They estimate 800 g m-2 for the whole profile. (no discussion of live vs. dead).

Srivastava et al. 1986, **299 g m-2** to 40 cm in a teak forest (tropical deciduous) for roots <2mm. Of this 299 g m-2, 139 or 46% are <1mm; total root biomass <8mm is 542 g m-2. Belowground net production and turnover in a 19-yr old teak plantation are 163 and 151 g m-2 yr-1 for roots <1mm and 1-2mm respectively. Total **NPP** for fine roots is **314 g m-2** yr-1. Mean rainfall is 992 mm

van Rees, (live only)2.683 km m^{-2} for total root length to 2.4 m depth, 90% of which is <2mm. No fine root biomass data, but length down to 2.45 m.

Wright 1955; no fine root data

Santantonio: by # roots, there are always 5-10-fold more roots <2mm than > 2mm.

<u>New manuscripts (not in original database)</u>
Safford LO and S Bell 1972 Biomass of fine roots in a white spruce plantation. Can J For Res 2:169-172.

Barker DJ, DM Zhang, AD Mackay 1988 Root distribution in a low fertility hill country sward grazed by sheep. New Zealand Journal of Experimental Agriculture 16:73-76.

Saarinen T 1996 Biomass and production of two vascular plants in a boreal mesotrophic fen. Canadian Journal of Botany 74:934-938. (root biomass to 2.3 m)

Make sure you get Moir and Bachelard 1969

Kellman 1990 (J Trop Ecol), for trop deciduous forests

See Nye and Tinker p.253 for a root length table for crops

see **Canadell and Roda** 1991 for fine root biomass (<2mm): 200, 130, and 70 g m-2 for 0-20, 20-40, and 40-60 cm (live + dead). La Castanya, Spain. 24% of root biomass (<10mm) was <2mm (400 out of 1630 g m^{-2})

See Higgins et al. Table 6 for mean root length with depth of 5 shrubs

See Kummerow and Mangan 1981, Table IV

Production notes:
Problem with how one estimates production. For example, Aber et al give 650 and 106 g m-2 yr-1 for NPP depending on the method (N-budget and min-max respectively). An average?? yields 3778 g m-2 yr-1. Similarly, McClaugherty has a wide range (4.1-11.4 Mg ha-1 for hardwoods and 3.2 to 10.9 for pine plantation). Powell and Day 1991 had similar variation (989 vs 345 for sequential coring vs ingrowth cores).

Mistakes in original ms:
1) Kummerow & Mangan root biomass too high (should have been 1297 g m-2). Same for Kummerow et al. 1977.

2) Ulrich mislabeled as Temperate coniferous when it should have been temperate deciduous.

3) Nepstad et al. listed as “total” in Table rather than “live”.

Note significant variation in ratio of live:dead (Kummerow et al. 1990, Mexico), from 1:2 to 2:1 in the dry and wet season (mostly dead in dry)

Check for SRL calculations: