C and N concentrations in different compartments of outgrown oak coppice forests under different site conditions in Central Italy

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ORIGINAL PAPER

C and N concentrations in different compartments of outgrown oak coppice forests under different site conditions in Central Italy

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Abstract

• ***Context*** Harvesting of Mediterranean oak coppice forests has been progressively suspended on a share of cover over the last decades. Positive growth trend in outgrown coppices no longer harvested on short rotations now drives natural forest restoration on wide areas, and it represents a potential carbon sink in view of global warming.

• ***Aims*** Our goals were to estimate carbon (C) and nitrogen (N) content per compartment in two deciduous oak outgrown coppice forests, aged differently and growing under unequal site quality, to verify whether C concentration across compartments is in agreement with the conventional conversion rate of 0.5.

• ***Methods*** Ecosystem C and N pools were assessed by multiplying the whole coppice mass (combining specific allometric functions, root-to-shoot ratio, and soil sampling) by respective C and N concentrations.

• ***Results*** The results point out that the largest percentage of N was stored in 15-cm topsoil (84.06 and 73.34 % at the younger and older site, respectively), whereas the proportion of organic ecosystem C pool was more variable, as a consequence of the amount and allocation of phytomass. We found that, in most cases, C concentration was less than the conventional conversion rate of 0.5, especially in deadwood, O layer, and root compartments.

• ***Conclusion*** The findings provide further knowledge of C and N storage into these new built-up forest types and the evidence that a detailed analysis may get higher accuracy in the pools estimate, producing a more reliable outlook on dynamics and climate change mitigation ability of these systems.

Keywords Mediterranean oak coppices · C and N concentrations · C and N stores · *Quercus cerris* · Phytomass · Climate change mitigation

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Contribution of the co-authors Di Matteo G, De Angelis P, and Fabbio G: conceived and designed the research trial.
Fabbio G: coordinating RISELVITALIA project 3.2 within this work was framed.
Di Matteo G, Tunno I, and Bertini G: carried out sampling, lab analyses, and data analyses.
Nardi P: carried out carbon and nitrogen soil data elaboration.
Di Matteo G, Bertini G, and Fabbio G: wrote the early version of the paper.
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1 Introduction

There is a current need for accurate estimates of carbon (C) and nitrogen (N) storage in forest ecosystems and individual tree components such as stemwood, branches, bark, foliage, deadwood, litterfall, stools, and roots (Gordon and Jackson 2000; Lamlom and Savidge 2003; Weggler et al. 2012; Di Cosmo et al. 2013; Sanquetta et al. 2013). Since direct measurement of phytomass, usually expressed as dry weight, is not feasible in practice, phytomass estimates are commonly derived by regression models which, in turn, are based on easily measurable tree variables. Another critical point is the conversion factor of 0.5, conventionally accepted by the scientific community for calculating C concentration from phytomass, whereas N concentration is subject to wider variability due to its rapid turnover in forest compartments. Hence, the final calculation of C and N pools is the result of a multiplication of two approximate estimates. Since estimating C and N storage in forest ecosystems is a key element in predicting the inherent climate change mitigation ability, a main point of concern is the use of accurate conversion factors to minimize the amount of error these estimates may produce. A major attention to the issue is where the recent changes in forest management may lead to a bias in the forest carbon sink estimate (Erb et al. 2013). This is the case over a large share of Mediterranean coppice forests comprising 8.5 million hectares in the five EU countries facing the northern Mediterranean rim (Amorini and Fabbio 1994). Across the coppice area, deciduous Turkey oak (*Quercus cerris* L.) forest occupies the intermediate vegetation belt between sclerophyllous and mountain deciduous broadleaved forest over some one million hectares in Italy. This type well depicts the dynamics of management established over the last decades. According to the National Forest Inventory (NFI 1988), the 41 % of cover was aged more than 20, that is, more than the customary rotation (12–14 years). Twenty years later (NFI 2006), 93 % (58 plus 35 %) of Turkey oak coppice forest was classified as mature (i.e., reaching the age of rotation) and outgrown (i.e., aged two to three times or more) at national level, the same share reached 98 % (45 plus 53 %) in Tuscany (Bertini et al. 2010).

Currently, applied research on coppice forests is dual-faceted; on the one hand, it focused on raising public awareness of the environmental values and ecosystem services connected with natural restoration in progress of the original, often residual, forest cover. On the other hand, management planning is devoted to solving problems connected with the increased lack of silvicultural practices, land abandonment, and related risks of wildfires (Fabbio et al. 2003). The resulting fully stocked stands, typical of the so-called “outgrown coppice area,” produce high-natural mortality rates due to inter-individual competition inside and between shoots of neighboring stools. This means further stocking in terms of litterfall, standing, and lying deadwood and its progressive incorporation into the system (forest floor and soil), i.e., a substantial input for carbon and nitrogen sequestration and storage, as compared with the former full harvesting of standing crop phytomass. Forest ecosystems in Italy show the N-limited conditions typical of many temperate forests and generally high level of base saturation (De Vos and Cools 2013), suggesting positive growth responses to the availability of additional N. Current deposition rates range between 7 and 24 kg N ha^{-1} $year^{-1}$ in Italy (Marchetto et al. 2008). Under these assumptions, these forest types are strategic for the: (i) amount and quality of ecosystem services following the conservation/restoration of forest landscapes, (ii) role as hotspots for biodiversity because of their heterogenous structures and potential dynamic patterns, (iii) inherent ability of carbon sequestration and nitrogen storage in standing crop and soil, and (iv) widespread cover and diffusion from coastal up to mountain environments.

Recent studies pointed out that most carbon-accounting protocols make use of the carbon conventional conversion rate of 0.5 to estimate regional or stand-level carbon stocks; this potentially results in significant systematic error (Ravindranath and Ostwald 2008; Dryw and O’Hara 2012; Weggler et al. 2012; Ruiz-Peinado et al. 2013). We postulate that a general application of the carbon conventional conversion rate for estimating ecosystem carbon density from phytomass stocks would lead to systematic errors in estimating phytomass carbon content, raising the question about its applicability across different tree compartments. The issue is of primary concern because it does not consider properly the impact of tree components such as bark, deadwood, O layer, stools, and roots on ecosystem C and N pools. To test this assumption, we investigated two Turkey oak outgrown coppice forests in Central Italy characterized by different age spans and site conditions with the following goals: (i) to compare the average carbon and nitrogen concentrations from the aboveground phytomass, belowground phytomass, and topsoil and (ii) to compare carbon density from these compartments with carbon density estimates derived through conventional carbon-accounting methods in which phytomass stock values are multiplied by a carbon fraction of 0.5.

2 Materials and methods

2.1 Site descriptions

The work was undertaken at two sites typical for Turkey oak vegetation in Tuscany, Central Italy (Caselli and Poggio Pievano forests). Both of them were managed under the coppice system since a few centuries ago and up to the 1950–1960s. Stand age dates back to the year of last coppicing. No silvicultural interventions or any kind of harvesting was performed over the full age span.

The older forest (Caselli: 43° 12′ N, 10° 52′ E; 305 m asl) is located in a sub-coastal site with prevailing aspect N. The forest covers both hilly sides and valley bottom. A well-structured, brown soil (Calcaric Regosols, FAO 1998) lies here on a limestone-marlstone bedrock. The annual mean temperature is 15.4 °C and mean annual precipitation is 841 mm. Summer rainfall deficit (summer rainfall 116 mm) is mitigated by frequent fogs coming from the close

Tyrrhenian sea. Site quality, calculated according to the relationship between tree height of 100 largest trees per hectare and stand age, is medium-high. Standing crop is aged 55. The tree population is arranged here according to a two-storied structure made up of Turkey oak, living quite exclusively in the upper-dominant layer, and by a number of small-sized tree population of secondary, shade-tolerant *spp*. (*Fraxinus ornus* L., *Ostrya carpinifolia* Scop., *Ulmus minor* Mill., *Acer campestre* L., and other minor *spp*.) building up the dominated layer. Site quality, inner microclimate, and the progressive raising of oak tree crowns made possible the re-establishment and survival of these accompanying *spp*. following the suspension of harvesting on short rotations. Mensurational parameters (Table 1) give the evidence of summary figures (whole tree population) and of their arrangement per layer, highlighting the differences between the oak layer (main crop) and the dominated layer (Fabbio and Amorini 2006).

The younger forest (Poggio Pievano: 43° 09′ N, 10° 54′ E; 570 m asl) is located in a hilly area far off the coastline with aspect S. Site position is in the upper slope. A Mediterranean leached and shallow brown soil (Calcaric Vertic Cambisols, FAO 1998) lies here on a limestone-marlstone bedrock. The annual mean temperature is 15.2 °C and mean annual precipitation is 726 mm. Summer rainfall deficit (summer rainfall 102 mm) and water shortage in the soil are being increased by the reduced soil depth, slope, and S aspect. Site quality is medium-low. Standing crop is aged 44. Tree population is arranged here on a single-storied, less developed stand structure made up quite completely by Turkey oak. Mensurational parameters at this site (Table 1) have to be compared with the main crop layer (oak-made) at former site.

Experimental permanent plots were established at both sites to undertake the long-term monitoring of natural dynamics occurring in outgrown, deciduous oak coppice forests. The plot area is 0.5 ha at both sites. Common features to these types, aged three to four times the typical rotation, is the full-stocking and the diffuse presence of standing and lying deadwood.

2.2 Phytomass and soil determinations

Phytomass equations for Turkey oak coppice forests developed by Nocetti et al. (2007) on a set of sites with Turkey oak vegetation in Tuscany and including sites close to those studied here were used to estimate dry weight of stem and branches using measured tree diameter at breast height (DBH) and tree height as independent variables. The calculation of stem (shoot) phytomass includes, as a rule in coppice forest mensuration, the stool mass above ground level. This assumption relies on the standard shoot-cutting level always carried out very close to the ground, thus not allowing the development of an aboveground stool mass between rotation cycles.

Hypogeal phytomass, consisting of rooting systems and stool mass under the ground level, was estimated on the basis of the hypogeal/epigeal mass ratio (Santantonio et al. 1977; Li et al. 2003; Hendricks et al. 2006). Since coarse and fine root mass were sampled and their mass was determined, this amount was subtracted from the overall hypogeal mass value to get the stool mass component only.

Bark portion of stem and thin branches was calculated as follows: [Bark volume (cm^3)=BA×(BT/10)], where BA is bark area (cm^2) and BT is bark thickness (mm). We selected 25 trees at both sites according to DBH distribution. As for stembark, four bark samples at breast height and along cardinal directions were sampled for each selected tree (sample size=4 bark samples×5 trees×5 DBH classes×2 sites). Bark portion of thick branches was assumed to be alike. As for thin branches' bark, four small-sized branches (diameter less than 3 cm) along the crown's cardinal directions were sampled. For each branch, three sub-samples were collected (sample size=4 branches×3 sub-samples×5 trees×5 DBH classes×2 sites). The density of stem and thin branches' bark was then determined. Phytomasses of stem and thick and thin branches' bark were determined by multiplying mean bark volume by mean basic density. Bark mass percentage was then subtracted from the tabulated values including bark. Foliage mass was estimated according to Cutini (1997). Standing and lying deadwood mass were estimated according to Bertini et al. (2010). O layer mass (organic layer until the mineral soil horizon) was determined by O layer weight-to-sampling area ratio. O layer was sampled soon after the winter season along a 40×40 m cross-shaped transect using circular collectors with a radius of 21.5 cm (sample size=20 litterfall samples×2 sites). Root mass was determined by root weight-to-sampling volume ratio. Cylindrical cores were extracted from 15-cm topsoil along a 40×40 m cross-shaped transect. Soil cores were sized as follows: diameter 8 cm, length 15 cm, and core volume 750 cm^3 (sample size=20 root samples×2 sites). A mass of 15-cm topsoil was determined by soil weight-to-sampling volume ratio by the extraction of cylindrical cores (sample size=20 soil samples×2 sites). Since bulk density measured by 15-cm topsoil cores does not account for large rocky fragments and gravel in the soil (Throop et al. 2012), five soil pits (diameter 30 cm, depth 15 cm, pit volume 10,600 cm^3) were excavated randomly at both sites to assess the rocky fraction. At least two operators then visually identified stones and its volume are assessed via displacement in water into a graduated cylinder to get the pit volume occupied by stones. Soil bulk density was then determined by dividing oven-dried mass by the core

Table 1 Mensurational parameters at the sites

Site	Stand age (years)	living shoots n (ha^{-1})	basal area (G) (m^2 ha^{-1})	DBH_m (cm)	H_m (m)	DBH_{dom} (cm)	H_{dom} (m)
Older	55	3,417	44.73	13.0		34.1	26.0
Upper layer (oak)		781	37.92	24.9	22.9		
Lower layer (other broadleaves)		2,636	6.81	5.8	8.6		
Younger	44	2,676	27.44	11.4	13	23.8	19.0

DBH_m mean diameter at breast height, *DBH_{dom}* dominant diameter at breast height based on 100 largest trees per hectare, *H_m* mean total height, *H_{dom}* dominant height based on 100 largest trees per hectare

segment volume corrected for the volume of rocky fractions.

2.3 C and N concentrations

2.3.1 Sampling procedures and lab analyses

The tree population was stratified into five DBH classes, each one representing 20 % of the living stem phytomass to sample all tree ranks, i.e., dominant to dominated trees. Sampling technique was set up as follows to collect samples on tree compartments and 15 cm topsoil: (i) living stemwood: Five trees per DBH class (=rank) were randomly selected at both sites (sample size=5 trees×5 DBH classes×2 sites) and woody tissues (radial cores without bark) were extracted at breast height by drill. (ii) Living stembark: Four bark samples for each selected tree were taken at breast height before stem coring (sample size=4 bark samples×5 trees×5 DBH classes×2 sites). (iii) Living branches: Four small-sized branches (diameter less than 3 cm) were taken along the crown's cardinal directions. For each branch, three sub-samples were collected (sample size=4 branches×3 sub-samples×5 trees×5 DBH classes×2 sites). Bark portion was separated from wood with a razor. To make bark wood separation easier, samples were dried at 60 °C for 24 h. Large branches (diameter over 3 cm) were not sampled because relative C and N concentrations were assumed to be similar to those occurring in the woody stem. (iv) Foliage: At the younger site, foliar C (47.80 %, Di Matteo, unpublished) and foliar N (2.13 %, Di Matteo et al. 2010) concentrations determined at the same site on sunny leaves of 10 and 15 trees of the main crop layer were used, respectively. At the older site, five trees per DBH class were randomly selected and three fully expanded sunny leaves (upper crown) for each tree were sampled (sample size=5 trees×5 DBH classes×3 leaves). (v) Standing dead trees (full shoots and snags): This population was sampled randomly by ten radial cores (sample size=10 trees×2 sites). (vi) Fallen dead trees: Wooden material was sorted into three decay classes (Hunter 1990, modified) according to structural integrity, wood texture, presence of bark, branches, and foliage (Table 2) and then arranged into coarse (CWD) and fine woody debris (FWD) (Lee et al. 1997). Sample size consisted of ten samples for each class (i.e., 10 samples×3 classes×2 sites). (vii) Stools C and N contents: The same concentrations as for woody roots were applied. (viii) O layer: Samples were sieved to 2 mm and the resulting mass divided into three classes: <2 mm, >2 mm, and woody portion (i.e., twigs and small pieces of wood and bark). (ix) Roots: Root samples were soaked for 40 h and sieved to 3,350, 2,800, 2,000, and 500 μm to avoid root losses. Roots were divided in two categories: coarse (further subdivided in ≥5,000 and 2,000–5,000 μm) and fine roots (<2,000 μm). Coarse roots ≥5,000 μm were measured manually with a caliber, while the other coarse subcategory was collected from three sieves: 2,000, 2,800, and 3,350 μm. Due to size and complexity to separate out fine roots (<2,000 μm) from soil particles, a different method was used, i.e., after all coarse roots selection, samples sieved at 2,000 and 500 μm were dried at 105 °C for 24 h and sieved again at 500 μm to preserve all fine roots. (x) Fifteen-centimeter topsoil: Soil samples were sieved to 2 mm to separate out root component. A solution of 10 % hydrochloric acid (HCl) was used to eliminate carbonates from soil samples and determine soil organic carbon (SOC) and total nitrogen (TN).

2.3.2 Elemental analyses

Phytomass and soil samples were oven-dried at 60 °C for 48 h in order to avoid C and N losses (KW apparecchi scientifici s.r.l. KW86AV, Siena, Italy) and milled afterwards (Thomas

Table 2 Definition of decay classes after Hunter (1990)

Decay class	Definition
Class A	Bark intact, small branches (<3 cm), twigs/leaves present, wood texture intact (Hunter class 1)
Class B	Bark intact/trace of bark/no bark, no twigs/leaves, wood hard, texture with large pieces (Hunter class 2+3)
Class C	No barks, no twigs, wood soft, texture with blocky pieces/ powdery texture (Hunter class 4+5)

Scientific 3383-L40 Swedesboro, NJ, USA and Fritsch Pulverisette 15, 55743 Idar-Oberstein, Germany).

Phytomass (15 mg) and soil (20 mg) samples were weighed with a microbalance (Gibertini Europa 4000 AR) in tin capsules, and total organic C and total N were analyzed in an Elemental Analyzer (Thermo Fisher Scientific, model FlashEA 1112 NC Analyzers, Bath, UK). Each analysis was replicated three times to ensure representativeness of the analyzed sample and reported as mean value of the three measurements. All data were expressed on oven-dried basis. Carbon and nitrogen contents were determined multiplying mean C and N concentrations of each component by the respective mass.

3 Statistics

Statistics of C and N concentrations and C/N ratios were carried out using PRISM software version 4.01 (GraphPad Software, Inc. San Diego, CA, USA). Means were compared by analyses of variance (ANOVA), and when significant differences (α=0.05) between means were detected, post hoc tests were performed using Tukey's HSD test for determining significance level.

4 Results

4.1 Phytomass

Total phytomass (i.e., living trees, deadwood, O layer, and hypogeal) was 238.14 Mg ha^{-1} at the younger site and 441.73 Mg ha^{-1} at the older site (Table 3). The proportion including deadwood, O layer, and hypogeal phytomass to total phytomass was 33.32 and 28.25 % at the younger and older site, respectively. Total phytomass was distributed at the younger site as follows: living stemwood > living stembark > full dead shoots and snags > stools > roots <2 mm > living brushwood > woody roots > O layer >2 mm > fallen dead trees decay class B > O layer woody > roots >2 mm > foliage > living brushbark > fallen dead trees-decay class C > O layer <2 mm > living thick branches wood > living thick branches bark > fallen dead trees-decay class A.

The older site was characterized by a higher amount of phytomass in the living tree compartment (i.e., stemwood, thick branches' wood, stembark, and brushbark), then fallen dead trees (especially in decay classes B and C), stools, and O layer (especially O layer <2 mm). Mean annual stemwood mass production was 2.69 Mg ha^{-1} at the younger and 4.25 Mg ha^{-1} at the older site, whereas mean yearly aboveground mass accumulation (i.e., stem, branches, and brushwood including bark, foliage, snags, and fallen dead trees) was found to be 4.21 and 6.30 Mg ha^{-1}, respectively. This difference was also observed in net primary productivity (NPP) (i.e., summing yearly aboveground mass+yearly roots <2 mm mass+yearly O layer >2 mm mass in Table 3), which was found to be 3.95 and 5.92 Mg ha^{-1} at the younger and older site, respectively.

The proportion of roots to total phytomass (i.e., living tree, deadwood, and O layer compartments) was, as expected, much higher at the younger (20.25 Mg ha^{-1}) than at the older site (16.08 Mg ha^{-1}). The proportion of O layer to total phytomass between the sites was 15.72 and 19.70 Mg ha^{-1} at the younger and older site, respectively. Root (stool included)-to-shoot (foliage included) ratios were 0.233 and 0.237 in the same sequence.

4.2 C and N pools

C concentration differed significantly in the phytomass compartments at both sites (p<0.001) (Table 4). C concentration was distributed as follows: living trees > deadwood > stools > roots > O layer >15 cm topsoil. N concentration ranged from 0.103 % (living stemwood) to 2.13 % (foliage) at the younger site and from 0.132 % (living stemwood and thick branches' wood) to 2.42 % (foliage) at the older site. N concentration at the O layer compartment was significantly higher than at the other compartments (p<0.001) at both sites according to the following distribution: O layer > roots > stools > living trees > deadwood >15 cm topsoil.

Ecosystem (i.e., total phytomass and 15-cm topsoil) C and N pools were 203.82 and 6.05 Mg ha^{-1} at the younger site and 285.02 and 6.70 Mg ha^{-1} at the older site, respectively. The living tree compartment contributed 37.66 and 6.96 % of the ecosystem C and N pools at the younger site and 52.95 and 12.14 % at the older site, respectively. The largest N pool was allocated in 15-cm topsoil (84.06 and 73.34 %), living stemwood (2.01 and 4.61 %), living stembark (2.33 and 3.76 %), and stools (1.72 and 7.81 %) at the younger and older site respectively. Root compartment contributed 2.74 and 2.32 % of ecosystem N pool at the younger and older site, whereas ecosystem C pools were 4.40 and 2.31 % respectively. Higher variability at roots C content was observed when compared with the other tree components (i.e., wood, bark, and O layer). This was because one half of root C concentration showed a wider variability around the lower values, with overall C concentration ranging between 27 and 48 %.

4.3 C/N ratio

Concentrations of total nitrogen (TN) and soil organic carbon (SOC) were found to be similar between the sites (around 0.26 and 4.4 % for TN and SOC, respectively) even with a marked variability across sampling points. Mean C/N ratios were

Table 3 Phytomass allocation per compartment

Compartments	Younger site (age 44)			Older site (age 55)		
	Phytomass			Phytomass		
	(Mg ha^{-1})	%	(Mg ha^{-1} year^{-1})	(Mg ha^{-1})	%	(Mg ha^{-1} year^{-1})
Living tree						
Living stemwood	118.30	49.68	2.69	233.82	52.93	4.25
Living brushwood	7.71	3.24	0.175	10.08	2.28	0.183
Living thick branches' wood	1.12	0.470	0.025	11.66	2.64	0.212
Living stembark	23.70	9.95	0.539	46.97	10.63	0.854
Living brushbark	3.19	1.34	0.073	8.17	1.85	0.149
Living thick branches' bark	1.07	0.449	0.024	2.34	0.530	0.043
Foliage[a]	3.70	1.55	0.084	3.90	0.883	0.071
Deadwood						
Full shoots and snags	16.90	7.10	0.384	9.82	2.22	0.179
Fallen dead trees—decay class A	0.441	0.185	0.010	0.81	0.184	0.015
Fallen dead trees—decay class B	6.32	2.65	0.144	12.16	2.75	0.221
Fallen dead trees—decay class C	2.92	1.23	0.066	7.18	1.63	0.131
O layer						
O layer <2 mm	2.62	1.10	0.060	8.57	1.94	0.156
O layer >2 mm	6.88	2.89	0.156	3.72	0.842	0.068
O layer woody	6.22	2.61	0.141	7.41	1.68	0.135
Stool[b]	16.80	7.05	0.382	59.04	13.37	1.07
Root						
Roots <2 mm	8.27	3.47	0.188	4.80	1.09	0.087
Roots 2–5 cm	4.47	1.88	0.102	3.76	0.851	0.068
Woody roots (>5 mm)	7.51	3.15	0.171	7.52	1.70	0.137
Sum	238.14	100	5.41	441.73	100	8.03

[a] Assuming foliage phytomass of 3.70 (younger site) and 3.90 Mg ha^{-1} (older site) based on Cutini (1997)

[b] Assuming stool phytomass of 16.80 (younger site) and 59.04 Mg ha^{-1} (older site) based on hypogeal/epigeal ratio

28.43 for O layer (including the three classes), 96.14 for fallen dead trees (including all decaying classes), 18.12 for 15-cm topsoil at the older site and 32.87, 88.47, and 17.23 at the younger site, respectively (Fig. 1). C/N ratios of O layer narrowed significantly ($p<0.001$) with decreasing class at both sites, especially for O layer <2 mm. A steady significant variation in the three decay classes was not found in C/N ratios of fallen dead trees at both sites due to the higher values showed by intermediate decay class.

5 Discussion

5.1 Site quality components, drivers, and dynamics of phytomass-necromass production

The analysis of C and N ecosystem pools highlights the role of soil fertility, especially the higher water availability and soil depth at the older site and, additionally, the stand age difference. Age of standing crop in outgrown coppice forests is a keypoint due to the positive growth dynamics typical of these forest types under good site quality. Under this condition, growth following the suspension of harvesting reaches early its highest rate within the ages of 35–40 and then holds quite steady levels of woody mass production for a number of years. Observational studies are anyway limited to maximum ages nowadays available at these forest types (50–60 years). Growth culmination is vice versa delayed and reached more progressively with lower rates at less fertile sites. Given the close relationship between growth pattern and site quality as highlighted by mensurational data, even a one/fifth age span between the two sites accounts for the difference found in phytomass-necromass production. Mensurational studies carried out at the same stands (Amorini et al. 1998; Di Matteo et al. 2010) showed a mean annual stem volume increment of 5.5 and 7.5 m^3 ha^{-1} at the younger (P. Pievano forest) and older site (Caselli forest), respectively. The same difference

Table 4 Concentrations (%) and contents of C and N (Mg ha^{-1}) in phytomass and 15-cm topsoil compartments

Compartments	Younger site (age 44)				Older site (age 55)			
	Concentration		Content		Concentration		Content	
	C	N	C	N	C	N	C	N
Living tree								
Living stemwood	47.77 (0.071)	0.103 (0.004)	56.37	0.122	46.97 (0.087)	0.132 (0.005)	109.82	0.309
Living brushwood	47.56 (0.180)	0.501 (0.040)	3.66	0.039	46.57 (0.102)	0.544 (0.016)	4.69	0.055
Living thick branches' wood	47.77 (0.072)	0.103 (0.004)	0.525	0.001	46.97 (0.087)	0.132 (0.005)	5.47	0.015
Living stembark	51.97 (0.293)	0.596 (0.038)	12.32	0.141	51.03 (0.153)	0.537 (0.018)	23.96	0.252
Living brushbark	49.18 (0.242)	1.06 (0.040)	1.57	0.034	47.46 (0.437)	0.935 (0.024)	3.87	0.076
Living thick branches' bark	51.97 (0.293)	0.596 (0.038)	0.556	0.006	51.03 (0.153)	0.537 (0.018)	1.19	0.013
Foliage[a]	47.80 (0.270)	2.13 (0.060)	1.77	0.078	49.22 (0.196)	2.42 (0.091)	1.92	0.094
Average	49.14 (0.203)a	0.727 (0.032)c	10.97	0.06	48.46 (0.173)a	0.748 (0.025)d	21.56	0.116
Deadwood								
Full shoots and snags	47.96 (0.172)	0.112 (0.008)	8.11	0.019	47.68 (0.224)	0.140 (0.016)	4.70	0.014
Fallen dead trees—decay class A	48.84 (0.154)	0.641 (0.063)	0.195	0.003	47.171 (0.509)	0.773 (0.091)	0.380	0.006
Fallen dead trees—decay class B	48.92 (0.473)	0.445 (0.027)	3.08	0.028	47.588 (0.768)	0.417 (0.052)	5.82	0.051
Fallen dead trees——decay class C	47.52 (0.540)	0.716 (0.042)	1.38	0.021	45.388 (0.545)	0.526 (0.049)	3.21	0.038
Average	48.31 (0.334)b	0.479 (0.035)e	3.19	0.018	46.95 (0.511)b	0.464 (0.052)e	3.53	0.03
O layer								
O layer <2 mm	34.81 (1.36)	1.63 (0.093)	0.905	0.042	20.37 (1.27)	1.32 (0.033)	1.73	0.113
O layer >2 mm	45.08 (0.983)	1.43 (0.038)	3.11	0.099	35.45 (1.28)	1.05 (0.059)	1.31	0.039
O layer woody	47.21 (0.262)	1.00 (0.038)	2.93	0.062	36.10 (1.42)	1.02 (0.051)	2.67	0.076
Average	42.37 (0.868)d	1.35 (0.056)a	2.31	0.068	30.64 (1.32)e	1.13 (0.047)a	1.90	0.076
Stool[b]	45.89 (0.752)c	0.618 (0.091)d	7.70	0.104	42.99 (0.552)c	0.885 (0.071)c	25.40	0.523
Root layer								
Roots <2 mm	41.34 (1.02)	1.03 (0.030)	3.43	0.085	37.34 (0.804)	1.03 (0.034)	1.79	0.050
Roots 2–5 mm	46.78 (0.413)	0.758 (0.032)	2.11	0.034	41.51 (0.489)	1.05 (0.051)	1.56	0.040
Woody roots (>5 mm)	45.89 (0.751)	0.618 (0.091)	3.44	0.047	42.99 (0.552)	0.885 (0.071)	3.23	0.067
Average	44.67 (0.728)c	0.801 (0.051)b	2.99	0.055	40.61 (0.615)d	0.988 (0.052)b	2.19	0.052
15-cm topsoil	4.65 (0.434)e	0.261 (0.026)f	90.67	5.09	4.22 (0.273)f	0.252 (0.019)f	82.30	4.91
Sum			203.82	6.05			285.02	6.70

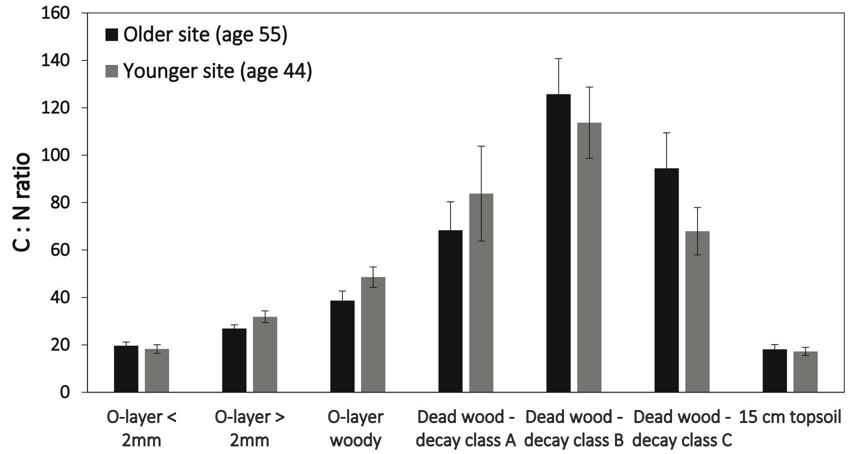
Values for C and N concentrations are mean with standard error in parentheses. Means with different letters between sites are statistically different at $p < 0.05$

[a] Assuming for younger site foliar C and N concentrations of 47.80 and 2.13 %, respectively, based on analytical foliage measurements from Di Matteo (unpublished data) and Di Matteo et al. 2010 respectively

[b] C and N pools calculated using the relative C and N concentrations as for woody roots

was observed even comparing the two sites at the same age by stand chronologies (Amorini et al. 1998). The lower water shortage in summer months at Caselli results in a more effective growing season (Cutini 1997; Bertini et al. 2010). The higher phytomass at the older site proves to be attributable to the higher site quality and related growth dynamics. Both sites exhibited site differences as specific leaf area (SLA) too (Cutini 1996; Di Matteo et al. 2005), with Caselli showing higher SLA values than P. Pievano. Common attribute to light-demanding species as Turkey oak in the case is the early occurrence of tree mortality when compared with shade-tolerant spp. Total deadwood amount is not very different between sites (29.97 vs 26.58 Mg ha^{-1}) at Caselli and P. Pievano, respectively, whereas fallen-to-standing dead trees ratio is the opposite (2:1 to 1:2) in full accordance with dynamics of deadwood formation (standing dead tree > stem breakage > snag > fallen deadwood > fragmentation). Stand age and site quality act as drivers of mortality rate. Standing deadwood-to-biomass percentage ratio is vice versa three times higher at Poggio Pievano (10.6 to 3.1) because of the more intensive stage of competition in progress at the younger site, the same phase being over at the older, more fertile site.

Fig. 1 Mean and standard error (*in bars*) C/N ratios for O layer, deadwood, and 15-cm topsoil measured at both sites. C/N O layer values are referred to three diametric classes; C/N deadwood values are referred to three decay classes of fallen dead trees



Lying deadwood-to-biomass percentage ratio is quite similar (6.0 to 6.3) at both sites. The distribution of fallen dead trees per decay class highlights the prevalence of the intermediate class B (60 and 66 %), followed by class C (36 and 30 %) and, by far, by class A (4 %) at the older and younger site respectively.

5.2 Coppice C and N stores

A concentration of 50 % is used worldwide to estimate C content in living tree compartments, whereas C concentration in forest soils is widely known to be less than 50 % (Lamlom and Savidge 2003; Malhi et al. 2008). In this analysis, C distribution at main forest compartments (i.e., living trees, deadwood, O layer, roots, stools, and soil) clearly showed the highest contribution of living trees and soil compartments in the ecosystem C pool, whereas almost all ecosystem N pool was stored in the soil, with a quite different N distribution in the phytomass between sites (Fig. 2). The study points out the very high percentage of N storage in the soil, whereas the proportion of organic C in the ecosystem pool is more variable, as a consequence of phytomass allocation. However, based on the evidence that a number of studies highlighted that deeper soil horizons are significant in terms of SOC and TN (Diochon et al. 2009 and references cited therein) and considering the no sampling of deeper soil horizons with uncertainties related with the estimation of deeper soil stoniness, we assume that all values associated with 15-cm topsoil (including ratios with other compartments) have to be interpreted with care. Based on Murillo (1994), higher soil stoniness could lead to a heavy overestimation of soil nutrients (even up to 20–30 %), whereas Callesen et al. (2003) reported a cumulative added error of 10–20 % to bulk densities in N pool estimate to correct for soil stoniness overestimation.

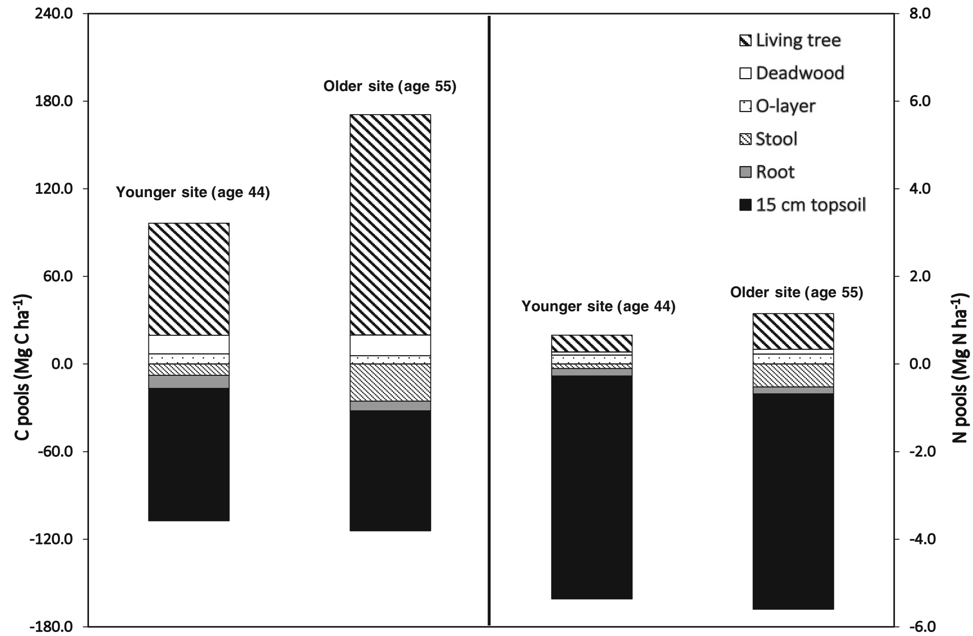
The higher phytomass at the older site results in a higher amount of ecosystem C pool compared to the younger site, being mainly due to the contribution of living stemwood. The living tree compartment, especially stemwood and stembark, largely contribute to the ecosystem C and N pool, but the high N contribution from the O layer and stool compartments is worth highlighting too.

5.3 Comparisons with conventional C concentration

The postulate that a general application of conventional C rate would lead to systematic errors in estimating ecosystem C density was broadly supported by data. Based on the evidence that stools, roots, O layer, and deadwood compartments have the potential to store large amounts of C in oak stands (López et al. 2003; Bruckman et al. 2011), we found significant differences in relative C concentration across compartments and between sites. In this study, maximum averaged site deviations from conventional C concentration were recorded as follows: −13.95 % as for O layer compartment (−27.59 % O layer <2 mm), −7.36 % as for roots compartment (−10.66 % roots >2 mm), and −2.37 % as for deadwood compartment (−3.5 % fallen dead trees, decay class C). The highest C concentrations were observed at the younger site compared to the older site, whereas living tree compartment was quite stable (−1.20 %). The general use of conventional C rate leads therefore to an overestimation of C pools in most tree compartments, especially for O layer, deadwood, and roots. This is of major evidence at the older site where the lower C concentration in O layer <2 mm (20.37 %) leads to an overestimation of 145.5 % in comparison with C conventional ratio.

Deadwood amount is built up by natural, high competition rate following the suspension of harvesting in fully stocked stands as coppice forests usually are already at the time of customary rotation. Typical physiognomy of a mature coppice forest is in fact a young, densely stocked crop. In former rotations acted—as a rule—at this stage, woody mass was harvested before the full occurrence of heavy competition and

Fig. 2 Distribution of C and N pools in forest compartments at both sites



related mortality. Drivers of the different dynamics in the post-cultivation phase (outgrown coppice forests) are species-specific and related first to tree species auto-ecology (Bertini et al. 2012), then to stand age and site quality; thus, the more fertile sites usually accelerating the progress of tree death and decay rates as well.

5.4 The issue of conversion C rate: an open debate

On a global scale, researchers theorize that mineral soil is the major terrestrial C and N sink (Post et al. 1982). Most global C and N estimates ignore other forest compartments such as the hypogeal phytomass, O layer, snags, and fallen dead trees. The same compartments heavily contribute to C and N stocking in Mediterranean forest ecosystems as deciduous oak coppice forests.

The evidence that C concentration detected in living stemwood and branches agrees with conventional C rate of 0.5 that bark phytomass exceeds 0.5 rate and that O layer and roots are dramatically lower than 0.5 rate would indicate that conventional C rate overestimates actual C density. C content in each tree component and in the whole tree is currently determined by multiplying phytomass by 0.5 according to IPCC recommendations (Penman et al. 2003), yet IPCC also published tables with *default* values of biomass expansion factor (BEF) and root-to-shoot ratio since they are lacking for most of the world's forests. The use of these *default* values associated with the conventional C rate could bias results and lead to systematic distortion in estimating phytomass and carbon content even though no other values are often available.

This study provided a suite of values varying as a function of site and environmental characteristics, progress of stand structure dynamics, and tree components analyzed. These values tended to be lower than conventional C rate, leading to a rebuttal of the rough consideration of the agreed rate allocated in the phytomass. A series of additional research questions arise from these results, such as the effect of successional stages in carbon and nitrogen pool distribution. For instance, regularly managed forests may not contain or usually do not reach the significant rotten wood amount that outgrown coppices have, but as forests get older and develop more complex standing structures, does carbon concentration change or does only phytomass distribution change over time? Thus, determining whether carbon concentration varies as a function of successional changes could provide highly valuable information concerning carbon content variation over time and space.

No longer managed coppice forests provide an useful benchmark for these investigations because (i) in opposition to former attention paid to harvesting standing mass for purposes of fuelwood production on short rotations, current much less intensive exploitation makes these widely diffused systems outstanding sinks, actively contributing C and N stocks; (ii) the rapid progress of structural changes affecting these forest types may provide, on relatively short time windows, further knowledge on the overall dynamics of semi-natural and no more managed systems.

5.5 The strategic role of Mediterranean coppice forests

The prevailing location of coppice forests in mountain environments, not provided with adequate road networks, made not profitable their exploitation for fuelwood over an increased forest area in the last decades. Current role attributed to a share of outgrown coppice forests, as in the cases presented here, is the restoration of a more functional forest cover in terms of biodiversity, capacity to provide enhanced societal and ecosystem services, improvement of landscape quality, and capacity to mitigate climate change.

This is ruled by the positive growth pattern due to the natural rearrangement of the original standing crop structure and stocking additional phytomass within the different compartments over the post-cultivation time and up to the ages observable now. A careful attention has to be devoted in the meanwhile to planning and managing at best the wildfire hazard, i.e., the most serious threat to forest restoration into Mediterranean sensitive environments. The proactive reduction of fire risk foresees, among the preventive counteracting measures, the consolidated practice of silviculture accelerating the natural process of coppice conversion into high forest. These practices cannot be in any way applied diffusely because they are expensive at least at early stages of implementation.

Within this general frame of reference, the paper's findings provide further knowledge of C and N storage into these emerging types and the evidence that a detailed analysis may get higher accuracy in the pools estimate and, in turn, produce a more reliable outlook on the dynamics and climate change mitigation ability of the concerned systems.

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