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Land Use Change and Forest Carbon Sink Assessment in an Alpine Mountain Area of the Veneto Region (Northeast Italy)

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In this study, we analyzed the variation of forest land cover in a mountain area of Veneto Region in northeast Italy. The analysis was done by comparing orthorectified aerial photographs taken in 1991 with orthophotos dated 2003, using photo interpretation of points with casual distribution on sample areas, according to a stratified sampling. The study yielded a statistically relevant increment of about 0.095% (ie about 42 ha) of forestland only up to 1500 m above sea level compared with the estimated forest cover for 1990, highlighting that this low increase was mainly due to abandoned grazing; the forest surface area estimate in 1990 was affected by a standard error of approximately 2.8%. We then estimated the carbon sink in the areas where forests had expanded. This was achieved by collecting biometric data in the field, and then using allometric functions. The annual carbon sink was estimated as 0.69 Mg ha^{-1} year^{-1}.

Keywords: *Kyoto Protocol; land use change; photo interpretation; carbon sink; Italy.*

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Introduction

In many European countries, landscape dynamics are characterized by forest expansion, a phenomenon that is mainly due to forest recolonization following the abandonment of traditional agricultural practices. The effects of these land use changes can be considered from the point of view of biodiversity, landscape conservation, and existing biotopes. Perhaps more importantly, forest expansion implies an increased potential for atmospheric carbon sequestration. An inventory of the areas recolonized by forest and an assessment of their carbon sink capacity thus also constitute focal issues in relation to the carbon cycle and the Kyoto Protocol (KP).

The KP obligates countries that have committed to reducing their greenhouse gas emissions to report on the balance between carbon sinks and sources derived from land use change activities (UN 1998, Article 3.3). These include all human-induced forest conversion activities since 1990 on land that was without forest for less than 50 years (reforestation) or for more than 50 years (afforestation) through forest plantation, sowing, and/or human actions to support natural propagation. Italy, taking the so-called broad approach in defining forest management (IPCC 2003), considers all afforestation and reforestation (AR) activities as human induced (Lumicisi et al 2007).

To assess afforestation, reforestation, and deforestation (ARD) activities it is necessary to (1) select a clear forest definition, (2) assess forest surface variations, (3) obtain information on the origins of the change processes, and (4) assess the sink capacity of new forest formations. The present study applied the forest definition used in the Italian National Forest Inventory. According to this definition, a forest is an area of at least 5000 m^2 covered by trees, with a crown cover of over 10% and a canopy width of over 20 m (ISAFA 1998).

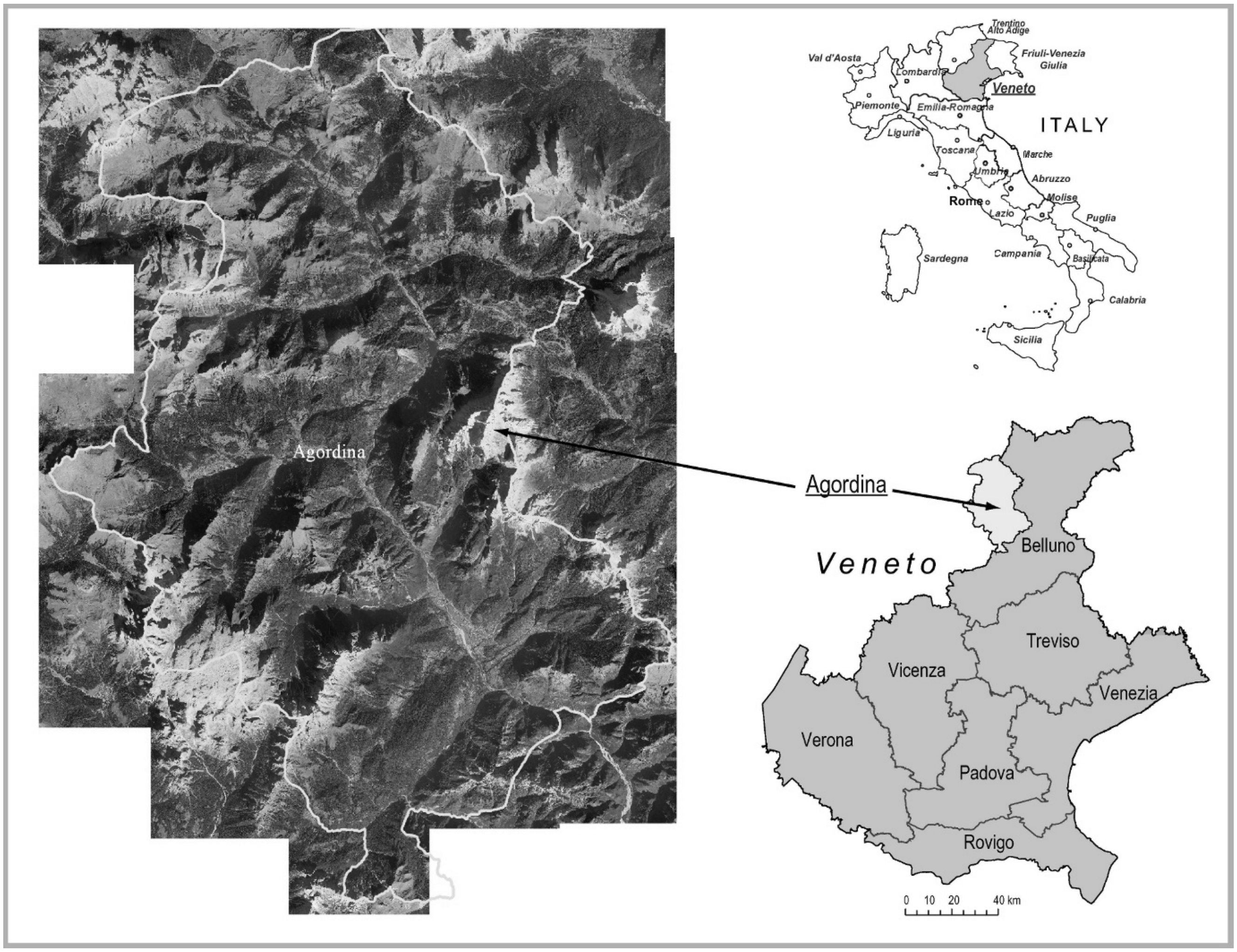
The objectives of the present study were to assess the forest surface changes since 1990 in one representative area of the mountainous part of Veneto Region (Agordina mountain community), and to assess the carbon sink capacity of this area.

Material and methods

Study area

Considering the available information and in agreement with previous studies (Salvadori et al 2006), we adopted one mountain community (MC) as a reference unit. A mountain community is a local body that unites Alpine and pre-Alpine municipalities with a view to developing marginalized mountainous areas. Area detection complied with Intergovernmental Panel on Climate Change (IPCC) reporting methods (IPCC 2003).

FIGURE 1 Geographical location of Veneto Region, with the Agordina mountain community shown in light gray, and forest cover in the Agordina mountain community (orthophotos from 2003). (Map and orthophotos by Veneto Region)



The study area was thus defined as the Agordina MC, which is representative of the alpine part of Veneto Region in terms of location and morphology (Figure 1). The Agordina MC consists of 16 municipalities and is situated in the northwest of Belluno Province. It covers an area of 65,916.29 ha at elevations between 300 and 3000 meters above sea level (masl). From south to north, forests in the study area range from pure or mixed formations of European hop-hornbeam (*Ostrya carpinifolia*) in the southern part to mountain beech forest (*Fagus sylvatica*), mixed formations of spruce and fir (*Picea abies* and *Abies alba*), mixed forests of spruce and beech, and spruce forests in the mesalpic area (the southern Alpine area with an average annual precipitation of 1400 mm and an average annual temperature of 7°C), the latter extending into the endalpic area (the northern and inner Alpine area with an average annual precipitation of 1000 mm and an average annual temperature of 5°C), where stone pine (*Pinus cembra*) and larch (*Larix decidua*) prevail above 1600 m asl (Del Favero and Lasen 1993).

Research methodology

The analysis of land use change in the Agordina MC was based on a multitemporal approach (Corona et al 2007; De Natale et al 2007). Aerial photographs were used for 1991, taken by the "Montagna Veneta" flight and then orthorectified; these photos were chosen because they dated the nearest to the KP baseline year (1990). The data for 2003 came from digital, color, orthorectified aerial photographs (orthophotos). Orthorectification was done based on technical regional numeric maps (Carta Tecnica Regionale Numerica, CTRN); these are digital maps produced by Veneto Region at a scale of 1:5000 and with all artificial and natural details reported; each CTRN covers a surface of about 900 ha.

The methodology proceeded with the steps described below.

Sampling frame: A multi-stage sampling was done using the following procedure (Philip 1994):

- Division of the sample (the MC) into subsamples called primary units (M), in this case represented by the CTRN;
- Extraction of a random sample (*m*) from the total set of primary units (*M*);
- Division of the sample primary unit (*m*) into smaller subsets called secondary units, which are random sample points at a density of 1/12 ha (optimum density according to Salvadori et al [2006]);
- Extraction of a random sample of secondary units from each primary unit;
- Survey of the attribute of interest, ie the sample points on the aerial photographs on which the interpretation is done, in every selected unit.

The sampling method was applied wherever both the CTRN and aerial photographs were available. After extracting the primary sample, random sample points were picked for photographic interpretation.

Photo interpretation by sample points: The sample points were classified into 3 land use categories: *forest*, *productive nonforest* (eg agricultural land), and *unproductive* (eg scree). The forest surface was assessed using the point-count method according to the Italian National Inventory (Tabacchi 2001). Each point was assigned to 1 of the 3 different land use categories according to the procedure proposed by De Natale et al (2003) and used in other studies (Corona et al 2007, De Natale et al 2007) (Figure 2). Ground surveys were used to classify points where classification by photo interpretation was uncertain.

Field measurements: All points classified as afforestation and reforestation were measured. For each point, 2 concentric circular sample areas were identified in which to obtain different attributes (De Natale et al 2004). The center of the sample area was the point at which the land use change had been detected, identified through a global positioning system. For the outer area, with a radius of 18 m and a surface of about 1000 m^2, the following attributes were surveyed:

- Previous land use;
- Forest origin (natural, artificial, mixed);
- Presence of regeneration (assessment of trees less than 2 m tall);
- Presence of shrub species.

The inner area, with a radius of 8 m and a surface of about 200 m^2, was investigated with regard to the following attributes:

- Tree species;
- Diameter of all trees with a diameter at breast height (Dbh) $>$ 3 cm;
- Tree height of some sample trees identified as representative of the forest (1–2 sample trees for each diameter class with a minimum of 4 sample trees in total);
- The height sample trees were core-sampled (taken at the base for trees with Dbh $<$ 15 cm and at 1.30 m for trees with Dbh $>$ 15 cm).

Data analysis: The tree rings were counted for all sample trees and all cores were analyzed with a computer-controlled tree ring measuring device. The statistical relevance of the land use variation detected between 1991 and 2003 was evaluated with the McNemar test for paired data that involves calculation of the statistics (Zar 1998):

$$X_c^2 = \frac{(|f_{12} - f_{21}| - 1)^2}{f_{12} + f_{21}} \qquad (1)$$

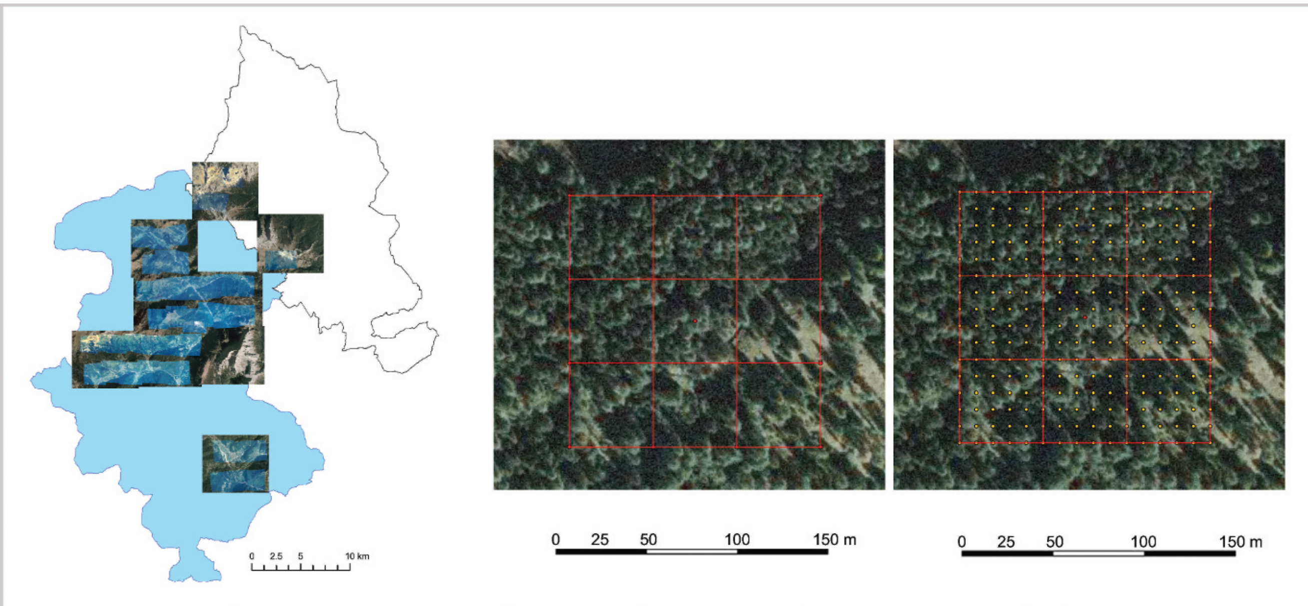
where f_{12} and f_{21} are the frequencies obtained from a 2 × 2 contingency table. The assessment of the proportion in each class and the relative rates of variance and standard deviation are described in previous studies (Corona et al 2007). In order to report all land use change values to 1990—the baseline year for the KP—the total forest surface variation was extrapolated between 1990 and 2006, the year of the field surveys.

Carbon sink assessment: The proposed methodology to assess carbon sink capacity is based on the application of allometric equations to the diameter distribution of the trees in the sample areas located at all points with land use variation. It is commonly believed that a species-specific equation should be used because tree species may differ in architecture as well as wood density (Ketterings et al 2001). However, a different approach was proposed by West et al (1999), who presented a general model, known as the WBE model, to estimate values of scaling exponents using a functional relationship (Enquist et al 1999; Enquist 2002). The model proposes that evolution by natural selection has resulted in an optimal fractal-like vascular network. As a result of this general principle, organisms should exhibit a common set of quarter-power scaling relationships with body mass. Allometric equations are generally based on empirical relationships in the form of a power function:

$$W = aDbh^b \qquad (2)$$

where W is the total aboveground biomass; a and b are the scaling coefficient and scaling exponent, respectively; and Dbh is the tree breast-height diameter (Niklas 1994). Both a and b are generally reported to vary with species, site, and age.

FIGURE 2 Location of the extracted photos taken in 1991 and 2003, and example of sampling photo-point classification with the support of the relevant grids. (Map by Veneto Region)



According to the WBE model, the aboveground biomass of tree species should scale against stem diameter with $b = 8/3$ (ie ~ 2.67), independently of species, site, and age (West et al 1999). The universal structure of the vascular network proposed at tree level by West et al (1999) has been empirically demonstrated (Anfodillo et al 2006).

Pilli et al (2006), through the analysis of numerous data sets of populations of broadleaves and conifers from all over the world (23 different species), defined values for a and b for different maturity stages of the trees (juvenile, adult, and mature). For juvenile trees the authors proposed a mean value of ln a equal to -1.638 (with a standard error of 0.0589) and a value for b equal to 2.08. The model is applicable to any forest vegetation type in order to directly estimate the total aboveground tree biomass.

Starting from the diameter distribution of the sample areas, the aboveground biomass present at the time of the survey was assessed using the following formula (Pilli et al 2006):

$$\ln W = -1.638 + 2.08 \ln Dbh \qquad (3)$$

Study of the cores taken from the sample trees provided age and mean annual increment in diameter, which were then averaged to obtain a single value for every species. The mean increment of all species was then used to estimate the diameter distribution and the aboveground biomass for 1990, removing from the current diameter the increment assessed for the 16 years since the baseline (all data were reported in hectares).

The carbon stock is assessed as 50% of the biomass (IPCC/OECD/IEA 1997; Nabuurs et al 2003). The annual mean sink can be estimated as the difference between the 1990 stock and the current stock divided by 16 years (years since the baseline),

$$C_{\text{sink}} = \frac{(C_n - C_0)}{y_n - y_0} \qquad (4)$$

where C_n and C_0 are the final and initial carbon stocks and y_n and y_0 are the final and initial years.

The data assessed for all the points with land use variation were then aggregated to obtain a single value of mean sink to be extended to all the surface variation of the MC.

Results

Land use change

Photo interpretation was done on a total of 1220 points, of which 5 could not be used because they were in shadow on both the aerial photographs and the orthophotos. A total of 1215 points were therefore used for the land use change assessment, ranging from 500 to 2400 masl.

A land use variation was found at 11 points in the Agordina MC:

- 3 changes from productive nonforest to unproductive;
- 8 changes from productive nonforest to forest (all classified as reforestation).

There were no points with deforestation.

TABLE 1 Land use change in the period 1991–2003 and mean annual value for all land use categories (500–1500 masl). The changes detected are from productive non-forest to forest and unproductive.

Land use type	Land use change (ha)	Standard deviation	Standard error (ha)	Annual variation (ha)	Standard error (ha)	Error (%)
Forest area	322.43	0.00025	8.99	26.87	0.749	2.79
Productive nonforest	−516.70	0.01746	11.31	−43.06	0.942	2.19
Unproductive	194.28	0.00016	5.79	16.19	0.483	6.14

The mean annual forest surface increase was 0.089% compared with the 1991 surface and equal to about 42 ha. This variation was statistically significant: the McNemar test yielded a value of $P < 0.025$.

The land use change data were then evaluated in terms of significance by subdividing the sample points with land use variation into altitudinal bands: the McNemar test reported a statistically relevant value for heights below 1500 masl, whereas the variation was not significant for the highest points.

In the 1991–2003 period, considering only the land below 1500 masl (36,500.42 ha; see Table 1), the annual percentage rate of forest surface change (error 2.81%) amounted to 0.074% of the total forest surface of the Agordina MC assessed for 1991, and 0.095% of the forest surface below 1500 masl assessed for 1991.

Subsequently the total forest surface variation in 2006 was estimated (confidence interval at 0.05 probability level):

- 26.87 ± 0.75 ha yr^{-1} of forest surface variation;
- 429.92 ± 12.08 ha of total variation between 1990 and 2006;
- Equal to 1.18% of the total surface of the Agordina MC;
- Equal to 1.53% of the forest surface assessed for 1991.

Field measurements

Biometric measurements were taken only in 6 of the 8 points showing reforestation because the other 2 were inaccessible. These 6 points showed different types of reforestation, all verified on the ground: 2 plantations (1 of larch and 1 of spruce), 1 example of ex-pasture natural forest regrowth (at about 1950 masl), and 3 examples of reforestation of meadow areas (2 of these points were close to villages and 1 was near an abandoned sawmill).

Spruce is the main species at all altitudes within the Agordina MC; other species are the sycamore maple (*Acer pseudoplatanus*), larch (*Larix decidua*), and mountain ash (*Sorbus aucuparia*).

Carbon sink assessment

Analysis of the cores of the sample trees was used to derive the age (Table 2) and mean increment of the different species (0.50 cm yr^{-1} for spruce, 0.67 cm yr^{-1} for larch, 0.56 cm yr^{-1} for maple; an average of 0.54 cm yr^{-1} for conifers and 0.44 cm yr^{-1} for broadleaves), as well as both the current and the 1990 diameter distribution (Figure 3).

The mean carbon sink for the period was assessed using equations 3 and 4. The single values obtained for each point were then averaged to acquire an average sink of 0.69 Mg C ha^{-1} yr^{-1} (standard deviation = 0.38) (Table 3). Multiplying this last value for the mean annual forest surface variation we obtained the mean annual sink (aboveground biomass) of the areas with afforestation/reforestation activities in the Agordina MC: 18.54 Mg C yr^{-1}.

Discussion and conclusion

Forest surface variation

Subdivision of the points into altitudinal bands was useful to better understand the dynamics in this area, which has a complex geomorphology. Comparing the annual forest growth rate obtained in this study with that obtained in analogous studies we can see that:

- For the Agordina MC the annual forest expansion rate is 0.095% of the forest surface below 1500 masl assessed for 1991 (equal to 26.87 ± 0.75 ha yr^{-1});
- For the Grappa MC (pre-Alpine area of Veneto Region) the annual forest expansion rate is 0.54% of the forest surface assessed for 1991 (equal to 28.08 ± 0.55 ha yr^{-1}) (Salvadori et al 2006);
- For Abruzzo Region in central Italy, Corona et al (2007) estimated an annual forest expansion of 0.60% of the forest surface assessed for 1990;
- For Trento Province in the Alpine region De Natale et al (2007) estimated an annual forest expansion of 0.10% of the total surface.

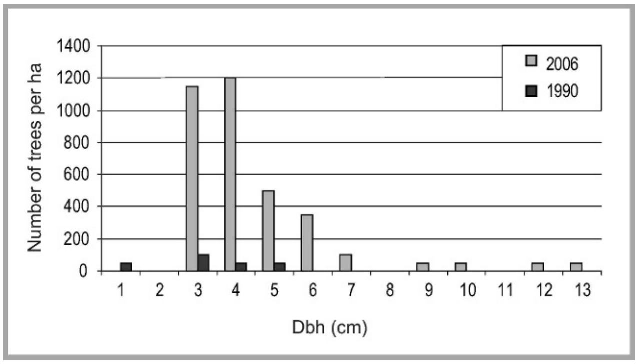
The different annual rates are due to regional socioeconomic reasons, geomorphology, and prevalent land uses in the different territories. Comparing the Agordina MC with the Grappa MC shows that the former has about 70% of the land covered by forest, with most of

TABLE 2 Diameter (Dbh), height (H), and age of the sample trees in 2006.

Sample point	Species	Dbh (cm)	H (m)	Age (yr)	Increment (cm yr^{-1})
2005	pa	8	6.5	22	0.36
	pa	5		18	0.28
	pa	13	10.0	17	0.76
	pa	3	2.5	17	0.18
747	pa	8	7.5	20	0.40
	pa	25	13.5	17	1.47
	pa	5	4.5	20	0.25
	pa	10	8.5	15	0.67
3660	pa	7	3.8	16	0.44
	pa	7	3.0	12	0.58
	pa	12	4.8	18	0.67
	pa	5	3.0	16	0.31
3991	ld	7	7.5	17	0.41
	ld	6	7.0	11	0.55
	ld	7	7.0	13	0.54
	ld	16	9.5	12	1.33
	ld	5	8.0	10	0.50
7416	pa	13	9.5	24	0.54
	pa	5	4.5	13	0.38
	pa	5	3.8	11	0.45
	pa	4	3.5	13	0.31
	sa	7	6.0	17	0.41
	sa	6	6.5	13	0.46
	sa	4	5.5	16	0.25
	sa	6	6.0	12	0.50
	sa	5	6.0	17	0.29
	sa	4	5.5	17	0.24
5831	ap	10	12.0	17	0.59
	ap	10	13.0	16	0.63
	ap	6	9.5	12	0.50
	ap	7	9.0	13	0.54

pa, *Picea abies*; ld, *Larix decidua*; sa, *Sorbus aucuparia*; ap, *Acer pseudoplatanus*.

FIGURE 3 Sample point 7461: 2006 and 1990 diameter distributions (coordinates 12°12′19.993″ longitude, 46°27′36.657″ latitude).



the rest of the territory situated above the timber line, while the latter is situated at lower elevations and only 29% of the land is covered by forest; therefore, the potential for forest expansion in the former is lower, with slower expansion (Körner 1998). These observations are also valid for Abruzzo Region, whereas Trento Province has features similar to Agordina MC.

Carbon sink assessment

The methodology used for the sink assessment of the afforested/reforested areas gives an initial idea of the potential of this territory as a carbon sink.

The assessment was done only for the tree aboveground biomass, without any reference to the belowground and organic soil biomass; nevertheless this estimate is indicative of the general trend, because the tree aboveground biomass increment is the highest contributor to the general increment of a forest ecosystem as carbon sink, especially in stands without logging (Nabuurs et al 2003). There are no studies available to compare the reforestation sink capacity in Italy. Data for the forest surface variation and carbon sink in Europe between 1950 and 1999 reported by Nabuurs et al (2003) shows an average sink of 0.32 Mg C ha^{-1} yr^{-1}, ie less than half of the amount obtained in this study for the Agordina MC (0.69 Mg C ha^{-1} yr^{-1}). Another study done for the whole of Europe shows an average net annual increment for Italy of 0.9 Mg C ha^{-1} yr^{-1} and a European average of 1.8 Mg C ha^{-1} yr^{-1}, considering carbon in woody biomass (Liski et al 2000). For the early 21st century, Eggers et al (2008) report a carbon stock change for tree biomass in Europe of 0.7 Mg C ha^{-1} yr^{-1}, mainly due to forest management, while AR activities have a smaller-scale effect.

First Commitment Period projection

Knowing the annual rate of surface variation it is possible to propose a forecast of the 2008 forest surface, hypothesizing that the annual rate will be constant in the future (a conjecture acceptable only for the short term) (Zanchi et al 2005). Regarding the First Commitment Period (2008–2012) projection, the forecasted 2008 surface with afforestation/reforestation amounts to 483.6 ± 13.50 ha; the forecasted forest surface variation between 1990 and 2012 is 618.03 ± 17.25 ha for the entire Agordina MC. If the carbon sink remains stable during the FCP, the carbon uptake in the formations with ARD activities will be 3.43 Mg ha^{-1}. Multiplying this value for the total ARD surface we obtain a sink of 461.11 Mg C.

Forest expansion is an important issue in the Italian Alpine area. The methodology used in this study to assess land use change is consistent with the *Good Practice Guidance* rules established by the International Panel on Climate Change, and it meets the Reporting Method 1 criteria by providing the associated error for the land use change assessment (IPCC 2003). Concerning the carbon sink estimation, further studies are needed to better investigate the potential of the new forest formations and the levels of uncertainty.

TABLE 3 Aboveground biomass (Mg ha^{-1}) and carbon sink of the sample points for trees with Dbh > 3 cm.

Sample point	1990 Biomass	2006 Biomass	C sink	Annual C sink
	Mg ha^{-1}	Mg ha^{-1}	Mg C ha^{-1}	Mg C ha^{-1} yr^{-1}
5831	4.53	41.17	18.32	1.15
7416	0.69	18.90	9.10	0.57
2005	0.27	3.31	1.52	0.10
747	17.51	51.56	17.03	1.06
3991	1.03	18.63	8.80	0.55
3660	1.17	23.42	11.13	0.70
Average	**4.20**	**26.17**	**10.98**	**0.69**

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