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Title: Matsucoccus bast scale in Pinus pinaster forests: a comparison of two systems by means of emergy analysis

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Abstract: The bast scale (Matsucoccus feytaudi) is responsible for the destruction of most of the Pinus pinaster forests in the Mediterranean area, causing resination, defoliation and subsequent death of the trees. This study was carried out in Cinque Terre National Park (Italy), in which pinewood are partially affected by the bast scale Matsucoccus feytaudi. A whole system evaluation is here proposed aiming at the assessment of the impacts, both on the environmental and economic side, arising from the P. pinaster losses in a certain territory. To this aim we compared a pinewood without visible damages from bast scale with a clearly damaged pinewood by means of emergy analysis. Bast scale reduced the arboreal composition of the stand favouring understorey species sprouting, which benefitted of increasing sunlight level caused by affected tree crowns reduction or trees fall. As a consequence of the changed forest's condition the system suffered an ecosystem services provision loss equal to 2,250 Em€ ha-1 year-1 that, if extended to the entire surface of the Cinque Terre National Park lead to a total loss of a million of Euro per year

Dear editor,
Please find the revised version of the manuscript from Turcato et al. now entitled: Matsucoccus bast scale in Pinus pinaster forests: a comparison of two systems by means of emergy analysis.

All the comments from the two reviewers have been taken into account and the paper was changed accordingly.
A detailed list of revision is appended below following the order of comments provided by reviewers.

Reviewer #1:

1. A more appropriate title for the paper could be "Comparison of systems affected .... Because the word "Whole" is very extensive in meaning and an analysis of sustainability or social management could be expected.

   The title was modified and the manuscript is now entitled: Matsucoccus bast scale in Pinus pinaster forests: a comparison of two systems by means of emergy analysis

2. The abstract is good but other results from the environmental point of view, could be included.

   Environmental results were added to abstract such as: "Bast scale reduced the arboreal composition of the stand favouring understorey species sprouting, which benefitted of increasing sunlight level caused by affected tree crowns reduction or trees fall"

3. This clearly defined and responds to the development of the work, however a change the word "pinewood" by "pine forest" is suggested. The study is relative to the insect invasion on biodiversity of forest and not on the forest product: pinewood.

   The term pinewood was changed with pine forest as suggested

4. The techniques and methods have been suitably chosen for this study. However, the methods for the determination of CO_2, N and P (nutrient consumption) should be included. It is not clear if they are co-product of forest biomass fertilization or human-induced. If an induced fertilization would be necessary to reevaluate the emergy analysis and other resources such as labor should be analyzed.

   Nutrient fluxes were considered as external sources needed for the primary production of the forest and thus accounted for the emergy analysis. We better described the procedure in material and methods as for example "Input items to pinewood stands are solar energy, wind, geopotential and chemical energy of rain, geothermal heat, runoff, transpiration and nutrient consumption (here considered as CO_2, N and P uptake required from environment to generate pinewood primary production)."

5. Table 4 shows the resources that were counted by the method of Odum. In this table were accounted the geothermal rain, chemical rain, rainoff but they are co-products of the same system and accounting should be duplicated.

   Table 4 has been modified and arranged to be clearer about the fluxes that were considered co-products during the calculation procedure.

6. Also is required to clarify on that table 4, if UEV were corrected by the factor 1.68, those appearing before the year 2000.

   A statement is now reported in the manuscript “In this evaluation we used the 9.26E+24 seJ baseline (Campbell, 2000) and emergy and transformity values based on different baselines were accordingly modified.” To clarify the homogeneity of the employed transformities.

7. Please, be careful with the International Units System. (sej) should be replaced by (seJ) page 15. Do not use symbols, for example (~) replaced by "approximately".

   Paper was checked and corrected accordingly

8. The data provided by Constance (1997) about the global value of services yearly provided by terrestrial ecosystems should be reviewed because new data from 2000 are reported in the literature.

   We found in recent literature a few other studies reporting economic values of global ecosystem services (e.g. de Groot et al., 2012) but data there reported are not matching or comparable with those reported in Costanza et al., 1997 (for example data were reported per unit area and not at global scale). As a consequence an update of Costanza’s data would imply assumption and bias not acceptable in this context.

9. On the Figure 3, the "transformity" should appear in the acsisa Y of the graphic

   Figure was modified

10. With regard to the economic evaluation conducted, Euro is used, though it would be advisable to do a comparison in dollars, for the comparison of the damage.

    Values in dollars are now reported

11. Conclusions should be more accurate and a new review is recomended because there are elements in the text that corresponding with the results and discussion item.

    Conclusions were re-arranged moving some parts in the discussion section (e.g. former lines 7-30 page 21) and making conclusion more direct and concise.

12. An update of the references is suggested.

    Reference list has been reviewed and updated adding a number of recent studies with particular attention to studies regarding the evaluation of ecosystem services from forests.

Reviewer #2:

13. to quote references more recent regarding the benefits forests provide for human wellbeing;

    Reference list has been reviewed and updated adding a number of recent studies with particular attention to studies regarding the evaluation of ecosystem services from forests. See for example the beginning of introduction section.

14. to correct all the scientific numbers in the text and in the tables (for instance 1114,9 has to be changed in 1,114.9)

    Manuscript was changed in accord with reviewer’s suggestion

15. to recognize the limits related to the use of emergy

    Limitations and related references were reported in the final part of material and methods

Matsucoccus bast scale in *Pinus pinaster* forests: a comparison of two systems by means of emergy analysis

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Abstract

The bast scale (*Matsucoccus feytaudi*) is responsible for the destruction of most of the *Pinus pinaster* forests in the Mediterranean area, causing resination, defoliation and subsequent death of the trees. This study was carried out in Cinque Terre National Park (Italy), in which pinewood are partially affected by the bast scale *Matsucoccus feytaudi*. A whole system evaluation is here proposed aiming at the assessment of the impacts, both on the environmental and economic side, arising from the *P. pinaster* losses in a certain territory. To this aim we compared a pinewood without visible damages from bast scale with a clearly damaged pinewood by means of emergy analysis. Bast scale reduced the arboreal composition of the stand favouring understorey species sprouting, which benefitted of increasing sunlight level caused by affected tree crowns reduction or trees fall. As a consequence of the changed forest's condition the system suffered an ecosystem services provision loss equal to 2,250 Em€ ha^{-1} $year^{-1}$ that, if extended to the entire surface of the Cinque Terre National Park lead to a total loss of a million of Euro per year

Keywords: Ecosystem services; maritime pine; *Matsucoccus feytaudi;* Cinque terre; ecological succession; complexity.

1. Introduction

Forests provide a wide array of benefits for human wellbeing, first of all wood forest products such as timber, usually the only accounted and monetized by economy but often just a small part of total value (Croitoru, 2007; Merlo and Croitoru, 2005). Forests, in fact, supply also a wide set of non-wood forest products as well as other services and externalities, probably least recognized but perhaps more important, such as watershed protection, landscape quality, soil and biodiversity conservation and recreation (Calder, 2007; Campbell and Tilley, in press; Deal and White, 2012; Deal et al., 2012; Lara et al., 2009; Leighty et al., 2006; Lucke, 2008; Merlo and Croitoru, 2005; Ninan and Inoue, 2013; Núñez et al., 2006; Patterson and Coelho, 2009; Townsend et al., 2012; Sedell et al., 2000; Wang and Fu, 2013; Vandekerkhove et al, 2009).

Forest's pests have considerable impact on the value and functionality of forest ecosystems, both directly (e.g. timber losses) and indirectly, as they may compromise the ability of the stand to provide services (Gatto et al., 2009).

In this context, direct economic impacts, linked to wood yield losses and increases of production costs (Kenis and Branco, 2010) are those most often described, also because they can be easily expressed in monetary values (Pimentel et al. 2002a, 2002b). On the contrary, monetary values are not so easily quantifiable for indirect costs related, for example, to changes in land use and landscape structure, public health concerns, biodiversity loss etc. (Born et al., 2005; Kenis and Branco, 2010). That is, a comprehensive economic evaluation should include the assessment of whole ecosystem goods and services value. Ecosystem goods and services (EGS) are the benefits humans receive from natural environments that are essential for our wellbeing. Adequately valuing EGS can help decision-makers better manage natural environments so they can continue providing valuable services (De Groot et al., 2012; Fisher et al., 2009; Farber et al., 2002; MA, 2005)

Current economic EGS-valuation methods consist of "internalizing externalities" by devising approaches to value non-market-traded goods and services. Odum and Odum (2000) suggest that we need to "externalize the internalities" by using solar energy as the basis for valuing goods and services provided by natural and human environments. Emergy analysis is a technique of quantitative analysis able to account direct and indirect solar energy used to maintain a system

(Odum, 1996). Also referred to as "embodied energy" or "energy memory", emergy could potentially fill a significant gap in adequately valuing EGS and better managing natural environments (Odum and Odum, 2000; Paoli et al., 2013; Vassallo et al., 2013).

By means of emergy analysis application, it is possible standardizing the values of monied and non-monied resources, services and commodities in a sole common unit (Brown and Herendeen, 1996).

Emergy units can be converted, in turn, into currency equivalent values: this conversion provides a mean for materializing the value of nature to policy-makers, who mainly base their decisions on monetary measurements. The undervaluation of ecosystems contributions to human welfare in public and business decision-making can be partly explained by the fact that they are not adequately quantified in terms comparable with economic services and manufactured capital (Costanza et al., 1997). Non-marketed ecosystem services are viewed as positive externalities that, if valued in monetary terms, can be more explicitly incorporated in economic decision-making.

In fact the design, implementation and management of policies that incorporate services provided by ecosystems are dependent on the availability of explicit information about ecosystem services (Cowling et al., 2008). These policy decisions need to be based on reliable estimates of current and expected trends in ecosystem service supply and their economic values (Vassallo et al., 2009a).

Information about the delivery of ecosystem services, joined with that related to the demand for them provides a baseline to measure losses and gains to be inserted in policy impact assessment and to address the development of financial instruments to finance investments in ecosystems (Maes et al., 2012; TEEB; 2010).

Here we apply emergy to a case study: mixed pinewood with maritime pines (*Pinus pinaster* Ait.) prevalent species located in Cinque Terre National Park (Italy). Maritime pine is a conifer from the western Mediterranean basin with a distribution exceeding 4 million hectares under broad ranges of elevation, climate and soil (Alía *et al.*, 1996) . Traditionally, *P.pinaster* in Italy has been used for resin and wood production, but actually pine forests have no economic importance.

Currently *P. pinaster* stands are affected by a phytosanitary problem caused by the bast scale *Matsucoccus feytaudi* Duc. (Hemiptera: Coccoidea: Margarodidae). The bast scale is a specific pest of maritime pine, widespread in the western Mediterranean basin. While in the Iberian Peninsula and south-western France, the insect is endemic and its impact on the host tree is negligible, in south-eastern France, Corsica and Italy the pest has already destroyed thousands of hectares of maritimse pine forest (Jactel et al., 1998; Riom, 1994). Forest pests have considerable impact on the value and functionality of forest ecosystems, both directly (e.g. timber losses) and indirectly, as they may compromise the ability of the stand to provide ecosystem services (Gatto et al., 2009). Compromising pine stands ecosystem services means risking a very important and protected Mediterranean habitat suitable for preventing soil erosion and reforesting highly degraded areas (Le Maitre, 1998), as well as managing watershed and storing carbon.

As a consequence, a direct economic evaluation of the *P. pinaster* is likely to strongly underestimate its value in the broader context of the EGS carried out by this system. A whole system evaluation is here proposed aiming at the assessment of the impacts, both on the economic and environmental side, arising from the *P. pinaster* losses in a certain territory.

To this aim we compared a pine forest without visible damages from bast scale with a clearly damaged pine forest by means of emergy analysis (Odum, 1996) examining the total amount of resources exploited in the two systems, and the ability to transform these resources in ecological service. Finally, moving from these results, a monetary assessment of the pine forest was proposed also considering the loss of value due to the bast scale.

2. Material and methods

2.1 Study area

The study area is in the eastern part of Liguria region (northwest Italy) inside Cinque Terre National Park (44°03”N, 9°37”E), an high hydrogeological risk zone (Cevasco et al., 2013).

Here, pinewoods belong to the protected habitat (EU Habitat Directive 92/43, Annex I) named “Mediterranean pine forests with endemic Mesogean pines” (cod. 9540). The pinewoods considered have a total extension of 764.5 hectares and an elevation range from 200 m to 600 m above sea level by G.I.S. analysis and surveys on the field.

The bast scale is responsible of pine disease within the study area (Binazzi, 2005). We counted trees that had visible resin on the stem and trees with a low crown density following the method, developed by ICP Forests (Fischer, 2010), in order to describe the damage level of the trees. In the Cinque Terre National Park bast scale infection is already detected at 2 levels of damaging, even if several areas in the national park are not still showing pest negative effects (approximately 279 ha are recorded as non affected, while 485 ha are showing negative effect due to bast scale invasion).

Taking into account this heterogeneity, two plots were identified as representative and analyzed. The first does not show negative effects caused by the pest and is considered non-affected by bast scale (P1-NA) while the second reveals pine trees strongly affected by bast scale (P2-A). Main characteristics of the plots are reported in Table 1.

Table 1 should be placed here

2.2. Field sampling

Using remote sensing (Landsat cartography) and field surveys (GPS technology) we randomly selected 2 geographic coordinates, used as centroids of two rectangular plots of 500 m^2 (20 x 25 m).

On these plots two sampling campaigns were performed during spring-summer 2011 and 2012 aiming at surveying trees and shrubs (in understorey vegetation) and at calculating the trees above and below ground biomasses and shrubs aboveground biomass and the relative annual biomass increase within each plot. At this purpose, all *P. pinaster* trees and all shrubs (six different species) were measured in each plot.

Biomass annual increment, for trees and understorey vegetation, was calculated as difference between biomass measured in 2011 and biomass measured in 2012.

2.3. Biomass estimation

Annual Net Primary Production (NPP) is the net amount of carbon captured by plants through photosynthesis each year (Melillo *et al.,* 1993). NPP is the sum of all materials that together are equivalent to the amount of new organic matter that is retained by live plants at the end of the time interval, and the amount of organic matter that was both produced and lost by the plants during the same interval (Clark et al., 2001).

To estimate biomass and carbon stock, generalized biomass equations may be advantageous over volume equations that need highly uncertain conversion and expansion factors (Vallet et al., 2006).

2.3.1.**Biomass from trees**

Total *Pinus pinaster* aboveground biomass (buds, cones, needle, branch wood, stem, stemwood, stembark) was estimated using the following allometric equation (Shaiek et al., 2011) based upon the diameter at breast height and tree age.

$W=aD^{b}\, age^{c}$

W is the biomass of the tree (Kg)
a, b and c are model parameters to fit by non-linear regression
D in diameter at breast height measured during sampling campaigns
Age is tree age estimated through core samples using increment borers.

According to MacDicken (1997), the ratio of belowground to aboveground biomass was considered equal to 0.2.
Mean annual litter production in a Mediterranean *Pinus pinaster* forest (leaves, bark, branches, flowers, fruits) was estimated by Santa Regina (2001) in 1,728 Kg ha^{-1}.
Also standing dead trees were measured, but obviously their increment was registered like zero.

2.3.2. Biomass from understorey vegetation

Understorey vegetation biomass was reckoned by the count of individuals of the most representative and frequent species within the plots. Volume and cover of each species was assessed. In case of some arboreous plant like *Quercus ilex* we measured stem diameter at breast height because we found precise allometric equations based on this data

Understorey vegetation in the plots is composed by following species: *Quercus ilex*, *Arbutus unedo*, *Ulex europaeus* subsp. *europaeus*, *Pteridium aquilinum* subsp. *aquilinum*, *Erica arborea*, *Cistus salviifolius.*
For each species, we applied allometric equations to estimate aboveground biomass in the plots as reported in Table 2.

Table 2 should be placed here

2.5. Soil erosion

The methodology chosen for the quantitative rill-interill erosion assessment is the Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1997; Wischmeier and Smith, 1978). RUSLE has been applied worldwide and is the most common methodology for the assessment of rill-interrill erosion processes also called sheet erosion processes. It has been extensively used to estimate soil erosion loss and to guide development and conservation plans in order to control erosion under different land-cover conditions (Mati and Veihe, 2001; Angima et al., 2003). RUSLE is considered a simple model, incorporating data that is easily available and/or accessible and delivers reliable results (Morgan, 1986). The RUSLE simulates rill and interrill soil erosion taking into account the effects of soil, topography, and land use. The model has the following expression:

A = R K L S C P

where A is the mean soil loss per year [Mg ha^{-1} y^{-1}]; R is the rainfall–runoff erosivity factor [MJ mm ha^{-1} h^{-1} y^{-1}]; K is soil-erodibility factor [Mg h MJ^{-1} mm^{-1}]; L is the slope–length factor and S is the slope–steepness factor (dimensionless); C is the cover-management factor (dimensionless); and P is the support-practice factor (dimensionless).

The methodology adopted included a bibliographical survey and basic data collection (including pluviometric, soil, landuse/cover and topographical data) in order to assess and adjust physical parameters included in the selected model.

R-Factor

The rainfall R-factor is a measure of the erosive force of a specific rainfall. It is generally determined as a function of the volume, intensity and duration of a rainfall and can be estimated from a series of storms to include cumulative erosivity from any time period (Prasannakumar et al., 2003).

Daily rainfall dataset of 6 years (2006–2012) were collected from Regional Agency for Ligurian Environmental Protection and were used for calculating R-factor. Specifically, the R-factor was calculated using daily and monthly data from a rain-gauge stations located in the study area. For the calculation of the R-factor we use the formula proposed by Angeli et al. (2004):

R = 4.17 * ∑ (p2 /P) – 152

where p is the monthly rain and P is the annual rain.

LS-Factor

This topographic factor is related to the slope length (L) and steepness factor (S) and is considered a crucial factor quantifying the transport capacity or in other words the effect of the topography on erosion due to surface runoff (Alexakis et al., 2013). To obtain the topographic factor a Digital Elevation Model of the area is required. The topographic parameters were delineated from a DEM based on contour lines of a 1:5,000 scale topographical map (Carta Tecnica Regionale). According to the equation derived from Moore and Wilson (1992), we calculated LS-Factor with Saga GIS:

$$LS = (As/22.13)n\ (\sin\beta/0.0896)m$$

where As is upslope area/unit contour width, β is slope steepness; $n = 0.4$ and $m = 1.3$.

K-Factor

The soil erodibility factor (K) refers to the average long-term soil and soil profile response to the erosive power of rainfall and runoff. It is considered as the rate of soil loss per unit of rainfall for a specific soil (Hadjimitsis et al., 2013). In this study we derive the K-factor data based on the soil samples. Laboratory analyses were conducted in compliance according to MiPAF (2000) in the regional chemical laboratory (Laboratorio Regionale Analisi Terreni e Produzioni Vegetali, Sarzana). The K-factor was finally calculated for the toposoil, using the Wischmeier and Smith (1978) formula:

$$K = [2.1*10-4(12-OM) * M1.14+ 3.25(s-2) + 2.5 * (p-3)] / 100*0.137$$

Where OM is the percentage of organic matter of the surface horizon calculated equal to 4 in cases where this value is exceeded, M is given by the equation number 5, s is the soil structure class and p is the soil permeability class.

$$OM= (\% sand + \% silt) * (100 - \% clay)$$

C-Factor

According to Prasannakumar et al. (2003) the C-factor represents the effect of plants, crop sequence and productivity level, soil cover and subsurface bio-mass on soil erosion. Natural vegetation plays a predominant role in reducing water erosion (Kheir et al., 2008) since it generally reduces the runoff speed and enhances infiltration processes. The C-factor values were derived by phytosociological field surveys according to Rusco et al. (2007).

P-Factor

The Support Practice factor (P) is defined as the ratio of soil loss after a specific support practice to the soil loss after traditional up and down ploughing cultivation (Wischmeier and Smith, 1978). The P-factor values range between 0 and 1, where 1 is given for the area where no anti-erosive practice is present and 0 for the areas where we have full anti erosion measures (Renard et al., 1997).

2.6. Ecosystem function evaluation – Emergy analysis

The general methods for employing emergy synthesis were given fully by Odum (1996, 2000). Since the emergy value of a flow is the sum of all emergy required directly and indirectly to create it, emergy values for all input items must first be determined (emergy input analysis) and then allocated to internal system pathways and exported items (emergy allocation) (Tilley and Swank, 2003). Odum (1996) suggested drawing an energy systems diagram that depicts the environmental basis of the ecosystem and its connection to the larger economy. This diagram is the basis for the application of emergy input analysis

It proceeds by calculating the solar emergy of each environmental and human-controlled (e.g. fuels, human service) input item by inventorying either its exergy (i.e. available energy), mass or money value and transforming it to solar emergy by means of appropriate unit emergy values (UEV). Unit emergy values are also reckoned as transformities (seJ/J) or specific emergy values, seJ/g, or emergy per unit money value).

Unit emergy values are calculated on the basis of the total annual emergy inflow to the biosphere from the sun, moon, and deep-earth heat sources that make up the whole annual emergy budget called baseline. The baseline emergy is the reference system for every process, good or service being the basis of everything physically happening in the biosphere (Brown and Ulgiati, 2010; Vassallo et al., 2009b). In recent years a number of modifications to the baseline have been introduced (Campbell, 2000; Odum et al., 2000). In this evaluation we used the 9.26E+24 seJ baseline (Campbell, 2000) and emergy and transformity values based on different baselines were accordingly modified.

Input items to pinewood stands are solar energy, wind, geopotential and chemical energy of rain, geothermal heat, runoff, transpiration and nutrient consumption (here considered as CO_2, N and P uptake required from environment to generate pinewood primary production).

Nonetheless total solar empower (total emergy flow per year) of pinewood does not correspond to the sum of all input items, since the general emergy rule is to use the larger source of co-dependent sources (Odum, 1996). Sunlight, wind, rain and runoff, which are co-products of the same phenomenon, the solar radiation heating the biosphere, cannot then be considered as independent inputs (Bastianoni et al., 2001). As a consequence total emergy ascribed to each plot is the sum of the greatest between these co-products, geothermal heat, evapotranspiration, CO_2, N and P.

When total empower of each plot is calculated, an emergy share can be ascribed to every internal processes occurring in pinewoods and to each product or service maintained by the pinewood. Identified forest services are: *P. pinaster* aboveground biomass increase, roots biomass increase, litterfall generation, understorey vegetation biomass increase and soil retention.

The solar emergy amount ascribed to each service was determined through the emergy allocation procedures. Allocation adhered to the emergy algebra rules that were sketched in Brown and Herendeen, (1996) and Odum (1996). In particular two main different process types can be identified:

- Co-products processes have the total emergy assigned to each by-product pathway, each process is a different kind and owns a different transformity.
- Split processes originates when a pathway divides into two branches of the same types and, the emergy is assigned to each 'leg' of the split based on the fraction of total energy on each leg.

Since processes on the pinewood forest provide product which differ from a physical and a functional point of view they were all considered co-products and thus the solar transformity of service was calculated as the total solar emergy divided by its energy content.

Transformity might be considered as a measure of efficiency: a lower transformity of a product reflects the ability to use less past and present work of the biosphere (emergy) to produce a unit of product (Vassallo et al., 2007; 2009a).

Finally, when an emergy share is ascribed to an internal product or an export, the latter step consists in the calculation of the corresponding monetary value.

Emergy is usually translated to money value, expressed in emergy-euros (i.e. em€), by dividing emergy flow by the average emergy-to-money ratio of an economic system. The emergy-to-money ratio is found by dividing total emergy use of an economic system by its gross domestic product. The average solar emergy-to-euro ratio of European Union equals to 1.71E+12 seJ $€^{-1}$ in 2010 (Pulselli et al., 2011).

Nonetheless, Pulselli et al. (2011) stated that emergy flow and ecosystem service values can be independent from each other just because ecosystem works independently of the economic fruition of it made by humans. Therefore, a direct quantitative relation between the two does not seem appropriate (Sagoff, 2011; Hau and Bakshi, 2004).

However, an indirect use of the relation between emergy and ecosystem service evaluation is possible by putting into relation the two entities. Campbell (2000) proposed a global emergy budget, required to maintain the entire biosphere, equal to 9.26E+24 $seJ \cdot y^{-1}$. Costanza et al. (1997) found that the global value of services yearly provided by terrestrial ecosystems ranges between 1.82 and 6.15E+13 $€ \cdot y^{-1}$. De Groot et al. (2012) provided updated values for global services ranging from Dividing the world ecosystem service value by the emergy flow to the biosphere, we obtain the amount of money that is, in average, produced by one seJ of solar emergy that can be considered as an estimate of the ability of the biosphere in providing a kind of economic wealth for humans.

This ratio has been named Environmental Emergy Money Ratio (EnEMR hereinafter). In fact if Emergy Money Ratio, in its classical definition links emergy to economy, the EnEMR is able to establish a link between environment and economy through emergy. EnEMR has a value between 5.09 E+11 $seJ \cdot €^{-1}$ and 1.51 E+11 $seJ \cdot €^{-1}$ depending on the minimum and maximum values calculated by Costanza et al. (1997): we precautionary employed the highest value.

The monetary value of a natural good or services can be calculated by dividing its emergy content by EnEMR.

3. Results and discussion

3.1. Biomass evaluation

Both trees and shrubs biomass were evaluated and results are reported in Table 3.

In P1-NA (not showing negative effects caused by bast scale) 22 trees (17 alive and 5 dead) were measured while in P2-A (revealing pine trees strongly affected by bast scale) 24 trees (16 alive and 8 dead) were measured .

Table 3 should be placed here

In P1-NA shrubs identified and measured were: *Quercus ilex* L. (young plants – max 2.5 meters), *Arbutus unedo* L., *Ulex europaeus* L. subsp. *europaeus*, *Pteridium aquilinum* (L.) Kuhn subsp. *Aquilinum; in P2-A Erica arborea* L., *Pteridium aquilinum* (L.) Kuhn subsp. *aquilinum, Arbutus unedo* L., *Cistus salviifolius* L. and *Quercus ilex (*young plant – max 2,5 meters).

Total biomass resulted 1.4 times higher in P1-NA than P2-A. This is mainly driven by *P.pinaster* biomass that was 1.45 times higher in P1-NA, despite fewer trees were counted. In P2-A, in fact, fewer and smaller trees were present and the biomass distribution showed a continuous decrease in number of trees at increasing size (Figure 1). On the contrary, P1-NA displayed a continuous distribution of trees with biomasses ranging from 0 to 300 kg.

Figure 1 should be placed here

Considering understorey vegetation, P2-A is able to maintain higher biomass and diversity due to the decreasing tree coverage and the following increased solar radiation allowed to reach lower wood's levels. As a matter of fact, the bast scale causes a regression in the ecological succession of the wood compromising the most complex structures (mature trees) and favoring smaller and more pioneer organisms such as shrubs. As a matter of fact, without the bast scale action, P1-NA stand is living a mature stage of vegetation evolution, characterized by a higher complexity shown by a well structured system. In fact P1-NA, covering a wider array of size ranges in tree layer composition, supports more biomass, as the system has reached a stable equilibrium. P1- NA pines are in good condition and the stand casts more shadow at ground level; the biggest understorey biomass contribution is given by species whose growth, mainly at seedling time, benefits by less exposed conditions, assuring lower stress linked to summer drought or direct sun light (*Arbutus unedo*, *Quercus ilex*). Anyway understorey species number is higher in P2-A, because of the presence of a wider and abundant component of pioneer species typical of Mediterranean maquis.

3.2. Soil erosion

The application of the RUSLE methodology allowed the quantification of the rill-interill erosion in the two plots. Results revealed that soil is loss at higher rate in P1-NA (1.25E+05 g y^{-1}) than in P2-A (3.33E+04 g y^{-1}). This is due to the different soil and environment characteristics that make P1-NA more subject to erosion than P2-A. This is also in accord with the general theory revealing that as shrub vegetation is increasing, protection of soil resources is also increasing and soil erosion is decreasing (Wischmeier, 1960; Elwell and Stocking, 1976; Morgan, 1986; Francis and Thornes, 1990; Alias et al., 1997).

Moreover, it is well known that different strata of the vegetation behave differently in terms of soil conservation (Zhang et al., 2005). For example grass and the litter layer were found to be more important than the canopy layers (Zhang et al., 2006). As a matter of fact, soil conservation not only depends on vegetation cover increases but also, and perhaps more importantly, on the development of a complex stratified structure (Wang et al., 2001; Wu and Zhao, 2001), especially the near ground layers (Wang et al., 2001).

Aiming at the assessment of the soil retention ability of the two plots, an estimation of the soil formation rate was needed. In Mediterranean environments, the rate of formation of soils is usually slow and the profiles are thin and poorly developed (Conacher and Conacher, 1998; Poesen and Hooke, 1997). In accord with García-Ruiz et al. (2013) we estimated a rate of soil formation equal to 1 t ha^{-1} yr^{-1}.

The balance between soil formation rate and soil loss rate revealed P2-A able to retain 1.67E+04 g y^{-1} of soil while P1-NA did not show soil accumulation but displayed an erosion rate of 1.25E+05 g y^{-1}.

3.3. Emergy of pinewood

Figure 2 is an energy systems diagram of the Cinque Terre National Park pine stands that shows the external sources, the internal processes and the provided services. The indigenous, environmental energies (solar radiation, kinetic energy of wind, precipitation and geothermal heat) interacted with the wood and understorey biomass to maintain internal cycles such as biomass increase, litter generation, water and soil cycles.

Figure 2 should be placed here

The energy flows identified in the energy system diagram are also listed in Table 4 and converted in emergy terms by means of appropriate unit emergy values. Total solar empower resulted equal to 2.75E+14 seJ y^{-1} in P1-NA and 2.18E+14 seJ y^{-1} in P2-A. Healthier woods require higher emergy fluxes (empower) to maintain more structures (both in number and complexity) in accord with the maximum empower principle (Odum, 1975; Odum, 1995), confirming the hypothesis of a shift backward in the ecological succession of the wood towards a more simple structure due to the bast scale invasion. The largest individual source of solar emergy to P1-NA was the phosphorous uptake, counting up to 7.33E+13 seJ y^{-1}, followed by chemical potential of rain (6.25E+13 seJ y^{-1}) and runoff (6.00E+13 seJ y^{-1}). P2-A total emergy was mainly driven by runoff (6.66E+13 seJ y^{-1}), followed by chemical potential of rain (6.25E+13 seJ y^{-1}) and phosphorous uptake (4.76E+13 seJ y^{-1}).

Table 4 should be placed here

3.4. Provided services

Table 5 lists the solar emergy values of the supplied services of the Cinque Terre National Park pinewood stands. Differently from the emergy input analysis in Table 4, where the solar emergy of forcing functions was the product of solar transformity and available energy, the solar emergy of a service or an export was determined by allocating incoming solar emergy to it according to emergy algebra rules.

Table 5 should be placed here

In this case *P. pinaster* aboveground biomass increase, roots biomass increase, litterfall generation, understorey vegetation biomass increase and soil retention were considered co-products and thus they resulted with the same solar emergy but different transformities (Table 5).

The highest solar transformity was displayed by soil retention service. Soil is an extremely expensive resource and requires a huge amount of emergy to be produced and maintained in the system. Comparing the two plots, P1-NA is un-able to maintain soil and thus the service is not provided while is more efficient (lower transformity to yield the same quantity of service) at releasing tree biomass (both above and belowground). In fact, even though P1-NA requires more emergy to be maintained (Table 4), a unit *P. pinaster* biomass increase (both aboveground biomass and root biomass) required 2.2 times emergy in P2-A than in P1-NA identifying *P. pinaster* stands affected by Matsucoccus poorly able to increase tree biomass. On the contrary P2-A displays higher efficiency at generating litterfall (1.25 times more efficient) and increasing understorey vegetation biomass (3.5 times more efficient) due to the higher biomass, number and species of shrubs detected (Figure 3).

Figure 3 should be placed here

These figures are the consequences of the changed structure of the stand after the Matsucoccus has affected *P. pinaster* trees. In intensively infested trees, resin droplets are found on the trunk (visible all year) and reddish needles occur on the lowest shoots; sap sucking by larvae induces intense resin exudation and weakening of the tree, resulting in growth decrease. Finally, intensively infested and weakened trees are more prone to attacks by bark beetles and pine weevils, which usually kill them. The reduced growth rate results in a poor efficiency at supplying annual biomass increase as a service. On the other hand, the reduced tree coverage due to the bast scale allows the lower levels of the forest for more solar radiation and thus increases the diversity and growth rate of understorey vegetation that, in fact, reveals greater efficiency in P2-A. Together with the increased understorey vegetation, an increased ability to retain soil was detected identifying affected stand as more able to supply this services in respect to the healthy and mature forest.

3.5. Economic valuation

Several authors attempted to calculate the value of market and non-market services provided by forests. In Mediterranean region Croitoru (2007) identified average values ranging from 57 to 204 € ha^{-1} $year^{-1}$ depending on the macro-region considered. Italian forest resulted among the highest rated summing up to 294 € ha^{-1} (Merlo and Croitoru, 2005).

Bernetti et al. (2013) evaluated the total economic value of Mediterranean pine forest in Tuscany and assessed an average value of 471 € ha^{-1} $year^{-1}$. Moreover, they calculated the median value of protected and non-protected forests which summed up to 2,899 € ha^{-1} $year^{-1}$ and 405 € ha^{-1} $year^{-1}$ respectively.

Costanza et al. (1997) adopting different methodologies quantified the value of global ecosystem services provided by forests up to approximately 1,000 € ha^{-1} $year^{-1}$.

All these studies estimated forests' value basing on users' perception of the supplied services. User perception is intrinsically affected by the comprehension of the system, by preferences and by the contingencies of the market (Bingham et al., 1995). Nonetheless, even if an ecosystem service is not perceived by humans or scarcely evaluated by market, it makes a contribution towards or even is essential for the existence of an ecosystem and preparatory to the provisioning of other services crucial for mankind survival (Vassallo et al., 2013). As a consequence, the value of an ecosystem service has to be assessed as the amount of resources invested by nature to maintain the ecosystem services themselves, independently from the presence of direct users and from the value they ascribe to a service (Pulselli et al., 2011). Emergy analysis allows obtaining this evaluation adopting a donor side perspective and ascribing the cost of directly and indirectly exploited resources as value of a service.

The application of emergy analysis brought to the identification of five different services provided by *P. pinaster* forest. The services are all co-products of the pinewood system maintained by all the inputs listed in Table 4 and thus they assume the same emergy of the whole forest. As a consequence P1-NA services are worth 10,800 Em€ ha^{-1} year^{-1} while P2-A services summed up to 8,550 Em€ ha^{-1} year^{-1}. The bast scale invasion provokes ecosystem services provision loss equal to 2,250 Em€ ha^{-1} year^{-1}. This difference might be interpreted as the loss of value due to the shift backward on the succession of a pinewood after bast scale invasion and it is the final consequence of the reduction in complexity of the system.

If this loss is projected to the entire extension of the Cinque Terre National Park pinewood forests, considering that 485 ha are reported as affected by bast scale invasion, a total loss of 1E+06 Em€ year^{-1} has to be accounted each year considering today's forest condition. In addition, bast scale is expected to cause more and more damage (Riom, 1994) to the pinewood forests in the next years and the ecosystem services loss will follow the trend.

This amount can be considered a reference in order to make further evaluations. First this estimate can be employed to raise awareness about the value and importance of ecosystem services. Lack of awareness and of accurate information may lead to warped evaluations of the value of a natural resource resulting in poor or badly directed management. Furthermore, calculated value could be employed by institutions to develop actions addressed to *P. pinaster* protection such as boosting of scientific research, mitigation procedures or restoration interventions. In the specific case, phytosanitary measures against introduction and spread of invasive plant pests must be justified by a science-based pest risk analysis, including an assessment of potential economic consequences (Soliman et al., 2012) taking also in consideration the value of ecosystem services provided (and in case lost).

4. Conclusion

Forests provide a wide array of services for human wellbeing: beside wood products it supplies a set of non-wood forest products, often non monetized. Forest pests strongly affect forests' functionality compromising the ability to provide these services. In particular, in Western Europe, the *Matsucoccus feytaudi* Duc. affects the maritime pine *Pinus pinaster* exposing a crucial and protected Mediterranean habitat to severe risks.

In order to ascribe an ecological and economic value to the real and potential damages generated by bast scale infection we analyzed a study case located in the Cinque Terre National Park (Ligurian region - NW Italy). First some base parameter (biomass estimation from trees and understorey vegetation and soil erosion) has been calculated for both an affected (P2-A) and a non-affected (P1- NA) pine stand. Later, we applied emergy analysis, a method able to evaluate the overall requirement of resources for both stands. This allowed the estimate of (1) total resources exploited to maintain the structure and functioning of the two ecosystems expressed in a unique unit of measure (solar emergy Joules); (2) the allocation of these resources to the five main ecosystem services reckoned for both stands that are: *P. pinaster* aboveground biomass increase, roots biomass increase, litterfall generation, understorey vegetation biomass increase and soil retention. Results showed that total biomass is greater in P1-NA stand, while soil balance revealed the ability to retain soil in the P2-A stand and a net erosion rate in P1-NA stand. The amount of resources required is greater in P1-NA system and the highest solar transformity was displayed by soil retention service, even if this is present only in P2-A. This study revealed that bast scale caused a regression in P2-A stand, reducing the arboreal composition and favouring understorey species sprouting, which benefitted of increasing sunlight level caused by affected tree crowns reduction or trees fall. As a consequence, thanks to understorey well developed and resistant root system, P2-A system has a good capacity to increase root biomass as well as to retain soil, while P1-NA seems less able to contribute to these ecosystem services.

As final assessment, emergy values were converted in money values in order to get an economic estimate of generated ecosystem services and the loss due to bast scale invasion. The bast scale invasion provokes an ecosystem services provision loss equal to 2,250 Em€ ha^{-1} $year^{-1}$ (equal to 2891 US$ ha^{-1} $year^{-1}$) that, if extended to the entire surface of Cinque Terre National Park, leads to a total loss of a million of Euro per year (approximately 1.28E+06 US$). This amount should be taken into account by managers when planning the governance of the territory and its resources and should be extended to each ecosystem in the area in order to reach an effective protection of natural resources.

At present, no means have been found to effectively fight the bast scale. If the pathogen would spread in Cinque Terre National Park not affected pine stands it will lead to the loss of a mature system which supports a big amount of biomass damaging an important habitat for biodiversity and human welfare. On the other side, affected systems show a better attitude in preserving slopes stability, thanks to an higher diversity of understory plants, which can also grow faster than trees. Considering that Cinque Terre National Park is a land affected by high hydrogeological instability a monitoring programme should be implemented to promptly register bast scale attack effects. At the beginning of attack, a selective cutting of affected trees could be suggested. The cuttings would reduce future coarse woody debris at ground level and increase sunlight radiation to the ground, allowing the rooting of more pioneer plants able to reduce soil instability during the bast scale infection. This kind of "guided regression" in vegetation dynamic would lead to soil erosion prevention. This management approach would drive the ecosystem to an intermediate stadium between low maquis and Mediterranean wood, maintaining high level of biomass and allowing to reduce ecosystem services loss as well as of the corresponding economic value.

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Appendix

Solar radiation = Area x solar radiation intensity		
Area	500	m^2
Solar radiation intensity	4.48E+05	$J\ m^{-2}\ year^{-1}$
Area	500	m^2
wind speed	5.52E+07	$m\ year^{-1}$
drag coefficient	0.003	
air density	1.3	$Kg\ m^{-3}$
3a Chemical = area x rain x water density x water Gibbs energy		
Area	500	m^2

	rain	1.47		m year^{-1}
	water density	1.00E+06		g m^{-3}
	Water Gibbs energy	4.74		J g^{-1}
	3b Geopotential = area x rain x water density x (mean elevation- min elevation) x g			
	Area	500		m^2
	rain	1.47		m year^{-1}
	water density	1.00E+06		g m^{-3}
	mean elevation	432	558	m
	min elevation	430	557	m
	g	9.8		m s^{-2}
4	**Runoff = area x runoff x (mean elevation- min elevation) x water density x g**			
	Area	500		m^2
	runoff	0.3	0.5	m year^{-1}
	mean elevation	432	558	m
	min elevation	430	557	m
	water density	1.00E+06		g m^{-3}
	g	9.8		m s^{-2}
5	**Geothermal heat = area x heat flow**			
	Area	500		m^2
	heat flow	2370		J year^{-1}
6	**Transpiration = area x transpiration x water density x water Gibbs energy**			
	Area	500		m^2
	transpiration	1.47		m year^{-1}
	water density	1.00E+06		g m^{-3}
	Water Gibbs energy	4.74		J g^{-1}
7	**CO_2 = carbon fixed + associated oxygen**			
	carbon fixed	9.54E+04	6.20E+04	g year^{-1}
	associated oxygen	2.86E+05	1.86E+05	g year^{-1}
8	**N = carbon fixed * redfield ratio**			

	carbon fixed	9.54E+04	6.20E+04	g $year^{-1}$
	redfield ratio	41 : 7 : 1		
9	**P = carbon fixed * redfield ratio**			
	carbon fixed	9.54E+04	6.20E+04	g $year^{-1}$
	redfield ratio	41 : 7 : 1		

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Figures captions

Figure 1: *P. pinaster* biomass distribution

Figure 2. Emergy system diagram of a *P. pinaster* wood

Figure 3: Transformities of internal processes in P1-NA and P2-A

Figure1
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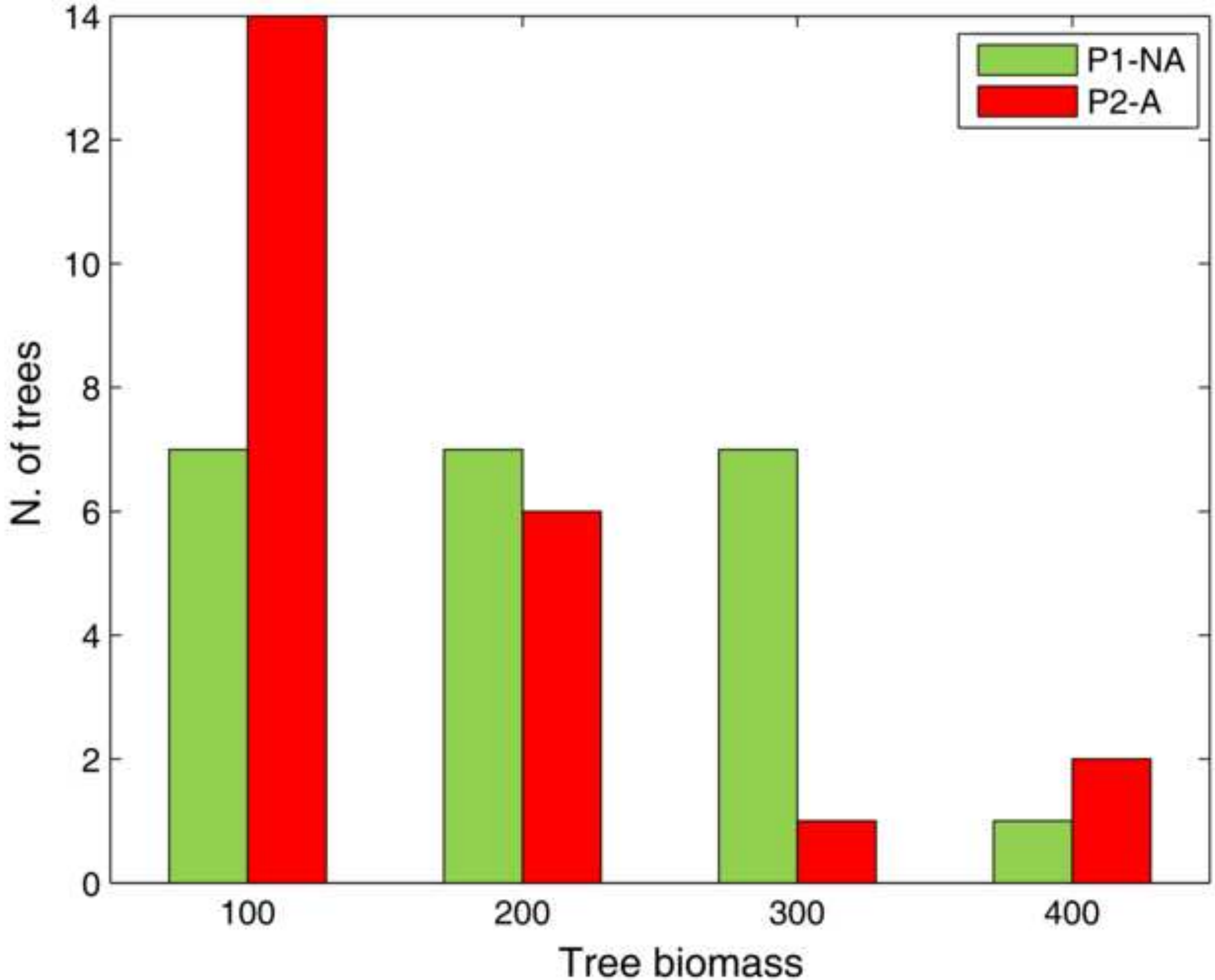

Figure2
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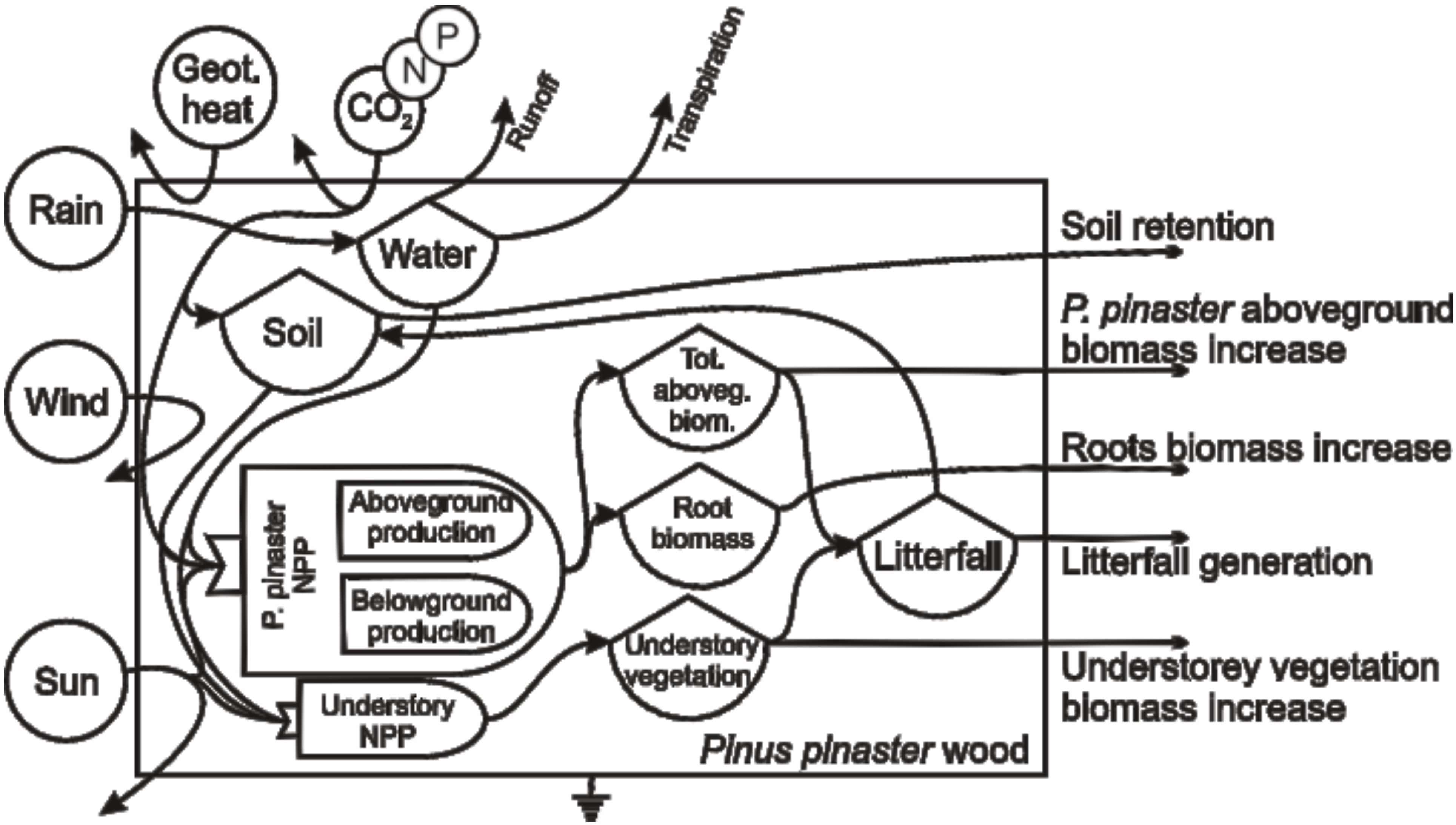

Figure3
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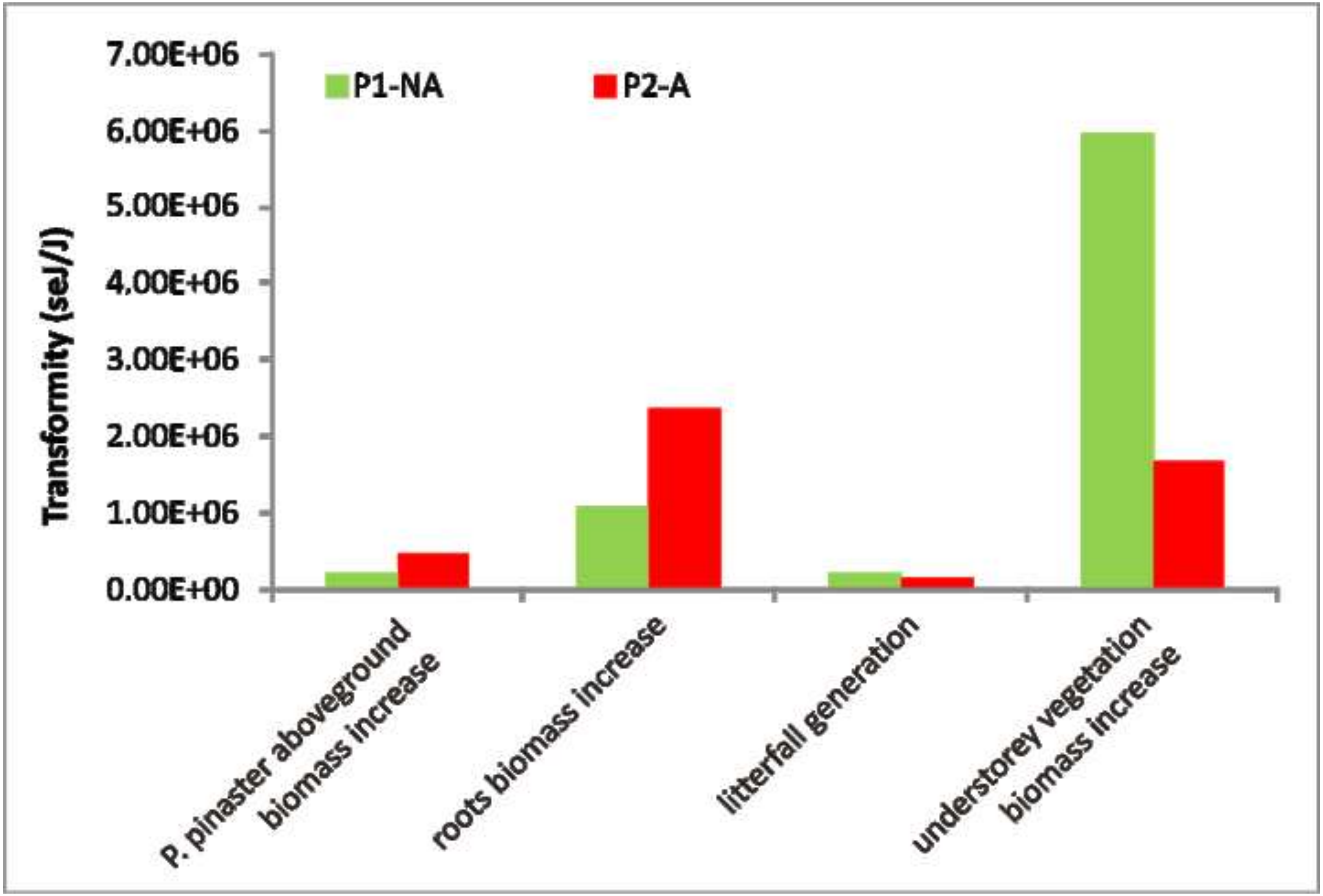

Table

Table 1: Main characteristics of the two plots selected for the analysis

	P1-NA	**P2-A**
Coordinates	44°08’51’’N, 9°41’33’’E	44°09’14’’N, 9°40’17’’E
Surface (m^2)	500	
Max altitude (m)	433	559
Min altitude (m)	430	557
Annual rainfall (mm)	1,474	
Slope	58%	36%
Soil (WRB classification, FAO 2006)	Regosols (Humic Dystric)	Hyperskeletic Regosol (Dystric)

Table 2. Allometric equations considered in understorey vegetation biomass estimation

Species	Allometric equation	Author
Arbutus unedo	Y= $1114{,}9 * x^{0{,}725}$	Blanco Oyonarte and Navarro Cerrillo, 2003
Cistus salviifolius	Y=$966{,}674 * x_1^{1.257}$	Castro *et al.,* 1996
Erica arborea	Y = $1090{,}8 * x^{0{,}812}$	Blanco Oyonarte and Navarro Cerrillo, 2003
Pteridium aquilinum subsp. *aquilinum*	$Vol_{\text{speciesgroup}} = \sum_{\text{species}} \frac{Cover_{\text{species}}}{100} 10\,000\, Height_{\text{species}}$ DM(t/ha)= $a_1 * Vol^2 + a_2 * Vol$	Porté et al., 2009
Quercus ilex	Stem biomass= $0{,}143 \cdot d^2$ Medium branches biomass = $0{,}0898 \cdot d^2$ Thin branches + leaves biomass= $0{,}0824 \cdot d^2$ Roots biomass = $0{,}254 \cdot d^2$	Ruiz-Peinado et al., 2012
Ulex europaeus subsp. *europaeus*	$Y = 8.324\, X_2 - 387.523$	Puentes and Basanta, 2002

Y:aboveground biomass (g); x: volume (m^3), x_1: cover (m^2), a_1: parameter 4,511E-09; a_2: parameter 3,897E-05 x_2:plant diameter (cm), d: diameter at breast height (cm).

Table 3. *P. pinaster* and shrubs biomass in P1-NA and 2

Species		**Total aboveground biomass (kg)**	**Total aboveground biomass (kg)**
		P1-NA (500 m^2)	**P2-A (500 m^2)**
Pinus pinaster	Living	3,798.83	2,704.07
	Dead	523.38	281.81
	Total *P. pinaster*	**4,322.21**	**2,985.89**
shrubs	*Arbutus unedo*	7.98	3.93
	Cistus salviifolius	1.94	20.05
	Erica arborea	-	20.46
	Pteridium aquilinum	-	1.59
	Quercus ilex	62.12	40.87
	Ulex europaeus subsp.	3.81	-
	Total understorey	**75.85**	**86.90**
Total biomass		**4,398.06**	**3,072.79**

Table 4. Emergy table of P1-NA and P2-A. Annual flows are referred to the plot extension equal to $500m^2$. Employed equations are reported in appendix.

	P1-NA					
		Annual flow	Unit	UEV	Ref.	Empower
1	Solar radiation	2.24E+08	J	1	Odum, 1996	2.24E+08
2	Wind energy	3.30E+08	J	1.43E+03	Odum et al., 2000	4.71E+11
3	Rain					
	3a Chemical	3.49E+09	J	1.79E+04	Odum et al., 2000	6.25E+13
	3b Geopotential	3.25E+09	J	1.03E+04	Odum et al., 2000	3.35E+13
4	Runoff	2.21E+09	J	2.72E+04	Lu et al., 2011	6.00E+13
5	Geothermal heat	1.18E+06	J	3.37E+04	Odum, 1996	3.99E+10
6	Transpiration	1.32E+09	J	2.81E+04	Odum, 1996	3.72E+13
7	CO2	3.81E+05	g	1.47E+08	Campbell et al., 2014	5.61E+13
8	N	1.63E+04	g	2.82E+09	Campbell et al., 2014	4.59E+13
9	P	2.33E+03	g	3.15E+10	Campbell et al., 2014	7.33E+13
	TOTAL (max among item 1,2,3,4 + items from 5 to 9)					**2.75E+14**
	P2-A					
		Annual flow	Unit	UEV	Ref.	Empower
1	Solar radiation	2.24E+08	J	1	Odum, 1996	2.24E+08
2	Wind energy	3.30E+08	J	1.43E+03	Odum et al., 2000	4.71E+11
3	Rain					
	3a Chemical	3.49E+09	J	1.79E+04	Odum et al., 2000	6.25E+13
	3b Geopotential	2.02E+12	J	1.03E+04	Odum et al., 2000	3.72E+13
4	Runoff	3.68E+09	J	2.72E+04	Lu et al., 2011	6.66E+13
5	Geothermal heat	1.18E+06	J	3.37E+04	Odum, 1996	3.99E+10
6	Transpiration	1.32E+09	J	2.81E+04	Odum, 1996	3.72E+13
7	CO2	2.48E+05	g	1.47E+08	Campbell et al., 2014	3.64E+13
8	N	1.06E+04	g	2.82E+09	Campbell et al., 2014	2.98E+13
9	P	1.51E+03	g	3.15E+10	Campbell et al., 2014	4.76E+13
	TOTAL (max among item 1,2,3,4 + items from 5 to 9)					**2.18E+14**

Table 5: Emergy table of internal process in P1-NA and P2-A

P1-NA				
		Annual flow	**Unit**	**Transformity (seJ/J)**
1	*P. pinaster* aboveground biomass increase	1.27E+09	J	2.16E+05
2	roots biomass increase	2.55E+08	J	1.08E+06
3	litterfall generation	1.27E+09	J	2.17E+05
4	understorey vegetation biomass increase	4.62E+07	J	5.95E+06
5	soil retention	no service provided		
P2-A				
		Annual flow	**Unit**	**Transformity (seJ/J)**
1	*P. pinaster* aboveground biomass increase	4.59E+08	J	4.75E+05
2	roots biomass increase	9.17E+07	J	2.37E+06
3	litterfall generation	1.27E+09	J	1.72E+05
4	understorey vegetation biomass increase	1.30E+08	J	1.68E+06
5	soil retention	9.36E+06	J	2.33E+07