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# Assessing the effect of alternative land uses in the provision of water resources: evidence and policy implications from southern Europe

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## Abstract

Ecosystem goods and services have been brought to the forefront of policy making all over the world. It is acknowledged that these goods and services underpin human well-being. The provision of water resources is among those services that have raised more attention, given its unquestionable value and global threats like climatic change. Nevertheless, the biophysical basis that determines the land-use/water interactions has been often ignored. For the formulation of sound decisions, it is necessary to extend the empirical basis that determines these complex relations. With this aim, the present paper analyzes the effect of alternative types of land cover in the provision of water resources. In doing so, we compare hydrological, meteorological and land-cover data obtained in 15 watersheds located in the Basque Country (Northern Spain). Moreover we discuss the implications of including water resources in land-use policy and planning and address areas for further research.

**Key words:** Water resources, land-use changes, ecosystem goods and services, climate change, biodiversity, payments for ecosystem services

*Highlights

- It is found a positive correlation between 'water productivity' and the land covered by pasturelands.
- A negative correlation can be observed between 'water productivity' and land area covered by exotic tree plantations.
- The positive effect of pasturelands in the provision of water is higher than the corresponding negative effect derived from increases in the area covered by exotic tree plantations.
- If policy makers aim to shift the current land use pattern, the provision of water resources could also encompass an argument for supporting traditional farming activities that maintain extensive pastureland and rangelands, while increasing water productivity

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**Abstract**

Ecosystem goods and services have been brought to the forefront of policy making all over the world. It is acknowledged that these goods and services underpin human well-being. The provision of water resources is among those services that have raised more attention, given its unquestionable value and global threats like climatic change. Nevertheless, the biophysical basis that determines the land-use/water interactions has been often ignored. For the formulation of sound decisions, it is necessary to extend the empirical basis that determines these complex relations. With this aim, the present paper analyzes the effect of alternative types of land cover in the provision of water resources. In doing so, we compare hydrological, meteorological and land-cover data obtained in 15 watersheds located in the Basque Country (Northern Spain). Moreover we discuss the implications of including water resources in land-use policy and planning and address areas for further research.

**Key words:** Water resources, land-use changes, ecosystem goods and services, climate change, biodiversity, payments for ecosystem services

## 1. Introduction

Since the concept of ecosystem services was popularized by Daily in the mid-1990s (Daily, 1997), it has increasingly attracted the attention of resource managers and policymakers all over the world (Costanza et al., 1997; De Groot et al., 2002; Ekins et al., 2003). Nowadays, it is acknowledged that ecosystem services underpin human well-being and economic development, although these are not always considered in the accounts of society (MEA, 2005a; TEEB, 2009). The provision of water resources is among those services that have raised more attention given its value for the society (Sivanappan, 1984; Andréassian, 2004; Carter et al., 2005; MEA, 2005b; Núñez et al., 2006; Calder, 2007; Ngigi et al., 2007; FAO, 2008; Lara et al., 2009; Weatherhead and Howden, 2009; Priess et al., 2011). It is recognized that the restoration or appropriate conservation of ecological 'infrastructures' can significantly contribute to the provision of fresh water supply in a cost-effective way, in the light of global phenomena like climatic change or the increasing water demand of ´modern´ societies. To give an idea, a survey in 2003 of the world's 105 largest cities, carried out for the World Wide Fund for Nature (WWF) and the World Bank, found that one-third of the population draw a substantial amount of their drinking water from protected forest catchments (Dudley and Stolton, 2003).

Precipitation is usually accepted as the major driver in the large-scale variability in monthly, seasonal and annual flows (Ward and Trimble, 2004). Nevertheless, from the policymaking perspective it is interesting to assess other sources of variability, like the effect of land-use changes on water availability, which have arguably similar consequences and are subject to human intervention (Latron and Gallart, 1995; Llorens et al., 1995; Gallart et al., 2005; Little et al., 2009). These causes have often been ignored or given little attention in policy making; however, for the formulation of sound decisions that would take into account the full range of ecosystem services, it is necessary to improve and systematically use science-based indicators that explain these biophysical relations between changes in land use and the provision of water resources.

The recognition of such interrelationship between forest and other land-use changes in the hydrological cycle is widely acknowledged (Bosch and Hewlett, 1982; Calder, 1992; Calder et al., 1997; Iroumé and Huber, 2002; Ward and Trimble, 2004; Brown et al., 2005; Farley et al., 2005; Calder, 2007; Huber et al., 2008; Lara et al., 2009; Little et al., 2009), but despite advances in recent years the interpretation of this relationship is still controversial. Results vary among geographical latitudes and can be influenced by several factors (e.g., changes in the seasonal flow, the bio-geographic characteristic of the watersheds, soil types or spatial scale). Hence, further empirical studies are required to bring the issue of water to the forefront of land-use policy and to settle a robust basis for decision making.

With this aim, the present study analyzes the effect of alternative land-use types (e.g., pasturelands, native forest and exotic plantations) in the provision of water resources in the Basque Country (Northern Spain). This is done on an annual and a seasonal basis, by comparing hydrological, meteorological and land-cover data obtained during the period 2004:1−2006:12 in 15 watersheds. This study area contains a wide range of vegetation types within a small geographical area, all of which have similar climatic, geological and topographic characteristics that provide an appropriate framework to test empirically the effect of alternative land uses in the provisioning of water resources. The rest of the article is organized as follows: Section 2 introduces the study area; Section 3 presents the data and methods used for the analysis; Section 4 contains the results of the study; Section 5 discusses these results and Section 6 concludes with the main policy implications that can be derived from the present case study.

## 2. Study area

The study area (43º 1'34'' to 43º 17'51'' N, 1º 54'56'' to 2º 38'11''' W) comprised 15 watersheds in the province of Gipuzkoa (Basque Country) following a longitudinal pattern from south to north. The latitude of the Basque territory and its geographical situation in the Bay of Biscay favor a high annual rainfall (1,500 mm), a mild temperature (annual mean is 13ºC) and seasonal distribution of rainfall. Consequently, the regime of the rivers is torrential, with high water in winter and low water in the summer months. The western basins are dominated by basic rocks – limestone, marl and basalt – while in the eastern basins, siliceous materials – granite, Paleozoic shale, sandstones and Triassic conglomerates – predominate.

(Insert Figure 1)

The formation of the soil is conditioned by steep topography of the slopes and high rainfall, always above 1,200 mm/year, resulting in poorly developed hillside soils that occupy over 90% of the surface of the basins. Steep slopes and the torrential regime of rivers are reflected in the hydrographs of the 15 watersheds with immediate responses to precipitation. Besides, in an annual scale the relationship between precipitation and runoff is almost homogeneous in all the area.

Hardwood forests are the potential vegetation of the area and, depending on the altitude, are separated into two main types: oak (*Quercus robur*), and beech (*Fagus sylvatica*) that is situated in higher elevations. The use of these lands for agriculture and livestock, at the expense of the original forest, dates back several thousand years, to the extent that potential oak forest occupies only 15% of its original territory. The meadows and crops that occupied the area until 50 years ago have been reduced to 23%, while tree plantations with exotic species (e.g., *Pinus radiate)*, which began during the second half of the twentieth century, now cover 48% of the potential oak forests. On the mountainside, the intensity of use was lower so beech forests and exotic plantations divide the territory, 39% and 37% respectively, while the mountain pastures are spread over the remaining 24%.

(Insert Figure 2)

A historical analysis of aerial photographs of the Basque region, see Figure 2, shows the conversion of pastureland and rangelands to fast-growing exotic plantations due to the abandonment of traditional cattle and sheep farming practices (characterized by a family structure dependent on small farming units, an aged workforce and a lack of generational replacement in such a context), and the government's promotion of afforestation policies in the middle of the last century (Ruiz Urrestarazu, 1999).

These changes of use have substantially altered the landscape of the basins and the practices of the forest plantations (clear felling, deep ploughing, construction of forest roads and burning of land), producing high rates of soil loss, loss of retention capacity and inability to cope with heavy rains (Edeso et al., 1997). Note that erosion rates from natural forests are likely to be amongst the lowest of any land use but this is not necessarily the case for plantation forest (Calder, 2007). For instance, the specific yield of suspended sediment exportation in Gipuzkoa province is between 90 and 150 t/km$^2$ per year which is attributed to the abundance of plantation forests.

## 3. Data and methods

In order to compare the relationship between water provision and alternative land uses, it is used data corresponding to precipitation, specific stream discharge per km$^2$ and land cover (percentage of area covered by vegetation type) for the 15 watersheds mentioned above.

In these watersheds, the presence of artificial surface is rather small (<7%) and there is a wide variety of land uses including herbaceous vegetation (meadows and pasturelands), native forest (oak and beech) and exotic plantations (large *Pinus radiata* plantations). This diverse picture provides the basis for analyzing empirically the effects of alternative land uses, in terms of different vegetation types, in the provision of water resources. The following paragraphs explain in more detail the spatial, meteorological and hydrological data used in the analysis and the method of analysis.

### 3.1. Land-use data: monitoring system

In 2005, the Basque Government created a detailed land-use map using a scale of 1:10,000 following the EUNIS classification (a detailed hierarchical system that provides a comprehensive typology for the habitats of Europe).[1] This was created by a digitalisation of all the polygons of vegetation using the orthophotos of the region. Then, to validate the information derived from this digitalization, exhaustive field work was carried out in each polygon.

In the present study, using Geographic Information Systems, the land-use types classified according to EUNIS have been reclassified into four main classes (artificial surface, natural forest, plantations and pasturelands). Then, the areas corresponding to each class in each of the watersheds were estimated using Social Research ESRI's ArcGIS 9.3. Table 1 includes a summary of alternative land uses and their sizes in each watershed.

(Insert Table 1)

The total area of the watersheds included in this study range from 2.77 hectares of Arriaran to the 796.5 hectares of Lasarte, whereas the cover of pasturelands, native forest and exotic plantations falls in the range of 11.37–71.05%, 15.78–46.25% and 9.27–59.79%, respectively. The descriptive statistics of those variables included in the regression analysis are represented in Table 2. As mentioned above, artificial zones are always below 7%. In some watersheds (e.g., Aitzu, Matxinbenta or Arriaran) there is a predominance of exotic tree plantations, which in some cases double the surface cover of native forest and triple that of pasturelands. In other cases (e.g., Alegia, Berastegi, and Lasarte), the presence of native forest and exotic tree plantations is similar. The native forest predominates in the case of Oiartzun and Urkulu, and the pasturelands predominate in the case of Berastegi, reaching almost 40% of the total surface cover.

(Insert Table 2)

[1] The EUNIS habitat classification is a comprehensive pan-European system to facilitate the harmonized description and collection of data across Europe through the use of criteria for habitat identification. It covers all types of habitat from natural to artificial, from terrestrial to freshwater and marine. For further information see http://eunis.eea.europa.eu/about.jsp

### 3.2. Discharge, precipitation and statistical analysis

Daily meteorological and hydrological data corresponding to precipitation and discharge for each watershed were provided by the regional authority (Diputación Foral de Gipuzkoa). In fact, in this territory there is an important network of gauging stations where several variables (meteorology, discharge and water quality-related parameters) are registered every 10 minutes. In the present study it has been considered daily data of precipitation and discharge for the complete period (2004:1–2006:12) in 15 watersheds of the province of Gipuzkoa (Table 1).

In order to detect anomalous values, this data was exhaustively verified. Short gaps in the data (<2.5 %) were filled by performing a linear interpolation. Once the data corresponding to precipitation and discharge were compiled, the analysis of the impact of the land cover on water provision is carried out as follows.

The specific monthly discharge ($\sum stream\ flow\ (m^3) / watershed\ area\ (ha)$) recorded in each watershed was divided by the precipitation ($m^3$) accumulated in the same area (ha) during the same period. The average values for this coefficient were obtained in seasonal and annual terms in the 15 watersheds for the period (2004:01–2006:12). Then, through simple, multiple and principal component regression methods, these average rates were regressed to those variables that represent the land-use cover corresponding to each watershed. That is, the multiple regression model analyzed is defined as

$$S_i = \beta_1 + \beta_2 Pasturelands_i + \beta_3 NativeForest_i + \beta_4 ExoticPlantations_i + \varepsilon_i, \quad i = 1,2,..., N \qquad (1)$$

where *S* is the specific discharge/precipitation ratio, the explanatory variables are different land-cover types defined above, $\varepsilon$ is the error term and *N* is the number of analyzed watersheds (in our case, *N=15*). The simple regression models estimated use the same dependent variable *S* but include only one of the three explanatory variables included in (1).

Finally, the principal component regression (PCR) is a standard estimation procedure applied when multicollinearity is found, and is described in, for example, Jolliffe (1986).

## 4. Results

This section presents the results obtained by means of several regression models using cross-sectional data of 15 watersheds described above. Basic descriptive statistics of these variables are presented in Table 2. As a first step, the results of simple regressions of *S* (as an indicator of water productivity) against the percentages of pasturelands, native forest and exotic plantations using sample means of the four seasons for the period 2004–2006 are presented in Figure 3. This figure shows scatter plots of the three pairs of variables analyzed and the estimated sample linear regression lines obtained by ordinary least squares (OLS). More details of each OLS estimation can be found below its corresponding scatter plots, namely estimated coefficients of the regression lines, *t*-statistics (in parenthesis) and determination coefficients.

(Insert Figure 3)

Figure 3 offers the first insight into the data analyzed. It clearly shows a positive correlation between *S* ('water productivity') and percentage of pasturelands. As can be seen from Figure 3, the maximum value of *S* is 79.45, which corresponds to the Amundarain watershed with over 70% of acidophilous pasturelands. The left hand side scatter plot in Figure 3 of S and percentage of pasturelands indicates clear positive correlation between these two variables. On the other hand, there is clearly a negative correlation between *S* and percentage of exotic plantations. The minimum values of *S* are 46.20 and 47.79 corresponding to the San Prudentzio and Matxinbenta watersheds respectively, where the plantations of *P. radiata* clearly prevail. Finally, the simple regression between *S* and native forest reveals no significant linear relationship.

Next step is the estimation of the multiple regression defined in (1) using cross-sectional data of 15 watersheds described above. Table 3 presents the OLS estimation of equation (1). These results are not satisfactory as none of the three explanatory variables is individually significant at any conventional significance level. Nevertheless, the three explanatory variables are jointly significant at 5% level as indicated by the F statistic and the determination coefficient is reasonably high in spite of the low number of observations.

(Insert Table 3)

The OLS estimation presented in Table 3 suffers from a high level of multicollinearity indicated by high values of variance inflation factors (VIFs) presented in the last column of Table 2 for the three explanatory variables. According to Myers (1990), values higher than 10 indicate serious multicollinearity. The same conclusion can be drawn by the apparent contradiction of relatively high value of determination coefficient (0.621) and high *p-values* of all explanatory variables.

In spite of the problem of multicollinearity, the OLS coefficient estimations in Table 3 have minimum variance in the class of linear and unbiased estimators if all the other basic assumptions are met, which seems to be the case. However, because of this multicollinearity, the variances of the estimated coefficients are very high, leading to imprecise estimations and difficult interpretation. That is why the PCR estimation procedure was applied. PCR considers subspaces spanned by subsets of the principal components of the matrix of explanatory variables from the original regression. The main idea is to use only a subset of components and exclude those with low predictive influence on the explained variable. There are several possible strategies to choose this subset described in the literature, e.g., Brown (1993) or Joliffe (1986). This analysis follows the so-called inferential approach, using only the set of principal components whose regression coefficients are significantly different from zero, which can be tested using the following statistics:

$$Q_i = \frac{N-p}{1} \times \frac{\hat{\gamma}_i^2 \, \lambda_i^2}{RSS_{RCP}} \sim F_{1,N-p} \, ,$$

where *p* is the number of estimated parameters in the PCR, $\hat{\gamma}_i$ are the PCR coefficients themselves, $\lambda_i$ are eigenvalues of a matrix formed by the explanatory variables of the original regression and $RSS_{RCP}$ is the residual sum of squares of the PCR. If this statistic is greater than the corresponding critical value of the Snedecor's F distribution, the corresponding coefficient is significant and is included in the subset of coefficients designated to retrieve the revised original parameters. The estimation of the model defined in Eq. (1) by PCR is presented in Table 4. Note that, as the principal components analysis of the matrix of explanatory variables is based on standardized variables, no standard error for the constant can be retrieved.

(Insert Table 4)

The interpretation of the estimated PCR coefficients is similar to the interpretation of the simple regressions presented by Figure 3 and is generally in line with the OLS estimations presented in Figure 3. The effect of *Pasturelands* is positive, confirming that an increase in this type of land cover raises the productivity of water measured as a specific discharge/precipitation ratio. On the contrary, there is a negative relationship between this ratio and the percentage of native forests and exotic plantations. This negative impact on water productivity is greater in the case of exotic plantations than in the case of native forest (in absolute values).[2] This shows that the effect of *Native forest* on water productivity is indeed negative but its effect is lower (in absolute value) than the effect of *Exotic plantations*. Therefore an increase of exotic plantations decreases water productivity more than an increase in native forest.

(Insert Figure 4)

(Insert Figure 5)

(Insert Figure 6)

[2] The negative effect of *Exotic plantations* on water productivity is greater than the negative effect of *Native forest* (in absolute values) at 20% significance level (*t*-statististic = 0.954), which is acceptable level given the low value of degrees of freedom. The positive impact of *Pasturelands* on the water productivity is greater than the negative effect of *Exotic plantations* (in absolute value), in this case at the conventional 5% significance level (*t*-statististic = 3.501).

(Insert Figure 7)

To complete the analysis presented above, Figures 4–7 present results of the model (1) estimated by PCR approach, but this time using data of seasonal rather than annual means. The parameter estimates of the four multiple regressions have the same signs as the parameters obtained by annual means. The scatter plots presented in Figures 4-7 show high stability in the positive effect of pasturelands, a negative effect of exotic plantations and a changing pattern for the native forest.

An important drawback of this analysis is that all the regression analyses above are carried out with a low number of observations and therefore their results should be interpreted with caution. Nevertheless, these results are supported by those obtained in other case studies (e.g. Oyarzún and Huber, 1999; Huber et al,. 2008; Little et al., 2009). Moreover, the main conclusions coming from the different models presented above coincide, and this supports the validity of the main results.

## 5. Discussion

From this analysis it can be observed a positive correlation between water productivity, defined as *S*, and the land covered by pasturelands. This relationship can be observed in annual and seasonal terms; that is, either when it is compared the percentage of land covered by pasturelands with the mean annual value of *S*, or when it is compared that percentage with the seasonal mean values of *S*. On the other hand, from the same analysis a negative correlation can be observed between *S* and the land area covered by exotic tree plantations. In short, an increase in the surface area covered by pasturelands implies an increase in *S*, while an increase in the surface area covered by exotic tree plantations (i.e., *P. radiata*) implies a decrease in *S*. Moreover, given that the unit for measuring pastureland and tree plantations is the same (percentage of surface occupied by each type of vegetation), the effect reflected by their corresponding coefficients can be compared. According to these coefficients, the positive effect of pasturelands in the provision of water is higher than the corresponding negative effect derived from increases in the area covered by exotic tree plantations. In annual terms, the effect of land covered by pasturelands over the provision of water resources is 50% higher than the exotic plantations (see Table 4).

These results are in line with the high evapotranspiration demands of *P. radiata and Eucalyptus spp.* addressed by several authors (Otero et al. 1994; Calder et al., 1997; Scott and Lesch, 1997; Farley et al., 2005; Jackson et al., 2005). Studies of the water balance of young plantations of *P. radiata* in southern-central Chile also reveal an increased depletion of the soil moisture reserves with stand ageing, as well as an increase in the canopy interception and evapotranspiration (Oyarzun and Huber, 1999; Huber et al., 2008). Furthermore, conversion to fast-growing tree plantations in this study area has led to a decrease in water quality due to increased sediment loads associated with clear cuts in plantations managed under sort-rotation periods (Lara et al., 2003, 2006; Oyarzun and Peña, 1995 in Lara et al., 2009).

Regarding native forests, it is worth to note that in the study area there are few cases in which the native forests appear in homogeneous formations (mainly beech forests), in most cases these are composed of secondary forests that grow spontaneously after the abandonment or cutting of coniferous forest. These formations have emerged recently due to abandonment of intensive forest exploitations and are dominated by pioneer species (ash, birch, cherries, etc.) These are very dynamic in their evolution towards more old-growth forests. Therefore, taking into account the insights of similar studies regarding more homogeneous native forests (Lara *et al*., 2009) and the results presented above, it is reasonable to think that in the long run, a potential conversion of fast-growing exotic tree plantations to native forest would be followed by an increase in the annual flows from catchments. Note that, in contrast to fast-growing plantation species, older and slower-growing native forests are likely to exhibit lesser reductions in flow (Calder, 2007). For further research, it would be also desirable to expand the study area to other Basque regions (Navarra and Araba) where the presence of homogeneous old native forest (beech and different oak forests) is significantly higher. Unfortunately, at the time this study was carried out, hydrological and land-cover data for these regions were not available or were not reliable enough.

## 6. Implications for policy

Regarding the policy implications that can be derived from the present case study,  it is worth noting that in contrast to other ecosystem goods and services (e.g., biodiversity or landscape beauty), water resources have a market price (although usually far below its real value). This particular feature should not be neglected, as it facilitates the inclusion of water resources in the social accounts and therefore public policy. Not surprisingly, water resources are at the heart of the emerging field of payments for environmental goods and services all over the world (Perrot-Maître and Davis, 2001; Johnson, 2002; Pires, 2004; Pattanayak, 2004; Corbera et al., 2007; Biao et al., 2010). Nonetheless, the success of such payment schemes is not free from criticism and, due to the complex institutional, economic and bio-physical interaction within the socio-ecological systems in which they are implemented, the achievement of the expected results is not always clear (Landell-Mills and Porras, 2001; Wunder, 2001; Hope et al., 2005). For further discussion regarding potential and limitations of payments for ecosystem services (PES), see also Goldman and Tallis (2009), Muradian et al. (2010; Norgard (2010), Kosoy and Corbera (2010); Pascual *et al*. (2010); Van Hecken and Bastiaensen (2010). Therefore, together with socio-economic and institutional analyses, empirical studies like the one presented here should encompass a prerequisite to assist policy makers and planners in making evidence-based decision before and during the implementation of this type of payments for ecosystem services.

In the Basque region if conversion of pastureland and rangelands to fast-growing exotic plantations persists in the future, then according to the results obtained in this case study, a decline in water availability due to these changes in land use is predicted. Moreover, this situation can be aggravated by climate change events. Note that, according to the IPCC's (2007) predictions, southern Europe would be seriously affected by climate change, in which the incidence of droughts is expected to rise significantly.

In contrast, if policy makers aim to shift the current land use pattern, the provision of water resources could also encompass an argument for supporting traditional farming activities that maintain extensive pastureland and rangelands, while increasing water productivity. Moreover, in the light of drastic reductions in timber prices,[3] the provision of water resources – together with other goods and services attached to these agro-ecosystems (e.g., soil protection, conservation of biodiversity or landscape quality) – may encompass an attractive alternative to current fast-growing *P. radiata* or *E. globulus* plantations, which, besides inducing significant decline in the available water, affecting soil protection and reducing the presence of biodiversity, are subsidised by the regional authority.

For all these reasons, it is considered that the provision of water, as a strategic resource for meeting the demand of our societies, should be brought to the forefront of any decision related to land-use planning; even more so in heavily industrialized and populated areas, like the Basque region, with high water demand. The inclusion of this resource in the societal accounts can shift current land-use policies. Predictions for the future are not, in general, encouraging with regard to the precipitation regime, so adaptive policy mechanisms would be required to overcome the potential difficulties of this new scenario. Moreover, land-use policies that take into account the provision of water resources can have other positive side effects, and foster the provision of other environmental goods and services such as biodiversity conservation. Other human activities, like traditional farming systems, would be also reinforced considering the impact of land use in the provision of water resources, and may encompass an economically attractive alternative to declining benefits derived from timber production. Thus, land-use policies that take into account the full spectrum of environmental goods and services may play a key role in the definition of effective land use policies. Identifying trade-off among such ecosystem benefits and other human interest would encompass a key challenge and further empirical evidence like that presented in this article would be required to shift land-use policy

[3] According to the biannual report of the Confederation of Foresters in the Basque Country, P. radiata prices for thick saw timber have fallen 30% since January to just under 32€ per m3 (Euskadi Forestal, 2009). The publication (and reports from the Basque Country) attribute this fall in prices primarily to Hurricane Klaus, which destroyed more than 40 million m3 of timber in the Landes region in nearby France in January 2009. However, this report also states that the real price of wood in 2007 – before Hurricane Klaus or the economic crisis – had already fallen to less than half the level in 2001.

to a more holistic perspective. The provision of other environmental goods and services – such as carbon sequestration (Canadell and Raupach, 2008; Lal, 2008; Miles and Kapos, 2008), biodiversity (Matthews et al., 2002; Caparrós and Jacquemont, 2003; Jandl et al., 2007; Caparrós et al., 2010) or soil protection (Jackson *et al*., 2005) – also varies significantly among ecosystems and land-use types, and the success of land-use policies could be dependent upon how alternative land uses interact with the water environment.[4] Recent efforts like the one encouraged by the UN, under the MEA (2005a,b) or the TEEB initiative (2009), shed some light in this direction but small- and large-scale experiments, such as paired watershed studies under adaptive management frameworks (Holling, 1978; Walters, 1986; Lee, 1993; Gunderson, 1999), would be also helpful to sustain this initiative with evidence-based scientific input. The comparison of paired watersheds, although costly, encompasses a unique opportunity to better understand the complex interactions between water use and land use in different timescales and provides a promising arena for future research.

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[4] Recent examples of integrated appraisals that consider the impact of alternative lan-uses over multiple ecosystem services simultaneously can be found in García-Quijano *et al*. (2007), Nelson *et al*. (2009) and Chisholm (2010).

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Table(s)

**Table 1.** Description of the watersheds according to their area (ha), land cover (%) and main vegetation type.

| Code | Watershed | Area (ha) | Artificial zones (%) | Pasture (%) | Native forest (%) | Exotic (%) | Dominant vegetation types according to 2005 chart data |
|---|---|---|---|---|---|---|---|
| AIT | Aitzu | 56.13 | 6.8 | 19.0 | 19.2 | 54.9 | *P.radiata* plantations, meadows |
| AIZ | Aizarnazabal | 269.77 | 4.2 | 26.3 | 20.7 | 48.8 | *P.radiata* plantations, mesophyllous pasturelands |
| ALE | Alegia | 333.34 | 4.0 | 26.9 | 32.5 | 36.7 | *P.radiata* plantations, *Q. robur* forests, meadows |
| ALT | Altzola | 464.25 | 5.2 | 22.9 | 20.6 | 51.3 | *P.radiata* plantations, mesophyllous pasturelands, oak forests |
| AM | Amundarain | 28.82 | 0.6 | 71.1 | 15.8 | 12.5 | Acidophilous pasturelands, beech forests |
| AR | Arriaran | 2.77 | 0.4 | 11.4 | 28.5 | 59.7 | *P.radiata* plantations, *Q. robur* forests |
| BAR | Barrendiola | 3.8 | 0.1 | 17.5 | 29.5 | 52.9 | *P.radiata* plantations, *Q. petraea* forests |
| BER | Berastegi | 33.34 | 2.3 | 39.8 | 26.9 | 31.1 | Meadows, mixed coniferous plantations (*P. nigra*, Larix japonica) |
| EST | Estanda | 55.02 | 6.4 | 21.9 | 20.1 | 51.6 | *P.radiata* plantations, meadows |
| IBA | Ibai eder | 66.73 | 2.0 | 19.8 | 26.4 | 51.8 | *P.radiata* plantations, beech and oak forests |
| LAS | Lasarte | 796.5 | 3.7 | 29.9 | 32.3 | 34.1 | *P.radiata* plantations , oak and mixed forests (ash, birch) |
| MAT | Matxinbenta | 13.69 | 0.8 | 14.3 | 25.1 | 59.8 | *P.radiata* plantations , oak and mixed forests (ash, birch) |
| OIA | Oiartzun | 56.6 | 4.8 | 34.0 | 39.9 | 21.3 | Qak and beech forests, acidophilous pasturelands |
| SAP | San Prudentzio | 121.78 | 5.7 | 23.5 | 22.8 | 48.0 | *P. radiata* plantations, Meadows, mixed deciduous forests |
| URK | Urkulu | 9 | 0.0 | 44.5 | 46.3 | 9.3 | Beech forests, acidophilous pasturelands, meadows |

**Table 2.** Descriptive statistics of the variables used in regression analysis

| | Mean | Standard deviation | Min | Max | VIF* |
|---|---|---|---|---|---|
| Cover type | | | | | |
| Pasturelands (%) | 28.17 | 14.91 | 11.37 | 71.05 | 44.09 |
| Native forest (%) | 27.1 | 8.19 | 15.78 | 46.25 | 12.45 |
| Exotic plantations (%) | 43.66 | 15.05 | 9.27 | 59.79 | 57.3 |
| Specific discharge/precipitation | | | | | |
| Yearly data (*S*) | 57.68 | 9.83 | 46.28 | 79.45 | |
| Winter (*Si*) | 92.24 | 15.8 | 74.94 | 119.55 | |
| Spring (*Sp*) | 61.43 | 13.04 | 45.85 | 93.85 | |
| Summer (*Sv*) | 19.77 | 10.33 | 7.94 | 39.29 | |
| Autumn (*So*) | 42.43 | 13.72 | 30.26 | 72.16 | |

*Variance inflation factor

**Table 3:** OLS estimation of the multiple regression model

| **Variable** | **Coefficient** | **Standard Error** | ***p*-value** |
|---|---|---|---|
| *Constant* | 50.93 | 78.10 | 0.53 |
| *Pasturelands* | 42.36 | 81.34 | 0.61 |
| *Native Forest* | -4.16 | 78.67 | 0.96 |
| *Exotic Plantations* | -9.77 | 83.39 | 0.91 |
| | | | |
| Number of observations | 15 | | |
| $R^2$ | 0.62 | | |
| Adjusted $R^2$ | 0.52 | | |
| F (overall significance of the regression) | *6.00* | *p-value: 0.01* | |

Notes: ***, **, * indicate the coefficients are statistically significant at the 1%, 5% and 10% levels respectively.

**Table 4:** PCR estimation of the multiple regression model

| Variable | Coefficient | Standard Error | *p*-value |
|---|---|---|---|
| *Constant* | 61.71 | | |
| *Pasturelands* | 31.18*** | 3.95 | <0.01 |
| *Native Forest* | -14.65** | 5.62 | 0.02 |
| *Exotic Plantations* | -21.27*** | 2.91 | <0.01 |
| | | | |
| Number of observations | 15 | | |
| $R^2$ | 0.62 | | |
| Adjusted $R^2$ | 0.52 | | |
| F (overall significance of the regression) | *5.98* | *p-value: 0.01* | |

Notes: ***, **, * indicate the coefficients are statistically significant at the 1%, 5% and 10% levels respectively.

Figure(s)

**Figure 1.** Study area and watersheds within the Basque region of Gipuzkoa.

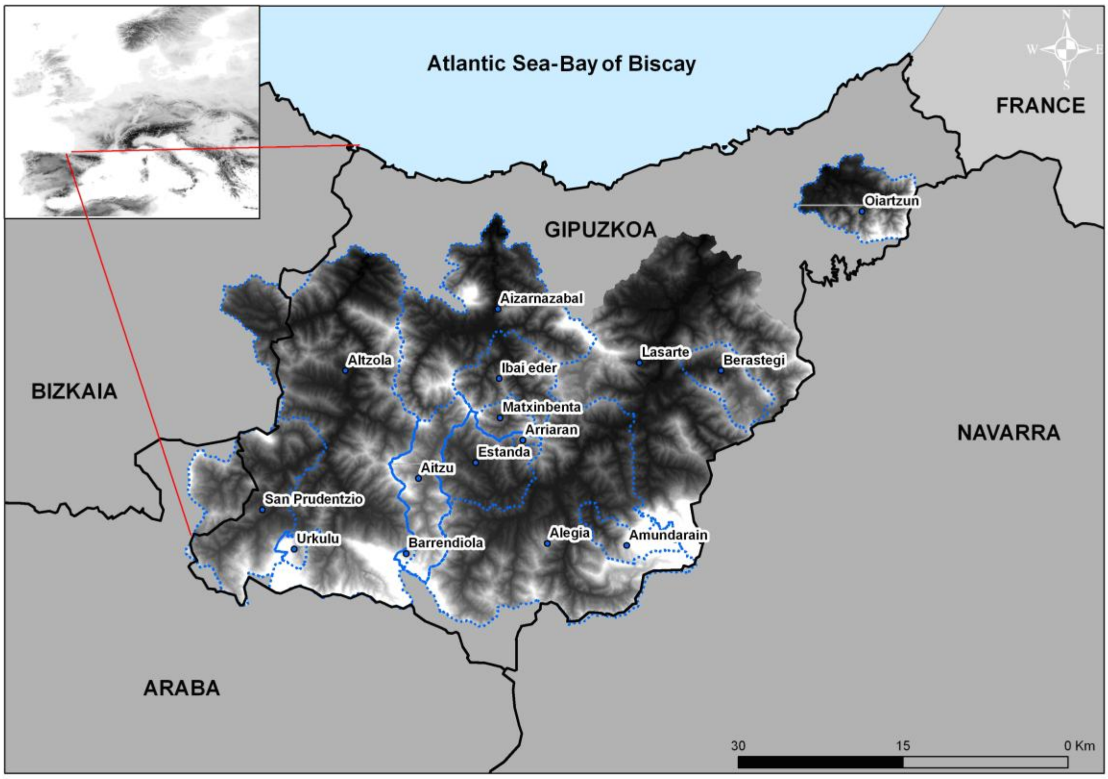


**Figure 2.** An illustrative example of changes in land use over the last century in Gipuzkoa: from meadows and pasturelands in 1954, to intensive *P. radiata* plantations in 2009 (*source: Regional Authority*).

**Figure 3.** Simple regression models.

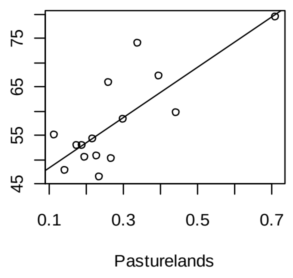
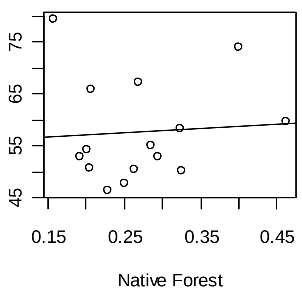
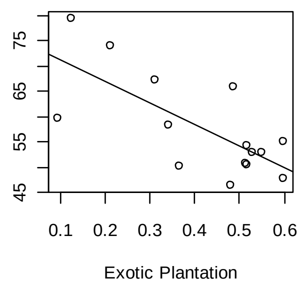
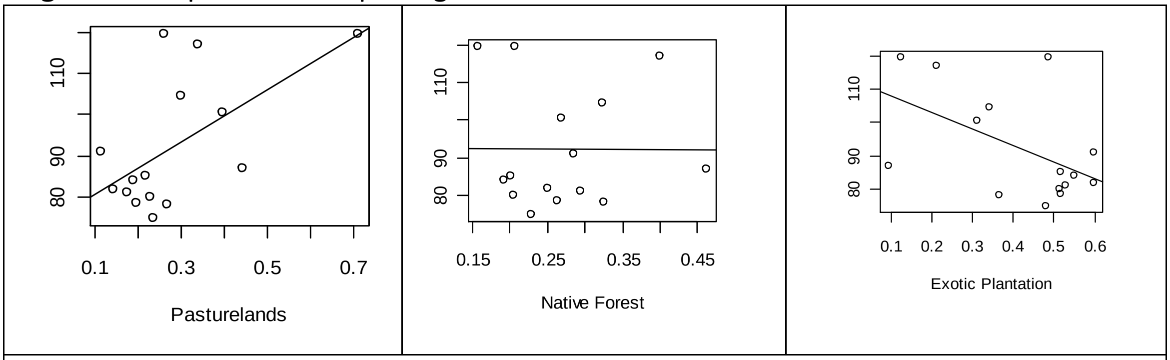
| | | |
|---|---|---|
|   |   |   |
| $\hat{S}_i = \underset{(12.04)}{43.06} + \underset{(4.59)}{51.89}\,Pasturelands_i$<br>$R^2 = 0.619$ | $\hat{S}_i = \underset{(5.9)}{55.40} + \underset{(0.25)}{8.41}\,NativeForest_i$<br>$R^2 = 0.005$ | $\hat{S}_i = \underset{(14.72)}{75.35} - \underset{(-3.7)}{42.49}\,ExoticPlantations_i$<br>$R^2 = 0.513$ |

**Figure 4.** Simple and multiple regression models: Winter

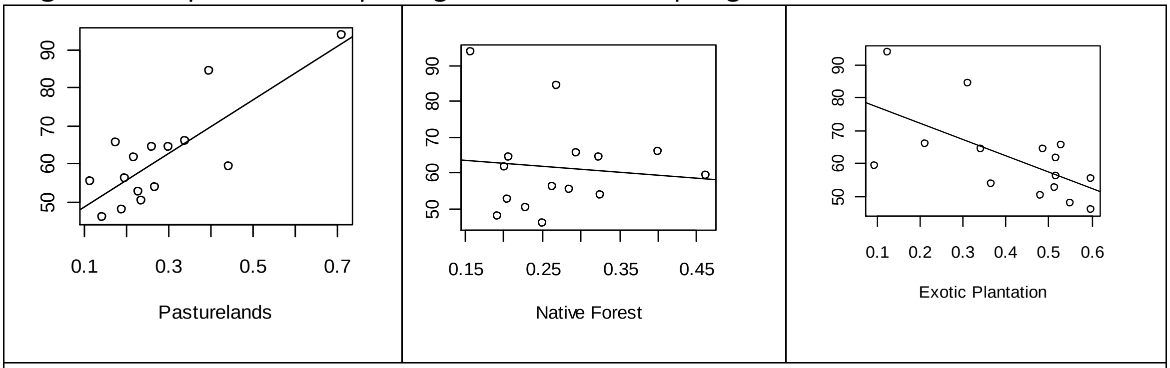



PCR estimation of the multiple regression model

| **Variable** | **Coefficient** | **Standard Error** | ***p*-value** |
|---|---|---|---|
| *Constant* | 98.99 | | |
| *Pasturelands* | 39.46*** | 8.24 | <0.01 |
| *Native Forest* | -27.72** | 11.73 | 0.04 |
| *Exotic Plantations* | -24.86*** | 6.24 | <0.01 |
| | | | |
| Number of observations | 15 | | |
| $R^2$ | 0.36 | | |
| Adjusted $R^2$ | 0.18 | | |
| F (overall significance of the regression) | *2.05* | *p-value: 0.16* | |

Notes: ***, **, * indicate the coefficients are statistically significant at the 1%, 5% and 10% levels respectively.

**Figure 5.** Simple and multiple regression models: Spring

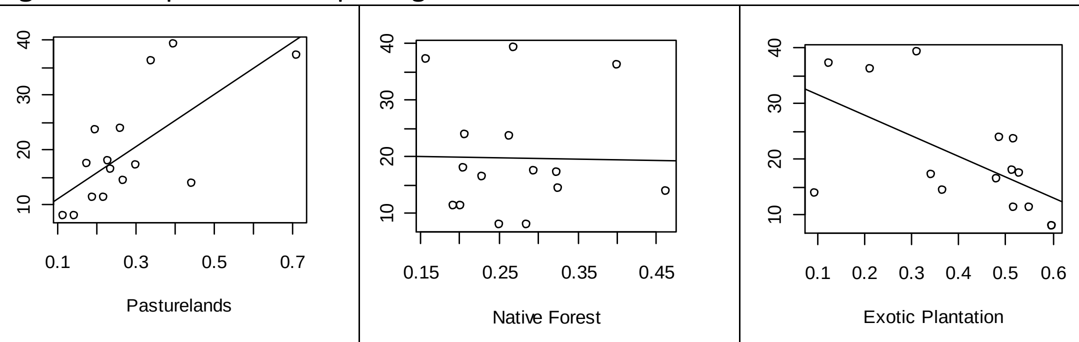



PCR estimation of the multiple regression model

| **Variable** | **Coefficient** | **Standard Error** | ***p*-value** |
|---|---|---|---|
| *Constant* | 71.67 | | |
| *Pasturelands* | 45.24*** | 5.04 | <0.01 |
| *Native Forest* | -45.88*** | 7.17 | <0.01 |
| *Exotic Plantations* | -25.37*** | 3.81 | <0.01 |
| | | | |
| Number of observations | 15 | | |
| $R^2$ | 0.65 | | |
| Adjusted $R^2$ | 0.55 | | |
| F (overall significance of the regression) | *6.77* | *p-value: <0.01* | |

Notes: ***, **, * indicate the coefficients are statistically significant at the 1%, 5% and 10% levels respectively.

**Figure 6.** Simple and multiple regression models: Summer

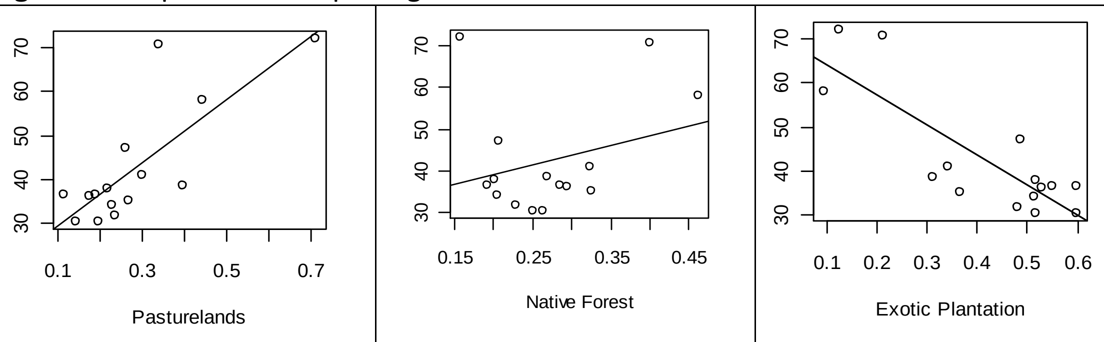



PCR estimation of the multiple regression model

| **Variable** | **Coefficient** | **Standard Error** | ***p*-value** |
|---|---|---|---|
| *Constant* | 25.13 | | |
| *Pasturelands* | 29.83*** | 4.89 | <0.01 |
| *Native Forest* | -22.44*** | 6.96 | <0.01 |
| *Exotic Plantations* | -18.47*** | 3.70 | <0.01 |
| | | | |
| Number of observations | 15 | | |
| $R^2$ | 0.47 | | |
| Adjusted $R^2$ | 0.33 | | |
| F (overall significance of the regression) | *3.29* | *p-value: 0.06* | |

Notes: ***, **, * indicate the coefficients are statistically significant at the 1%, 5% and 10% levels respectively.

**Figure 7.** Simple and multiple regression models: Autumn




PCR estimation of the multiple regression model

| **Variable** | **Coefficient** | **Standard Error** | ***p*-value** |
|---|---|---|---|
| *Constant* | 42.22 | | |
| *Pasturelands* | 39.57*** | 4.96 | <0.01 |
| *Native Forest* | -11.28** | 7.05 | 0.13 |
| *Exotic Plantations* | -33.64*** | 3.75 | <0.01 |
| | | | |
| Number of observations | 15 | | |
| $R^2$ | 0.69 | | |
| Adjusted $R^2$ | 0.60 | | |
| F (overall significance of the regression) | *8.26* | *p-value: <0.01* | |

Notes: ***, **, * indicate the coefficients are statistically significant at the 1%, 5% and 10% levels respectively.