Supplementary File S1. SFM Criteria

COMPLETE DESCRIPTION OF THE CRITERIA IDENTIFIED FOR THE SUSTAINABLE MANAGEMENT OF MEDITERRANEAN FORESTS AT THE FOREST MANAGEMENT UNIT SCALE

This appendix exposes the criteria of sustainable forest management (SFM) under Mediterranean conditions identified in this research, applicable at the forest management unit (FMU) scale. In the following pages some tables have been developed, one for each criterion. These tables show the name of the criterion in the first row, it s description in the second row, and examples of actions and procedures to accomplish the criterion in the third row. Some tables include a fourth row of remarks to clarify some concepts and to set the scope of the criterion to avoid overlaps with other criteria.

ECONOMIC CRITERIA

Persistence and stability of forest resources
Silviculture guarantees that a minimum quantity of the forest resources that are utilised for profitability at the forest mangement unit stays permanently in it and continues after pests and diseases.
- Harvesting combines opening up spaces with soil and new plants protection (Madrigal, 2003). - Keep suitable densities according to species and site quality (Madrigal, 2003). - Diversity at different levels: population (genetic diversity), species diversity and landscape diversity. There is no need either to substitute species or to create mixed forests, but to get young forests made of several species, some of them principal resources and some of them secondary in terms of exploitation but with an important ecological function for the principal ones (Madrigal, 2003). - Silviculture is applied along the whole lifecycle of the forest (Madrigal, 2003). - Species adapted to site (soil and climate) (Generalitat Valenciana, 2011). - Avoid dead wood with cork after silvicultural treatments and forest fires (Generalitat Valenciana, 2011). - Genetic diversity and improvement: silviculture focuses not only on individuals which

grow faster or which have the best morphological characteristics (Thompson, 2011).

- Seed origin control of material used for forestations or enrichment plantations[1] (Ruano, 2003).
- The integration of the conservation of genetic resources into the management requires the application of "on site" methods (in the natural distribution area), both with a dynamic character (which promote continuous evolution of genetic resources in natural environments) and static (outstanding individuals); those are complemented with methods from out of the natural distribution area with a dynamic character (introduced populations plantations) (Strasbourg S2, 1990; *in* Generalitat Valenciana, 2011b). These genetic conservation and improvement programs affect in the following way to the forest manager (Generalitat Valenciana, 2011b):
    - *Promote the correct use of genetic resources for natural environments restoration and in productive sectors.*
    - *The participation of forest owners is required in conservation actions that affect them.*

Profitability of forest resources

When planning the management it has to be considered obtaining in-kind incomes (products) and money incomes, annual or periodic, variable or constant.

- The silvicultural organisation model establishes the obtaining of in-kind incomes (Madrigal, 2003).
- To get money incomes it is necessary to know production costs, market prices, study the demand and commertialise the products (Madrigal, 2003).
- The accomplishment of this criterion implies considering possible subsidies and payments for ecosystem services (PES)[2] available for the FMU. Both will be included as part of the money incomes.

COMMENT: this criterion has to be accomplished at the FMU level (neither stand level nor regional level) and it does not necessarily imply the getting annual constant incomes. For in-kind annual constant incomes, a balanced tree ages or tree dimensions distribution in the FMU has to be achieved. However, for constant incomes a minimum forest area is needed in order to obtain a balanced organisation of trees. Forest properties are generally small in Spain, making it difficult to comply with this criterion at the FMU level. This criterion can be achieved at a higher level (county, regional); therefore, it is recommended to promote association among forest owners and regional/county management of forests, but this is out of the scope of this research.

[1]These are plantations carried out under the forest canopy whose objective is to increase the number of species of the tree layer (Madrigal, 2003).

[2]They are agreements between producers of an ecosystem service and people (or their representatives) who are benefiting from it. By means of the agreement the beneficiaries pay a prearranged money quantity to the producers (Generalitat Valenciana, 2010).

Diversified exploitation of forests
As part of the management an inventory of present and potential goods and services of the forest has to be done and the best use of them has to be determined.
- Study of possible uses and compatibilities and establishment of priorities among them (Deshler, 1979). - Optimisation techniques (Madrigal, 2003). - Multi-criteria analysis (MCA) techniques. - Explore new products and their markets. - It contributes to comply with this criterion having a mosaic of diverse vegetation formations (tress, scrubs, pastures) (Madrigal, 2003).

Economic criteria refer to all forest resources (goods and services) that can be managed to commertialise and sell. They correspond to provisioning services. However, there are provisioning services that do not provide any incomes to the forest owner: decoration or aromatic plants (moss, holly, mistletoe, rosemary, etc.), asparagus, snails, fungi, berries and so on. If in the future there exist economic compensations for them (because of direct selling or because of PES), and an active management is developed for their exploitation, that management will be included in this three criteria.

SOCIAL CRITERIA

Employment and working conditions
The number of job posts (and thus, employees) in the FMU is appropriate to the management tasks that are carried out, employees working conditions are good and they have suitable training to develop their functions.
- Development of the management in a profitable way so that it generates or maintains the number of job posts. - Avoid temporary contracts as far as possible (Madrigal, 2003). - There is a risk prevention plan which and all the workers know the prescriptions that affect them. Reference documents for health and safety matters are: • International Labour Organisation prescriptions (ILO, 1998; ILO, 2005). • *Manual para la asistencia técnica en prevención de riesgos laborales. Sector forestal* (EUROQUALITY y ASEMFO, 2002). • *Trabajos forestales* (Gobierno de España, 2006).

Recreation

There are infrastructures in the FMU for its social use in different ways: leisure (picnic, walking, trekking, fauna watching, camping), sports or hunting.

- Maintenance and improvement of the infrastructures for the activities mentioned in the description: picnic and camping areas, walking paths, climbing walls.
- Creation of new infrastructures if there exist demand for their use and they are economicly affordable.
- Management of hunting fauna: places for the animals to eat and to drink, fences, species and populations inventories, establishment of the number of individuals from each species to hunt per time period.

COMMENT: in many Spanish Mediterranean forests hunting represents the only, or the most important, income source. Nevertheless, in this research it is kept in "recreation" and "social criteria" because its practice has more of a cultural meaning than of a provisioning and feeding one (Generalitat Valenciana, 2011). It happens the same with mushroom and berry picking; however, hunting has some sportive features (challenge, competitiveness, watching and shooting the press) that make it more suitable for this criterion.

Visual character

Management maintains the visual features of the FMU that identify it and make it attractive and improves them when they have been degraded.

- Outstanding visual elements of the landscape, either due to their natural appearance or due to human action, will be conserved (Council of Europe, 2000).
- Unwished contrasts will be avoided (Madrigal, 2003).
- Some visual diversity will be looked for (but nor excessive, because it could lead to a feeling of disorder – Madrigal, 2003) both vertical (strata) and horizontal (mosaics of vegetation formations) (Gobierno de España, 2002).
- A balanced tree ages or tree dimensions distribution assures visual continuity of the landscapes (Madrigal, 2003).
- In reference to visual considerations, it corresponds to the forest manager to identify management guidelines and silvicultural treatments to comply with the visual prescriptions of those planning regulations that affect the FMU. If these regulations do not exist or they are not very specific, the forest manger will establish his/her own rules to conform to this criterion.

COMMENT: in order to agree to maintain the visual character and to get constant incomes, it is convenient to get those balanced tree ages that Madrigal (2003) proposes. However, people feels more attracted to tree formations where the tree layer is made by individuals with similar ages and heights. Thus, this equilibrium will have to be considered at FMU level, with interstand heterogeneity but intrastand homogeneity with respect to tree age and size, so that there are some places with mature and high trees (very attractive for people); places holding these characteristics can be prioritised near picnic areas, paths or roads.

Historical and cultural heritage

Management preserves the features and places of the FMU holding a historical or cultural meaning, either tangible (charcoal kilns) or intangible (pilgrimages), natural or artificial.

- The meaningful features of the landscape that represent a historical or cultural meaning, either due to their natural appearance or due to human action, will be preserved (Council of Europe, 2000).
- Inventory of elements and places with a historical or cultural heritage character.
- The forest manger establishes conservation procedures, and restoration ones if it is appropriate.
- Participatory processes can be of great help for the inventory of elements, traditions and places with a historical or cultural meaning, and to decide how to carry out their conservation.
- The law on Spanish Historical Heritage (*ley 16/1985, de patrimonio histórico español* – Gobierno de España, 1985), defines what constitutes the ethnographic heritage (related to customs and traditions) and establishes economic subsidies for the conservation and recovery of the historical and cultural heritage. Likewise, the law on Spanish Natural Heritage and Biodiversity (*ley 42/2007, del patrimonio natural y de la biodiversidad* – Gobierno de España, 2007), determines the cultural character derived from the use of certain biological, geological and other natural resources, and it provides subsidies and procedures for their conservation.

Participatory processes
Take account of stakeholders and affected people's experience and points of view in forest management decisions.
- It stays open to the necessities of each case (except when it is compulsory because of laws or planning regulations) the way in which the process will be carried out, the stakeholders to include, over which management matters the process will be about, and how will the input from participants included in the final decisions.

Education
Forest management favours society's education and awareness on the cultural, environmental and economic significance of forestry and natural areas.
- Information boards and desks (information desks mainly in protected areas or FMU with outstanding features) to inform about the fauna, flora, meaningful historical and cultural characteristics, the resources of the FMU and good behaviour procedures (Generalitat Valenciana, 1993; Gobierno de España, 2002; Gobierno de España 2003). - The use with an educational goal by education centres and institutions, associations, clubs and travel agencies. It would be interesting to have mechanisms for forest owners to offer their FMUs for this purpose and get an economic compensation for that.

Research
The use of forests as an object of scientific studies, either to improve the management (and the information on its goods and services) or to increase the knowledge of other disciplines (ecology).
- As an object of forest policy more forest research is promoted, and more forest information (statistics) (Generalitat Valenciana, 1993; Gobierno de España, 2002; Gobierno de España, 2003). - It would be interesting to have mechanisms for forest owners to offer their FMUs for scientific research and get an economic compensation for that. - Monitoring, assessment and information on the degree of accomplishment of management objectives and the state of the forests, in a periodic and systematic way. Templates to fill in should publicly available or, at least, accessible to researchers and managers. This information pick up (statistics) constitutes a starting point for research.

This group of criteria refers to cultural ecosystem services plus two requisites of a sustainable management: "employment and working conditions" and "participatory processes". Both in the social and the ecological group there are criteria that correspond to ecosystem services that are not provisioning, but which could provide money incomes to the FMU by means of PES or subsidies. These are: "recreation", "visual character", "education", "research" or "biodiversity and habitats". When this situation comes, incomes derived from managing such criteria will be included as part of the money incomes (as it has been mentioned in the criterion "profitability of forest resources"), but their management (their objectives and the way to meet them) will remain in the criteria group where they originally where.

ECOLOGICAL CRITERIA

Biodiversity and habitats
Management keeps species and habitats diversity and habitats connectivity in order to maintain and improve forest capacity to recover after disturbances.
- The achievement of this criterion depends upon the accomplishment of six subcriteria which are described next.

Flora diversity
Maintenance and improvement of vegetation diversity in grass and scrubs layers.
- Inventory of vegetation species and development of conservation procedures. - If diversity is going to be increased, the effects of the introduction of new species on the ecology of the system should be studied: an increase in the number of individuals in a population and in the number of species in an ecosystem has to be compatible with the management objectives and the stability of the system (AENOR, 2007).
COMMENT: this subcriterion refers only to grass and scrubs layers because tree layer is considered an economic resource and its diversity has been taken into account in the criterion "persistence and stability of forest resources".

Fauna diversity

Maintenance and improvement of wild animal species diversity existing in the FMU.

- Inventory of wild animal species and development of conservation procedures.
- The same preventive measures as the ones indicated for the subcriterion "flora diversity" have to be taken if it is necessary to introduce individuals of one species or to increase the number of species (AENOR, 2007).

COMMENT: the management of hunting fauna is not included in this subcriterion.

Endangered species

The management maintains and increases the populations of these species in the FMU.

- Revise the "List of Wild Species under a Special Protection Status" (scientific, ecologic, cultural, outstanding values, rare or endangered species) and, inside this list, the species included in the "Spanish List of Endangered Species", and the existence of endemic species (Gobierno de España, 2007; 2011); also revise the "Valencian List of Endangered Flora Species" (Generalitat Valenciana, 2009) and the "Valencian List of Endangered Fauna Species" (Generalitat Valenciana, 2004).
- Inventory of species included in the previous lists that are present in the FMU and development of conservation procedures.

Alien species

Cautious introduction of alien species and control of existing ones to avoid that they become invasive.

- Study the effects of introducing alien species, and avoid it they are expected to change noticeably the ecology of the FMU (European Union, 2010).
- Invasive species will be eliminated or their spreading will be controlled (European Union, 2010).
- If it is ecologically advisable and economicly affordable: reintroduce species that have been moved aside by invasive species.

Habitats
Knowledge, maintenance and improvement of the different habitats existing in the FMU (lakes, rocky walls).
- Inventory of habitats and development of conservation procedures. - Special care should be paid to threatened habitats, habitats having endangered species and habitats having economicly important species (Council of Europe, 1992).

Ecological connectivity
Management avoids habitat fragmentation and favours connection among them.
- Continuity among different vegetation structures, avoiding barriers to fauna movements and seed dispersal (Gobierno de España, 2002; Gobierno de España, 2003). - Green corridors between distant natural ecosystems (Gobierno de España, 2002; Gobierno de España, 2003).

Hydrological regulation
An important element of the hydrological cycle is vegetation that increases infiltration and reduces the quantity and speed of runoff. This attribute of vegetation offers important services: controls erosion, reduces the number and magnitude of floods and refills aquifers. The aim of this criterion is to maintain and improve these services through the management of vegetation structure and composition.
- The achievement of this criterion depends upon the accomplishment of five subcriteria which are described next.

Erosion

Management keeps erosion rates under bearable levels.

- Erosion stays under a bearable level of soil loss which is different depending on the area, and this level is constantly monitored (Generalitat Valenciana, 2011).
- Preventive techniques should be applied (soil protection covers) where there is a potential erosion risk and corrective techniques where soil losses are above a bearable level (Generalitat Valenciana, 2011).
- Keep, protect and broaden vegetation covers made of several strata, in order to reduce runoff speed (Generalitat Valenciana, 2011).
- Reduce damage to scrubs and grass, and avoid soil compaction when carrying out silvicultural treatments (Generalitat Valenciana, 2011).

Soil productivity

Management does not change soil productivity and improves it whenever necessary (reforestations) if the soil is short of nutrients[3].

- Leave rests of silvicultural treatments (dead Wood, leaves and branches) to provide nutrients and organic material to the soil (Pemán y Navarro, 1998; Madrigal, 2003).
- In reforestations and enrichment plantations: avoid (in case of plough, etc.) big affections to soil texture, structure and soil profile except when site conditions require it (Pemán y Navarro, 1998; Madrigal, 2003).
- If fertilisers are necessary (reforestations, enrichment plantations, poor soils, plant nurseries), only recommended quantities will be used and authorised products having the lesser impact on the environment; the products will be used in the suitable time of the year. The objective of these prescriptions is to reduce nutrient decay (AENOR, 2007).
- In general, to comply with this subcriterion, soil preservation and improvement procedures can be applied, like: bioengineering techniques or enriching mud (Generalitat Valenciana, 2011).

COMMENT: forestry does not act directly on the soil. Indirectly, silvicultural treatments can cause compaction due to machinery, or they can cause surface cracks because of vegetation drag. But forest

[3]Soil productivity is defined by soil texture, structure, organic material content, depth, nutrients and water storage capacity (FAO, 2005).

management does not affect directly on the soil profile and fertilisers are not usually applied. An exception to the previous are reforestations, enrichment plantations and intensive exploitations (plantations, nurseries); in all of them it can be necessary, not always, the use of fertilisers and, just in reforestations and enrichment plantations, to vary slightly some soil properties (horizons, hydrology).

COMMENT 2: organic detritus are favourable for the accomplishment of some criteria (this one or *biodiversity and habitats*) and unfavourable for pest spread. As a tradeoff, it is proposed to avoid dead wood with cork and establish maximum quantities for the other detritus, so that the habitat is improved but the ecosystem stability is not altered.

Aquifer filling

Management favours vegetation structures that maintain or increase aquifer filling rates.

- Maintain, protect and increase forest covers with several strata (Generalitat Valenciana, 2011).
- Vegetation structures whose characteristics (densities, ages, species) optimize the area covered by vegetation, so that infiltration is maximised and water consumption is minimised. The aim is to reduce evapotranspiration. All this implies that vegetation densities will not be the maximum possible ones, but medium densities in order to have some extra water in the soil which percolates for groundwater recharge (Generalitat Valenciana, 2011).

COMMENT: due to the type of silviculture required, this subcriterion is in conflict with flood control, erosion prevention and profitability. For three of them, higher densities of the tree layer than for aquifer filling are necessary. It is necessary when planning forest management to establish clearly the objectives and the priorities among them and to divide the FMU into zones, each zone with a different main objective. This choice of objectives will not be possible when a regulation coming from an upper level establishes the need to manage a specific forest area for groundwater recharge because its water fill overexploited aquifers or aquifers supplying a lot of inhabitants.

Floods

Create vegetation structures that avoid floods or reduce their negative impacts.

- Higher vegetation density (especially the tree layer) which increases infiltration and reduces runoff speed (Generalitat Valenciana, 2011).
- Vegetation structures with several strata, and broadleaves if possible (Generalitat Valenciana, 2011).

- There are no obstacles to free water drainage in the FMU, except the construction of transverse dykes, which retain water and reduce discharge rates (see COMMENT).

COMMENT: the forest owner is responsible for dyke construction only when there are private water streams or riverbeds inside the FMU. Even in these cases, dyke construction will have been previously recommended or ordered by an upper level authority.

Mass flows

Management prevents landslides and avalanches.

- Preventive techniques: slope drainages, moorings, geometric correction of the slope profile, etc. (Ayala *et al*., 2006).
- Planning and management divide into zones considering risk maps and create forest covers that contribute to soil stability: strata, densities, species, etc. (Ayala *et al*., 2006).

Forest fires

Management prevents forest fires and facilitates extinction, so as to keep the frequency, intensity and consequences of forest fires in an ecologically sustainable and socially acceptable level.

- Extinction aid infrastructures: tracks, firebreak areas, water diposits (Generalitat Valenciana, 2011).
- Silviculture reduces the amount of fuel, vertical vegetation continuity (between strata) and horizontal vegetation continuity (inside the same vegetation structure and in the limit between vegetation structures) (Generalitat Valenciana, 2011).

Carbon storage

Forest management contributes to global climate change mitigation through maximising biomass synthesis and maintaining soil carbon storage capacity.

- The achievement of this criterion depends upon the accomplishment of two subcriteria which are described next.

Vegetation
Vegetation structure and composition that favour biomass synthesis.
- Higher percentages of areas covered by trees[4] compared to areas not covered by trees or covered by scattered trees (Generalitat Valenciana, 2011). - Promote young vegetation structures in zones whose main objective in to maximise carbon storage[5]. It is recommended to tend to young conifers vegetation structures under thinning programs (Generalitat Valenciana, 2011). - Diversify species in mature vegetation structures (Generalitat Valenciana, 2011). - Maintain densities that favour tree carbon synthesis: high percentages of area covered by trees in pure mature vegetation structures, and medium for mixed ones; the area covered by scrubs in vegetation structures including a tree layer must be small (Generalitat Valenciana, 2011).

Soils
Maintain and improve soil capacity to store carbon[6].
- Avoid frequent and big changes of soil structure in reforestation, enriching plantations and track and firebreaks developments: it has to be said that reforestation works, most of them use machinery, often imply soil disturbances which can derive in soil carbon losses in the first years of the reforestation (Generalitat Valenciana, 2011)[7]. - Promote vegetation structures with broadleaves or, if not possible, mixed ones[8] (Generalitat Valenciana, 2011).

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[4] Carbon storage capacity in ecosystems covered by trees is about 73t CO_2/ha, and in ecosystems not covered by trees 17t CO_2/ha. Low density scrubs store more carbon tan high density ones but, in general, the types of vegetation structure that store more carbon are those where scrubs storage contribution is less (between 2% and 7%) than that of the trees (Generalitat Valenciana, 2011).

[5] Forest ecosystems capture CO_2 when they are young. However, as they get more mature the growing rate is reduced and so does CO_2 storage, until it becomes almost nothing. In general, young conifer vegetation structures, especially if thinnings are applied, and riparian forests consisting of fast growing trees, are those with the highest carbon storage capacity. Also, pure mature vegetation structures whose area covered by trees is between 70% and 100% have less carbon storage capacity that the same vegetation structures with less area covered by trees (Generalitat Valenciana, 2011).

[6] Most carbon stored by forests is in the soil, which contains around three times more carbon than vegetation. Dead leaves, small branches and harvest detritus get into the soil structure and decomposes into stable organic aggregates, which can stay thousands of years (Generalitat Valenciana, 2011).

[7] Soil carbon losses are caused by climatic factors – mainly temperatura – erosion, organic material mineralization, and carbon leakage (Generalitat Valenciana, 2011). Breaking soil structure favours contact between stable organic aggregates and oxygen, and increases soil carbon losses (FAO, 2002).

[8] In arid and Mediterranean climates, the highest average soil carbon content appears in vegetation structures with a deciduous tree layer, which doubles that of pastures and scrubs, and it is 60% more than in vegetation structures with a conifer tree layer (Generalitat Valenciana, 2011).

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