Soil Disturbance Surveys in Pine Tree Plantations of the Basque Country

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Forests are known to be the ecosystems that best protect soils and watercourses (Horswell & Quinn 2003). Nevertheless, in commercially managed forests where stands are clear-cut and heavy machinery is used for harvesting and site preparation, the maintenance of forest soils sustainability is greatly questioned because plant cover is disturbed and the risk of erosion intensifies. Nevertheless, forestry areas are exposed to disturbance at lower frequency than traditional agriculture, although the disturbance is more severe. Inter-rotation period is defined as the period between clear felling of a mature plantation and the complete re-establishment of the next rotation (Constantini *et al*. 1997).

Pinus radiata plantations that are harvested every 30-40 years account for 60% of the forest surface in the Basque Country. Besides, the steep and mountainous terrain which is characteristic of the Atlantic part of the Basque Country along with the high precipitation that is distributed all year round (1500-2000 mm $year^{-1}$) makes erosion hazard to be very high in this region, mostly during inter-rotation period. The forestry practices that are used more in this region are: i) clear-cut with chain saws; ii) harvesting using skidders and iii) site preparation using the following techniques: a) clearing harvest residues and understorey vegetation with the front blade of a bulldozer followed by b) ripping in order to facilitate plantation and to improve the physical structure of the soil. If the slopes are steeper (>30%) site preparation is usually fulfilled without machinery and residues are pushed into windrows manually. There are not reliable statistics about the practices involved in forestry operations or about the surface treated with these practices. Nevertheless, almost all the harvesting and over 50% of site preparation involve the use of heavy machinery (foresters Confederation, personal communication). The socio-economic structure of the forest sector and the increasing demand for wood and paper products have led to increased mechanisation and use of heavy machinery in forest operations in the Basque Country, and this fact is going to increase in the following decades.

During the inter-rotation period the plant cover disappears leaving the mineral soil exposed to rainfall for periods of time with different lengths depending on site characteristics and on the forest practices used (Olarieta et al. 1997). In the Basque Country the effect of mechanisation during the first year may lead erosion to change from 8 tn/ha when site preparation is done manually to 60 tn/ha when machinery is used for this purpose (Olarieta et al. 1999). The effect of machinery can also be seen in terms of a 50% reduction of organic matter in forest soils and significant reductions of other essential nutrients (Merino et al 1998; Merino & Edeso, 1999; Olarieta et al. 1999).

Thus, it is important to develop a quick and easy procedure to measure the disturbance of the soil caused by forest practices during harvesting and site preparation in the Basque Country in order to asses the effects of the use of heavy machinery and to evaluate forest practices themselves. This is the main aim of the present study.

1. Soil Disturbance Evaluation Procedure

A soil survey recording form (an electronic counterpart has also been developed using FileMaker Pro 6.0 database) has been designed in order to standardise data recording and processing. In the front cover of it some general data about the stand (Owner, surface, mean slope, prescription…) have to be recorded. It has to be also recorded, if possible, some parameters about previous harvesting such as harvested species, mean height of harvested trees, dominant height, mean diameter, total harvested volume, tree density when harvested. Afterwards, data about the practices involved must be recorded; the name of the contractor, the machinery used, date when forest practices are done and if possible, soil moisture status when practices are done. Another set of data that has to be reported is the one that has to deal with harvest residues and protection of watercourses. This set of data includes the following items: Kind of riparian buffer zone (natural riparian forest, planted riparian forest, shrub-land area, grass-land area, no buffer area, not relevant), number of crosses between roads and watercourses, minimum distance to a riparian buffer zone/river from a road, length of a road that lies parallel to a water course and maximum slope to it. The harvesting residues are recorded as chopped (chopped and evenly spread through the entire surface of the planted area), piled, burnt, windrows and removed (removed from the planted area of the stand). Windrows are recorded in a different way. If distance from windrow to

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windrow is just enough to plant 3 rows of trees (around 10 m with the nowadays forest management for radiata pine in the Basque Country), and thus, erosion prevention is maximised these windrows are recorded as windrows/erosion; if the distance between them is larger or if they are just pushed perpendicular to the slope they are recorded as windrows.

2. Soil Disturbance Categories Definition

The procedure developed in this study is based on the Soil Conservation Surveys Guidebook published by the British Columbia Ministry of Forests (2001). This survey method takes the stand as the unity for carrying out the procedure because forests operations are mainly done at this landscape level, and because of operational feasibility. In the procedure proposed in this study, stand level surveys will also be done.

In the first place, the soil disturbance categories defined by BC Ministry of forests (2001) were revised and modified in order to be useful for the particular case of the Basque Country.

The first soil disturbance category to take into account is the one called "Unplanted Structures". This category involves structures in the stand that will be left unplanted in the future. There are two subset of structures counting for this category: 1) lineal structures as access structures (roads), fire-brakes, electrical laying, gas pipelines… and 2) non lineal structures as landing areas, backspar trails… These unplanted structures must be built or considered under prescription. This category will be used to estimate the stand surface occupied by this kind of structures and thus, the surface that is going to be left unplanted in order to evaluate the correct technical prescription and to estimate the losses of productive surface. For structures (roads, paths…) constructed for machinery travelling or left unplanted crossing a watercourse it will be noted in the front cover. If the structure runs parallel to a watercourse the minimum distance to it or to the buffer riparian forest (if it is smaller than 50 m), the length of the structure that is parallel to the river and the slope to it will be measured.

The following disturbance categories are the ones evaluated in the area to be reforested. These disturbance categories are mainly due to i) the incorrect use of the machinery during forest operations e.g. travelling around the whole area, passing by many times on the same place, pushing the shovel into the mineral soil forming gouges… ii) because machinery is used under improper moisture contents of the soil. These categories are grouped from severe disturbance to no disturbance at all the following way: Gouges/dislodged soil; compacted areas; wheel or track ruts; scalps and not disturbed.

2.1 Gouges/dislodged soil

These disturbance categories are those that deal with improper use of the machinery. The front blade of bulldozers and skidders have to be operated some centimetres above forest soil to encompass clearing of harvesting residues but sometimes these blades are pushed into the mineral soil for several meters removing the upper part of mineral soil.

a) Deep gouges (**D**). Excavations into mineral soil deeper than 30 cm measured from undisturbed mineral soil or to bedrock at the survey point.
b) Wide gouges (**W**): Excavations into mineral soil that are i) deeper than 5 cm measured from undisturbed mineral soil at the survey point and ii) deeper than 5 cm or to bedrock, on at least 80% of an area of 3 m^2.
c) Long gouges (**L**): Excavations into mineral soil that are i) deeper than 5 cm measured from undisturbed mineral soil at the survey point and ii) deeper than 5 cm or to bedrock on at least 80% of an area 1 x 3 m.
d) Ripping furrows (**S**): Furrow generated during site preparation using a ripper or similar equipment at the survey point. The angle deviation from the horizontal line is also measured at the bottom of the trench. If ripping is a prescribed operation, the category where the furrow trench at the survey point lies is also recorded.
e) Ripping mounds (rest-balk) (**N**). Rest-balk generated during site preparation using a ripper or similar equipment at the survey point. If ripping is a prescribed operation the category where the mound lies at the survey point is also noted.
f) Dislodged soil (**E**). Accumulations of dislodged mineral soil (mounds) with or without harvest residues that are i) higher than 5 cm at the survey point and ii) higher than 5 cm on at least 80% of an area of 3m^2.
g) Removed stumps (**T**): Stumps that have been pushed out from the soil by the machinery. It may be the stump itself or the hole left when the stump was removed.

2.2 Compacted areas

Due to repeated machine traffic, or because logging areas are not properly designed and the area to be reforested is used for this purpose, some areas of the area to be reforested may get compacted. Prior fulfilling the survey, a quick determination is done in an adjacent and mature forest in order to have forest floor depth and compaction reference values for the evaluation. Compaction is assessed with a hand penetrometre easily. This is achieved selecting two points in the middle of the mature stand, 100 m away

from access structures. From these points 15 points are randomly selected using 2 different randomly generated number lists: one (from 0 to 360) for compass bearing and the other one (from 0 to 25) for distance from the centre point. In each of these 30 points forest floor depth to mineral soil is measured and soil strength (as resistance to penetration) are measured. Compaction is assessed relative to the 90th percentile of the values estimated this way. When resistance to penetration in the survey point and the area surrounding is bigger or equal this figure, then the soil is considered as compacted.

a) Big Compacted Areas (**A**): Compaction estimated as explained before i) at the survey point and ii) compaction on 100% of an area of 100m^2.
b) Small Compacted Areas (**C**): Compaction estimated as explained before i) at the survey point and ii) compaction on at least 80% of an area of 3 m^2.

2.3 Wheel or track ruts

Wheel or track ruts are impressions or ruts in the soil caused by heavy equipment traffic. They are mainly done when the soil is wet (close to field capacity). This category does not require the survey point to be assessed for evidence of compaction.

a) Deep Ruts (**H**): Impressions in the soil with a width of 30 cm and a minimum depth of 15 cm from the forest floor or 5 cm from the mineral soil at the deepest point in the perpendicular cross-section, over the entire length of 2 m. Depth is measured from the surface of the undisturbed forest floor or from the mineral soil to either the forest floor surface in the bottom of the rut or the mineral soil surface in the bottom of the rut if a forest floor is not present.
b) Superficial Ruts (**G**): Impressions in the soil with a width of 20 cm and a minimum depth of 5 cm measured from the mineral soil at the deepest point in the perpendicular cross-section, on at least 50% of a length of 2 m. Depth is measured from the surface of the undisturbed forest floor or from the mineral soil to either the forest floor surface in the bottom of the rut or the mineral soil surface in the bottom of the rut if a forest floor is not present.

2.4 Scalps

Scalps are areas where the forest floor has been removed either by the improper use of the front blade or by the pushed trunks when logging is done.

Forest floor is considered removed when the underlying mineral soil is exposed or it is covered by:

1) Fine woody slash, not decomposed needles, or dislodged rotten wood.
2) Dislodged forest floor that is less than half the depth of the undisturbed forest floor (reference value estimated as commented above).

Forest floor is not considered as removed when it is:

1) Intact forest floor of any depth, typically showing roots growing into the mineral soil.
2) Exposed mineral soil covered by dislodged forest floor that is at least half the depth of the undisturbed forest floor (dislodged forest floor must be similar to the adjacent undisturbed forest floor to be acceptable).

a) Very Wide Scalps (**B**): Areas where the forest floor has been removed i) at the survey point and ii) forest floor removed on at least the 80% of an area of 9 m^2.
b) Wide Scalps (**M**): Areas where the forest floor has been removed i) at the survey point and ii) forest floor removed on at least the 80% of an area of 3 m^2. This category is not considered when the prescription allows the use of machinery.

2.5 Harvest Residues

Harvest residues with neither mineral soil nor forest floor that have been piled in the area to be reforested either to minimise the erosion hazard or to facilitate planting operations. They will not be counted as disturbance category as it will be impossible to assess for soil condition underneath them unless they are burnt.

It will be positively taken into account and it will be noted as such in the front cover if:

1) Residues are pushed into windrows following the contour of the land and allowing 3 rows of trees to be planted (around 10 m for radiata pine) to minimise erosion risk.
2) Residues are chopped and spread uniformly all over the stand to minimise raindrop impact and to provide for organic matter and nutrients for the next rotation.

It will be negatively taken into account and it will be noted in the front cover if:

1) Residues are burnt although the soil has no visible damage as defined in the category “Burnt Harvest Residues”
2) Harvest Residues are removed from the area to be reforested even if they are pushed to the bottom of the stand or to an Unplanted Structure.

a) Wide Harvest Residues (**R**): Piles of harvest residues higher than 30 cm i) at the survey point and ii) piles occupying at least 80% of an area of 9 m^2.

b) Harvest Residues. Windrows (**K**): Harvest residues piled on strips i) at the survey point and ii) residues on at least 80% of an area of 4 x 0.5 m.
c) Burnt Harvest Residues (**I**): Piles of burnt harvest residues i) at the survey point and ii) burnt residues occupying an area of 3 m^2. Burnt residues will be considered if the underlying soil shows a massive and oxidised structure different from undisturbed soil. If residues are burnt but no clear affection to soil is recorded, it will be noted in front cover but these areas will be considered as scalps.

2.6 Not evaluated

Not Evaluated (**X**): The survey point falls on a stone, a stump, or other element that cannot be evaluated.

2.7 Not disturbed

Not disturbed (—): The survey point falls on not disturbed soil or on a disturbance category smaller than the ones mentioned above.

2.8 Forest Floor Absence

Forest floor absence (**O**): The survey point falls on whichever category defined above (with the exception of X) but the forest floor is not present. The category is reported as the symbol that represents it and it will be encircled.

3 Survey Methods

3.1 Estimation of the riparian buffer system

If the stand is close to a watercourse the type of riparian buffer system (e.g. riparian forest, shrubs, grassland, not present…) must be recorded in the front cover. To estimate the area occupied by it or the mean width that it has, the lineal structure surveying is carried out (see below). The width and its slope are also measured at ten intervals. The width is considered as the distance from the top part of the riverbank to the imaginary line that connects the trunks of the outer trees or to the end of the vegetation. Calculations are also done as in the "Lineal Structure Surveying".

3.2 Lineal Structure Surveying

A different survey for different lineal structures must be made; for example roads, fire-brakes or electrical lines. If different roads differ in width more than 2 m they are also be considered as different structures, and as such they are surveyed. For each structure the whole horizontal length and at least ten horizontal widths will be measured to estimate the area occupied by it. A visual estimation of the length of the structure to be surveyed is done and this is divided into at least ten intervals in order to estimate the length at which the width is going to be measured. The width is measured as the distance from the outer points of it considering as part of the structure the upper part of the cut and the end of the horizontal plane unless if there is a the fill. If this happens, and if the fill is left unplanted the fill is also considered as part of the structure. The length of this interval and its slope is then recorded along with the width of the structure at that point and its slope. The first width to be measured is set up at half of this interval and afterwards the measures are done on the interval basis. The slopes are recorded in order to estimate the horizontal area of the structure and to be able to estimate the percentage of the stand's surface that is covered by such structures. When the interval for width measurement falls in a landing area it is not recorded and the length that falls in the landing area is not considered for lineal structure calculation. If it falls on a junction of structures the point for width measure is moved until the junction finishes and the width is measured there. The next width is the measure at the point where the interval falls. When the structure is close to a watercourse (less than 50m) it is also recorded with a "V". With the width values measured this way and the t table (one sided, 90% or 95%, depending on the accuracy needed for the survey) the width confidence interval can be calculated and thus the area error for the surface that each structure occupies. Besides, the proportion of structures that are close to watercourses can be assessed. Roads are supposed to be one of the most important elements for erosion and for sediment delivery to rivers.

3.3 Non-Lineal structures

Non-lineal structures are landing areas, logging areas… that are left unplanted. To estimate the area occupied by these structures, four measures are taken in each of them. The length of the structure is divided into quarters and the width at the first and third quarters along with their slopes are measured. The width of the area is also divided into quarters and the length of the area and their respective slopes at the first and the third quarter are measured. The mean of the horizontal lengths and of the horizontal widths are calculated and the area is estimated as the product of these figures for each of them, that can afterwards be added up to estimate the percentage area occupied by these structures.

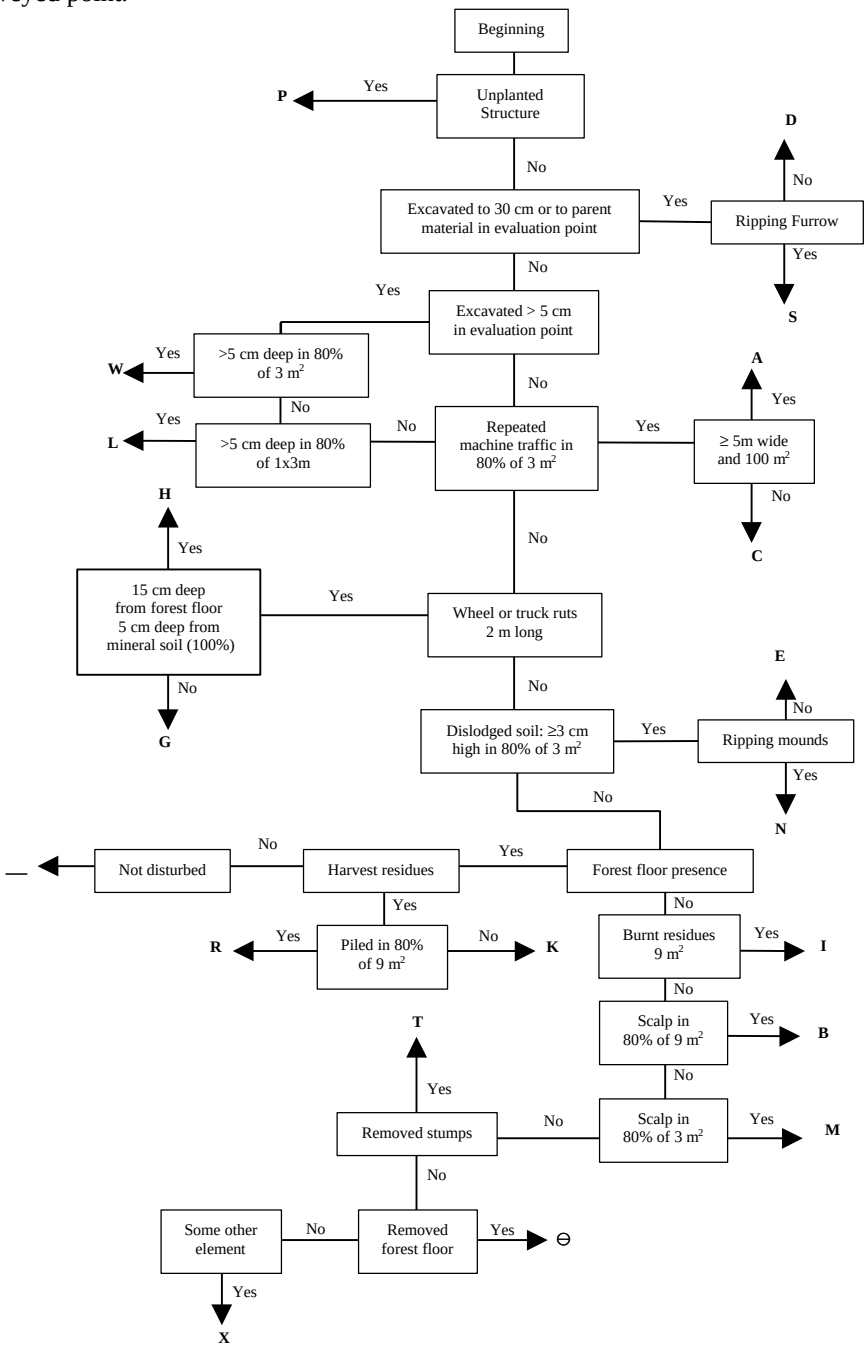
The percentage of the surface that is occupied by unplanted structures is calculated as the horizontal surface of roads and landing areas to the total area of the stand and the area to be reforested is considered as the subtraction of the stand area from the sum of the areas of roads and landing areas and the percentage for the rest of unplanted structures are referred to this area to be reforested.

3.4 Transect surveys for disturbance categories in the area to be reforested

A regular grid of points to be surveyed are laid out in the area to be reforested using parallel transect lines. They are laid out perpendicular to the maximum disturbance assessed visually. Normally, and taking into account the practices used for forest operations in the Basque Country, this maximum disturbance coincides with the slope. Distance between transects and between the points that are going to be surveyed are calculated depending upon the surface of the area to be reforested. If the surface is smaller than 1.0 ha distance from point to point in each transect is 4 m and distance form transect to transect will be calculated to survey 100 points regularly. From 1 ha onwards the distance between points will be 5 metres and the distance between transects will be calculated to be 200 points to 2 ha, 300 points to 5 ha and 500 to areas to be reforested bigger than 5 ha. The first transect is laid out using a randomly generated number list from 0 to 100, and this figure will be used as the percentage of the distance between transects calculated before. Once the grid of points is laid out in field the survey is done recording a disturbance category as defined before to each point following the guide presented below. In order to evaluate each point the maximum disturbed surface around the point will be considered. With these figures and with the probability tables (90 or 95 % depending on the accuracy needed for the estimation) for the binomial distribution the percentage of the surface of the area to be reforested and its confidence limits can be assessed.

4 Guide for assessing disturbance categories.

The following dichotomous guide (fig 1) is used to assign a disturbance category to each surveyed point.



5 Results

Fifteen different stands were surveyed in the Basque province of Bizkaia. The maximum distance between stands is around 40 km. Harvesting, logging and site preparation had been done the same year. None of the stands were harvested by hand and skidder was always used for this operation. Site preparation was done by machinery in 40% of the sites, whereas in the rest of the stands plantation was achieved manually. Harvesting and site preparation was done in the end of 2002 or the beginning of 2003 and soil moisture was high when these operations were carried out. The results from these surveys are presented in table 1.

Table 1. Results from forest soil disturbance surveys carried out during 2003 in 15 stands in the Basque Country. Stands are divided by site preparation practice. All of them were harvested with skidder. The name of the locality served as code for each stand. "Unplanted structures" is the percentage of the area occupied by these structures referred to the whole stand minus the confidence interval for the one sided t distribution at 90% probability. "Disturbed area" and "forest floor removal" are the percentage of the area occupied by these categories referred to the planted area (stand surface *minus* unplanted area). Confidence interval for the binomial distribution at the 90% probability is subtracted to this figure. "Ripping furrows" is the percentage of furrows in slopes >30% referred to the total number of furrows surveyed. Mean slope (%) of these furrows in brackets.

	Surface (ha)	**Mean slope (%)**	**Harvest Residues**	**Unplanted Area (%)**	**Disturbed Area (%)**	**Forest floor Removal (%)**	**Ripping furrows in slopes > 30%**
Manual site preparation							
Aretxabalagane	0.5	15	Windrows	7.51–0.32	59–5.5	47–5.6	NR*
Autzagane	1.5	14	Removed	2.29–0.14	47–6.9	57–3.8	NR*
Astei	1.5	39	Removed	9.53–0.63	74–6.1	70–5.7	NR*
Egia	1.5	25	Removed	3.13–0.21	21–5.7	22–5.8	NR*
Etxaso 1	0.25	10	Windrows	7.5–0.46	75–6.1	73–5.9	NR*
Santa Lucia 1	1.5	30	Burnt	20.66–1.1	83–4.3	77–5.0	NR*
Sarasolalde	2.5	10	Removed	1.56–0.09	55–4.8	49–4.8	NR*
Xaibiko Landa 1	0.6	20	Removed	9.50–0.75	41–6.8	40–6.8	NR*
Xaibiko Landa 2	0.5	10	Removed	9.20–0.66	38–6.8	31–6.5	NR*
Mean (sd.)	1.2 (0.7)	19.2 (10.2)		7.8 (5.7)	55 (20.2)	52 (19.1)	
Mechanical site preparation							
Baluga	5.0	25	Piled	22.43–2.11	87–2.9	91–4.2	21.7 [38.33]
Etxaso 2	0.75	10	Windrows	1.73–0.11	40–6.8	44–6.9	0 [0]
Maiaga	0.4	14	Removed	5.64–0.33	62–6.8	64–5.0	0 [0]
Santa Lucia 2	0.8	46	Removed	6.63–0.48	97–2.7	97–6.9	66.7 [52.36]
Txareta	0.7	31.5	Removed	10.14–0.78	81–4.5	85–5.3	27.8 [42.71]
Txorierrota	1.5	12	Removed	8.37–0.42	74–6.1	75–6.1	5.9 [32.49]
Mean (sd.)	1.5 (1.7)	23.1 (14.0)		9.2 (7.1)	73 (20.2)	76 (19.6)	20.4 (25.5)

*NR: Not relevant

Stands were relatively small, but private owners mainly own forest plantations in the Basque Country, and most of the properties are around 1 ha in surface. Nevertheless, it is striking that the mean slope of the surveyed stands with manual site preparation is smaller than the ones that preparation is achieved mechanically. None of the surveyed practices were achieved bearing in mind possible erosion hazards and the ones with steepest slopes had harvest residues removed. In none of them these residues were chopped (a very rare practice in the Basque country). Some years ago, piling and burning harvest residues were a regular practice. Nowadays it seems that burning is not so usual and this practice was just recorded in one stand.

The unplanted area ranges from 1.6% to 22.4% of the surface of the whole stand. But in absolute figures the maximum surface occupied by unplanted structures was around 1 ha. Road density in this stand is so high that future production is lessened by improper technical prescription.

The use of machinery during harvesting, logging and/or site preparation causes high impacts on the planted area. Validation of this visual characterisation is reported elsewhere. The smallest percentage of soil disturbance was found in "Egia" stand, but 80% of them had more than 50% of the surface disturbed, and just one of the stands where mechanical site preparation was done had less than 50% of its surface disturbed. The practices involved in forest operations also reduce the organic matter content during the inter-rotation period. This fact may have a great impact in future forest nutrition and in the maintenance of a proper soil structure for plant production. When ripping is used as site preparation technique a significant number of the furrows are done on slopes considered as too high for this operation. It is striking the case of "Santa Lucia 2" that has a mean slope of 46% and ripping was used for site preparation.

When the disturbance categories are kept in mind, future production could be threatened in these stands, and it seems that practices must be corrected to improve forest management in The Basque Country. The soil disturbance survey tool developed in this study has been shown as very useful one. It is easy to perform and once disturbance categories are redefined for each particular forest management system and when the electronic records are developed it is a very quick evaluation procedure that could be implemented as a feedback tool towards Sustainable Forest Management.

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