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Research Article

Contribution of the Failure Mode Analysis and Criticality Evaluation method to the rehabilitation of cork oak (*Quercus suber*) forests in Algeria

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ABSTRACT

The *Quercus suber* formations are experiencing significant degradation imposed by both climatic factors and anthropogenic aggression as well as by ineffective management. To stop this process, it is vital to take care of the source factors of danger which are the rainfall regression, the fires, the grazing land and the sylvicultural works. The method chosen to set the prerequisites for a strategy to safe-guard the cork oak forests, is the one used to identify failures in systems: Failure Mode Analysis and Criticality Evaluation (FMACE). The results sought are recorded in a matrix based on the following points:

- Identification of hazard and risk sources.
- Segmentation of the factors causing hazards.
- Risk evaluation (severity, frequency, non-Detection).

The assessment of the dysfunction at the origin of the degraded state of *Quercus suber* formation, helps to target the main threats to this ecosystem. They are recapitulated as follows:

1. Lack of knowledge of the functioning of the cork oak ecosystem and absence of a typology.
2. Lack of mastery of *Quecetum suberis* sustainable management techniques.
3. Poor quality of seedlings intended for restocking.
4. Very strong anthropogenic pressure induced by the grazing land, fires and cork exploitation.
5. Mal-adjusted management facing the stadium of deterioration and of climatic warming.

Key words: *Quercus suber* regression, Failures, Analysis, Evaluation Matrix, Rehabilitation, Algeria.

INTRODUCTION

Very worrying is the situation of Algerian forests in general and those of *Quercus suber* in particular. The permanent impact of overgrazing, a succession of dry years during these last four decades, and sylvicultural work have profoundly disturbed this ecosystem. *Quecetum suberis* is an overexploited ecosystem, weakened by natural (climate and soil) and anthropogenic (overgrazing, overexploitation, fires) pressures. The majority of cork oak forests in Algeria are more than 100 years old and their reconstitution through a strategy of adaptation of sylvicultural techniques and assistance becomes more than imperative.

Benabdeli (1978) and Zeraia (1981), found that it is a seriously threatened formation without no planned action. In 1952, Boudy signalled that this species regenerates badly, the rare young seedling cannot support the dry season for more than six months and on average during four successive years. This situation has made impossible all regeneration for this ecosystem, whose composition and structure are in an advanced stage of degradation. The reconstruction impose therefore imperatively requires voluntarist human action: at least a prolonged defense and, most often, reforestation (Quéze *et al.*, 1990).

Cork production in Algeria declined sharply from 35 000 tonnes (T) in 1965 to less than 8 000 T in 2010 (Fig. 1). According to Mezali (2003), to cover the local needs and generate an export surplus, cork demand would be 30 000 T/year considering the processing capacity installed. Cork production, which currently stands at 12 000 T/year, will

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have to increase significantly in the coming years, thanks to simple operations of management, repopulation and improvement of the access conditions to certain massifs. The cork oak renovation and extension program over 20 years since 1980 did not allow to increase cork production. And no strategy has been adopted for the rehabilitation of algerian cork oak forests. It is completely illusory to want to preserve and extend this already very fragile ecosystem without knowing the causes and dangers that threaten it.

The works exploitation of several authors (Djinit, 1977; Benabdeli, 1978; Zeraia, 1981; Alatou, 1984; Belabbas, 1996; Et tobi, 1996; Merouani, 1996; Djaoud, 2003; Belghazi *et al.*, 2003; Messaoudene, 2008), allows to target the main constraints hindering both the preservation and rehabilitation of the *Quercus suber* formations:

- Irregularity of formations and physiognomy imposed by fires and grazing,
- Presence of all degradation stages and lack of rejection by sowing,
- Dominance of maquis at very clear tree strata and dense maquis,
- Clear maquis with dense undergrowth,
- Old fossil forest tree without future,
- Dominant regressive tendency of productive cork oak forests,
- Lack of cork-cultural traditions and / or appropriate sylviculture,
- Strong natural installation of conifers and competition by other species,
- High failure rate in reforestation.

MATERIALS AND METHODS

It is based on the following approach:

- Diagnosis of the *Quercus suberis* grouping
- Superficies fluctuation
- Contribution of the FMACE method
- Identification of constraints
- Hazard and risk assessment.

Pragmatic diagnostic: Since there are no forests proper, the *Quercus suber* formations are characterized by their heterogeneity, their instability and their bioclimatic, ecological and floristic vulnerability. More than 60% of this situation is due to the lack of control over the forest area and by the most often thoughtless interventions. Exploitation and especially safe-guard conditions currently raise many problems that the manager is not in a position to resolve or at least deal with.

To these totally “matorralised” forest pseudo-formations, general foresters have applied too much exploitation and conservation techniques developed for European forests, techniques which have proved disastrous in the Mediterranean area. On this subject Quézel (1976), noted that « the situation is alarming and a solution must be found in the coming decades if we do not want to witness the almost general destruction of this plant landscape which undoubtedly constitutes an essential factor for the ecological equilibrium of the Mediterranean region.

- How many hectares (ha) since independence have been realised with a success rate of only 25%? It is difficult, if not impossible, to answer this question in view of the decline of cork oak area in Algeria.
- Why has the area decreased from 430 000 ha in the 1950s to less than 230 000 ha today?
- How many good quality seedlings have been produced in specialized nurseries and under acceptable phyto-technical conditions? Less than 5 million seedlings in 50 years.

About forest management, which must be a bible for each type of forest stand or formation, the forest sector is still very much lagging behind. The management imperfections based on conventional forest cutting techniques are known, and have led to an often catastrophic regression of forest stands.

All forest management studies are based on a division of the forest into management units, called series, whose area does not exceed one thousand hectares. They are themselves divided into parcels which must always be served by a road of coachable exploitation, of the most geometric shape possible and of surface which is almost homogeneous and variable, oscillating between 1 and 10 ha depending on the importance of the forest.

Summarizing the bases governing development, Lavagne (1976) mentioned that current development does not take sufficient account of the ecological possibilities of the environment. It is surprising that after 40 years of independence, no planning method adapted to ecological particularities semi-arid and arid forests is not developed, except the forest pre-management initiated by Grim (1989).

The forest inventory established in 1984 by the National Study Office for Rural Development (NSORD), indicates that of the 230 000 ha of cork oak, 61% are represented by old forests tree, 37% by young forests tree, 1% by perch and 1% by copses. 24 years later, and following reforestation and repopulation works, the NSORD reveals in 2008 a subericole heritage of 357 231 ha (Figure 2). The surface area of *Quercus suber* increased, but also the proportion of old forests tree from 61% to 68%. The proportion of perch, on the other hand, improved from 1 to 4,7%. The most abundant are those over 100 years old, which explains the difficulty of natural regeneration (Bouchaour-Djabeur, 2016).

The lack of sylvicultural interventions for a rejuvenation of the cork oak forests and the lack of their own management justifies the decline of the national production. However, more than 90% of the cork oak forests belong to the state public domain, which could have enabled easier, uniform and profitable management of the system, given that decision-making power is centralized (Zeraia, 1981).

Synthesis on the FMACE method: The FMACE is a tool used in the quality and safety approach to the operation of systems. This is the acronym for Failure Mode Analysis and Criticality Evaluation. The method always involves a qualitative identification of the causes, modes and failures effects. There follows a quantitative evaluation of the occurrence frequency of these failures, their severity and probabilities. Applied to fairly complex situations, this method made it possible to identify sources of danger with fairly good precision. Hence his choice with regard to the difficulties to identify the causes at the origin of the cork oak forest situation in Algeria.

Benabdeli and Harrache (2008) emphasize that the aim of this approach is to identify and understand the system operating mode, which allows to identify failures and treat them before they occur, with the intention of eliminate or minimize the associated risks.

FMACE is a more precise and modern means than the classic diagnostic made by foresters; it should make it possible to increase the « MTBF » (Mean Time Before Failure). Its use allows to target the failures of the management system, both technical and organizational of *Quercetum suberis* ecosystem, then revise the classic approach to management formations.

Overview of some already known constraints: In 2012, Benabdeli noted that the major constraints hampering any sustainable governance of forest formations, require a new management approach induced by a sustainable management strategy that remains to be developed. The latter must revolve around the following elements:

- To characterize the forest area ecologically and map it on a medium scale.
- To evaluate the different pressures weight and the ecosystems response.
- To identify the iso-potential areas allowing a stands typology.
- To initiate a pre-management adapted to each typology.
- To control the formations fonctionning dynamics (structure and potential).
- To opt for educational sylviculture to prepare management formations.
- To develop a sustainable management plan for the various forest formations.

Methodology used for contraints evaluation: The use of the FMACE method justified above has been retained and should make it possible to achieve the objectives set, namely:

- Make a diagnostic essentially focused on identifying the danger sources that have caused risks for this species.
- Risk assessment after identifying degradation sources of cork oak formations.
- Target the main disturbance indicators that constitute the faillure ecosystem causes, and allow us to understand the failure modes in order to deal with them.

Application possibilities to *Quercus suber* formations: All formations in *Quercus suber*, whatever their composition, location, potentiality and degradation stage, can be initially identified by the main disturbance indices. These are the causes of ecosystem failure, and allow to understand failure modes, which inform about the failure effects. It will then be possible to correct all the anomalies found in order to opt for a rehabilitation strategy.

The failure mode can be easily identified if there are enough elements on the ecosystem functioning and its characteristics. But this phase makes it possible, above all, to identify the main causes associated with it by drawing on the experiences we have. For criticality, this is the quantitative part of the study where it is recommended to note:

- The Gravity **(G)** of the effects associated with each failure mode.
- The Frequency **(F)** of occurrence of each failure mode.
- The probability of not detecting **(D)** the failure mode.
- The Criticality **(C)** is then defined as the product of the three factors: **C = G x F x D.**

The results obtained are recorded in an evaluation matrix based on the following points:

- Identification of hazards sources and risks.
- Segmentation of hazard source factors.
- Risk evaluation (Severity, Frequency, non-Detection).

The appreciation scale of the different degradation factors of the cork oak forests retained is based on 5 levels (1: very weak; 2: weak; 3: medium; 4: strong; 5: destructive).

Use of a FMACE matrix: In order to identify the main constraints at the origin of the catastrophic situation of the various *Quercus suber* formations, three matrices resulting from the FMACE method were retained and carried out:

- An identification matrix of failures, their causes and their effects.
- A segmentation matrix of the factor's danger source.
- A synthesis matrix evaluating the criticality through gravity, frequency and non-detection.

The development of failures matrix allows initially to target the constraints and to classify them according to their source and their aggressiveness. The latter depends on three causes: organizational, technical or natural; each of them, generates effects, generating a criticality that must be evaluated to prioritize the actions to be undertaken.

RESULTS AND DISCUSSION

The approach focused on identifying and assessing the failures impact on the rehabilitation of cork oak formations has made it possible to develop three matrices:

1. Organizational failures can be grouped into eight (8) types. Each can have and to different degrees, impacts on cork oak stands (Table 1).

2. The technical failures which are identified through the reading of publications and communications directly or indirectly related to the cork oak, are thirteen (13) in number (Table 2).

3. We have identified four (4) natural failures, each of which acts according to its intensity and its impact on the different cork oak formations (Table 3).

Failure synthesis

Classification by failure type: The classification by failure type (Table 4) makes it possible to better determine the major rehabilitation axes of the Quercus suber stands. Technical failures come first and are the main sources of ecosystem degradation. This result is confirmed by all the publications and communications where the problem of failure of rehabilitation and management techniques has been treated.

Organizational failures come in second place since all technical actions depend on them. They bring together the financial, training and management aspects. In the last position, they are the natural failures whereas they are often cited as main constraints.

Table 1: Organizational failures

Factor-source	Gravity	Frequency	No Detection	Score
Development research program very long term	4	5	2	40
Sustainable management strategy	5	3	3	45
Financing of plots that can be developed over 15 years	3	5	4	60
Verification and validation of the research results and development	5	4	3	60
Identification of responsibilities in operations financed	5	4	2	40
Land clearance by protecting endangered spaces	5	3	4	60
Resources valorization to reduce rural pressure	3	4	1	12
Continuous training and coaching in the context of sustainable development	4	5	4	80
Average	4.25	4.12	2.87	49.62

Table 2: Technical failures

Factor-source	Gravity	Frequency	NoDetection	Score
Functioning of cork oak ecosystems	4	5	4	80
Sustainable management of cork oak formations	5	3	4	60
Planting techniques	3	5	4	60
Seedlings quality	5	5	3	75
Living space and density per hectare	4	4	3	48
Cork exploitation	3	3	2	18
Exploitation as rangelands	2	5	1	10
Control of human action	4	4	4	64
Pest attacks	4	3	1	12
Formations typology	5	5	3	75
Genetic aspects and adaptation	4	3	5	60
Rehabilitation techniques of cork oak forests	5	4	4	80
Reallocation of forest formations	3	2	4	24
Average	4	4	3.20	51.23

Table 3: Natural failures

Factor-source	Gravity	Frequency	No Detection	Score
Decreased rainfall	4	5	2	40
Temperature increase	4	3	4	48
Development of secondary species	3	4	2	24
Regressive formations dynamics	4	5	3	60
Average	3.75	4.25	2.75	43

Table 4: Classification by failure type

Failure type	Number	Gravity	Frequency	No Detection	Score
Organizational	8	4.25	4.32	2.87	49.62
Technical	13	4.00	4.00	3.20	51.23
Natural	4	3.75	4.5	2.75	43,00

Failures evaluation of all types: Faced with the multitude of constraints hampering the rehabilitation and even the development of cork oak surfaces in Algeria, it is imperative to opt for a pragmatic approach allowing to:

- Target the danger sources through a exhaustive inventory to understand the possible risks.
- Identify and make an inventory of the various risks facing the cork oak ecosystem.
- Classify the degradation causes of the cork oak forests and locate them in space and time.
- Recapitulate all the failures and evaluate their role in the current situation of the cork oak forests in Algeria.

A synthesis matrix gives a global overview allowing to make a classification of the cindynic causes to be taken care of to elaborate a rehabilitation strategy of the Algerian cork oak forests. The prerequisites for the success of rehabilitation operations can be recapitulated by making a classification based on the failure factors and the value of their evaluation greater than 40 (since the average in table 3 is 43), without taking into account the type (Table 5).

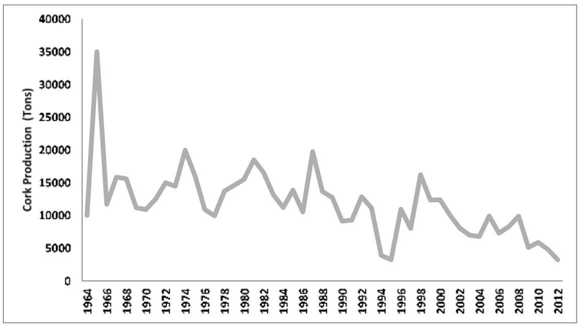

Fig. 1: Annual Fluctuation (1963 - 2012) of cork production in Algeria (in tons) (DGF, 2013)

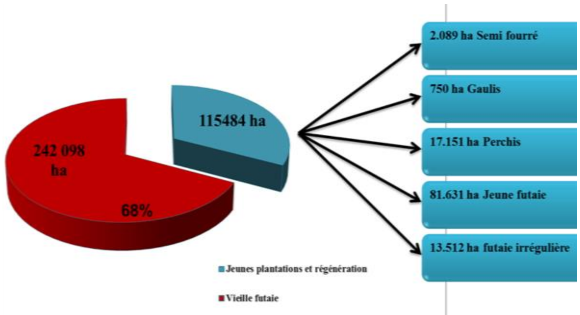

Fig. 2: Composition of the Algerian cork oak forest (NSORD, 2008 in DGF, 2013)

Identification and classification of the main failures of all types: Table 5 is used to classify the main failures and rank them in order of importance. The latter are only constraints hindering the sustainability of this ecosystem important for biodiversity and forest economy (Table 6).

Prerequisites to be lifted for the rehabilitation of cork oak forests: In the development of a rehabilitated cork oak forest strategy, the use of the FMACE method combined with the

Table 5: Failures evaluation of all types confused

Factor-source	Score	Type	Classification
Functioning of cork oak ecosystems	80	Technical	1
Continuous training and coaching in the context of sustainable development	80	Organizational	2
Rehabilitation techniques of cork oak forests	80	Technical	3
Formations typology	75	Technical	4
Seedlings quality	75	Technical	5
Control of human action	64	Technical	6
Regressive formations dynamics	60	Natural	7
Verification and validation of the research results and development	60	Organizational	8
Land clearance by protecting endangered spaces	60	Organizational	9
Planting Techniques	60	Technical	10
Financing of plots that can be developed over 15 years	60	Organizational	11
Sustainable management of cork oak formations	60	Technical	12
Genetic aspects and adaptation	60	Technical	13
Living space and density per hectare	48	Technical	14
Temperature increase	48	Natural	15
Sustainable management strategy	45	Organizational	16
Development research program very long term	40	Organizational	17
Decreased rainfall	40	Natural	18
Identification of responsibilities in operations financed	40	Organizational	19

Table 6: classification of the main failures

Factor-source	Score	Type	Classification
Functioning of cork oak ecosystems	80	Technical	1
Rehabilitation techniques of cork oak forests	80	Technical	2
Continuous training and coaching in the context of sustainable development	80	Organizational	3
Formations typology	75	Technical	4
Seedlings quality	75	Technical	5
Control of human action	64	Technical	6
Regressive formations dynamics	60	Natural	7
Land clearance by protecting endangered spaces	60	Organizational	8
Genetic aspects and adaptation	60	Technical	9
Verification and validation of the research results and development	60	Organizational	10
Planting Techniques	60	Technical	11
Financing of plots that can be developed over 15 years	60	Organizational	12
Living space and density per hectare	48	Technical	13
Temperature increase	48	Natural	14
Sustainable management strategy	45	Organizational	15
Development research program very long term	40	Organizational	16
Decreased rainfall	40	Natural	17
Identification of responsibilities in operations financed	40	Organizational	18

Cause and Consequence Diagram made it possible to identify 25 failures, of which only 18 are supposed to be important.

By grouping together the content of these 18 failures, it is possible to have only 5 determining axes that should be taken care of and which are:

1. Study of the functioning of the cork oak ecosystem with the typology elaboration.
2. Cork oak training and research program for the modern techniques mastery.
3. Sylvicultural techniques of cork oak, production and planting in semi-arid areas.
4. Sustainable development of spaces around cork oak formations to reduce human pressure.
5. Integration of small and medium-sized enterprises in the promotion of cork oak products and by-products.

Conclusion: It would be completely illusory to want to preserve and rehabilitate cork oak forests in Algeria without putting in place a strategy stemming from a precise diagnosis, focused on a methodological approach. The latter, as demonstrated previously, must be based on the determining points identified above, making it possible to deal with all the technical, organizational and natural failures.

After having protected the cork oak forests and understanding their functioning through a typology, their development can only be initiated by a real management of the factors danger source inducing potential and permanent risks. The proposed strategy is based on the following points:

- To understand the cork oak forests functioning through a typology.
- Identify failures and classify them in impact order.
- Professionalize stakeholders.
- Classify failures starting with that of organizational and then technical order.

The mastery of regeneration techniques and a good understanding of the functioning of the *Quercus suber* ecosystem in Algeria, are the two cindynic causes which threaten this ecosystem and constitute today more than ever, a priority for the manager of this species.

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