The role of technical and scientific knowledge production, transfer and dissemination in fire planning and policy[1]

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Abstract

The size of burned areas and the damages of wildfires in Portugal in the last decade promoted a political and technical reflection about the system of defense of the forest against fires. Far beyond initiatives in the planning, prevention, preparedness, suppression and recovery that have been drawn and are partially in implementation, a holistic approach of the knowledge used in the scope of wildfires in Portugal was carried through, because the capacity to create, to spread out and to use the knowledge and the information is the main factor for the economic development and the social welfare.

We mapped the technical and scientific knowledge that is used in the system of defense of the forest against fires, studied the results transference, diffusion and dissemination mechanisms, characterized national scientific and technological production and fulfilled an international benchmarking in the areas of the scientific research and technological development. One demonstrates that the base of knowledge necessary to deal with problems about planning, prevention, preparedness, suppression and the recovery encloses vast and diverse scientific domains, such as natural sciences, forestry and agricultural sciences, engineering and technological and social sciences. We found out that Portugal has scientific capacity (individual and institutional) to support the technical and scientific knowledge production and to participate actively in international projects of I&D, but the system of defense of the forest against fires discloses a low level of incorporation of the available knowledge, little innovation, organization deficit and low qualification of human resources.

In order to overcome the problem identified and achieve the desired goals, research and development activities need to gain scale and critical mass through an internationalization strategy (scientific networking and development of inter-regional projects) while it is crucial to increase the capacity of absorption, the social capital and the level of knowledge at operational level, through staff recruitment and training and the creation of the organization with stimulus that promote the effectiveness and the efficiency. Particular attention must be given to accountability, establishment of goals and quantified objectives. Simultaneously attention must be paid to diffusion of technical and scientific knowledge and dissemination through the diversification of action and co-ordination on public policies.

[1] Part of the work was done in the scope of the Technical Proposal of National Plan of Defense of the Forest against Fires, prepared for the Portuguese Government and published in www.dgrf.min-agricultura.pt and www.isa.utl.pt/pndfci.
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Introduction

Since 1980, more than 2.7 million hectares got burnt, which means one third of the national territory. Forests perform a structural role in the country, particularly as far as environment, water resources, rural development, nature preservation, biodiversity, tourism and energy. Therefore, in a country where 68% of its territory is occupied by wild land (5.7 million ha), one can easily come to the conclusion that the functional vitality of that land is of the utmost importance for the country and the quality of life of the coming generations. As the rate of afforest land is burning about 2.7% per year (100.000ha/year), it's unsustainable to attend that goal, whereas in other European countries the average is lower than 1%. In Spain, where vegetation and weather conditions maybe considered as similar, that value does not go over 0.6% per year. In Portugal, in 2003, 20 persons got killed, 2,500 buildings were damaged, 7,000 farmers suffered severe damages and 40,000 land owners saw 423,000ha burnt, which is to say that 8% of afforest land got burnt (5% of the national territory). Perhaps that is the reason why in 2003, forest fires began to be regarded as a national problem. Up to 2003, and in the previous years, when the burnt area reached exceptionally high values, society acted towards the forest fires in a non systemic and reactive way, producing legislation and injecting more money and material means in order to solve the problem. These isolated and uncoordinated measures did not produce satisfactory results as it was to be confirmed in 2003 and 2005. It was unanimously recognized that the tragic situations experienced in the last two years were not only due to adverse weather conditions, but to some other causes, particularly structural ones.

After 2003 the response was more organized and systemic. The structural reform of the forest sector started. In 2004, 124,000 ha got burnt, and after a very dry winter in 2005, the burned area reached 320,000ha. The Government presented several solutions related with organization and fighting resources. In 2006, only 75,000ha were burn. Although that represents a good result, one can easily understand that, in a general way, it is still rather soon to expect results or to come to the conclusion that the changes have been either appropriated and efficient or enough. Whatever the effective result may have been or will be a new cycle in forest protection has begun.

The Law nº 156/2004 (later on nº 124/2006) foresees the conception of a National Plan of Defense of the Forest against Fires (PNDFCI), approved by the Government. In December of 2004, a team of experts was contracted to produce a technical proposal. The work was developed in close collaboration with public institutions and main stakeholders were involved. The diagnosis encompassed several issues, such as analysis of major public policies that play important role in the fire problem, international benchmarking, analysis of previous actions undertaken in prevention, pre-suppression, suppression and recovery, analysis of communications, logistics and information technologies and analysis of organization, human resources and training. The technical proposal of the plan (presented to the Government in September of 2005) offered thus, a holistic approach to the problem. It was approved and considered by stakeholders as the optimal technical solution, with quantified goals, organization, re-engineering needs, resources, pointers, milestones, economics, calendar and budgeting and also an implementing schedule. The reports are available at http://www.isa.utl.pt/pndfci

Although the study has been approved and presented for public discussion, it was not fully adopted by the authorities and Government. The technical study for the Portuguese National Plan for Prevention and Protection of Forest against Fires was later on, changed by the Government to meet the political needs and to accommodate the institutions resistance. A final version of the plan was published by the official entities on April of 2006 and can be downloaded at http://www.dgrf.min-agricultura.pt/dfci/ Although the plan defines a strategy and articulated different players for active forest management, creating the conditions for the gradual reduction of forest fires, unfortunately no budget or funding was presented to reach a political agreed goal of 2% of afforest annual burning rate in 2012, instead of the technical desired 1%, by 2010.

The problem of fire in Portugal is complex and multiple solutions can help to solve the problem. But, according to several experts, in Portugal there are all the pieces of the jigsaw puzzle necessary to build one of the best forest defense systems against fire in the world, however, the same report notices the absence of a plan and a strategy that makes them work in an integrated way. (Beghley & Quisenberry, 2004). Today, knowledge and the information is the main factor for the economic development and the social welfare (OCDE, 1999). So in the technical proposal of the plan we studied, in a holistic framework, the knowledge base used in the system, its production, transfer and dissemination concerning the scope of wildfires in Portugal. Based on those findings, a proposal for public policies and actions was designed in the scope of the plan. In this paper some results are presented and discussed.

2. The knowledge base mapping of "wildfire cycle"

The defence of forest against fires demands a broad knowledge base on several scientific and technological areas, which have their origin in different institutions and agents. This knowledge can be incorporated in technological goods (e.g. machinery and equipment) or come from immaterial sources (e.g. scientific literature, seminars, staff recruitment) (Smith, 2000). In the technical proposal of the PNDFCI we have employed the method proposed by Smith (idem) – knowledge mapping – which allows us to have a systemic view of the kind of knowledge employed and make the diagnosis of the scientific and technological system.
The method develops according to the following stages (idem):

1) Identification of the main activities of forestry planning and support to fight, prevention, pre-suppression and suppression of wildfires and recovery of burnt areas, support to the affected population (activities of "the wildfire cycle");
2) Identification of the technology and technique used in these actions;
3) Identification of the scientific or technical knowledge underlying the technology and technique used (incorporated in goods or immaterial means);
4) Identification of the institutions (universities, enterprises and government) that supply that knowledge to the agents of forest defence against fires (DFCI).

In our technical proposition we have separated the analyses in five parts:

- Planning of the forest spaces;
- prevention of fire ignition and propagation;
- Pre-suppression of fires;
- Suppression of fires;
- Mitigation of effects and recovery of burnt areas.

On table 1 we present the "controlled fire" and "use of fire fighting hand tools" events as examples of the result of mapping

Table 1 — *Examples in the prevention and suppression areas*

Activity	Technique e tecnology	Base Knowledge	Institutions (examples)
…	…	…	…
Management of forest fuel loads	Prescribed Fire	Forest fuel; Fire behaviour; Fire risk; Fire ecology	DEF-ISA, UTAD (university); ADAI, CEABN-ISA (S&T); DGRF (Government); Forestis (land owners)
…	…	…	…
Tactics and fighting operations	Use of firefighting handtools	Operation with firefighting handtools, building of fire suppression breaks	COTF, ENB (IPsFL); DGRF (Government); AFOCELCA (enterprise)
…	…	…	…

The results achieved show that DFCI employs knowledge of the following scientific and technological areas: Biological Sciences (of Earth and Space), Agricultural Sciences, Engineering and Technology (Mechanical Engineering and Electrothecnical and Informatics Engineering), Social Sciences (several disciplines in this area).

Table 2 — *Examples of contributions of knowledge by scientific dominion.*

Scientific dominion	Main Sciences	Contributions (examples)
Natural sciences	Biology Meteorology	Knowledge of the ecology and resources; Evaluation of the dynamic risk
Agricultural Sciences	Forestry Sciences	Land use planning & forestry management; Fire suppression breaks and use do backfiring; Recovery of productive material
Engineering and Technological Sciences	Mechanical and Electrothecnical Engineering, Informatics	Combustion and propagation of fire; Information and decision support systems Communications (warning, alert and operations)
Social Sciences	Economy; Sociology; Psychology; Geography; Law; Social Communication	Economics of forestry resources; Education campaigns; Forestry policies and of land use management

Some themes are more specific of forest fires and they can even become specializations of knowledge. For instance, fire ecology, the propagation of fire fronts (fire spread models), characterization and management of forest fuel; cartography and geographic information systems; fire risk management and the strategies, tactics and fighting of wildfires. On the other hand, we have scientific matters, which are common to several engineering and economic activity areas. Among others, we can mention the geographic information systems and the communication technologies.

Some issues are getting an increasing importance: supported value of forest resources; relationship between forest fire and natural environment, namely as far as the carbon level, soil erosion and torrential correction are concerned; public participation in the management of fire risk.

3. The national system of science and technology – the Portuguese case

The scope of knowledge areas, the diversity of shapes in which this one may be available and the natural globalization of scientific knowledge make this analysis a rather complex one. In order to obtain a systemic and objective view we shall have to assume simplifications and limitations of the concept and of the analysis fields. So, we have considered the following analysis topics: creation of scientific knowledge; technological development; knowledge diffusion by means of teaching and professional training; knowledge transmission through the activity of enterprises.

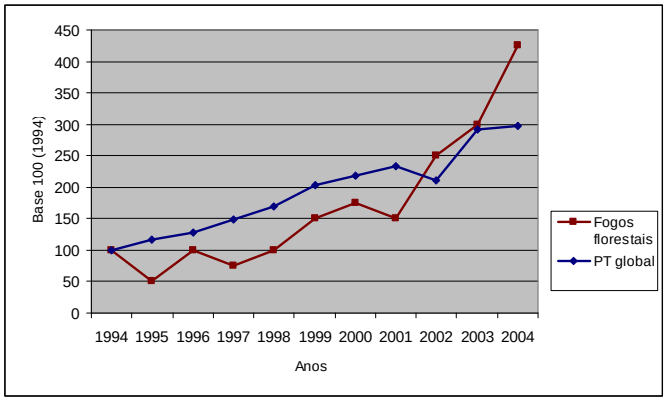
3.1. Knowledge production

3.1.1. Scientific production

Scientific production on the forest fire issue, internationally acknowledged, corresponds to only 0.2% of the national production (six essays a year on average). On table 3 we

present the evolution of the Portuguese scientific production, normalized per 100 in year 1994.

Figure 1— Evolution of the global national scientific production on forest fires



The number of essays on the subject of forest fires has increased three times in the decade 1994 – 2004 and its evolution is similar to the national scientific production. We can notice a highly concentrated scientific production: three authors (2.7%) have participated in almost half of the publications whilst two thirds of the authors have published only one essay.

Table 3 — *Distribution of essays by domain*

Subject	Nº of essays	Nº of national authors	Nº of foreign authors	International Shared authorship *	Factor of Impact**	Quotations
Fuel mapping	3	5	2	0,33	1,212	5
Fire Risk	4	7	4	0,50	1,041	22
Fire behaviour	12	18	8	0,42	0,955	42
Prescribe Fire	2	10	0	0,00	1,210	4
Remote sensing and GIS	16	36	32	0,69	1,968	253
Surveillance and fire detection	2	6	4	1,00	1,612	11
Fire effects	8	18	16	0,75	1,069	38
Atmospheric effects	4	7	17	0,75	2,581	22
Combustion	2	2	4	1,00	0,590	11
Mechanical and Civil engineering	2	5	2	0,50	0,160	0
Geography/Sociology	3	7	2	0,67	1,065	6
Total	58	-	-	0,60	-	414

* % of shared publications among national and international authors
** Average impact factor in science magazines
*** Citation from others authors about number of publications

The essays have focused mainly in remote detection (and other subjects related with GIS), fire behaviour and the effect of fire on living beings, soil and water (to which we

can add the effects on atmospheric environment). The three subjects include 36 essays which stand for 62% of the total number.
The levels of internationalization (60%) are superior to the global national average which, on the period we are observing, has grown from 37.6% to 48.6% (Gomes and others, 2006). In the case of remote detection/GIS and fire effects (including on the atmosphere), they reach 70 to 75%.

From the dates of conclusion of PhD thesis registered in National Observatory for Science an indicator of the maturity level was obtained. The thesis on the fire front propagation appears in the beginning of the eighties' while those concerning controlled fire have begun later, by the end of the decade.

The thesis on spatial spread of fire came forth in 1990. The PhD dissertations on fires and atmospheric effects are more recent, dating from the end of the nineties'. We notice that the more recent subjects are those which present higher impact. This feature proves the existence of different growth dynamics in the different scientific and technological subjects.

3.1.2. Technological development

In the study on the national technological development 28 new technologies were registered (table 4). The information systems (including meteorology) and the decision support system are the most relevant.

Table 4 — *New technologies*

Kind of technologies	Number	Scope	Patents	Promoters	Enterprise involvement
Information systems	7	All	-	State, Public and private enterprises	4
Meteorological information	2	Fuel management and suppression	-	State, Public and private enterprises	1
Support decision systems	5	Fuel management and suppression	-	Universities and non lucrative institutions (IPsFL)	0
Fire spread simulators	5	Planning	-	Universities and non lucrative institutions, State	0
Surveillance and detection systems	5	Detection	2	Private enterprises Universities and non lucrative institutions	3
Suppression equipments	4	Suppression	-	Private enterprises and non lucrative institutions	3
Total	28	-	2	-	11

The fire front spread simulators are regarded as supporting tools for forest planning and decision at the level of prevention (e.g. fuel management) and of pre-suppression (planning of the fire fighting means). They are on the frontier of scientific knowledge and they are supported by public funds. The information systems (including meteorology) are developed by governmental institutions and or by enterprises. They are business opportunities and they can be associated to the need of modernization of public administration.

3.1.3. Knowledge transfer

Forestry university studies focus the issue of forest fires at the different graduation levels. Our study has demonstrated that there is a high scientific and technological potential at the professor's, institutions and infra-structural level. As far as fire physics are concerned we can mention FCT da UC e o IST da UTL. The most relevant institutions are located in Lisbon, Coimbra and Trás-os-Montes (Vila Real and Bragança).

Several diagnosis on the issue of forest fires have stressed that the professional training is a crucial matter of the forest defense system against fires (Beighley, Quesinberry, 2004; Bessa, and others, 2004). The *Escola Nacional de Bombeiros* (National Firemen School) is the pedagogic authority for the professional training of firemen and forest fire fighters. Its three training centers are situated in the south, centre and north of the country, not far from the university institutions in the area of DFCI. The diagnosis achieved showed how difficult it was to obtain information that allowed us either to evaluate the professional training needs or to characterize in detail both the trainees and the trainers. And it was not possible either to evaluate the quality and efficiency of the training. As a result of this diagnosis, the need for a global plan for the professional training of the DFCI[4] agents was stressed.

3.1.5. Knowledge diffusion through market

Knowledge diffusion through market can be typified in consulting enterprises and technical services of forestry planning and management, information and communication technology with a special reference to the geographical information systems, telecommunications and electronics looking for market in the area of automatic surveillance and detection, sale of goods and equipment used in fire suppression. There are some technologies and tools for the support of decision for which there are no commercial enterprises (e.g. fire spread simulation models, and fire risk indicators).

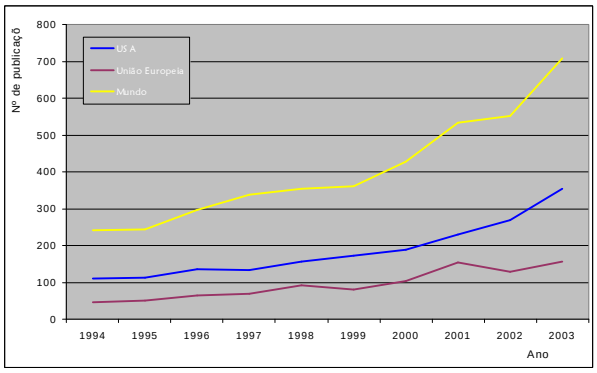
[4] Defense of the forest against fires (in portuguese, *defesa da floresta contra incêndios* – DFCI).

4. Benchmarking exercise

4.1. Scientific production

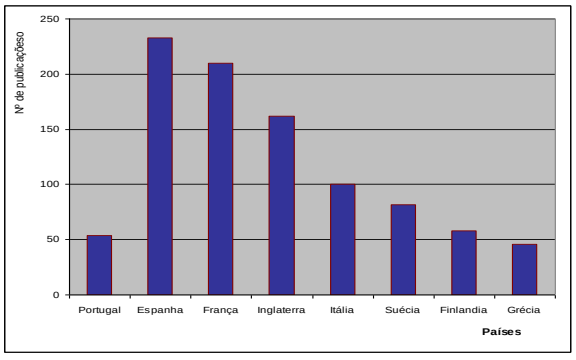
In the period 1994-2003 more than 4,000 specific essays on forest fires were registered all over the world. We can notice that scientific production increased three times in only one decade and that the USA production corresponds to about one half of the world production. The number of essays of the EU countries is about one half of the USA number, which illustrates the difference in dimension between this country and European countries.

Figure 2— Evolution of the scientific production on the issue forest fires (1994-2004)



In the same period, the USA average evolution was similar to that of the EU countries but with two different growth periods. The growth rate from 1994 to 2000 was 9.3%, but from 2000 to 2004 it raised to 23.4%. In 2000 a presented report to the President of the USA gave origin to the National Fire Plan. These results show the importance that this country has given to R&D activities in their national plan. The national evolution is similar to that of the EU countries and the rest of the world, with three times more essays, but the Portuguese scientific production corresponded to 6% of the EU production.

Figure 3— Evolution of the scientific production on the issue forest fires in EU countries (1994-2004)



As we can see from the above figure, there are two outstanding regions: Mediterranean countries (Portugal, Spain, France, Italy and Greece) and the Northern countries (Sweden

and Finland). In Southern countries, forest fires have a relevant social, economic and environmental importance. Although in the other countries forest fires have a much smaller impact but their scientific production is rather high (more than 1300 essays per million inhabitants against the 639 in the EU -25)

4.2. Technological development

The research done in sp@cenet, in the period 1995-2005, allowed us to register 180 world patent related with forest fires (table 5)

Table 5 —*Number of patents per country and type of technology*

	Telecom	Information systems	Detection	Suppression	Indirect	Backfiring	Aerial combat	Suppression vehicles	Retardants	Safety equipment	Other	No data	Total
USA	2	2	4	1	2	0	7	2	6	3	2	0	31
Korea	2	0	1	3	1	0	0	0	1	0	0	10	18
Canada	0	0	0	2	0	0	1	2	0	1	1	0	7
Russian	0	0	2	10	9	5	10	6	2	1	6	2	53
China	0	0	2	6	4	0	3	0	2	0	1	4	22
Australia	0	0	0	0	0	0	0	0	0	0	1	0	1
Japan	0	0	0	3	1	0	0	0	1	0	4	0	9
EU	0	0	11	2	7	0	5	3	2	2	7	1	40
Other	0	0	0	1	0	0	2	1	2	1	0	1	8
Total	4	2	20	28	24	5	28	14	16	8	22	18	189

The greater number of patents registered is in the fire suppression area (direct, indirect and aerial combat; suppression vehicles and retardants material), followed by the surveillance and detection equipments and technologies where EU countries are superior. Russia is the country with a greater number of registered patents (equipments, tactics, vehicles and aircrafts for fire fighting). USA has the leadership in the development of retarding and safety equipment.

Through the research on EU projects with the development of technologies suitable for forest fires, the following results were obtained: predominant relevance of the development of information and decision support systems (in more than 50% of the cases); in four projects (in a total of 5) fire behaviour simulators are developed and, in other five, detection and surveillance technologies are also developed. Portugal participates in about one half of the referred projects: five are related to information and decision support systems and, in other four, fire behaviour simulators models are developed.

4.3. National system of science and technology

The national science, technology and innovation systems have influence upon knowledge production and diffusion in the area of forest fires.

In order to understand better this impact a benchmarking exercise between Portugal and the USA and Spain and France was done (table 6)

Table 7 — *Indicators for Portugal, USA, Spain and France*

	Portugal	USA	Spain	France
Afforest area (millions ha)	3,3	226	14,4	15,2
% of afforest county area	37	25	29	28
Science essays (10 years; ISI)	54	1865	233	210
Number of essays in fire / afforest area	16,4	8,3	16,2	13,8
Number of essays in fire/ researchers (1000 active population (in 2003)	2,7	1,5	2,5	1,1
R&D expenditure / GDP (%) (in 2003)	0,79	2,59	1,05	2,15
Number of researchers / 1000 active population (in 2003)	3,6	9,0	4,9	6,8

In Portugal, country where there is the greatest percentage of forest land and the greatest percentage of burnt forest areas as well, we notice that the Portuguese community is devoted to the study of forest fires, as one can realize through the ratio between the number of scientific essays on this subject and the number of researchers (scientific community dimension) or of forest land hectares (indicator of the problem dimension).

But there are scale problems, proper to a small country, and the national scientific system is still under the principal national references, as we can realize by the intensity of R&D (R&D expenditure/GDP) and by the number of researchers in relation to the working population

5. Key findings and discussion

The results obtained from the knowledge mapping have shown the existence of a wide knowledge base institutionally distributed. This fact arouses some questions, among which we point out:

- How to integrate and consolidate the scientific and technological skills?
- Which study lines should be promoted, which ones should be given priority in a public funded plan?

It is crucial to bring together the mechanisms and processes of integration of the knowledge coming from different areas with the need of effective spreading of that same knowledge to the agents who work in the defense of forest against fires. A public policy measure we wish to propose is the creation of a knowledge network in the scope of forest

defense against fires which can promote the sharing and diffusion of information and skills.

The findings achieved by the study of scientific production demonstrate that this one is strongly marked by the national science and technology system and by country dimension. We notice a highly concentrated publishing of scientific essays (few authors with a great number of essays) and the existence of different dynamics in the principal specialization areas in the forest fires issue. These results allow us to bring some topics into the discussion:

- How to gain scale?
- The forest fires problem is a priority or else an opportunity for research?
- Public funding should rather be devoted to investigation or to innovation?

We propose two political measures in the scope of scientific activity:

- To promote the internationalization and trans-frontier cooperation, mainly in the European Mediterranean region.
- Public funding and grants should be focused for the resolution of specific problems, integrating activities of demonstration and diffusion of knowledge in a culture of accountability and efficiency.

The outcomes of the technological development analysis show the existence of regional differences: Russia and China have a relevant role in innovation and fighting means; the USA are leaders in retardants products; the UE countries develop prevention and forecasting means, namely surveillance equipments, information systems and fire front propagation models.

Portugal is well integrated in communitarian technological development plans but it is a country with a very low level of innovation as we can realize considering the number of patents. The analysis of development of products at the national level, has shown that there are differences in the level of participation of the enterprises and the contributions of university knowledge. Among the several possible questions, always comes out one

- Shall we develop an internal technology or shall we import one?
- How to promote innovation?

We consider that technological development in the area of forest fires must be looked upon as an opportunity for increasing the value of scientific results through partnerships between Universities and enterprises. And, on the other hand, it must be promoted through public markets for the purchase of equipment for the national forest fire defense system.

As far as knowledge transfer is concerned we notice an unequal situation between Universities and professional training schools. In the former case, there is a high potential of teachers and institutions and in the latter we have notice that there is a shortage of trainers and that it is necessary to create a strict and reliable system for the diagnosis of needs, monitoring activities and evaluation of the professional training efficiency. As the principal measure we must emphasize what has been stated in the technical report:

- Implementation of a global professional training of the DFCI agents which must monitored, accompanied and evaluated.

6. Conclusion

The diagnosis study carried out in Portugal allows us to demonstrate that there is capacity of knowledge production potentially useful for forest defense against fires, but institutions and operational agents present a low level of ability and innovation to answer the challenges of prevention and mitigation of fire risk. Considering that knowledge is a crucial element for development and that public policies have influence on the scientific and technological knowledge and innovation, we find it is relevant to integrate a knowledge management element in a technical proposal for a national plan for the defense of forest against fires.

- The national diagnosis has revealed the existence of a scientific capacity that must be consolidated and directed to applied research and development, in view of the resolution of problems, with a greater social accountability, in a multidisciplinary way, involving entities of different nature, in order to achieve relevant results that can be used in the short term (production of knowledge mode 2).
- To increase the capacity of absorption of knowledge at operational levels, we must raise the educational backgrounds and skills of firefighters, recruiting staff with higher levels of education.
- To promote the use of the available knowledge increasing efficiency of operations and activities, at all levels of the system, tasks must have quantified objectives and low relations cost/benefit solutions must be encourage.
- Sharing and diffusion of knowledge must assume a crucial role within the system, especially in the professional training of the agents of forest defense against fires.
- All initiatives presented must be carried out in a context of strictness and evaluation for which the practice of public invitations, observation, monitoring and improvement can be a valuable contribution.

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