LIFE Project Number
<LIFE15 ENV/IT/000183>

Final Report
Covering all project activities (01.07.2016-30.06.2020)

Reporting Date
<20/11/2020>
revised on 07/12/2020

MOTTLES
MOnitoring ozone injury for seTTing new critical LEvelS

Data Project

Project location	Italy - France – Romania
Project start date:	01/07/2016
Project end date:	30/06/2020
Total budget	1,838,406 Euro
EC contribution:	1,079,093 Euro
(%) of eligible costs	60 %

Data Beneficiary

Name Beneficiary	Institute of Sustainable Plant Protection - National Research Council (Now Institute of Research on Terrestrial Ecosystems – National Research Council)
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MOTTLES FINAL REPORT

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2. List of keywords and abbreviations

AISF	Accademia Italiana di Scienze Forestali
AOT40	Accumulated Ozone over Threshold of 40 ppb
CCA	Climate Change Adaptation
CL	Critical Levels
CLec	Critical Levels based on ozone concentrations in the air
CLef	Critical Levels based on stomatal ozone flux
CLRTAP	Convention on Long-range Transboundary Air Pollution
CNR	Consiglio Nazionale delle Ricerche (Italy)
CONECOFOR	CONtrolli ECOsistemi FORestali
COST	European Cooperation in Science and Technology
CREA-FL	Council for Agricultural Research and Economics - Foresta legno (Italy)
DO3SE	Deposition of Ozone and Stomatal Exchange (model)
EA	External Assistance
EEA	European Environment Agency
EC	European Commission
EFDC	European Forest Data Centre
EFI	European Forest Institute
FACE	Free Air Controlled Exposure
FISE	Forest Information System for Europe
FO3X	Free-Air Controlled Exposure
FR	France
Fst	Stomatal ozone flux
FTP	File Transfer Protocol
GA	Grant Agreement
GHG	Greenhouse gas
GIEFS	Groupe International d'Etudes des Forêts Sud-européennes (France)
GPRS	General Packet Radio Service
g_{sto}	Leaf-level stomatal conductance

ICP Forests	International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests
ICP Modelling & Mapping	International Co-operative Programme on Modelling and Mapping of Critical Loads and Levels and Air Pollution Effects, Risks and Trends
ICP Vegetation	International Co-operative Programme on Effects of Air Pollution on Natural Vegetation and Crops
INCDS	Institutul Național de Cercetare Dezvoltare în Silvicultură "Marin Drăcea" (Romania)
IPCC	Intergovernmental Panel on Climate Change
IRET	Institutes of Sustainable Plant Protection (Italy)
IT	Italy
ITP	In the plot
IUFRO	International Union of Forest Research Organizations
IVL	Swedish Environmental Research Institute
JRC	Joint Research Centre
KPI	Key Performance Indicator
KO	Kick-off (meeting)
LCA	Life Cycle Assessment
LESS	Light Exposed Sampling Site
MTR	Mid Term Report
NEC	National Emission Ceilings
NECD	National Emission Ceilings Directive
OFD	Open field plot
ONF	French National Office of Forests
PAR	Photosynthetically Active Radiation
PMP	Project Management Plan
PMT	Project Management Team
PODY	Phytotoxic Ozone Dose above a threshold Y of uptake
ppb	part per billion
PR	Progress Report
RCP	Representative Concentration Pathway
RO	Romania
SCC	Social Carbon Cost

SGS	Start date of the growing season
SIB	Stakeholder Involvement Board
Tg	Teragram
TEV	Total Economic Value approach
UNECE	United Nations Economic Commission for Europe
UNFF	United Nations Forum for Forests
WRF	Weather Research and Forecasting

3. Executive summary

MOTTLES (LIFE15 ENV/IT/000183), funded under the LIFE *Environment and Resource Efficiency* sub-programme, set up a **new European forest monitoring network** to help defining new biologically-sound legislative standards, i.e. with real correspondence to the plant responses detected in the forest. Hence, MOTTLES **equipped a set of 17 sites** from existing networks (ICP forests, and MERA) with new instrumentation in order to obtain for the first time reliable data for the in-field quantification of the **Phytotoxic Ozone Dose** (PODY). PODY is a new and more effective metric proposed as legislative standard rather than the present AOT40, which is based on O_3 concentrations only. PODY is based on estimation of the amount of ozone (O_3) entering stomata during a given time period. This novel monitoring strategy requires active monitoring, that means O_3 concentrations are recorded at forest sites by active sensors in real time (1-hour), instead of the traditional passive monitoring (where passive samplers are collected and analysed every two weeks). The data are transferred by remote to a lab repository. Real time O_3 concentrations are then combined with meteorological parameters to estimate PODY, and with forest health indicators (visible O_3 foliar injury, crown defoliation and hourly radial growth) in order to estimate **critical levels** for O_3. The critical levels are proposed to be used as new legislative standards for forest protection in Europe.

The **new-generation monitoring system of O_3 effects** on European forests is the main result of MOTTLES, realized under action B1. The MOTTLES sites of Italy and Romania are now included in the national lists of NEC sites (National Emission Ceilings Directive 2016/2284) and will continue their activity in the After-LIFE. A delay was recorded at the beginning of the project, due to minor delays in purchasing the instruments and in accessing the sites, so that the entire 2017 growing season was not available at 5 sites. The active and remote management of the MOTTLES stations resulted particularly useful during the lockdown conditions following to COVID-19 pandemic, so that data recording continued even without physical access to the sites. MOTTLES dendrometers were also used to estimate **seasonal tree phenology** (Action B1). Thanks to hourly O_3 and environmental data, yearly AOT40 and PODY values were calculated for the years 2017, 2018 and 2019 under action B2, and different Y thresholds were tested. Combining the results of 3 years of monitoring, action B3 recommended POD1-based critical levels: **12 and 5 mmol m^{-2} for broadleaved species and conifers**, respectively. Meanwhile PODY is adopted as legislative standard, MOTTLES recommends using the following AOT40-based critical levels for ≥ 25% of crown defoliation in a plot: 17 and 19 ppm.h for conifers and broadleaved species, respectively. Field test and standardization of PODY use in O_3 risk assessment for forests is one of the main MOTTLES best practices (Action B3). Compared to radial growth and crown defoliation, the **visible O_3 foliar injury** resulted as the best plant response indicator of O_3 injury to forests. Action B4 produced exceedance maps for 2017, 2018 and 2019 in order to define the effectiveness of air pollution control European directives. For 2017, we found exceedances at 6 out of 12 sites evaluated (1 in France, 2 in Romania and 3 in Italy); for 2018, all the Italian sites exceeded the POD1-based critical levels, together with 1 French site; for 2019, we found exceedances at 2 sites in France and Romania and 3 sites in Italy. Action B4 resulted also in the production of **printed guidelines** for improving the **effectiveness of air pollution control strategies** for ecosystem protection. To favour harmonization and cross-validation of survey results, a species-specific **atlas of visible O_3 foliar injury** was realized and made available online at the MOTTLES website https://mottles-project.wixsite.com/life.

A validation system was also developed for non-validated visible foliar O_3 injury, by making use of an O_3 free-air controlled exposure (FACE) facility (Action B1). The FACE device was also used to complete the parameterization of species-specific stomatal conductance for estimating PODY for all target species of the MOTTLES network (Action B2). This ozone FACE remains available to interested stakeholders in the After-LIFE.

MOTTLES was a unique opportunity to compare the active O_3 monitoring system with the traditional passive samplers both in economic and environmental terms (**Life Cycle Analysis**). Action C2 found that the MOTTLES active system was more sustainable even after 5 years from installation, leading to a **saving for the whole network of 102 tons CO_2-eq in case of deciduous forests and 194 tons CO_2-eq in case Mediterranean evergreen woods.** These savings increased over time. Despite high costs of installation, the economic costs of the new system for site managers after 5 years resulted in savings of **9-10 k€ per site** in the case of deciduous forests and **20-23 k€** in the case of an evergreen Mediterranean forest, mainly due to lower travel and personnel costs than in the passive system. An estimation of the total economic value of O_3 effect on Italian forests confirmed a **significant impact of O_3**, ranging from **1.2 B€ to 3.0 B€ of capital value** (average from 382 to 949 €/ha). The annual damage ranged from 46.3 M€ to 61.9 M€ (average 15-19 €/ha per year). Under Action C1, questionnaires to assess the awareness of citizens about the air pollution and climate change issue were disseminated. A Contingent Valuation Method was used to evaluate the **willingness to pay** to save forests from climate change: 100€ yearly for the next 10 years. MOTTLES results were summarized in a toolbox of best practices about O_3 monitoring and the definition of critical levels for European forests (Action C3). Finally, by combining a review of present forest management practices for adaptation to climate change (Action C3) with the numerous feedbacks received by stakeholders (Action D2), MOTTLES developed guidelines with recommendations and effective adaptation measures for sustainable forest management with an important focus on the management of urban forests. All key findings were collated and disseminated to a **wide range of stakeholders** for long-lived exploitation of results, e.g. by educational activities (311 students reached), scientific papers (x 18) and presentations at stakeholder-oriented meetings and conferences (x 54).

All **project objectives**, technical interventions and reporting expected from the project proposal were **achieved and respected**. Due to some unforeseen changes in the availability of personnel in the final phase of the project, the support of external companies was required in order to respect the deadlines. This deviation did not determine substantial modification to the budget.

CNR ensured the project coordination. In Italy, CNR provided scientific knowledge for field campaigns (e.g. assessment of crown defoliation, visible O_3 foliar injury, radial growth), statistical studies, and was in charge of the station set-up. CREA-FL provided scientific knowledge for modelling O_3 fluxes and correlating forest responses and O_3 metrics. In France, ARGANS collaborated with CNR for equipment set-up and GIEFS was in charge of the surveys of O_3 impacts. In Romania, INCDS was responsible for equipment set-up and field campaigns. CREA-FL collaborated with CNR in deriving maps of O_3 risk and analysing the best criteria and thresholds for O_3 pollution protection. All partners contributed to dissemination activities as well as the socio-economic assessment of the project.

Figure 1 shows the links among the core actions inside the MOTTLES project.

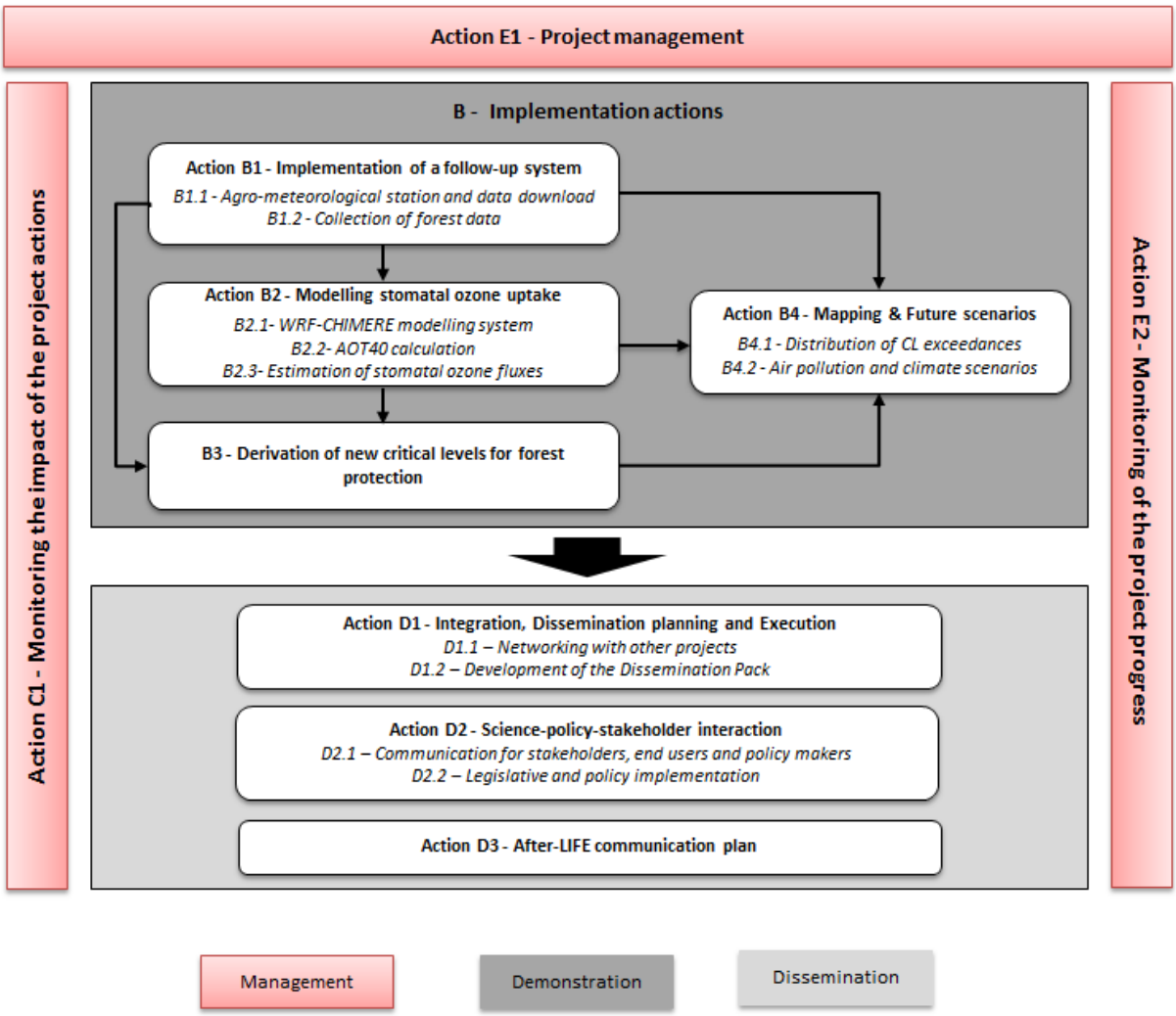


Fig. 1 - Core actions of the MOTTLES project

4. Introduction

Climate change and air pollution are interlinked and challenging for European forest management. Ground-level tropospheric ozone (O_3) is a phytotoxic air pollutant formed from photochemical reactions from its precursors such as nitrogen oxides (NO_x) and volatile organic compounds (VOCs). While O_3 is a normal component of the troposphere, its background concentrations in the Northern Hemisphere have doubled since pre-industrial times, with negative effects on human and forest health. The surface O_3 concentrations are expected to increase with climate change. Exposure to elevated O_3 concentrations produces biochemical and physiological changes in plants with inhibition of carbon assimilation by photosynthesis when O_3 penetrates into the leaf through stomata. Once in the leaves, O_3 causes cellular damage and may cause early leaf shedding and visible leaf injury. Such damage may be exacerbated by environmental stress. Hence, **O_3 pollution has large impacts on plant functioning, forest ecosystem productivity and other forest services**.

At European level, O_3 is regulated by directives that limit emissions of precursors based on AOT40, i.e. a concentration index, calculated as sum of the hourly exceedances above the concentration of 40 ppb, for daylight hours (8am-8pm) during the growing season. Over these limits, national and regional regulatory agencies must provide countermeasures. Thanks to monitoring and scientific studies, it was found that exceedances of these limits do not match the pollutant effects recorded as forest health indicators, therefore **AOT40 does not seem to be an optimal standard for the protection of forests against O_3**, especially during warm seasons when stomata close in response to drought stress.

MOTTLES set the objective of establishing a new European forest monitoring as a basis for defining **new legislative standards** that are **biologically significan**t, i.e. with real correspondence with the plant responses detected in the forest. Since O_3 background concentrations are increasing, it is important to define appropriate and realistic critical levels, representative of actual field conditions, to **a) protect vegetation; b) improve understanding and monitoring of O_3 effects on ecosystems; c) scientifically assess the effectiveness of air pollution control strategies and d) undertake measures for abatement of O_3 precursors emissions.** Hence, MOTTLES equipped a set of 17 forest sites belonging to existing networks (ICP forests, and MERA) with new instrumentation in order to obtain for the first time reliable field data for the quantification of the **Phytotoxic O_3 Dose (PODY)**. PODY is a new and more effective metric proposed as legislative standard which is based on estimation of the amount of O_3 entering stomata during a given time period. The novel MOTTLES monitoring strategy is based on active monitoring, that means O_3 concentrations are recorded at forest sites by active sensors in real time (1-hour), instead of the traditional passive monitoring (where passive samplers are collected and analysed every two weeks).

Following the revision of the NEC Directive (National Emission Ceilings Directive 2016/2284), the interest in calculating PODY based on site-specific monitoring is increasing in Europe. A harmonized procedure for calculating PODY at forest sites is the main MOTTLES output of the impacts on environmental policies. **The exceedances of PODY critical levels and visible foliar O_3 injury are now recommended as indicators in the revised NEC Directive**. The EU Member States shall monitor the impacts of air pollution (including O_3) upon ecosystems, based on a network of monitoring sites representative of their habitats**. MOTTLES, unique in Europe, is able to provide those O_3 indicators for forest ecosystems**.

Indeed, sites of Italy and Romania are now included in the national lists of NEC sites, which is a major long-term policy-related effect of MOTTLES.

The monitoring stations will continue collection of O_3 and environmental data after the end of the project. All the European critical levels will be periodically revised as new scientific information becomes available. The analysis of the monitored data for estimating the critical levels as well as the mapping of the critical level exceedances will be carried out once a year as part of the partners' institutional activities, with the aim to assess the effectiveness of air pollution control strategies in the European Union. The validation of guidelines by MOTTLES allows the transfer of these innovative methodologies for a more coherent policy on forest protection in Europe, in response to the climate change challenges. The application of the MOTTLES method will make a positive contribution to the convergence and policy leading up to the effectiveness of forest monitoring by providing a framework for research and analysis. The results were transferred to ICPs for encouraging the adoption of this new monitoring approach at pan-European scale and beyond. MOTTLES demonstrated that the new system is also **sustainable from an environmental and economic point of view** in the longer time, hence we wish that our results may stimulate the development of similar networks all over the world.

Fig. 2 - MOTTLES team at the first progress meeting (04/07/2017)

5. Administrative part

5.1 Description of project management process

Project management activities: i) ensured the interfaces with the European Commission (EC) and the partners of the consortium; ii) monitored the project tasks and iii) ensured a nominal progress while keeping the project risks under control. A management structure supported reliable day-to-day management and effective decision-making.

Project Coordinator

The overall project coordination was carried out by CNR (**Elena Paoletti**) who is the single point of contact for the project for the EC and external communication.

Elena Paoletti, senior scientist, is a forest eco-physiologist and works in particular with the impacts of air pollution and climate change on forest ecosystems. She is Deputy of IUFRO Division 8 "Forest Environment", vice-president of SISEF (Italian Society of Silviculture and Forest Ecology) and Chair of the Scientific Advisory Board of the European Forest Institute (EFI). Invited speaker or chairperson at several scientific meetings, she was member of the organizing/scientific committee of > 50 meetings.

The Project Coordinator was responsible for overall coordination, i.e. all aspects of project management, including technical actions, schedule monitoring, direct interactions with the partners of the consortium, and management of all actions and financial issues covered by the Grant Agreement (GA). The Project Coordinator exchanged regular information with the EC and stakeholders, in order to give the best overview of all the achievements during the contract.

Every year, an annual work plan specified in detail the timing of technical execution and related financial expenditure. The dashboard established a calendar of activities and expected results. Each year, the following issues were defined: expected results to be achieved, activities to be performed, and budget specifying funds needed to carry out the annual work plan.

Project Management Team

The Project Management Team (PMT) was the ultimate decision-making and principal management body, responsible for long-term and major strategic decisions, for discussing and suggesting solutions, project changes, tasks distribution and related resources. The PMT ensured scientific coordination of actions and performed scientific review of deliverables for submission to the EC. The PMT included Project Coordinator **Elena Paoletti**, Quality Assurance Controller **Elisa Carrari** and two leaders having an excellent proven track record in line with the project: **Ovidiu Badea** (INCDS) and **Pierre Sicard** (ACRI-HE & ARGANS).

Quality Assurance Controller

Elisa Carrari was recruited as quality assurance controller since September 2016 to the end of the project but she had to quit her role earlier, i.e. in February 2020. She was responsible for all administrative matters with the EC including: contract follow-up, invoicing processes, contract negotiation. She tracked production of deliverables, maintained the list of action items and

provided support for organisation of meetings and reviews. She supervised implementation and maintenance of the MOTTLES database for reporting and management, including adaptation of the structure after changes in the work plan and the consortium. The Quality Assurance Controller reported to the Project Coordinator and advised her on the matters mentioned above and under her responsibility. From March to June 2020 the project coordinator with the help of the PMT was in charge of this role.

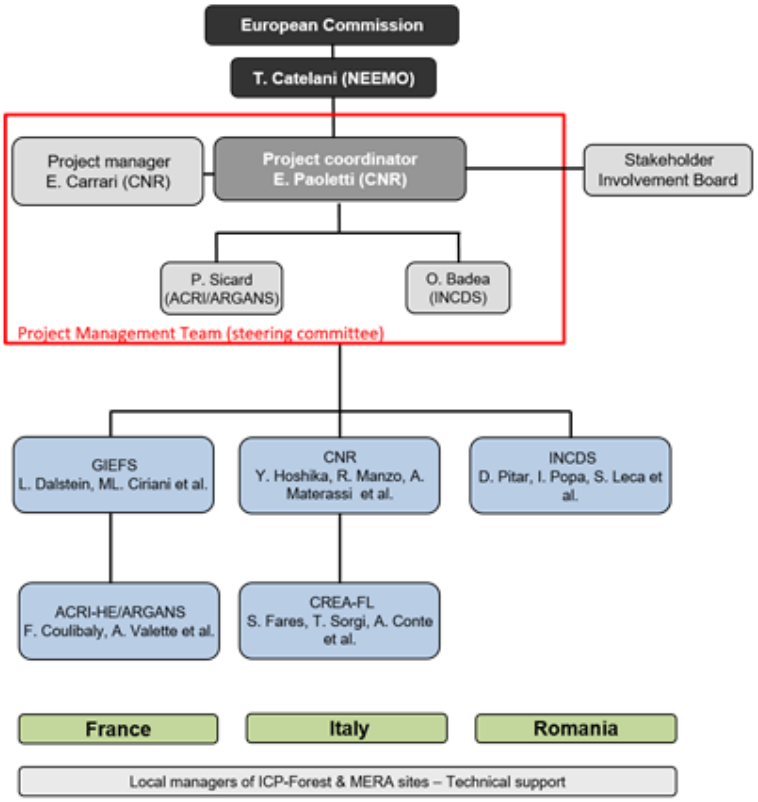


Fig. 3 - Schematic representation of the MOTTLES partnership

5.2 The project team

CNR, Consiglio Nazionale delle Ricerche-Istituto di Ricerca sugli Ecosistemi Terrestri, via Madonna del Piano 10, 50019 Sesto Fiorentino (IT)

In addition to the Project Coordinator, other CNR personnel were:

Raffaella Manzo, **Francesca Pesciolini**, **Giovanni Torraca**, **Anna Romagnoli**, and **Maurizio Meoni** (permanent technicians), coordination support (Action E) and maintenance of the whole website (Action D2) from July 2016 to December 2018 (except Anna Romagnoli and Raffaella Manzo involved in the project until April 2019). **Moreno Lazzara** (permanent technician), scientific technician, support to field work (Action B1) for the entire project duration. **Alessandro Materassi**, **Gianni Fasano**, and **Francesco Sabatini** (permanent technicians), scientific technicians in charge of the equipment set-up at Italian sites (Action B1). A. Materassi and F. Sabatini for the entire project duration, and G. Fasano until December 2019. **Elisa Carrari** project management assistance, quality assurance controller and surveyor in the field (all actions) up to February 2020.

Sandra Podda (temporary contract as grant fellow), biochemist for the validation work at the FACE system in Sesto Fiorentino (Action B1) from February 2017 to January 2018. **Alessandro Anav** (temporary contract as grant fellow), modeller for the elaboration of maps of critical level exceedances (Actions B2, B3, and B4) from February 2017 to January 2019. **Alessio Giovannelli** (permanent scientist), expert in xylogenesis and dendrometers (Action B1) for the entire project duration. **Yasutomo Hoshika**, researcher, in the first year (from July 2016 to May 2017) he was granted by another project (FP7 ECLAIRE), however his work was largely pertinent to MOTTLES, and thus he collaborated with MOTTLES partners. He is expert in modelling of environmental responses of plant species to changing environments, such as O_3 stress (Action B2). For 2 technical seminars (e.g. ICP Vegetation in 2016), he was the most adequate person to represent the project and to present the technical results. The associated costs (travel and subsistence) until May 2017 are eligible. He got a temporary contract as CNR researcher granted by MOTTLES from 1st June 2017 to 31st December 2018. From 1st January 2019 he was hired as permanent staff by CNR and continued to contribute to MOTTLES.

ACRI-HE until 31st December 2017, 260 route du Pin Montard BP 234, 06904 Sophia-Antipolis cedex (FR)

Pierre Sicard, Dr in atmospheric chemistry, was involved in the PMT (action E1), in charge of the equipment set-up at French sites and provided scientific knowledge for meteorological and chemistry modelling, modelling stomatal O_3 uptake, statistical studies and derivation of critical levels (actions B). He was leader of actions B3 and D1 for scientific networking and outreach activities.

Other personnel:

François-Regis Martin-Lauzer, scientific director, expert in Air and Meteorological modelling and interactions with stakeholders. Activities in B1 for partnership agreement with local forest managers (French sites) and in action E1 for administrative and financial issues. **Anne Vallette**, responsible for all the contractual and administrative matters with the EC. Actions D1 and D2 for dissemination activities.

ARGANS from 1st January 2018, 260 route du Pin Montard BP 234, 06904 Sophia-Antipolis cedex (FR)

Pierre Sicard, PMT, leader of Actions B3 and D1. **François-Regis Martin-Lauzer**, scientific director, involved for the entire project duration. **Anne Vallette**, administrative issues, involved for the entire project duration. **Fatimatou Coulibaly**, Junior engineer, as internship granted by MOTTLES from 13th March 2018 to 31st August 2018. From 1st September 2018, she was hired as permanent staff and worked in Actions B2 and B3 - Deep bibliographic review on critical levels definition; and Action D1 - Dissemination and publication. **Jérôme Lebreton**, internship from 18th May 2020 to 30th June 2020. Actions B3 and B4 - Technical support for mapping of environmental and forest data.

GIEFS (Groupe International d'Etudes des Forêts Sud-européennes), 69 avenue des Hespérides, 06300 Nice (FR)

Laurence Dalstein (permanent scientist until 28th February 2018) was in charge of field coordination and training of the campaigns for the assessment and the validation of the O_3-

induced injury. GIEFS was leader of Action D2 "Science-policy-stakeholder interaction". **Marie-Lyne Ciriani** (temporary technician until 31st August 2019) was responsible for in-field surveys, data validation, inter-comparison exercise, data processing and communication with foresters. **Camille Peracchia** (from 5th August 2019 to 31st October 2019), internship/engineer, support for intercalibration training courses for visible injury assessment (Action B1). **Anumol Govind Shashikumar** (from 2nd January 2020 to 19th June 2020), Engineer. Redaction of the report and interpretation, statistics on the data (Action B1).

INCDS (Institutul Național Marin Drăcea), Bulevardul Eroilor 128, Voluntari (RO)

INCDS was leader of actions B2 and C1. INCDS participates and contributes to dissemination activities (Action D1) and for the provision of the network to other projects also aiming at meeting information needs of EC (Action E1).

Ovidiu Badea (senior scientist), Dr in forest management, involved in the PMT, provided scientific knowledge for crown condition assessment, tree growth assessment, statistical studies and derivation of critical levels (Actions B) for the entire project duration.

Other personnel:

Diana Pitar (Silaghi), in charge of Action C1, expert in O_3 fluxes modelling and O_3 visible injuries assessment for the entire project duration (except January 2018 - March 2019 when she was on maternity leave). **Ionel Popa** and **Flaviu Popescu**, experts in tree growth measurements and modelling for the entire project duration. **Stefan Leca**, in charge of the equipment set-up at Romanian sites for the entire project duration. **Șerban Chivulescu**, **Adrian Dobre** and **Raducu Stanculeanu**, in field equipment set-up and in field measurements team for the entire project duration. **Adriana Gatu**, responsible for the financial reporting (for the period January 2018 - March 2019). **Anghelus Cristian**, Technician for the entire project duration. **Nedea Gabriel**, Technician for the entire project duration. **Garcia Duro Juan,** Junior scientist in tree growth modelling (additional personnel only in February 2020).

CREA-RPS (Consiglio per la Ricerca in Agricoltura e l'analisi dell'Economia agraria - Centro di ricerca per lo studio delle relazioni tra pianta e suolo, Via della Navicella 2/4 Rome (IT) until 31st August 2017; now **CREA-FL** (Consiglio per la Ricerca in Agricoltura e l'analisi dell'Economia agraria-Foreste e Legno), Viale Santa Margherita, 80 Arezzo (IT)

Silvano Fares (scientist), Dr in Forest Ecology. He contributed to the equipment set-up at Italian sites and provided scientific knowledge for modelling stomatal O_3 uptake (Actions B1 & B2). He was leader of Action B4. CREA-FL participated and contributed to dissemination activities (Action D1) and project management (Action E1).

Other personnel:

Tiziano Sorgi, and **Filippo Ilardi**: permanent technicians involved in field campaigns (Action B1) for the entire project duration. **Luca Salvati**: permanent scientist involved in statistical analysis and future scenario (Action B4) until 28 February 2020. **Valerio Moretti:** technician (temporary), assigned to MOTTLES from April 2018 to February 2019 (Actions B1 & D1) and from April 2019 to March 2020 (Actions B3 & C1), strongly involved in field set up for his long activity and experience on CONECOFOR sites. **Adriano Conte,** PhD-student in Forest

Ecology with Dr Silvano Fares. Expert in plant ecophysiology, in particular in the analysis of O_3-induced injury in the field. Although not directly assigned to MOTTLES, he provided strong and helpful scientific and technical support in the project and collaborated with GIEFS, INCDS and CNR. Their excellence and involvement were necessary for the good implementation and success of the planned activities. Thus, for some technical seminars or meetings (e.g., KO meeting, visit at Castelporziano), Adriano Conte was the most authorized and adequate to represent the project and to present the technical part and results. The associated costs (travel and subsistence) may be eligible. From 1st August 2019 to the end of the project, he was hired as technician (temporary) for setting up field station and instrumentation, mathematical model and measuring methodology for environmental monitoring and data collection at ICP-Forest sites (Actions B1, B2 & B4); assessment of the project actions impacts on local economy and population (Actions C). **Alessandro Alivernini,** Researcher (temporary) from December 2017 to December 2018, junior scientist, ecophysiologist: support in field surveys (e.g. crown condition, growth, and phenology) for air pollution and climate change impacts on forests at selected sites (Italy); parameterisation of the stomatal O_3 flux model with local data (Actions B1, B2 & B4).

5.3 Action Leaders

The **Action Leaders**: i) coordinated activities and ensured communication amongst participants; ii) took decisions on technical methods; iii) ensured the timely production of deliverables and iv) coordinated interaction and collaboration with other actions.

Table 1 - List of Action Leaders

Action	Name of the responsible
B1 - Set up of the monitoring system and data collection	E. Paoletti
B2 - Modelling stomatal ozone uptake	O. Badea
B3 - Derivation of new critical levels for forest protection	P. Sicard
B4 - Mapping & Future scenarios	S. Fares
C1 - Monitoring the impact of the project actions	D. Silaghi
C2 - Assessment of the project actions impacts on socio-economy	E. Carrari
C3 - Forest health & resiliency through integrated management practices	E. Carrari
D1 - Integration, Dissemination and Execution	P. Sicard
D2 - Science-policy-stakeholder interaction	L. Dalstein-Richier
D3 - After-LIFE Communication plan	P. Sicard
E1 - Project Management	E. Paoletti
E2 - Monitoring of the project progress	E. Carrari

5.4 Partnership agreement status and key contents

A partnership agreement was established between the Coordinating Beneficiary CNR and the associated beneficiaries (GIEFS, ACRI-HE/ARGANS, CREA-FL and INCDS) and signed on 13th September 2016. This partnership agreement specified the rules applied during the project life for the best cooperation and activities implementation such as the role and obligations of the coordinating beneficiary and associated beneficiaries, common obligations, conflict of interest, technical activity reports, confidentiality, financial reporting and payment terms. An original copy of the signed document was delivered to each partner.

5.5 Communication between partners

The project coordinator ensured timely, appropriate exchange of information about the project status, work planning and issues of importance and relevance to partners. Internal communication was maintained through telephone, Skype, and e-mail communication, regular progress reports from partners, and the project website. Partners and the project coordinator met regularly along the project to ensure a smooth and efficient project management. Since March 2020 according to the lockdown due to COVID-19, meetings took place on-line. An agenda was developed prior to each meeting and circulated. Copies of agendas and brief decision minutes were drafted and circulated to all partners. Typically, a physical meeting took 3 days, excluding travel. Meetings took place at partner institutions offering meeting facilities at limited cost. Some items (Table 2) were regularly updated and presented at progress meetings, and some topics were included in the progress reports.

Table 2 - Topics and update of the Project Management Plan

Topic	Updated with	Frequency
Management rules to be applied	New rules	As necessary
Precise description of work	Depending on the progress and difficulties met, work and schedule adaptations may be proposed	As necessary
Resources allocated to deliver project	Depending on the progress and difficulties met, revision of resource allocation may be proposed, as well as leader of activities in case of failure	As necessary
List of deliverables and the due date of delivery	Status of deliverables	Monthly
List of actions	Status of actions; new and closed actions	Continuous
Travel plan and budget	Meetings pre-organised; new meetings not initially planned; current expenditure, remaining budget	Monthly
Risk assessment and mitigation actions	New risks; new mitigation actions; status of previously identified risks	Monthly

5.6 Communication with the EASME and Monitoring team

The coordinator beneficiary had frequent contacts with the monitoring team. Whenever there was need the coordinator (E. Paoletti) or the Project manager assistant (E. Carrari) received support from T. Catelani (NEEMO external monitoring team). The regular face-to-face reviews and exchanges of information through emails and by telephone allowed ensuring a smooth and efficient management of the project. Beneficiaries reported MOTTLES activities to the monitor monthly until January 2019, after which 6 quarterly reports were delivered, according with modification in NEEMO requests.

In addition, monitoring visits were organized every year, on 21 November 2016, 21 May 2018, and 28 May 2019 in Florence, and online on 24 April 2020 due to the COVID-19 lockdown. On these occasions the monitor provided essential advice for the realization of the project, as in the case of the realization of progress reports, in the compilation of the project indicators and for project amendments. After each monitoring and progress report visit, the beneficiaries received letters from EASME (in the person of Milina Schumannova), specifically:

1) Ares(2017)3490333 - First monitoring visit, received on 11/07/2017;
2) Ares(2017)5921770 - Mid Term report, received on 04/12/2017;
3) Ares(2018)5905288 - Second monitoring visit, received on 19/11/2018;
4) Ares(2019)5076373 - Progress Report & third monitoring visit, received on 03/08/2019;
5) Ares(2020)2888553 - Fourth & joint monitoring visit, received on 04/06/2020.

Letters and specific replies are attached to this report (Annexes 1-5).

Moreover, NEEMO supported the beneficiary coordinator in occasion of the two amendments to the Grant Agreement (described in §5.7), as well as communication regarding the modification in coordinating beneficiary details delivered to EASME on 8 August 2019 and accepted without amendment request on 10 October 2019 (Annex 6).

5.7 The changes due to amendments to the Grant Agreement

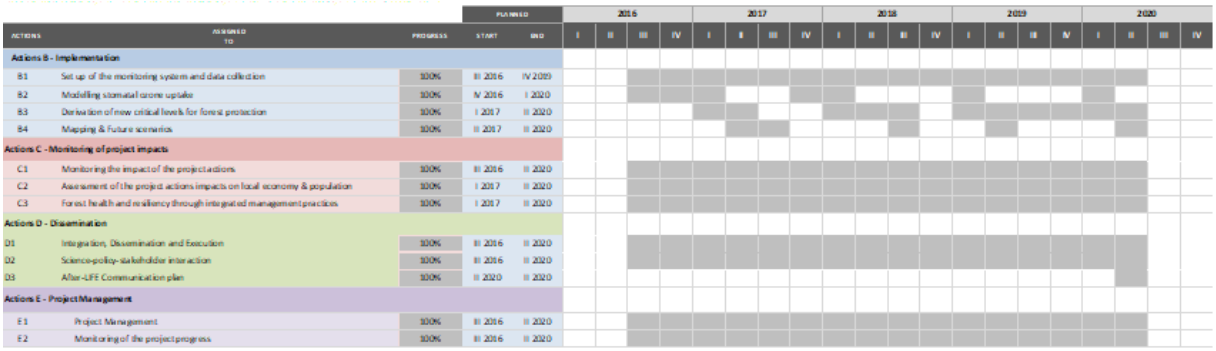
Following the re-organization of CREA, MOTTLES is now in charge of CREA-FL (Council for Agricultural Research and Economics - Forestry and Wood), and no longer to CREA-RPS (Council for Agricultural Research and Economics - Soil-Plant System). The project is still under Silvano Fares' coordination. For this reason, EASME asked for an Amendment in the MTR letter of revision. The procedure of an amendment for *associated beneficiary administrative modification* started as soon as the letter was received, and was completed in November 2017 (Annex 7). The amendment was accepted with the letter available as Annex 8. Such a change did not affect the quality and quantity of work carried out by CREA-FL in MOTTLES as well as the financial duties of CREA-FL in MOTTLES.

The associated partner ACRI-HE sold on 31st December 2017 all the activities to ARGANS, headquarters in Plymouth UK, with former ACRI-HE as French branch. This cession led to the removal of ACRI-HE from the Trade and Company register, from the 8th of March 2018. The reasons for this change were not known before the signature of the grant agreement. Therefore, we informed the external monitoring team (NEEMO) and all associated partners during the second visit in Florence in May 2018. An amendment procedure for *partnership modification* started just after the monitoring visit and was completed in December 2018 (Annex 9). The

amendment was accepted with the letter available as Annex 10, the required documentation was signed and sent back to EASME on 4th December 2019 (Annex 11).

6. Technical part

For each action and sub-action, we describe the activities conducted and resulting outputs during the whole project. The technical details are given in milestones and deliverables attached as annexes to the present report.



ACTIONS		ASSIGNED TO	PROGRESS	PLANNED START	PLANNED END	2016 I	2016 II	2016 III	2016 IV	2017 I	2017 II	2017 III	2017 IV	2018 I	2018 II	2018 III	2018 IV	2019 I	2019 II	2019 III	2019 IV	2020 I	2020 II	2020 III	2020 IV
Actions B - Implementation																									
B1	Set up of the monitoring system and data collection		100%	III 2016	IV 2019																				
B2	Modelling stomatal ozone uptake		100%	IV 2016	I 2020																				
B3	Derivation of new critical levels for forest protection		100%	I 2017	II 2020																				
B4	Mapping & Future scenarios		100%	II 2017	II 2020																				
Actions C - Monitoring of project impacts																									
C1	Monitoring the impact of the project actions		100%	III 2016	II 2020																				
C2	Assessment of the project actions impacts on local economy & population		100%	I 2017	II 2020																				
C3	Forest health and resiliency through integrated management practices		100%	I 2017	II 2020																				
Actions D - Dissemination																									
D1	Integration, Dissemination and Execution		100%	III 2016	II 2020																				
D2	Science-policy-stakeholder interaction		100%	III 2016	II 2020																				
D3	After-LIFE Communication plan		100%	III 2020	II 2020																				
Actions E - Project Management																									
E1	Project Management		100%	III 2016	II 2020																				
E2	Monitoring of the project progress		100%	III 2016	II 2020																				

Fig. 4 - Timetable of the project activities

Action B1: Set up of the monitoring system and data collection

Foreseen start date: 01/07/2016 Actual start date: 01/07/2016
Foreseen end date: 30/06/2020 Actual end date: 30/06/2020

Beneficiary responsible - CNR

Aim - Set-up and maintenance of the integrated monitoring stations, core of MOTTLES, by installing the system at each site for on-line recording of environmental and O_3 data at 1-h resolution, collection of plant-response indicators (e.g. radial growth, crown defoliation, visible foliar O_3 injury), harmonization of monitoring approaches and intercalibration training.

Description of the activities

Sub-action B1.1 - Agro-meteorological station & data download

Set up of a permanent monitoring network for ozone effects on EU forests (Annex B1.1)

All partners contributed to the selection of the 17 forest sites in France, Italy and Romania (Fig. 5). To maximize synergies, they were selected from main European networks involved in air quality monitoring (EMEP/MERA in France, and ICP–Forests in Italy and Romania). The selection was based on type of vegetation (representative of main biogeographical regions) and exposure to a range of O_3 pollution, and resulted in 9 sites in Italy, 4 in France and 4 in Romania. The network covers large soil and climatic gradients, 4 biogeographical areas (Atlantic, Alpine, Continental, and Mediterranean) and 9 major forest types of Europe, extending from the sclerophyll forests of the Mediterranean area at Castelporziano (Italy) to the mountainous beech forests of the Alpine region of Romania. The mean annual temperatures range from ca. 2°C in Fundata (Romania) to ca. 17°C in Castelporziano (Italy). This various environment hosts 11 dominant target species (7 broadleaved and 4 coniferous).

The staff of CNR and CREA-FL in Italy, ACRI-HE/ARGANS in France and INCDS in Romania upgraded the sites to create the novel permanent network. The novel monitoring system is able to record real time meteorological and O_3 values in open areas (*open field*–OFD, Fig. 6) as required for PODY calculation, while the traditional method used passive ozone samplers that provide values accumulated over 2-3 weeks. Soil moisture and plant–response indicators are recorded into the forest (*in the plot*–ITP, Fig. 6) following a modified ICP Forests monitoring approach. All MOTTLES sites are equipped with one OFD station and a nearby ITP station. The average distance between OFD and ITP is 600 m. Each OFD station is equipped with sensors for measuring the variables needed to calculate PODY and that cannot be measured within a forest i.e.: rainfall, air temperature, relative humidity, air pressure, solar radiation and surface O_3, measured by an active monitor. Each ITP station is equipped with soil moisture and soil temperature sensors placed at 10 cm depth, as they are representative of the soil conditions affecting PODY. Power supply is assured by solar panels or mains - when present - and backup batteries. The upgrade of the Italian sites was carried out thanks also to the help of the external assistance Misurando.

Verification of good functioning and site maintenance (Annex B1.2)

From March 2017, a control of good functioning of the monitoring stations was conducted annually by CREA-FL, ACRI-HE/ARGANS and INCDS in each country under the supervision of CNR technicians. The maintenance of the Italian sites required also the help of the external assistance Misurando.

Data collection and upload (Annex B1.3)

Meteorological and O_3 data acquisition was conducted by the national responsible (P. Sicard in France; T. Sorgi in Italy; and S. Leca in Romania); data were provided to the general responsible F. Sabatini (CNR) for uploading to the MOTTLES FTP every 2 months from March 2017 to June 2020 (ftp.mottles.altervista.org).

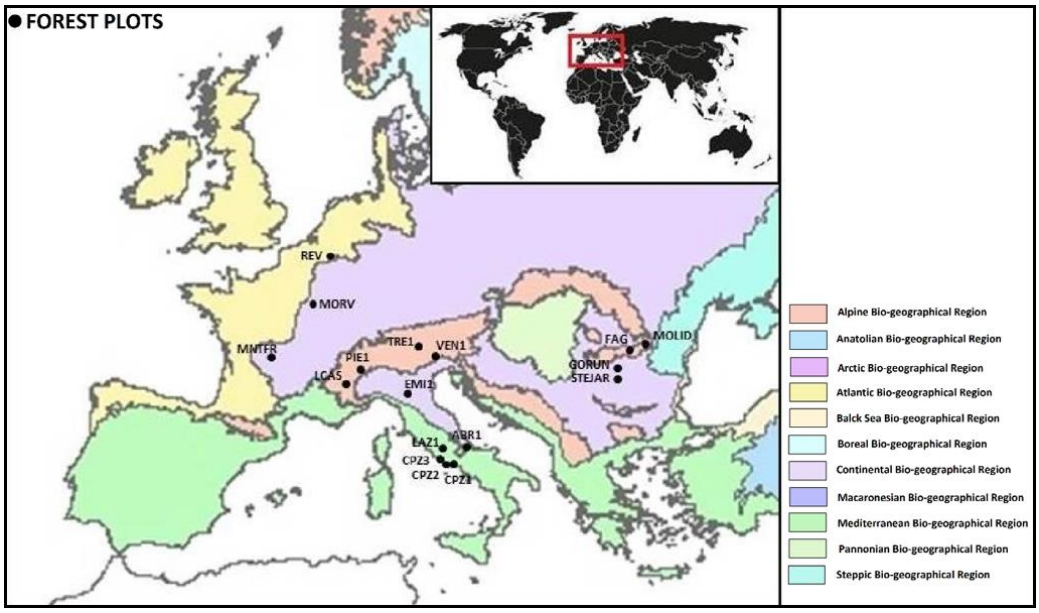


Fig. 5 - MOTTLES monitoring network

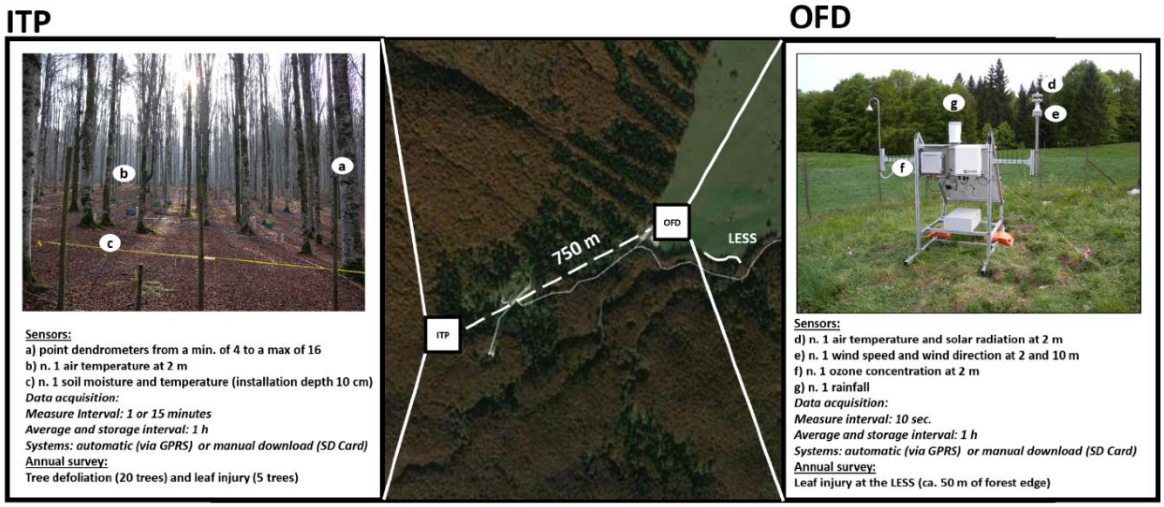


Fig. 6 - The MOTTLES monitoring station (VEN1)

Data validation

Data validation since March 2017 was regularly conducted by the data general responsible (F. Sabatini-CNR) (Annex B1.4a). Procedures were discussed during the 2nd progress meeting. A specific procedure of gap filling was applied by A. Conte and L. Salvati (CREA-FL) when necessary (first year) (Annex B1.4b). **Every year, MOTTLES network records and validates 2.2 million of data.**

Sub-action B1.2 - Collection of forest data

Forest surveys

Common field protocols and survey documents for visible injury and crown assessment were developed (Annex B1.5-B1.6) for use by all MOTTLES surveyors. A protocol for soil sampling and measure of Field Capacity (FC) and Wilting Point (WP) was also developed and refined during the 2nd Progress Meeting (Annex B1.7). Every year, from end of August to beginning of September, field campaigns were carried out: crown defoliation and visible O_3 injury in Italy, France and Romania were assessed by the surveyor teams (E. Carrari, Y. Hoshika, A. Conte, M. Lazzara in Italy; L. Dalstein-Richier, M-L. Ciriani, C. Peracchia in France; S. Leca, Ș, Chivulescu, A. Dobre and Raducu Stanculeanu in Romania). Tree phenology was assessed by direct observation or modelling every year, direct observations were conducted in Romania from March to November by S. Leca (INCDS), while for the other 2 countries data were modelled by A. Anav (CNR) by using a latitudinal model.

Fig. 7 - E. Carrari and Y. Hoshika during MOTTLES surveys (August 2017)

Measurements at FO3X (Annex B1.8)

A free-air exposure system was used to validate visible foliar O_3 injury, reproducing it in potted plants of selected species, and to parameterize the stomatal conductance of species occurring at our sites but not yet available in the literature. FO3X is a last generation three-dimensional free air controlled exposure (FACE) facility, already available at CNR (Sesto Fiorentino). Leaf-level measurements for validation of visible injury in *Vaccinium myrtillus*, *Sorbus aucuparia* in 2018 and *Pinus pinea*, *P. halepensis* and *P. pinaster* at the FO3X facility were conducted by Y. Hoshika, E. Carrari, M. Lazzara, and S. Podda (CNR). The plants were purchased from local nurseries. Species to be measured at FO3X were selected by the three surveyor teams during the forest inventory of the previous year.

Intercomparison courses and intercalibration exercises (Annex B1.9)

During the project, surveyors participated to 2 intercomparison exercises and 4 intercalibration courses:

1) Tree crown defoliation assessment organized by MOTTLES (12 September 2016; Brasov, Romania).
2) Intercalibration course on ozone visible foliar injury of ICP Forests organized by MOTTLES (13-15 September 2016; Brasov, Romania).
3) 4. ICP Forests Expert Panel on Ambient Air Quality and the Intercalibration Course on ozone induced symptoms (28-30 August; Trento, Italy).
4) Intercalibration course on ozone visible foliar injury of ICP Forests (10-13 September 2018; Poreč, Croatia).
5) Intercomparison exercise on ozone visible foliar injury and crown condition organized by MOTTLES (5 July 2017; Castelporziano, Italy).
6) Intercomparison exercise on ozone visible foliar injury organized by MOTTLES (4 September 2019; Val Sessera, Italy).

The consortium worked on the report about the **"forest health status at each site: ozone data, crown condition, phytosociological and visible injury**", that was revised in Bucharest during the 2nd Progress meeting (Annex B1.10). Besides, a **list of sensitive tree species (conifers[1] and broadleaves[2])** for the forest sustainable management was defined by all partners and uploaded to the website[1]. To facilitate the transfer of the leaf symptom analysis method, an **atlas of O_3 injury validated for the MOTTLES project[3]** (Annex B1.11) was created by E. Carrari (CNR) with M-L. Ciriani and L. Dalstein (GIEFS). The atlas contains a photographic collection of visible leaf injury detected in the field or reproduced by the ozone FACE.

Problems and delays

Delays in purchasing the instruments and in accessing the sites resulted in a slight postponement of first data acquisition, so that the entire 2017 growing season was not available at 5 sites out of 17. However, a procedure of gap filling was applied on those site datasets in order to allow the calculation of indicators and CLs. The milestones "*Verification of good functioning of the monitoring stations*" and *"Transmission of first data transmitted by GPRS stored by the FTP at CNR and validated"* were postponed according to the time shift of the stations set-up, which was completed on 31st March 2017 instead of November 2016. This delay did not affect the scientific results of the project, as the vegetative activity of plants and thus stomatal uptake are stopped during winter time.
For the Romanian plot MOLID, the O_3 monitor is installed inside the National Meteorological Administration facility. During 2017, several problems occurred and INCDS technicians replaced and recalibrated the O_3 monitor several times. The main reason for the lack of O_3 data for this site in 2017 was the power supply deficiency, in particular surges or spikes. This monitor had no auxiliary power supply and no automatic data acquisition and transmission. The auxiliary power supply problem was solved in 2018 and an Uninterruptible Power Supply backup source was installed. Another problem was that the back-up monitor that replaced the

[1] https://mottles-project.wixsite.com/life/coniferous-species
[2] https://mottles-project.wixsite.com/life/copia-di-broadleaf-evergreen-specie
[3] https://mottles-project.wixsite.com/life/atlas-ozone-injury

broken one had some calibration problems; even if we tried to calibrate it several times, the quality of the registered data was bad and we decided to exclude them from the 2017 dataset. A new 2BTech monitor was installed in January 2018, and then the measurements were regularly conducted.

Fig. 8 - P. Sicard (ARGANS), Y. Hoshika (CNR), M. Lazzara (CNR), F. Coulibaly (ARGANS) during an intercomparison exercise in Val Sessera (4 September 2019).

The "in the plot" field station TRE1 at *Passo Lavazè* was hit by the Vaia wind storm on 28-29 October 2018. Vaia caused considerable damages to the Italian forests, causing the loss of 8 million cubic meters of standing trees with wind gusts velocity over 140 km/h. The remote signals of the data logger were interrupted on 22nd December, 2018. On the contrary, the "open field" station is still functioning. The data recorded by MOTTLES dendrometers and soil sensors permitted to follow the dynamic of tree fall during the Vaia storm, and are a unique dataset during this event. This can provide important information about forest management in preventing catastrophic events related to climate change. For this reason, the MOTTLES researchers were invited to present these results at a meeting on forest management related to wind storms (Annex B1.12). In June 2019, after snow melting, the CNR technicians went to the site to re-install the sensors and re-establish the connections of the OFD station.
Minor technical issues during the whole period and in each site were recorded, easily solved with visits for maintenance by technicians. Due to the high number of sites in Italy, CNR asked for the external assistance (Misurando) to work on the site maintenance together with CREA-FL and CNR technicians. In this way the monitoring site network was functioning well at the end of the project for the After-LIFE activities.
As the complete dataset was not yet available in 2017, beneficiaries submitted to EFDC & FISE the following 4 scientific papers of fundamental significance to understand the project methodologies, produced by beneficiaries within the project (Annex B1.13):

• De Marco A., Vitale M., Popa I., Anav A., Badea O, Silaghi D., Leca D., Screpanti A., Paoletti E., 2017, Ozone exposure affects tree defoliation in a continental climate. Science of the Total Environment 597: 396-404.

• Sicard P., Anav A., De Marco A., Paoletti E., 2017, Projected global tropospheric ozone impacts on vegetation under different emission and climate scenarios. Atmospheric Chemistry and Physics 17: 12177–12196.
• Anav A., Liu Q., De Marco A., Proietti C., Savi F., Paoletti E., Piao S., 2018, The Role of Plant phenology in stomatal ozone flux Modeling. Global change biology 24: 235-248.
• Hoshika Y., Fares S., Savi F., Gruening C., Goded I., De Marco A., Sicard P., Paoletti E., 2017, Stomatal conductance models for ozone risk assessment at canopy level in two Mediterranean evergreen forests. Agricultural and Forest Meteorology 234: 212-221.

Evaluation and results

All the project objectives and expected results were reached and action B1 was finalized on time. The network was successfully created and is working well. MOTTLES collects **2.2 million data in real time per year**. Since the NEC makes this type of monitoring mandatory in all Countries, this new generation monitoring could be adopted at pan-European scale. The NEC Directive recommends the concurrent monitoring of forest response indicators and O_3 standards across Europe. Quantitative and qualitative data related to O_3 pollution, climate change and biodiversity are currently used to clarify cause-effect relationships between O_3, climate and forest responses. The active and remote management of the MOTTLES monitoring stations resulted particularly useful during the lockdown conditions linked to COVID-19 pandemic, allowing the continuation of data recording even without the possibility to reach the sites. The forest inventories in 2017, 2018 and 2019 conducted by MOTTLES surveyors, provided information necessary for the realization of the Atlas on visible foliar O_3 injury, which is on-line and was updated every year. We shared important MOTTLES outputs with JRC (EFDC&FISE) thanks to figshare.

All the **milestones** and **deliverables** were achieved, the values of **indicator of progress** respected or even exceeded the expected values; therefore, the action was concluded successfully.

All action B1 expected results were achieved:

- Set up of a permanent new-generation monitoring system for the ozone effects on EU forests - ***Completed***
- A comparable European-wide forest information and collection system at European level - ***Completed***
- Support the adoption of this new-generation monitoring system at pan-European scale - ***Completed***
- Concurrent monitoring of forest response indicators and ozone standards across Europe - ***Completed***
- Quantitative and qualitative data related to ozone pollution, climate change and biodiversity - ***2017, 2018 and 2019 completed***
- Pooled database to clarify cause effect relationship between ozone, climate and forest responses - ***2017 2018 and 2019 completed***
- Provision of validated data to the EFDC & FISE of the EC - ***Completed***
- Better understanding of air pollution & climate change impacts on forests - ***Completed***
- An atlas of validated ozone visible foliar injury for European forest species - ***Completed***
- Lists of sensitive tree species for the forest sustainable management - ***Completed***

Deliverables	Expected in the GA	Actual	Status
Mid-term report on the forest health status at each site: ozone data, crown condition, phytosociological and visible injury (Annex B1.10)	07/2018	07/2018	Completed
Atlas of validated ozone visible foliar injury for European forest species (released with the Progress report) (Revised version Annex B1.11)	07/2019	04/2019 revised 10/2019	Completed

Milestones	Expected in the GA	Actual	Status
Planning of activities Action B1	07/2016	09/2016	Completed
Intercalibration training course (Annex B1.9)	09/2016	09/2016	Completed
Inter-comparison exercises, data validation and provision to the EFDC & FISE (Annexes B1.4a, B1.9, B1.13)	10/2016	07/2017	Completed
Agro-meteorological and ozone station installed (Annex B1.1)	11/2016	03/2017	Completed
Verification of good functioning of the monitoring stations (Annex B1.2)	12/2016	04/2017	Completed

Indicators of progress	Expected in the GA	Actual
Set up of fully equipped MOTTLES stations	17	17
Number of recorded trees for crown conditions & visible injury per site	20	20
Phenology characterized per site	1 set per year	1 set per year
Crown condition & visible injury evaluated per site	1 set per year	1 set per year
First data transmitted by GPRS stored by the FTP at CNR and validated	01/11/2016	31/03/2017
Organization of intercalibration & data validation exercise	1	4
Organization of inter-comparison exercise	1	1

Action B2: Modelling stomatal ozone uptake

Foreseen start date: 01/10/2016 Actual start date: 01/09/2016
Foreseen end date: 31/03/2020 Actual end date: 31/03/2020

Beneficiary responsible: INCDS

Aim - Calculate species-specific stomatal O_3 uptake by the DO3SE model for sites distributed in France, Romania and Italy, by using data on soil type, hourly meteorological data (air temperature, relative humidity, soil water content and solar radiation) and hourly O_3 concentrations obtained from monitoring stations.

Description of the activities

The **database was built** in October 2016 by I. Popa (INCDS) and the first data collected in action B1 was uploaded in July 2017 by I. Popa (INCDS). The 2017 milestone shows the procedure for building and updating the database (Annex B2.8). Since October 2017, data collected in action B1, validated and stored by F. Sabatini (CNR) in the MOTTLES FTP were merged and cross checked by I. Popa (INCDS) for action B2. After February 2018, the database was updated every 2 months with the same modality to have a complete database at the beginning of each year (Annex B2.1). The **report on species-specific parameterization of stomatal ozone flux** was completed by I. Popa (INCDS) and Y. Hoshika (CNR) and delivered with the Progress and Final report (Annex B2.4).

Sub-action B2.1 - WRF-CHIMERE modelling system

CREA-FL, CNR and INCDS worked together on the setting up of the WRF-CHIMERE model. The set-up was transferred to Action B4 and then used for spatializing and mapping the exceedances of the critical levels established in Action B3. A summary of the analysis is available in Annex B2.2 and published in Anav et al. 2017 (Annex D1.9o).

Sub-action B2.2 - AOT40 calculation

The R script for computing AOT40 adapted to MOTTLES database format by four different approaches (Directive, ICP-forests, MOTTLES, Survey) was created by D. Pitar and I. Popa (INCDS) in July 2017 and updated continuously according to requirements of the dataset recorded in different years. From January 2018, I. Popa (INCDS) led the calculation of AOT40 for each monitoring site based on available validated measurements and transferred results to action B3 (definitive results for 2017-2018-2019 are available in Annexes B2.3a-c).

Sub-action B2.3 – Estimation of stomatal ozone fluxes

The R script for computing PODY adapted to MOTTLES database format by four different approaches (Directive, ICP-forests, MOTTLES, Survey) was created by D. Pitar and I. Popa (INCDS) in July 2017 and updated continuously according to requirements of the dataset recorded in different years. From January 2018, I. Popa (INCDS) led the calculation of PODY for each monitoring site based on available validated measurements and transferred results to action B3. Some re-calculations were necessary in March 2018 especially after the application of gap filling and new DO3SE model parameters obtained at FO_3X (definitive results for 2017-2018-2019 are available in Annexes B2.3a-c).

From October 2016 to September 2018, in fact, I. Popa (INCDS) and Y. Hoshika (CNR) defined the new species-specific parameterization for MOTTLES species: after a deep bibliographic research to collect parameterization data for MOTTLES target species, species occurring at MOTTLES sites without available data of stomatal conductance (g_{max}) in the literature necessary for the calculation of the *f* functions were defined during the field campaigns of 2017. A specific parameterization for two target dominant species (*Phillyrea latifolia* and *Alnus glutinosa*) was then conducted for the first time thanks to MOTTLES at the FO_3X facility (Annex B2.4). CREA-FL and CNR researchers selected three Eddy-covariance towers to compare two types of stomatal O_3 fluxes estimation (CPZ1, ABR1). Agreements with tower managers and verification of data availability were conducted in the first two years of the projects. The comparison between Eddy co-variance and MOTTLES fluxes on the 2017, 2018, 2019 datasets supported the validity of the MOTTLES approach (Annex B2.5). Every year, data were transferred to Action B3 for critical level calculation. In the first year, we used literature data developed within the previous LIFE project FO_3REST (Annex B2.7).

Problems and delays

Due to the delay in site installation, the milestone "*Building and update of database of data collected in B1*" for the first year was postponed by 9 months, such deviation from the project proposal did not affect the achievement of final results of action B2. Non-validated data in the FTP induced some errors in the first O_3 flux calculations. The R script needed to be revised several times before working well. The problems were solved during the 2nd progress meeting. During the project the collected quantitative/qualitative forest data related to climate change, air pollution, biodiversity and forest conditions were planned to be transferred to the European Forest Data Centre, for inclusion into the Forest Information System for Europe of the EC. During the 3rd monitoring visit held in May 2019 the beneficiary informed that FISE and EFDAC information systems were contacted for the submission of MOTTLES results in 2017 (Annex B1.13). However, no reply or feedback was received. In fact, the last datasets available on the relevant webpage of the Joint Research Centre Data Catalogue[2] referred to 2006, and the contact point did not reply. Therefore, EASME helped the beneficiaries in contacting JRC. By following the indications provided by Dr. Daniele De Rigo (JRC), two groups of figures and data were uploaded to the figshare website:

- one group for POD at https://figshare.com/s/090430811eca46c0112f.
(DOI: 10.6084/m9.figshare.12528365)
- one group for AOT40 at https://figshare.com/s/836d21cd750aeff9c1cb
(DOI: 10.6084/m9.figshare.12528149)

A main issue for the submission to the JRC Data Catalogue was the preparation, validation and export of metadata in XML format. For this task we tried the metadata editors[3] (software used to fill and save it as .xml file) as suggested by Dr. De Rigo but some of them were discontinued and did not work (e.g. the Greek INSPIRE metadata editor had issues with the coordinates to define the area of the study). We found another Excel metadata editor[4], and we are actually working on validating and exporting the metadata in the requested format, it should be easy to complete this task. We would respectfully recommend JRC to develop a clear tutorial for assistance to users of the revised FISE.

[2] http://data.jrc.ec.europa.eu/collection/FISE
[3] https://inspire-reference.jrc.ec.europa.eu/vocabularies/tags/metadata-editor
[4] https://github.com/GeoSmartCity-CIP/Excel-Metadata

Evaluation and results

The expected results are achieved, i.e.t AOT40 and PODY were calculated for the years 2017, 2018 and 2019. The deliverable of the action "Report on species specific parameterization of stomatal ozone flux" was anticipated by 3 months. In addition,a new parameterization for two species that were missing in the literature (*Alnus glutinosa, Phillyrea angustifolia*) was carried out. The selection of the best species-specific approach was defined. Thanks to the help of EASME and NEEMO, the milestone regarding the delivery of the dataset to EFDC&FISE was completed by delivering AOT40 and POD1 results, despite the procedure is not totally clear (Annex B2.6).

All the **milestones** and **deliverables** were achieved, the values of **indicator of progresses** respected the expected values; therefore, the action was concluded successfully.

All the **expected results** are completed:

- Calculation of AOT40 and stomatal ozone uptake above different thresholds Y - ***2017, 2018, 2019 completed***
- Refining old parameterization and developing new parameterization for the major forest species in main forest biomes of Europe - ***Completed for 11 species***
- Validation of DO3SE model by comparison between measured and modelled stomatal O_3 fluxes - ***Completed for the species not yet validated in the literature***
- Species-specific parameterization of DO3SE model across different EU environments - ***Completed***
- Selection of the best species-specific approach - ***Completed***

Deliverables	**Expected in the GA**	**Actual**	**Status**
Report on species-specific parameterization of stomatal ozone flux (released with the Progress report) (Annex B2.4)	07/2018	04/2018	Completed

Milestones	**Expected in the GA**	**Actual**	**Status**
Building and update of database of data collected in B1 (Annex B2.8)	10/2016	07/2017	Completed
Building and update of database of data collected in B1 (Annex B2.1)	10/2017	10/2017	Completed
Building and update of database of data collected in B1 (Annex B2.1)	10/2018	10/2018	Completed
Building and update of database of data collected in B1 (Annex B2.1)	10/2019	10/2019	Completed
AOT40 & PODY values transferred to Action B3 for critical levels derivation (Annex B2.7)	01/2017	01/2017	Completed

AOT40 & PODY values transferred to Action B3 for critical levels derivation (Annex B2.3a)	01/2018	01/2018	Completed
AOT40 & PODY values transferred to Action B3 for critical levels derivation (Annex B2.3b)	01/2019	01/2019	Completed
AOT40 & PODY values transferred to Action B3 for critical levels derivation (Annex B2.3c)	01/2020	01/2020	Completed
Provision of validated stomatal ozone fluxes to EFDAC and FISE (Annex B2.6)	06/2018	06/2018	Completed
Provision of validated stomatal ozone fluxes to EFDAC and FISE (Annex B2.6)	06/2020	06/2020	Completed
Indicators of progress	**Expected in the GA**	**Actual**	**Status**
Number of sites where DO3SE model applied	17	17	Completed
Number of sites where eddy-covariance campaigns were carried out	2	2	Completed
Building and update of database of data collected in B1	15/10/2016	15/10/2016	Completed
Submission of validated data to the EFDC & FISE	1 set per year	1 set per year from 06/2020	Completed
Transfer of PODY & AOT40 to Action B3 as a basis to elaborate species-specific thresholds of ozone injury	1 set per year	1 set per year from 01/2018	Completed

Action B3: Derivation of new critical levels for forest protection

Foreseen start date: 01/01/2017 Actual start date: 01/01/2017
Foreseen end date: 30/06/2020 Actual end date: 30/06/2020

Beneficiary responsible: ARGANS (former ACRI-HE)

Aim - Define the best criteria for the EU forests protection from O_3 in a changing climate, derive proper flux-based critical levels (CL) for forest protection and contribute to the UNECE activities.

Description of the activities

Since the start of the project, P. Sicard (ACRI-HE/ARGANS) led the project activity to contribute to the UNECE activities. Four talks on the MOTTLES methodology were presented at IUFRO (September 2017, October 2017, and May 2019) and ICP-vegetation (March 2018) events. The talks (Annex B3.1, and Annex B3.2) allowed to obtain important feedbacks from MOTTLES stakeholders. A deep bibliographic review on critical levels definition was completed in March 2018, and allowed to define a consistent methodology on critical levels definition (Annex B3.3).

The selection of the best plant-response parameters and O_3 metrics was led by ARGANS. MOTTLES results indicated **visible foliar O_3 injury as a suitable parameter to describe O_3 impacts on vegetation, and POD1 as the O_3 metric to be adopted to derive critical levels.**

In April 2017, the critical levels for 2016 were defined by ACRI based on literature data and transferred to action B4 for mapping: for O_3 sensitive conifers, 19 mmol m^{-2} for *Pinus cembra* (high O_3 sensitivity) and 32 mmol m^{-2} for *Pinus halepensis* (moderate O_3 sensitivity). For broadleaved species, 25 mmol m^{-2} for *Fagus sylvatica* (moderate O_3 sensitivity) and 19 mmol m^{-2} for *Fraxinus excelsior* (high O_3 sensitivity). From March to April 2018, ARGANS in collaboration with CNR researchers and post-docs realized a statistical analysis between AOT40 and PODY and forest responses in order to have preliminary results for critical levels 2017 (Annex B3.4). From February to March 2019, the critical levels 2018 were defined based on the MOTTLES dataset 2017-2018 by using the MOTTLES methodology (Annex B3.5). Results were then transferred to action B4 for mapping. From February to May 2020, the critical levels 2019 were defined based on the dataset 2017-2018-2019 by using the MOTTLES methodology (Annex B3.6). Results were then transferred to action B4 for mapping.

From March 2018, Y. Hoshika (CNR) and P. Sicard (ARGANS) started to work on Chapter 3 of the Modelling and Mapping Manual of the LRTAP Convention on UNECE ICP-Vegetation by attending the 31st Task Force Meeting - International Cooperative Programme on Effects of Air Pollution on Natural Vegetation and Crops (5-8 March 2018, Dessau-Roßlau, Germany). The new version of the Modelling and Mapping Manual will be probably published in 2021. From this meeting, the consortium published **3 papers** on "*Derivation of species-specific thresholds and critical levels*" as main inputs for UNECE activities "Mapping Critical Levels for Vegetation".

1. Sicard et al. (2020). Epidemiological derivation of flux-based critical levels for visible ozone injury in European forests. Journal of Forestry Research, 1-11 (Annex B3.7).

2. Hoshika et al. (2020). Flux-Based Ozone Risk Assessment for a Plant Injury Index (PII) in Three European Cool-Temperate Deciduous Tree Species. Forests 11, 82 (Annex B3.8).
3. Hoshika et al. (2018). Testing a ratio of photosynthesis to O_3 uptake as an index for assessing O_3-induced foliar visible injury in poplar trees. Environmental Science and Pollution Research 25, 8113-8124 (Annex B3.9).

Problems and delays

Due to the small deviations in data collection explained in action B1, calculation of PODY and AOT40 based on MOTTLES data started from end of December 2017 and the derivation of critical levels was performed from January to April, 2018. In April 2017, the critical levels values transferred to Action B4 for mapping were taken from the literature (Annex B2.7). In 2017-2018, the dataset was not sufficient, because a minimum of 2 years of data is requested to derive reliable critical levels, so in April 2018 we made correlations between ozone metrics and forest responses. The first set of CL defined on MOTTLES dataset was delivered in April 2019 based on the dataset 2017 and 2018. In May 2020, we derived definitive critical levels based on 3 years of data (2017-2018-2019).

Evaluation and results

From the 2017-2018-2019 datasets, it was possible to have important information on which effect parameters and O_3 metrics are the best to derive the critical levels, which allowed to publish the first suggestions for a new policy for forest protection with a publication entitled "*Toward the definition of epidemiologically based stomatal-flux critical levels for forest protection against ozone: the MOTTLES approach*" (Annex D1.9a).This represents the first support provided by MOTTLES monitoring activities to future EU forest monitoring and management policies.

From flux-effect relationships, we derived flux-based critical levels (CLef) for forest protection against visible foliar O_3-like injury. We recommend **CLef of 12 and 5 mmol m^{-2} POD1 for broadleaved species and conifers**, respectively (Annex B3.6).

All **milestones** and final **deliverables** were achieved, with problems for the milestone: Provision of validated critical levels to EFDAC & FISE. We submitted the published CLef to JRC on 17 September 2020 by email to Daniele.DE-RIGO@ext.ec.europa.eu (Annex B3.10) since the online system https://data.jrc.ec.europa.eu/contact did not work.

The **expected results** are:

- Selection of the best effect parameter and O_3 metrics to derive the best and suitable species-specific critical levels – ***Completed***
- Suggestion of proper standards and critical levels as new policy for forest protection - ***Completed***
- Decision-support tool for European authorities. European legislation will adopt new criteria to assess ozone risks based on our new calculations - ***Completed***
- Provision of open-access data for incorporation into the EFDC & FISE - ***Incomplete***
- Support to future EU forest monitoring and management policies - ***Completed***

Deliverables	Expected in the GA	Actual	Status
Paper on species-specific thresholds and critical levels" as provision/inputs for UNECE activities "Mapping Critical Levels for Vegetation" (Annex B3.7-8-9)	01/2020	06/2018 01/2020 06/2020	Completed

Milestones	Expected in the GA	Actual	Status
Critical levels values transferred to Action B4 for mapping (Annex B2.7)	04/2017	04/2017	Completed Based on literature data
Critical levels values transferred to Action B4 for mapping (Annex B3.4)	04/2018	04/2018 revised 09/2018	Completed for dataset 2017
Critical levels values transferred to Action B4 for mapping (Annex B3.5)	04/2019	04/2019	Completed for dataset 2017+2018
Critical levels values transferred to Action B4 for mapping (Annex B3.6)	04/2020	06/2020	Completed for dataset 2017+2018+2019
Provision of validated critical levels to EFDAC & FISE (Annex B3.10)	06/2018	06/2020	Incomplete
Provision of validated critical levels to EFDAC & FISE (Annex B3.10)	06/2020	06/2020	Incomplete

Indicators of progress	Expected in the GA	Actual	Status
Number of sites where the model was applied	17	17	Completed
Critical level values transferred to Action B4 for mapping	1 set per year in April	1 set per year April 2018, April 2019, March 2020	Completed
Submission of validated data to the EFDC & FISE	1 set per year	3 sets on 06/2020	Incomplete

Action B4: Mapping & Future scenarios

Foreseen start date: 01/04/2017 Actual start date: 01/04/2017
Foreseen end date: 30/06/2020 Actual end date: 30/06/2020

Beneficiary responsible: CREA-FL

Aim - i) identify ozone hot-spots; ii) assess large-scale mature forest injury by O_3; iii) define which threshold Y is the most biologically-based; and iv) define more consistent and realistic critical levels (CL) for forest protection across EU to support the elaboration of sustainable management strategies.

Description of the activity

Sub-action B4.1 - Distribution of critical level exceedances

In June 2017 ENEA elaborated maps based on literature data under the supervision of CREA-FL, since the dataset of 2017 was not yet completed (Annex B4.1). From April to June 2018, ENEA worked on the elaboration of maps of critical levels exceedance produced for 2017 based on data recorded by MOTTLES (Annex B4.2). In March 2019, ENEA carried out the elaboration of exceedance maps produced for 2018 based on MOTTLES data (Annex B4.3) and worked on the comparison of exceedances of POD computed using critical levels 2017-2018. In June 2020, ENEA worked on the elaboration of exceedance maps for 2019 based on MOTTLES data and compared the exceedances of POD by using critical levels 2017-2018-2019 (Annex B4.4). From January 2020, the consortium started to work together for the deliverable "*How to assess the effectiveness of air pollution control strategies for ecosystem protection*". Results were clearly translated for stakeholders. The consortium decided to finalize the deliverable, to be more intelligible for policymakers and stakeholders, with the support of an external collaboration. The deliverable was completed in June 2020 (Annex B4.5).

Sub-action B4.2 - Air pollution and climate scenarios

In May 2017, CREA-FL, ENEA and CNR selected O_3 level scenarios: **RCP 8.5 was selected as a high radiative forcing pathway, reaching more than 8.5 Wm^{-2} by 2100** (Annex B4.6). S. Fares with his collaborators (CREA-FL) and the external assistance (ENEA) worked further on the coupled model WRF-CHIMERE (from Action B2) and its implementation to produce O_3 fields over the study domain. The results over Europe show limited hot-spot areas in central, South and Eastern European forests with exceedances slightly increasing from a reference year (2016) to a simulated year (2100) (Annex B4.7). This result is due to the fact that the predicted reduction of O_3 precursors emissions is compensated by climatic changes that stimulate the stomatal uptake of ozone.

Problems and delays

All the expected results and indicators are completed, however maps produced in 2017 are based on literature data.

Evaluation and results

Meteorological, AOT40, PODY, forest data and critical levels collected in actions B1-B3 were used for mapping. Maps allowed to define regional vulnerability to climate change stressors by investigating North-South and East-West transects: **Alpine and Continental biogeographic regions are more vulnerable than Atlantic and Mediterranean**. We also identified the O_3 hot spots (high exceedance of POD1 > 3 mmol m^{-2}): e.g. CPZ1, VEN and FAG in 2017, MNTFR, MORV, ABR1, TRE1, VEN1 and STEJAR in 2018, VEN, MNTFR, MOLID and STEJAR in 2019. An example for the year 2018 is shown in Fig. 9. Very importantly, we found that air pollution control measures must be coupled with climate change control measures for successfully limiting the stomatal uptake of ozone by European forests.

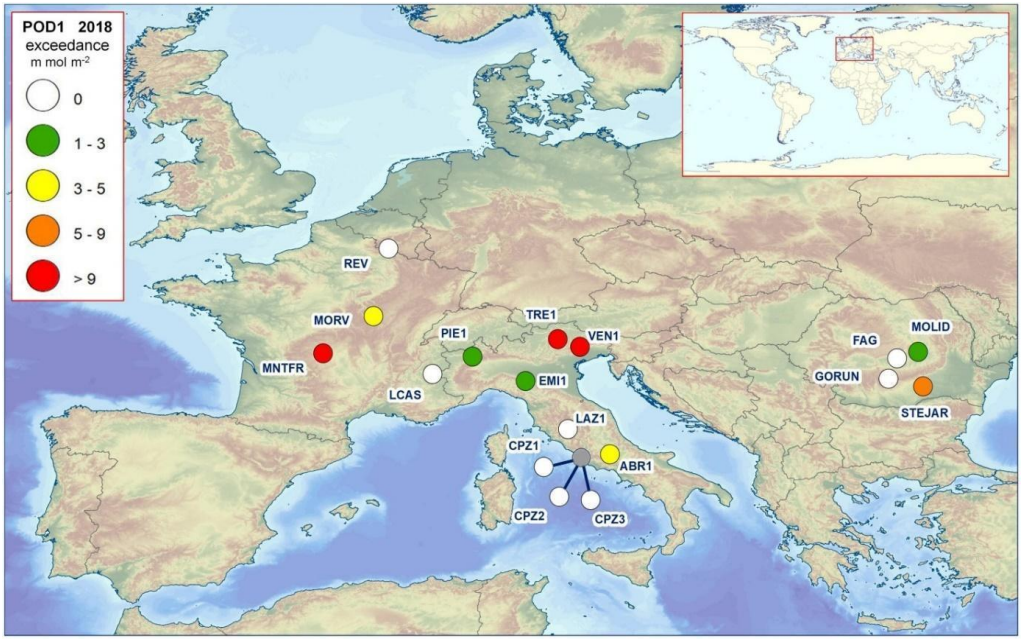


Fig. 9 - Exceedance of the suggested flux-based critical levels (CLef: 5 and 12 mmol m^{-2} for conifers and broadleaved species) for dominant tree species at each site for the year 2018.

All **milestones** and final **deliverables** were achieved, values of **indicator of progresses** respected always the expected values; therefore, the action was concluded successfully.

All the **expected results** are completed:

- Definition of regional vulnerability to climate change stressors by investigating N-S & E-W transects - ***Completed***
- Identification of ozone hot-spots - ***2017, 2018, 2019 completed***
- Assessment of large-scale mature forest injury by O_3 - ***2017, 2018, 2019 completed***
- Consistent, realistic and proper species-specific critical levels for forests protection against O_3 - ***Completed***
- Modelling & mapping of observed and projected changes in critical levels exceedances – ***2017, 2018, 2019 completed***
- Quantification of long-term changes in critical levels exceedances - ***Completed***
- Indicators supporting the impacts assessment of future policies at European/national levels - ***Completed***
- Support to the elaboration of effect-based abatement strategies in pollutant emissions - ***Completed***

- Management options for adaptation: an overview for policy makers and practitioners - ***Completed***
- Support to the future EU air quality decision making - ***Completed***
- Management options for adaptation: an overview for policy makers and practitioners - ***Completed***
- Support to the future EU air quality decision making - ***Completed***

Deliverables	**Expected in the GA**	**Actual**	**Status**
Guidelines book "how to assess the effectiveness of air pollution control strategies for ecosystem protection": an overview for policy makers and practitioners (Annex B4.5)	06/2020	06/2020	Completed

Milestones	**Expected in the GA**	**Actual**	**Status**
Scenarios and configuration of simulation model (Annex B4.6)	04/2017	05/2017	Completed
Application of simulation model (Annex B4.7)	05/2017	05/2017	Completed
Results of data processing - Maps of CL exceedances (Annex B4.1)	06/2017	06/2017	Completed (literature data)
Results of data processing - Maps of CL exceedances 2017 (Annex B4.2)	06/2018	06/2018 revised 09/2018	Completed
Results of data processing - Maps of CL exceedances 2018 (Annex B4.3)	06/2019	04/2019	Completed
Results of data processing - Maps of CL exceedances 2019 (Annex B4.4)	06/2020	06/2020	Completed

Indicators of progress	**Expected in the GA**	**Actual**	**Status**
Number of air pollution scenarios analyzed	4	4	Completed
Number of climate change scenarios considered	3	3	Completed
Maps of ozone risk indicators PODY and AOT40	1 per year	1 per year from 2018	Completed for 2017-2018-2019
Maps of critical level exceedances	1 per year	1 per year from 2018	Completed for 2017-2018-2019

Action C1: Monitoring the impact of the project actions

Foreseen start date: 01/07/2016 Actual start date: 01/07/2016
Foreseen end date: 30/06/2020 Actual end date: 30/06/2020

Beneficiary responsible: INCDS

Aim - Define the project impacts in terms of population and local authorities' awareness, knowledge and sensitivity about risk related to air pollution and climate change.

Description of the activities

INCDS identified performance indicators at the initial situation with updates in August 2016. D. Pitar (INCDS) revised the milestones "Impact of the project: initial situation" after we received the MTR evaluation letter (December 2017), according with the suggestions of the monitor during the monitoring visit. The new version, which contains the explanation of the values of the expected indicators, was delivered with the in progress report (Annex C1.1). From December 2017, INCDS led the activities for the elaboration of questionnaires with ACRI-HE/ARGANS and CNR as support. The final version of questionnaires was ready in May 2018 and consisted of 25 questions. It investigated how the general public responds to and learns about environmental problems in general and about air pollution and climate change in particular. Questions were drafted thanks to the numerous exchanges, contacts and face-to-face meetings (Actions D1 & D2) that we had since the beginning of the project. The questionnaire contained a special session to define the target audience. INCDS elaborated the results of questionnaires for the "in progress situation". First results were available in July 2018, they were discussed and used as input for the evaluation of the "*Impact of the project: in progress situation*" delivered with the present report (Annex C1.2). In June 2020, with the help of the external assistance AISF, questionnaires were disseminated and results evaluated to update the situation at the end of the project (Annex C1.3)

INCDS in collaboration with CNR regularly updated the evaluation of project audiences by using questionnaires, websites and social networks indicators. The assessment was delivered with the Progress and the final report (Annex C1.4). INCDS in collaboration with CNR and CREA-FL (in Italy) and ARGANS (in France) regularly updated the project indicators and performance indicators. The assessment was delivered with the Mid-term, the Progress and the present report (Annex C1.5). The Project coordinator was contacted by EASME in December 2017 in order to fill the online Key Project-level Indicators (KPI) database. In January 2018, E. Paoletti and E. Carrari (CNR) with the help of the NEEMO Monitor, filled up the defined and evaluated indicators according with the provided rules (Annex C1.6), the final KPI evaluation was done on September 2020 after the end of the project (Annex C1.7).

Problems and delays

The Milestone "*Impact of the project: initial situation*" was considered inconsistent by EASME, because the results of the questionnaires mentioned in the project proposal were not presented. The delay in the dissemination of the questionnaires was due to the need to carefully identify the target audience. For that, numerous exchanges, contacts and face-to-face meetings (Actions D1 & D2) were essential to draft the specific questionnaires in agreement with the target audience. The questionnaires were then elaborated and disseminated. At the same time,

the milestone "*Impact of the project: initial situation*" was revised, according to the suggestions of the monitor during the monitoring visit.

Evaluation and results

The expected values for action-specific indicators and performance indicators reached or even exceeded the expected values. The milestone that was not considered adequate in the MTR was revised and delivered with the progress report. Therefore, all objectives and expected results were reached.

All **milestones** and final **deliverables** were achieved, as well all the **expected results** are completed:

- Achievement of expected values for action-specific indicators - ***Completed***
- Achievement the expected values for performance indicators - ***Completed***

Deliverables	**Expected in the GA**	**Actual**	**Status**
Inputs for the deliverable in Action C2 "Statement of project-related impacts" (Annex C1.3)	06/2020	06/2020	Completed

Milestones	**Expected in the GA**	**Actual**	**Status**
Impact of the project: initial situation (Annexes C1.1)	10/2016	10/2016	Completed - Revised after MTR revision (delivered 04/2019)
Impact of the project: in-progress situation (Annex C1.2)	07/2018	07/2018	Completed (updated and delivered on 03/2019)

Action C2: Assessment of the project actions impacts on socio-economy

Foreseen start date: 01/01/2017 Actual start date: 01/09/2016
Foreseen end date: 30/06/2020 Actual end date: 30/06/2020

Beneficiary responsible: CNR

Aim - Assess the impact of all project actions on the socio-economic conditions of the local populations and on ecosystem functions

Description of the activities

The economic, social and environmental impacts of the MOTTLES activities were assessed by different approaches, as explained below:

Sub-action C2.1 - Economic valuation

In January 2017, CNR in collaboration with ACRI-HE/ARGANS, defined the methodology for the economic evaluation (Total Economic Value, TEV). Then, CNR established a collaboration with the University of Firenze for the implementation of the TEV analyses with Italy as case study. The study was completed in June 2020 and will be published in the after-LIFE to make this innovative approach available and facilitate transfer to other countries. The main results confirm a **significant impact of O_3 on Italian forests, estimated as total potential damage from 1.2 B€ to 3.0 B€ of capital value** (average from 382 to 949 €/ha). The annual damage ranges from 46.3 M€ to 61.9 M€ (average 15-19 €/ha y^{-1}). Italian regions are affected by O_3 in different ways. Total damage partially follows the forest surface (from 0.97 M€ in Aosta Valley to 303.80 M€ in Tuscany equivalent to 0.03 M€ and 9.10 M€ per year). The average capital value shows the different influence of O_3 in the regions. The greater impacts are registered for Liguria (1,472 €/ha), Lombardy (1,272 €/ha), Campania (821 €/ha) and Piedmont (803 €/ha). Furthermore, a Contingent Valuation Method was used, implemented through questionnaires (Action C1) to assess the **willingness to pay to save forests from climate change**, a third of the respondents declared to be ready to pay **100€ yearly for the next 10 years to reduce European greenhouse gas emissions.** Completed results are included in the deliverable "Statement of project-related impacts on local economy, environment and population, including MOTTLES savings in CO_2 equivalents as well as photochemical oxidant formation equivalents (LCA)" (Annex C2.1).

Sub-action C2.2 - Social impact assessment

In January 2017, CNR in collaboration with ACRI-HE/ARGANS, defined the methodology for evaluating the impacts of ozone pollution on global food security. The results obtained by action B3 "*Derivation of new critical levels for forest protection*" were expanded to a larger scale. We used the methodology developed in MOTTLES for one study on the most important food species (wheat).

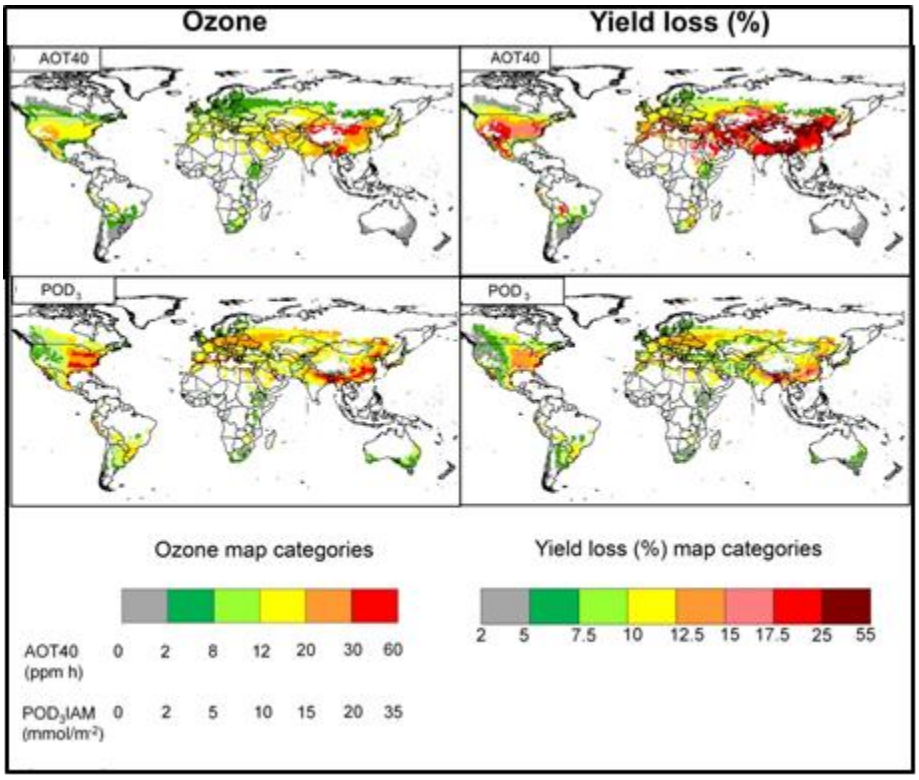


Fig. 10 - AOT40 (ppb h) and POD3 (mmol m^{-2}) and the negative effects of ozone pollution on wheat yield presented as the % yield loss for AOT40 and POD3.

We found that globally, 39.7% of the **lost production** occurs in Developed Countries (DC), 31.8% in Upper Middle Income Countries and Territories (UMIC) and 26.8% in Lower Middle Income Countries and Territories (LMIC). Mean percentage yield losses are highest for LMIC (10.7%), followed by 9.5% for UMIC and 9.1% for DC. This analysis also shows that some of the highest percentage yield losses occur in the top wheat-producing countries of the world such as China, India, United States and Russia (11.7%, 12.2%, 10.1% and 10.8% respectively), which corresponds to **45 Tg of lost grain yield**. For these countries, the greatest within-country production losses are in the warm-temperate-dry climatic regions of China (12.8 Tg) and the tropical-dry-climates of India (8.8 Tg), where >80% of the wheat is irrigated. Details and results are included in the deliverable "*Statement of project-related impacts on local economy, environment and population*" (Annex C2.1).

Moreover, an *ex-ante* analysis of environmental conditions in the study area was also conducted, the activity was led by CNR in collaboration with CREA-FL (in Italy), ARGANS and GIEFS (in France) and INCDS (in Romania). A specific interview for experts in forest monitoring was elaborated and disseminated from January to July 2018. The objective of this survey was to compare the situation before and after the installation of the new monitoring system, results are available in Annex C2.2.

Sub-action C2.3 - Environmental impact assessment

In July 2018, CNR selected a reliable Life Cycle Assessment (LCA) expert to conduct a comparison between the traditional method of forest monitoring and the innovative MOTTLES

approach by using data from MOTTLES. E. Carrari presented the first results of the LCA study at the Expert workshop organized by INCDS on 19th September 2019 (Annex C2.3).

The results are included in the action deliverable "*Statement of project-related impacts on local economy, environment and population*" (Annex C2.1) and showed that the active monitoring system had high environmental costs related with the installation of sensors and power supply. However, over time, the highest cost was represented by travels. Therefore, **the active O_3 monitoring system resulted as the most sustainable after 20 and after 10 years for both forest types**, i.e. deciduous and Mediterranean evergreen forests. Considering only the carbon footprint, the MOTTLES monitoring system resulted more sustainable even after 5 years, leading to a **saving for the whole network of 102 tons CO_2-eq in case of deciduous forests and 194 tons CO_2-eq in case Mediterranean evergreen woods.** These savings increased over time up to **218** and **402 tons CO_2-eq in 10 years** and **450 and 819 tons CO_2-eq in 20 years** respectively for the two forest types. Three scenarios of different distances (30, 400 and 750 km) were also investigated.

Problems and delays

The Milestone "*Impact of the project: initial situation*" was considered inconsistent by EASME, because it did not include the study on the ex-ante socio-economic conditions in the study area. Hence, we revised the milestone "*Impact of the project at the initial situation*" and delivered it with PR and FR (Annex C2.4). The *ex-ante* evaluation is focused on the monitoring costs. Then, the new report includes the evaluation of the size of the company who manages the monitoring systems in the different countries and replies to the interviews regarding the cost of the traditional monitoring system. In this way we had an assessment of the monitoring costs before the beginning of the project; with the milestone "*Impact of the project at the in progress situation*", delivered with the Progress Report we compared the costs of the novel active monitoring implemented by MOTTLES with the traditional system (Annex C2.2).

Evaluation and results

This action has provided extremely positive results, demonstrating how the implementation of the new monitoring system entails **lower environmental impacts compared to the traditional system and a considerable economic saving for site managers, in addition to a better protection of the forests from ozone pollution**. The results of the sub-actions are/will be of great support to the transfer, replication and continuation of MOTTLES monitoring practices. All **milestones** and final **deliverables** were achieved; therefore, the action was concluded successfully.

All the **expected results** are completed:

- A study of the impacts of the project actions on local economy and population with a focus on wood production - ***Completed***
- A quantitative assessment (LCA) over the environmental impacts - ***Completed***

Deliverables	Expected in the GA	Actual	Status
Statement of project-related impacts on local economy, environment and population, including MOTTLES savings in CO2 equivalents as well as photochemical oxidant formation equivalents (LCA) (Annex C2.1)	06/2020	06/2020	Completed

Milestones	Expected in the GA	Actual	Status
Impact of the project: initial situation (Annex C2.4)	10/2016	10/2016 revised on 04/2019	Completed Revised after MTR revision (delivered on 04/2019)
Impact of the project: in-progress situation (Annex C2.2)	07/2018	07/2018 revised on 04/2019	Completed Revised after MTR revision (delivered on 04/2019)

Action C3: Forest health and resiliency through integrated management practices

Foreseen start date: 01/01/2017 Actual start date: 01/09/2016
Foreseen end date: 30/06/2020 Actual end date: 30/06/2020

Beneficiary responsible: CNR

Aim – Summarize the new knowledge produced in MOTTLES for evaluating expected risks and benefits of adaptation/mitigation options, and transfer of scientifically-sound information to policy makers and the general public, so that MOTTLES results can last in the long term. Major aim is improved awareness about the benefits of an O_3-oriented management of forests.

Description of the activities

At the beginning of the project, all partners analysed the literature and defined the main indicators of forest health: visible foliar O_3 injury, crown defoliation, radial growth. The assessment is made in terms of canopy, whole tree, and stand attributes (Annex C3.1). A review on present forest management practices for adaptation to climate change, realized in collaboration with the IUFRO *Task Force on Climate Change and Forest Health* and the COST Action PROFOUND, was delivered with the Mid-term report and presented at the *28th IUFRO conference for Specialists in Air Pollution and Climate Change Impacts on Forest Ecosystems (Tokyo, 22-26 October 2017)* (Annex C3.2). The presentation entitled "*Sustainable forest management options for forests under severe ozone and nitrogen pollution*" received a **special award** addressed to the young MOTTLES researcher E. Carrari.

Evaluation of ozone-oriented management strategies by combining MOTTLES data with modelling simulations, and by targeted discussions with the SIB and other relevant stakeholders (IUFRO, EFI, EEA, SISEF) started since October 2017 until the end of the project (table 3). INCDS worked for the implementation of MOTTLES recommendations and best practices in the management of its forests (Annex C3.3) with focus on: the options for an ozone-oriented sustainable forest management; the scientific, environmental, social and economic advantages of the new MOTTLES monitoring system; the use of PODY for assessing ozone risk to forests; the survey of visible foliar ozone injury and the MOTTLES atlas of injury; dendrometers and radial stem growth; the ozone critical levels for forests; and the management of urban forests to minimize ozone pollution.

In March 2018, MOTTLES researchers started a collaboration with Tuscany Region (stakeholder: local policy maker), and developed innovative guidelines for the sustainable management of urban forests in Tuscany aiming to the improvement of air quality (Annex C3.4). The guidelines entered into force on 28 November 2018 with "Bollettino ufficiale Regione Toscana"[5]. Such a result was a fundamental input for the final deliverable of action D2 as it will help local urban managers to select the best suited tree species for maximising air quality.

The Integrated tool box of practices summarizing the new knowledge for evaluating expected risks and benefits of adaptation/mitigation options and a summary for stakeholders was translated into the 3 MOTTLES languages (FR, IT and RO) (Annex C3.5).

[5] https://servizi.toscana.it/RT/statistichedinamiche/piante

Problems and delays

In consideration of the importance of the final deliverable, the PMT decided to finalize the deliverable "*Integrated tool box of practices summarizing the new knowledge for evaluating expected risks and benefits of adaptation/mitigation options: summary for stakeholders*" with the help of an external collaboration (ARCHES-Conseils) to improve transferability to stakeholders. and because of the earlier end of the contract with the project manager assistant (E. Carrari terminated her contract on 29th February 2020) who was leader of action C3. From March 2020, the action was led by the project coordinator E. Paoletti (CNR) without changes in the project activities and results.

Table 3 - Summary of selected ozone management options

Management option		Ozone-oriented
BEST STAND AGE	**Mature forests**	Younger plants are prone to injury due to higher stomatal uptake
BEST STAND STRUCTURE	**Moderate density**	O_3 concentration decreases quickly below the canopy -> moderate density reduces the within-canopy O_3 exposure but reduces also tree-tree competition for water and nutrients
	Uneven aged structure	Reduces within-canopy O_3 exposure, as trees of the lower layers have lower exposure
	High species mixture	A mixture of tolerant and less sensitive species contributes to the maintenance of ecosystem services
HARVESTING RECOMMENDATIONS	**Best time: Autumn**	Wood produced in high O_3 exposure sites may not be as strong as in lower exposures.
		Autumn harvest reduces risk of windthrow
UNDERSTOREY MANAGEMENT	**Controlled burning**	Early-abscised leaves from O_3 polluted trees decomposed more slowly, these results in litter accumulation. This practice can reduce risk of fire
SOIL AMENDMENTS	**N & P amendments**	Plants are less sensitive to ozone, when they are accompanied by realistic amounts of N and P
MONITORING STRATEGIES	**Permanent monitoring network**	Defining critical O_3 levels exceedances is essential to maintain and promote needed forest ecosystem services

Evaluation and results

A deep bibliographic survey showed a low level of knowledge about current forest management practices for adaptation to O_3 pollution. It was insufficient to carry out a meta-analysis as originally proposed by MOTTLES. The meta-analysis was replaced by a detailed review, hence, the overall project objectives and the expected results remained unchanged. Such review of forest management practices for adaptation to climate change was delivered with the MTR and presented at two conferences. Further results were achieved thanks to numerous discussions with forest management experts (foresters, technicians, etc.) and other stakeholders (urban managers, local authorities).

All **milestones** and final **deliverables** were achieved; therefore the action was concluded successfully.

All the **expected results** are completed:

- Which kind of forest age, density, structure, fertility is more tolerant of ozone pollution - ***Completed***
- Which species and species mixtures maximise the air quality benefits of forests - ***Completed***
- Which management is more appropriate for limiting the injury by disturbances in ozone-impacted forests - ***Completed***
- Which management is more appropriate to reduce ozone-induced wood loss - ***Completed***
- Which management is more appropriated to different policy settings in terms of forest protection from ozone - ***Completed***

Deliverables	**Expected in the GA**	**Actual**	**Status**
Integrated tool box of practices summarizing the new knowledge for evaluating expected risks and benefits of adaptation/mitigation options and a summary for stakeholders in EN, IT, FR & RO (Annex C3.5)	06/2020	06/2020	Completed

Milestones	**Expected in the GA**	**Actual**	**Status**
Review of present forest management practices for adaptation to climate change (Annex C3.2)	06/2017	06/2017	Completed
Evaluation of ozone-oriented management strategies and discussions with the SIB and other relevant stakeholders (Annex C3.3)	06/2019	06/2019	Completed

Action D1: Integration, Dissemination and Execution

Foreseen start date: 01/07/2016 Actual start date: 01/07/2016
Foreseen end date: 30/06/2020 Actual end date: 30/06/2020

Beneficiary responsible: ARGANS (former ACRI-HE)

Aim - Synthesize key findings, collate, maintain and disseminate reliable information generated by MOTTLES, provide the basis of dissemination campaigns and results exploitation, prepare and conduct outreach activities with a wide range of stakeholders, create the basis for long-lived exploitation of MOTTLES results, help practitioners and decision makers to make use of the new knowledge generated by MOTTLES.

Description of the activities

Every year, results of this project were broadcasted to local authorities (Italian, French and Romanian Ministry of Environment, Regione Toscana), public bodies (University of Florence), and forest bodies (ICP, IUFRO, EFI, and AISF). These various actions have strongly interested the managers of forests (e.g. ONF, Carabinieri Forestali) for the protection and conservation of forests by an adapted global management.

Sub-action D1.1 - Networking with other projects (Annex D1.1)

The project provided a platform for networking with other LIFE projects with a focus on the establishment of a platform to gather the future information needs of EC and other stakeholders, in particular with regard to climate change, sustainable forest management, biodiversity, and air pollution. The wider aim of this initiative was to establish **close cooperation** between scientific and stakeholders that are or were involved in the targeted environmental problems. In total MOTTLES shared its experience during **9 events** involving around **80 LIFE projects.**

Main outputs:

- Intense cooperation with LIFE projects: AForClimate, SMART4Action, VEG-GAP, GoProFor, FRESh, SYSTEMIC
- Networking with other European projects: DIGITGAME (Erasmus+), MITIMPACT (INTERREG Alcotra)
- Realization of NEC monitoring network in Italy, as result of the collaboration with SMART4ACTION
- Inclusion of MOTTLES good practices in the online database GoProFor https://www.lifegoprofor-gp.eu/best-practice/296/eng

Sub-action D1.2 - Development of dissemination and communication plan

MOTTLES disseminated its objectives, activities and results through the following tools:

a) Noticeboards (Annex D1.2)

MOTTLES implemented 17 Noticeboards, placed at each site of the network, 9 in Italian, 4 in French and 4 in Romanian. All versions, including an English version are also available at the MOTTLES website[6].

Fig. 11 - LIFE platform meeting in Madrid, Spain (13-14 March 2018)

Fig. 12 - Inauguration of the first MOTTLES noticeboard in Italy (LAZ1), with the participation of Carabinieri forestali.

6 https://mottles-project.wixsite.com/life/publications

b) Brochure of project presentation (Annex D1.3), Brochure of project results (Annex D1.4), Leaflet (Annex D1.5)

A total of **697 leaflets & 262 presentation brochures** were distributed to MOTTLES audience. Leaflet and presentation brochure were created and printed by internal project personnel, without determining costs for the budget. The CDs envisaged by the GA (250 copies) were not realized as this type of product in recent years is no longer popular, therefore we decided to create a second type of brochure, not mentioned in the GA, that was printed in **1000 copies** by external assistance (Compagnia delle Foreste). This brochure contains the project results (Annex D1.4) and was to be distributed at the final project events. Due to the COVID-19 restrictions, those events were not realized therefore at the moment no copies have been distributed, but it is possible to download the brochure at MOTTLES website. The distribution of this brochure will be carried out in events foreseen in the After-LIFE plan (Annex D3.1).

Table 4 - List of leaflets and brochures distributed during the whole project duration

Event	n. of leaflets /brochures distributed
"Ozone and Vegetation: The contribution of the research in Italy"	50 leaflets
33rd Task Force Meeting of ICP Forests, Bucharest	100 leaflets
LIFE project networking organized by AFORCLIMATE	30 leaflets
25th anniversary of the LIFE Program, Firenze (Italy)	50 leaflets
28th IUFRO conference for Specialists in Air Pollution and Climate Change Impacts on Forest Ecosystems	70 leaflets
LIFE Platform Meeting on CCA in Agriculture and Forestry	50 leaflets
International Conference on Ozone and Plant Ecosystem	107 leaflets
International workshop organized by INCDS	100 leaflets
Congress of Silviculture	100 leaflets
ICP-vegetation expert panel	40 leaflets
International Conference on Ozone and Plant Ecosystem	107 brochures
Congress of Silviculture	100 brochures
ICP-vegetation expert panel	40 brochures
EU airclean forum	15 brochures

c) Gadget distribution

At the KO meeting, in September 2016, the partners decided to produce the following gadgets with the MOTTLES logo and LIFE logo: pens, USB drives, T-shirt, labels. Those were distributed for the first time at the first progress meeting held in Rome in July 2017. The gadgets were distributed to those people involved in the project but also to external guests. In detail, 30 polo shirts, 30 pens and 30 USB pens were distributed. Each associated beneficiary member received 50 pens and 200 adhesive labels, for a total of 200 pens and 800 labels. Each associated beneficiary managed the distribution of gadgets individually. 107 pens and USB pens were distributed to the participants at the expert workshop organized by CNR in Florence from 21 to 25 May 2018 (International Conference on Ozone and Plant Ecosystem). In addition, 50 pens were distributed at the LIFE Platform Meeting on CCA in Agriculture and Forestry (13-14 March 2018 Madrid) and 70 pens at the 28th IUFRO conference for Specialists in Air Pollution and Climate Change Impacts on Forest Ecosystems: "Actions for Sustainable Forest Ecosystems under Air Pollution and Climate Change" (very specialised audience), in Fuchu, Tokyo, Japan (October 2017).

Fig. 13 – Examples of MOTTLES gadgets displaying the LIFE logo

Table 5 - List of gadgets distributed during the whole project duration

Gadget type	Printed copies	n. of gadget distributed per type
T-shirts	30	30
Pens	500	453
USB drive	150	133
Labels	2100	800

A detailed report on brochures, leaflets and gadgets distribution is available in Annex D1.6.

d) Project website (Annex D1.7), Facebook, Twitter, & Newsletters (Annex D1.8).

The project website was online since October 2016, realized and managed by CNR. Initially the website was http://mottles.ipsp.cnr.it/, in 2019 due to the transfer of the MOTTLES project to IRET-CNR institute (see paragraph 6.3), the MOTTLES website changed domain, the new **website**[7] was completed in October 2019 and broadly disseminated. Website and social network pages were/will be regularly updated with pictures and information about main events and results of MOTTLES. MOTTLES has **241 followers** on Fb and **96 followers** on Twitter. Six **newsletters** were disseminated every 6 months from January 2017 to a mailing lists of around 2000 personal and institutional addresses. All newsletters are uploaded at the website.

e) Realization of scientific papers x18

The publication of MOTTLES results in scientific journals allowed the project to be disseminated within the international scientific community and the MOTTLES scientific consideration to be consolidated.

1. Sicard et al. (2020). Epidemiological derivation of flux-based critical levels for visible ozone injury in European forests. Journal of Forestry Research. (Annex B3.7)
2. Hoshika et al. (2020). Flux-Based Ozone Risk Assessment for a Plant Injury Index (PII) in Three European Cool-Temperate Deciduous Tree Species. Forests. (Annex B3.8)
3. Hoshika et al. (2020). Developing Ozone Risk Assessment for Larch Species. Front. For. Glob. Change. (Annex B3.9)
4. Paoletti et al. (2019) Toward stomatal–flux based forest protection against ozone: The MOTTLES approach. Science of the Total Environment. (Annex D1.9a)
5. De Marco et al. (2019) Impacts of air pollution on human and ecosystem health, and implications for the National Emission Ceilings Directive: Insights from Italy. Environment International. (Annex D1.9b)
6. Fares S, et al. (2019). Ozone and particle fluxes in a Mediterranean forest predicted by the AIRTREE model. Science of the Total Environment. 682: 494–504. (Annex D1.9c)
7. Feng, Z., De Marco, A., Anav, A., Gualtieri, M., Sicard, P., Tian, H., ... & Paoletti, E. (2019). Economic losses due to ozone impacts on human health, forest productivity and crop yield across China. Environment International, 131, 104966. (Annex D1.9d)
8. Mills, G., Sharps, K., Simpson, D., Pleijel, H., Broberg, M., Uddling, J., ... & Agrawal, M. (2018). Ozone pollution will compromise efforts to increase global wheat production. Global change biology, 24(8), 3560-3574. (Annex D1.9e)
9. Hoshika et al. (2018). Testing a ratio of photosynthesis to O_3 uptake as an index for assessing O_3-induced foliar visible injury in poplar trees. Environmental Science and Pollution Research. (Annex D1.9f)
10. Paoletti et al. (2018) Five-year volume growth of European beech does not respond to ozone pollution in Italy. Environmental Science and Pollution Research. (Annex D1.9g)

[7] https://mottles-project.wixsite.com/life

11. Sicard et al. (2017) Projected global tropospheric ozone impacts on vegetation under different emission and climate scenarios. Atmospheric Chemistry and Physics. (Annex D1.9h)
12. Ochoa-Hueso et al. (2017) Ecological impacts of atmospheric pollution and interactions with climate change in terrestrial ecosystems of the Mediterranean Basin: Current research and future directions. Environmental Pollution.(Annex D1.9i)
13. Braun et al. (2017) Epidemiological analysis of ozone and nitrogen impacts on vegetation – Critical evaluation and recommendations. Science of The Total Environment.(Annex D1.9j)
14. Hoshika et al. (2017) Stomatal conductance models for ozone risk assessment at canopy level in two Mediterranean evergreen forests. Agricultural and Forest Meteorology (Annex D1.9k)
15. De Marco et al (2017) Ozone exposure affects tree defoliation in a continental climate. Science of the Total Environment. (Annex D1.9l)
16. Fares et al. (2018). Ozone flux in plant ecosystems: new opportunities for long-term monitoring networks to deliver ozone-risk assessments. Environmental Science and Pollution Research. (Annex D1.9m)
17. Paoletti et al. (2017) A new-generation 3D ozone FACE (Free Air Controlled Exposure). Science of the Total Environment. (Annex D19.n)
18. Anav et al. (2016) The Role of Plant phenology in stomatal ozone flux Modelling. Global Change Biology. (Annex D1.9o)

f) Presentation at conferences and workshops with stakeholders (Annex D1.10)

Presenting the MOTTLES rationale and results to 21 conferences and workshops allowed the project to interact with major stakeholders e.g. ICP Vegetation, SISEF, IUFRO, NEC, scientists, policy-makers, forest experts, and air quality experts. Feedbacks were used for developing the MOTTLES guidelines. In total, 54 presentations were given.

g) Press releases (Annex D1.11)

Six press releases were prepared and disseminated via national newspapers or the web.

1. On-line article[8] **"Pollution atmosphérique: 27 ans de mesures dans les Écrins"** realized by the National Park "Des Ecrins" on 13 September 2018.
2. Article **"L'ozone, le soufre et l'azote"** about forest and air pollution in the regional newspaper Le Dauphiné Libéré, on 31 August 2018.
3. The on-line article[9] **"Alberi contro l'inquinamento, arrivano le linee guida per la messa a dimora nei centri urbani"** on 21 November 2018
4. Newspaper article **"Troppo smog in città? Ci pensano gli alberi. Le nuove linee guida"** in the national newspaper "La Nazione" on 22 November 2018.
5. Two articles reporting the description of the International workshops realized by MOTTLES in the international web journal **IUFRO News** (in 07/2018 and 11/2018).

[8] http://www.ecrins-parcnational.fr/dossier/pollution-atmospherique-27-ans-mesures-ecrins
[9] http://www.toscana-notizie.it/-/alberi-contro-l-inquinamento-arrivano-le-linee-guida-per-la-messa-a-dimora-nei-centri-urbani?fbclid=IwAR05Y-7DfB1Btlw70zRgVjOkdQuawKEn5nn3fGUIqKk3yVsUJ-tm4yMUlWU

6. Article[10] **"Protecting forests against ozone"** published on 19/09/2019 in "Ready, steady, green! LIFE helps farming and forestry adapt to climate change".

h) Policy briefs (Annex D1.12)

The following policy briefs were circulated through the MOTTLES website:

1. "MOTTLES: the LIFE project to protect forests from ozone"
   Author: Silvano Fares (CREA-FL) (Annex D1.12a)
2. "Ozone levels fall in rural areas, but rise in cities"
   Author: Pierre Sicard (ARGANS) (Annex D1.12b)
3. "Why do we still need to derive ozone critical levels for vegetation protection?"
   Authors: Alessandra De Marco (ENEA), Pierre Sicard (ARGANS) (Annex D1.12c)
4. "Ozone monitoring and National Emission Ceiling Directive (NECD)"
   Author: Alessandra De Marco (ENEA) (Annex D1.12d)

Fig. 14 - E. Paoletti during the shooting of the video for the LIFE project AFORCLIMATE on sustainable forest management.

i) MOTTLES videos

[10] https://ec.europa.eu/easme/sites/easme-site/files/life_cca-forest_agri-.pdf

1. On the 3rd of September 2016, a documentary[11] on the role of plants in fighting ozone pollution was presented during the most famous Italian scientific program "Superquark". One of the MOTTLES scientists, Silvano Fares, talked about this issue from Castelporziano, where there are three sites of our monitoring network.
2. The project coordinator Elena Paoletti explained the importance of the Sustainable Forest Management in the view of pollution and climate change in a video[12] realized by Compagnie delle Foreste for the LIFE project AFORCLIMATE.
3. Presentation video about MOTTLES realized by Compagnia delle Foreste, uploaded on social networks and MOTTLES website in session "about us" and in the home page https://mottles-project.wixsite.com/life/about-us

j) Layman's report (Annex D1.13) realized with the support of the external company Compagnia delle Foreste in the three languages of MOTTLES partners.

k) Events and workshops organized by MOTTLES

A) *Expert workshop: International Conference on Ozone & Plant Ecosystems* [13]

Date: 21-25 May, 2018
Location: Florence (Italy)
N. of participants: 107
Countries represented: 29
Total n. of presentations: 98 (51 oral and 47 poster presentations)

Large dissemination activities to publicize the event were carried out. MOTTLES was the main sponsor, its logo was present on website, published material and gadgets (Annex D1.14).

Fig. 15 - The MOTTLES team at the Experts' workshop "*International Conference on Ozone & Plant Ecosystems".*

[11] https://www.youtube.com/watch?v=qfbbj6ETbzY&feature=emb_title
[12] http://www.compagniadelleforeste.it/blog/189-cambiamento-climatico-e-foreste-video-per-aforclimate.html
[13] https://conference2018.wixsite.com/ozoneandplants

B) *International workshop "Forest Science for a Sustainable Forestry and Human Wellbeing in a Changing World completed"* [14]

Date: 18-21 September, 2018
Location: Bucharest (Romania)
N. of participants: 233
Countries represented: 16
Total n. of presentations: 89 oral presentations and 62 poster presentations

The project MOTTLES was one of the main organizers (Annex D1.15).

Fig. 16 - MOTTLES team at the International workshop *"Forest Science for a Sustainable Forestry and Human Wellbeing in a Changing World completed.*

l) Educational activities for students (Annex D1.16a) and site guided tours (Annex D1.16b):

MOTTLES partners were involved in education programmes (x 10 sessions) at European universities, post-graduate levels and primary and secondary schools. In total we reached **311 students**.

[14] https://incdsconference85.wixsite.com/conference

Student type	Number of students
Primary school	28
Secondary school	42
University school	227
Thesis students and internships	6
PhD and Post Doc	8

Fig. 17 - E. Paoletti (CNR) during a seminar for University students (6 December 2016).

MOTTLES organized **7 site tours** involving a total of **178 participants** including students (high school and university), scientists, policy makers and practitioners:

- 1 at the site EMI1 (Italy)
- 4 at the ozone FACE facility of Sesto Fiorentino (Italy)
- 2 at the sites CPZ1 and CPZ2 of Castelporziano (Italy)

Fig. 18 - Visit of the ozone FACE facility in Sesto Fiorentino (25 May 2018).

m) Training courses & expert workshop (Annex D1.17)

Transfer of knowledge aimed to circulate the innovative aspects and results achieved. The MOTTLES partners attended workshops dealing with topics related to MOTTLES (forestry, sustainable development, climate change, air pollution). Special attention was given to workshops bridging science and policy, such as UNECE/ICP. In total MOTTLES participants actively participated in **14 workshops and courses**, always presenting a talk or poster about the project activities and discussing them with stakeholders.

Fig. 19 - MOTTLES at the "EU AIRCLEAN forum" in Bratislava in November 2019.

Problems and delays

In order to reduce travel costs, the noticeboard set up was combined with agrometeorological station installation; hence it was delayed from October 2016 to March 2017. Dissemination plan was not considered sufficient by EASME, then it was revised accordingly and was released with the Progress Report and the Final Report (Annex D1.18). A slight delay in the dissemination of the brochures can be noted. The CDs envisaged by the GA (250 copies) were not realized due to the disposal of this type of product in recent years, therefore a second type of brochure was created and printed. Due to COVID-19, the International workshop of Paphos, which was expected to host a MOTTLES session and the final MOTTLES project meeting, was postponed to May 2021 (as After-LIFE activity). The reduction of the travel budget during the revision phase of the project proposal forced us to co-finance largely the dissemination activities of MOTTLES; despite this, it was necessary to reallocate part of the budget in favour of the travel category without causing substantial changes in the budget.

Evaluation and results

The whole MOTTLES consortium was strongly involved in dissemination and reached a considerable pool of interested parties. This is evidenced by the high participation in MOTTLES events, by the number of visits to the website or the number of social network followers. All this interest produces a **notable awareness-raising** to reduce the air pollution impacts on forests as well as a better understanding of forest biodiversity in a context of climate change and the transfer of know-how, best practices and methodology on the O_3 monitoring approach. Furthermore, participation in numerous workshops and courses formed a large group of **European-level experts**. All events depending on travel were largely co-funded allowing the reach of indicators and expected results. Due to the emergency situation linked to COVID-19 the final workshop was postponed. However, the two workshops foreseen in the project proposal were successfully completed. All the other **milestones** were achieved and final **deliverables** were completed thanks to an external assistance, therefore the action was concluded successfully. Values of **Indicator of progresses** always exceeded the expected values.

All the **expected results** and indicators are completed:

- Project website operational, on-line and regularly updated - ***Completed***
- 17 notice boards implemented - ***Completed***
- More information and awareness-raising to reduce the air pollution impacts on forests - ***Completed***
- Better understanding of forest biodiversity in a context of climate change - ***Completed***
- Comparable Europe-wide forest information for a healthy and resilient forest structure - ***Completed***
- Creation of a network of European experts - ***Completed***
- Organisation of one experts' workshop - ***Completed***
- Transfer of know-how, best practices and methodology on the O_3 monitoring approach - ***Completed***

Status of Milestones & Deliverables

Deliverables	Expected in the GA	Actual	Status
Website (Annex D1.7)	10/2016	10/2016	Completed
Notice boards (Annex D1.2)	10/2016	03/2017	Completed
Communication and dissemination plan (Annex D1.18)	10/2016	10/2016	Completed Revised after MTR (04/2019)
Layman's report (Annex D1.13)	06/2020	06/2020	Completed

Milestones	Expected in the GA	Actual	Status
Notice boards set-up	10/2016	03/2017	Completed
Website operational and on-line	10/2016	10/2016	Completed
First distribution of leaflets and brochures (Report on brochures and gadget distribution Annex D1.6)	10/2016	Leaflet 10/2016 Brochure 05/2018	Completed
Experts' workshop organized by CNR (Annex D1.14)	03/2019	05/2018	Completed
International workshop organized by INCDS (Annex D1.15)	03/2020	09/2018	Completed

Indicators of progress	Quantity expected in the GA	Current quantity delivered
Notice boards set-up	01/10/2016	03/2017
Number of places where the notice boards are posted	17	17
Website implementation	01/10/2016	01/10/2016
Number of web visitors	50/month	195/month
Number of experts' workshops organized	1 - 50 participants	Ozone & Plants (05/2018) : 107

		INCDS Conference (09/2018): 233
Number of printed Layman's reports	500	500
Number of leaflets & brochures & CD distributed (replaced by a second brochure)	400 & 250 & 250	697 & 262 & 0 (715 & 280 & 500 printed copies)
Number of people that received the e-newsletter	300	233 (followers of MOTTLES Facebook page) + 2000 people receiving the newsletters
Number of articles published in scientific journals	6	18
Announcements in international conferences	4	52
Number of school class/university visits	6 - 300 students	10 - 311 students
Number of participants in international conferences	50	107 (Florence) + 233 (Bucharest)
Number of on-site free guided tours	3	2 CPZ1+1 EMI1 + 4 FACE

Action D2: Science-policy-stakeholder interaction

Foreseen start date: 01/07/2016 Actual start date: 01/08/2016
Foreseen end date: 30/06/2020 Actual end date: 30/06/2020

Beneficiary responsible: GIEFS

Aim - i) update forestry legislation to reflect current context and the requirement for improved forest management planning and monitoring; ii) propose to policy-makers: usable legislative standards and proper regional policies for forest protection; iii) propose to forest/park managers and other stakeholders a guideline that is proper and policy relevant with recommendations and effective options for a strengthening a sustainable forest management to ensure a healthy forest ecosystem and resilience to climate change challenges.

Description of the activities

From the beginning of the project all the partners participated to events in order to present MOTTLES to the main stakeholders and then to transfer the project know-how and results. The action was mainly carried out by GIEFS as responsible for the action and CNR as project coordinator. This action resulted specifically in the organization and/or participation in **8 meetings with foresters** and site managers, **24 oriented meetings** of one day with stakeholders, **16 events of communication with policy-makers** and local/international stakeholders, and **2 main events** (Stakeholder-oriented workshops).

MOTTLES main stakeholders were:

- Italian Ministry of Environment
- Romanian Ministry of Environment
- French Ministry of Environment
- United Nations Forum on Forests (UNFF)
- International Union of Forest Research Organizations (IUFRO)
- National Emission Ceilings Commission
- European Forest Institute (EFI)
- ICP-Vegetation
- ICP-Forests
- Carabinieri forestali
- French National Office of Forest (ONF)
- Italian Society of Silviculture and Forest Ecology (SISEF)
- Italian Academy of Forest Sciences (AISF)

From June 2018 to July 2019 M-L Ciriani and L. Dalstein (GIEFS) led the work to complete the "Report on existing and future science-policy interactions and needs" (Annex D2.1). The report was based on results of questionnaires on "Policies on environmental problems, air pollution and climate change" filled by stakeholders during the international workshops and stakeholders included in the SIB (Annex D2.2). In January 2020, all partners started to work together to the "Guidelines with recommendations and effective adaptation measures for sustainable forest management". This main deliverable derives from the results of action C3 discussed with stakeholders at main workshops (examples). The guidelines were completed in June 2020 (Annex D2.3) and contain a description of sustainable forest management practices

for adaptation to climate change, realized in collaboration with the IUFRO Task Force on Climate Change and Forest Health and the COST Action PROFOUND and in collaboration with Regione Toscana.

Sub action D2.1 Communication for stakeholders, end users & policy makers

Interaction with foresters and site managers (Annex D2.4)

Awareness of local site managers and foresters (e.g. ONF in France and Carabinieri Forestali in Italy) about the effects of O_3 pollution on vegetation was carried out during the first stage of the project by all partners i.e. the selection of forest MOTTLES plots (Annex B1.1). In total **8 events** were organized mainly back to back to site installations, including **17 foresters and site managers**, belonging to the following organizations: Parco di Carrega, Carabinieri forestali, CNR-IBAF, Regione Piemonte, MERA, Morvan National Park officials, private landowners.

Main outputs:

- Awareness on the effects of the O_3 on vegetation.
- Awareness on the functioning of MOTTLES stations.
- Support of all site managers and foresters involved in the management of the station.
- Proposed to enlarge the monitoring system to the entire MERA network.

Fig. 20 - Meeting with the site managers of ABR1 (Italy) on 25/06/2017

Oriented meetings of one day with stakeholders (Annex D2.5)

In line with action D2, under sub-action D2.1 "*Communication for stakeholders, end users & policy makers*", CNR organized many meetings of one day with stakeholders to bridge gaps between scientific research and practical application of the results. During the total project

duration, participants attended **24** meetings involving **790** national and international stakeholders.

In general, those meetings had the following key results for the project:

- The realization of the **Monitoring Site Network "NEC Italy"** in collaboration with the Italian Ministry of Environment, Carabinieri Forestali and the LIFE project SMART4Action (Annex D2.6).
- The first "**Guidelines for the management of urban forests aiming to improve air quality**" in collaboration with Tuscany Region (Annex C3.4).

Fig. 21 - E. Paoletti meets Dr. John Parrotta (IUFRO president) on 19/01/2020

Communication with policy-makers and local/international stakeholders (Annex D2.7)

The whole consortium carried out an intense communication with its main stakeholders, especially politicians (local and national levels) and members of NGOs. In total MOTTLES beneficiaries participated actively in 16 **events**, reaching a total of **6900 members** of organizations related with forests, politicians and international authorities.

Main outputs of such activity are:

- Awareness of the new monitoring system implemented by MOTTLES among major entities working on forests at national and international level (EFI, SISEF, IUFRO, EFI, UNFF, Carabinieri Forestali, Italian Ministry of Environment).
- The realization of the **Monitoring Site Network in Romania** in collaboration with Romanian Ministry of environment (Annex D2.6)
- Increase awareness of main issues related with Forest health, Pollution and Climate change.
- Transfer relevant project results to policy-makers and stakeholders.
- Assessment and analysis of existing science-policy interactions and means of communication.
- Definition of present and future policy needs.
- Development of novel methods to improve science-policy interface at different scales.
- Transfer the experience of European Policies in terms of air quality standards.

- Participation in the workgroup for forests of the council of the European Union: "Establishing Strategic priorities on forests for the period 2019-2020 and the guidelines for a new European forestry strategy after 2020".
- Transfer of MOTTLES Guidelines to main decision makers.

Sub action D2.2 Legislative & policy implementation

Organization of decision-makers & Stakeholder-oriented workshops

1. *Workshop on Ozone and Plant Ecosystems* (Firenze, 21-25 May 2018) (Annex D2.8)

It was organized by CNR in collaboration with MOTTLES main stakeholders: the International Cooperative Program on Effects of Air Pollution on Natural Vegetation and Crops (ICP vegetation), International Union of Forest Research Organizations (IUFRO) and Tuscany Region (regional policy-makers). In addition to the creation of bridges between science and decision making, MOTTLES distributed questionnaires to the experts: how stakeholders respond to and learn about environmental problems in general and about air pollution and climate change impacts, in line with action D2.

2. "*Bridging science and decision-making for monitoring ozone harm to forests*" (Bucharest, 18-21 September 2018) (Annex D2.9-10)

A specific session was held at the International workshop "Forest Science for a Sustainable Forestry and Human Wellbeing in a Changing World" organized by INCDS, with the main aim of transferring the MOTTLES guidelines to all stakeholders (policy-maker session).

Main topics:

a) Challenges in monitoring the stomatal O_3 fluxes at forest sites: lessons from the LIFE project MOTTLES.
b) Assessment on O_3 foliar injury on French MOTTLES plots: correlation with O_3 levels and sensitivity of species - Comparison with results on national plots.
c) Tree growth monitoring under changing environment: effect of O_3 pollution on interannual stem growth dynamic of O_3 sensitive species.
d) Data management, validation and ozone flux calculation in the MOTTLES.
e) Ozone risk assessment for European forests: a modelling approach.
f) Modelling stomatal O_3 flux: the role of plant phenology and rooting depth.
g) Modelling stomatal O_3 flux using multi-layer canopy.

Sub action D2.3 Maximizing the local environmental benefits by implementing other EU policies

The MOTTLES coordinator E. Paoletti was nominated national expert for ozone within ICP-Forests so that the MOTTLES data will contribute to the ICP-Forests database for Italy (Annex D2.11). In addition, the MOTTLES scientist D. Silaghi was nominated Chair of the ICP-Forests Expert Panel on Ambient Air Quality, within the working Group on Effects of the UNECE CLRTAP (http://icp-forests.net/page/expert-panel-on-ambient-air).

GIEFS analysed the relevance of EU policies to MOTTLES (Table 6) and identified which MOTTLES activities and outcomes represent direct practical benefits, this was the base for the questionnaires disseminated among stakeholders (Annex D2.8).

Table 6 - EU policies relevant to MOTTLES

EU policies	**Relevance to MOTTLES**
National emission ceilings	It seems that the national emissions ceilings are not adapted for the south countries of Europe because, even if we don't reach the critical level, we can have many injuries because some species are more sensible and also because the meteorological conditions can enhance the symptoms.
White Paper on "Adapting to Climate Change: towards a European Framework for action" (COM(2009)147)	We have to consider not only the European critical level of ozone for the injuries on forests but also needs to integrate the local and meteorological conditions. So we could imagine that the critical level is a mean level inserted in a larger marge for example of 20 % more or less. Like that some special conditions of high altitude, humidity and temperature could explain the high or less reactivities of some forest species towards ozone.
EU Forest strategy	We could propose for the specific survey of forest to have a special look on trees living in high altitude, for example on conifers where the local conditions of humidity are different and also for the south of Europe where the conditions of temperature and humidity on altitude can modify more the interpretation of the results so the marge of 20% of error on the critical European level could be a reality for these special cases.
Air quality directives	The air quality should integrate the error marge for forests and take real measures of protection to reduce the GES level, by implementing new pollution control strategies, especially in the transport sector with new energy components such as H2 or electricity.
EU Biodiversity Strategy EU Habitat directive	Considering that climate change is a reality and therefore the measures taken today to protect areas with high biological potential are important to maintain, for example through measures taken in favor of the creation of Natura 2000.

Problems and delays

Limited budget for some travel activity, due to the unexpected reduction during the proposal revision, forced us to co-finance by other projects and sources to maintain the high standard of dissemination level we proposed in the original proposal. During the KO meeting, MOTTLES consortium decided to convert the "Decision makers and Stakeholder-oriented workshop

(coupled with the Expert workshop organized by CNR)" in form of Questionnaires distributed at the workshop.

Evaluation

During the KO meeting we decided to anticipate the two decision-makers stakeholder-oriented workshops, in order to have more time to process the results. For this reason, many results were achieved earlier than foreseen. Due to the emergency situation linked to COVID-19 the final workshop was postponed to the After-LIFE. However, the two workshops foreseen in the project proposal were successfully completed. All the other milestones were achieved and final deliverables were completed.

- Active support and involvement of relevant stakeholders (multi-actor approach) - ***Completed***
- Decision-makers & Stakeholder-oriented workshop - ***Completed***
- Contributing to develop and broaden the dialogue among all levels of responsibility from EU to local level - ***Completed***
- Understanding of stakeholder perceptions and information improvement for EU policy making and evaluation - ***Completed***
- Report on existing and future science-policy interactions and needs - ***Completed***
- Recommendations for uptake of results in policy and management processes - ***Completed***
- Development of science-based strategies, methods and recommendations for policy-makers and managers - ***Completed***
- Usable, intelligible and policy-relevant guidelines & standards for forest protection/conservation - ***Completed***
- Guideline with recommendations & effective adaptation options for a sustainable forest management: a healthy and resilient forest structure - ***Completed***
- Indicators supporting the elaboration of effect-based abatement strategies in pollutant emissions to assess the future policies - ***Completed***
- Efficient and effective integrated policies - ***Completed***

Status of Milestones & Deliverables

Deliverables	Expected in the GA	Actual	Status
Reports on existing and future science-policy interactions and needs (Annex D2.1 and table 6)	07/2019	07/2019	Preliminary version delivered on 04/2019
Guideline with recommendations and effective adaptation measures for sustainable forest management (Annex D2.3)	06/2020	06/2020	Completed

Milestones	Expected in the GA	Actual	Status
Session of the final International workshop organized by INCDS: specific mechanism to transfer the guidelines to all stakeholders (Annex D2.9)	03/2020	Anticipated to 09/2018	Completed
Decision makers & Stakeholder-oriented workshop (coupled with the International workshop organized by INCDS) (Annex D2.10)	03/2020	Anticipated to the int. conference in 09/2018	Completed
One-day meetings with stakeholders organized by CNR (Annex D2.5)	12/2016	12/2016	Completed
One-day meetings with stakeholders organized by CNR (Annex D2.5)	12/2017	12/2017	Completed
One-day meetings with stakeholders organized by CNR (Annex D2.5)	12/2018	12/2018	Completed
Decision makers & Stakeholder-oriented workshop (coupled with the Expert workshop organized by CNR) (Annex D2.8)	03/2019	Anticipated to 05/2018 Ozone & Plants conference in Florence	Completed

Action D3: After-LIFE Communication plan

Foreseen start date: 01/04/2020 Actual start date: 01/03/2020
Foreseen end date: 30/06/2020 Actual end date: 30/06/2020

Beneficiary responsible: CNR

Aim - plan for project legacy through dissemination and maintenance of products as part of the project activities once project completion. The After-LIFE communication plan, in English, is designed and implemented to secure long-lasting impacts and submitted to the EC with the final report. The plan includes development of a Legacy Plan, enabling the identification and planning of relevant opportunities (e.g. funding) and activities (e.g. dissemination). This plan reports the Risk Register (e.g. ensuring continuity of activity). Moreover, The Knowledge Exchange Strategy set out the approach to engaging with target audiences and the mechanisms and media to be used (e.g. educational courses, expert advice and policy briefs).

Description of the activities

ARGANS in collaboration with CNR and with the support of an external company (Compagnia delle Foreste) established the After-LIFE Communication plan (Annex D3.1). The realization of the plan started in April and was completed in June 2020. In the long term after the project ends, the monitoring network will be maintained and expanded, data will continue to be collected and used for refining critical levels and mapping CL exceedances. Results will be transferred to major stakeholders via different tools. In the 5 years after the project ends, the MOTTLES active system will save 174 tons of CO_2 relative to the traditional passive system. In addition, we identified the resources needed for such activities in the next 5 years, in particular 124 k€ from the agreement with Carabinieri Forestali and Ministry of Environment of Italy (Annex D2.6, which includes funding to the establishment of a new MOTTLES station in Southern Italy) and 86 k€ of the project structural funds (Fondo di rotazione) obtained from the Italian Ministry of Research. Other expenses will be covered by the personnel costs of the partners, for an estimated value of about 200 k€ in 5 years. In addition, a follow-up proposal was submitted to LIFE Governance and is at present under evaluation. The partnership was extended to Croatia and Lithuania for expanding the MOTTLES network to these countries. The partners are motivated to work again together and to apply for common financial sources.

Problems and delays

The external support for the realization of the milestone was not foreseen by the GA, but the consortium decided for it considering the shortcomings received by EASME on the Communication Plan in the MTR evaluation letter.

Evaluation

The action was completed on time.

Action E1: Project Management

Foreseen start date: 01/07/2016 Actual start date: 01/07/2016
Foreseen end date: 30/06/2020 Actual end date: 30/06/2020

Beneficiary responsible: CNR

Aim - Establish an efficient management of interactions with EC and consortium regarding all administrative and contractual issues; efficient consortium coordination, ensuring all partners agree on common strategic, technical and scientific orientations and objectives; efficient project control, appropriate quality assurance, ensuring results are effective, available in time and within budget; proactive/reactive process, anticipating possible problems by performing risk assessments allowing fast decisions and keeping project risks under control.

Description of the activities

General activity realized:

- Status of deliverables, actions, travel plans and risks were evaluated every month.
- Every month, useful financial information and documents were sent to the project Coordinator. The first financing was made available to the partners soon after the approval by the EC. The time worked for the project was registered every day and timesheets were signed monthly. Further details on the financial activities are below.
- Every month (every 3 months since January 2019 upon the monitor's request), a short report was submitted to the external monitoring team. Further contacts with the team by phone or email allowed clarifying unclear aspects.
- A revision of the work plan e.g. about the time of the reports to the EC was carried out in agreement with the external monitoring team and the EC (Annex E1.1).
- Contacts with stakeholders allowed consolidating a competent and interested SIB (Annex D2.2).

Moreover, under Action E1, the coordinator together with the PMT organized:

- One KO meeting (Annex E1.2)
- Three Progress Meetings (Annexes E1.3a-b-c)
- Four Monitoring visits (Annexes E1.4a-b-c-d)
- The final meeting via web conference (Annex E1.5)

Three post-docs hired by MOTTLES i.e. Y. Hoshika (CNR), A. Anav (CNR), A. Alivernini (CREA) as temporary staff were then **hired as permanent staff** by CNR, ENEA and CREA, respectively. This was possible thanks to the type of contract financed by MOTTLES, resulting therefore in an important impact of the project. This unexpected change determined the need to revise the project budget (see paragraph 9.1). The whole consortium, coordinated by CNR, worked together on the revision of MOTTLES activities according to the evaluation of the Mid-term Report (Annex 2). An amendment of Grant Agreement in relation to the changes of the associated beneficiary CREA-FL was required by EASME with the MTR evaluation letter. The Amendment was carried out by the project coordinator and CREA-FL responsible and accepted by EASME on 16th November 2017 (Annex 8). An amendment of Grant Agreement was also necessary for the cession of activities of ACRI-HE to ARGANS. The request realized by CNR,

in collaboration with ACRI/ARGANS personnel was submitted on 20th December 2018 (Annex 9) and approved by EASME on 05/08/2019 (Annex 10).

Expenditure statements with the whole financial documentation were monthly updated by the MOTTLES coordinator and the project manager assistant with the collaboration of personnel who are responsible for the administration for each partner. Four evaluations of the performance indicators were conducted by CNR with the help of each partner, at the initial situation, at the Mid Term report, at the Progress report and at the end of the project. According to the EASME request of 11/12/2017, the Key Performance Indicators (KPI) online-database was updated with MOTTLES values in January 2018 (Annex C1.6). The final KPI evaluation was done in September 2020 after the end of the project (Annex C1.7).

Problems and delay

Some weaknesses in our reporting system were fixed early thanks to a very fruitful face-to-face meeting with the external monitoring team (see paragraph 6.3). The KO meeting was postponed by three months in order to couple the event with the intercalibration course. Two-months postponement of the 2nd Progress meeting. Unforeseen modification of the contract of E. Carrari (project manager assistant and quality assurance controller) (see paragraph 9.3).

Evaluation and results

The overall project objectives and the expected results were unchanged. The weaknesses underlined by the monitor during the 1st monitoring visit were fixed, allowing the achievement of the expected results:

a) Definition of a well-organised team - ***Completed***
b) Organization of MOTTLES Kick-off and Progress meeting organised - ***Completed***
c) Elaboration of the Management plan - ***Completed***.
d) Evaluations of progresses with respect to performance indicators - ***Completed***
e) Implementation of Stakeholder Involvement Board - ***Completed***
f) Mid Term, Progress and Final Report including progress of performance indicators – ***Completed***

Status of Milestones & Deliverables

Deliverables	Expected in the GA	Actual	Status
Management Plan (Annex E1.6)	10/2016	10/2016	Completed
Progress report including the progress of performance indicators	01/2017	Cancelled*	
Mid-term report including the progress of performance indicators	07/2018	10/2017	Completed
Progress report including the progress of performance indicators	01/2019	04/2019	Completed

Final report including the progress of performance indicators	06/2020	06/2020	Completed

**This deliverable now coincides with the mid-term report due to the anticipation explained in Annex E1.1*

Milestones	**Expected in the GA**	**Actual**	**Status**
Kick-off meeting (Annex E1.2)	07/2016	09/2016	Completed
Implementation of SIB (Annex D2.2)	11/2016	11/2016	Completed
Progress with respect to performance indicators (Included in the Progress report)	12/2016	12/2016	Completed
1st Progress Meeting (Annex E1.3a)	07/2017	07/2017 in Rome Italy	Completed
Progress with respect to performance indicators (included in the Progress report)	06/2018	10/2017	Completed
2nd Progress Meeting (Annex E1.3b)	07/2018	18 September 2018 i.e. back to back with the international workshop organized by INCDS	Completed
Progress with respect to performance indicators	06/2019	04/2019	Completed
3rd Progress Meeting (Annex E1.3c)	07/2019	07/2019 in Suaceva, Romania	Completed
Progress with respect to performance indicators (Annex C1.5)	06/2020	06/2020	Completed
Final meeting (Annex E1.5)	05/2020	25/05/2020 on line	Completed

Action E2: Monitoring of the project progress

Foreseen start date: 01/07/2016 Actual start date: 01/09/2016
Foreseen end date: 30/06/2020 Actual end date: 30/06/2020

Beneficiary responsible: CNR

Aim - Ensure that the project is in compliance with the key contractual and remains in line with the Grant Agreement, and detecting problems at an early stage where it is still possible to change aspects of the project and thus steer it towards a successful outcome

Description of the activity

The Monitoring and working Plan was prepared by the consortium during the kick-off meeting in 2016 and was distributed to all partners (Annex E2.1). A detailed and specific calendar of activities and a budget related to planned activities and expected results was established, including expected results, activities to be performed, tasks to be undertaken, and needed costs. Each-period performance was checked against the calendar of activities, the indicators of progress and the budget. The annual dashboard was discussed with the partners, and refined as needed to correct small deviations. A self-evaluation of the project viability was completed on 10/2017 and submitted with the MTR. Every year the annual dashboard was discussed among all partners during the progress meetings (KO meeting: Annual dashboard 2016/2017; 1st Progress meeting: Annual dashboard 2017/2018; 2nd Progress meeting: Annual dashboard 2018/2019; 3rd Progress meeting: Annual dashboard 2019/2020). At the same time a checking of the advancement was done.

Problems and delays

Annual dashboard 2017-2018 delivered with the final report was not considered sufficient, hence it was revised and delivered with the Progress Report (Annex E2.2). In consideration of the anticipated end of the contract of the project manager assistant (E. Carrari terminated her contract on 29th February, 2020) who was leading action E2, the consortium decided to ask for external support for its conclusion. From March 2020, the Action was led by the project coordinator E. Paoletti (CNR) without changes in the project activities and results.

Evaluation and results

The overall project objectives and the expected results were unchanged as specified in the project proposal and confirmed during the kick-off meeting.

- Development and implementation of the monitoring protocol - ***Completed***
- Periodic checking of the advancement - ***Completed***
- A well-organised and efficient technical execution - ***Completed***
- An efficient project control ensuring that project results are effective, available in time - ***Completed***

Status of Milestones & Deliverables

Deliverables	Expected in the GA	Actual	Status
Monitoring and working Plan (Annex E2.1)	01/2017	10/2016	Completed

Milestones	Expected in the GA	Actual	Status
Self-evaluation of the project viability (submitted with the Mid Term Report)	01/2017	10/2017	Completed
Annual dashboard 2016-2017 (Annex E2.2)	07/2016	11/2016	Completed
Annual dashboard 2017-2018 & Periodic checking of the advancement (Annex E2.3)	07/2017	07/2017	Completed, revised on 3/2018
Annual dashboard 2018-2019 & Periodic checking of the advancement (Annex E2.4)	07/2018	07/2018	Completed
Annual dashboard 2019-2020 & Periodic checking of the advancement (Annex E2.5)	07/2019	04/2019	Completed
Final checking of the advancement (in the present report)	06/2020	06/2020	Completed

6.2 Summarizing the status of the actions, milestones and deliverables

Table 7 - General status of actions, milestones and deliverables. Roman numbers refer to annual quarters.

ACTIONS	Foreseen start-date	Actual start-date	Foreseen end-date	Actual end-date	Notes
B1 Set up of the monitoring system and data collection	III 2016	July 2016	IV 2019	II 2020	Without extra costs, we are still recording data and working at site maintenance. In this way, the network can be active for the After-LIFE
B2 Modelling stomatal ozone uptake	IV 2016 IV 2017 I 2019 IV 2019	Sept. 2016 Oct. 2017 Jan. 2019	I 2017 I 2018 I 2019 I 2020	Mar. 2017 Febr. 2018 Mar. 2019 Mar 2020	
B3 Derivation of new critical levels for forest protection	I 2017 I 2018 I 2019 I 2020	Jan. 2017 Mar. 2018 Mar. 2019	II 2017 II 2018 II 2019 II 2020	June 2017 Oct. 2018 Apr. 2019 Apr 2020	
B4 Mapping & Future scenarios	II 2017 II 2018 II 2019 II 2020	Apr. 2017 Oct. 2018 May 2019	III 2017 III 2018 III 2019 II 2020	Aug. 2017 Sept. 2018 May 2019 June 2020	
C1 Monitoring the impact of the project actions	III 2016	July 2016	II 2020	June 2020	
C2 Assessment of the project actions impacts on local economy and population	I 2017	Sept. 2016	II 2020	June 2020	
C3 Forest health and resiliency through integrated management practices	I 2017	Sept. 2016	II 2020	June 2020	
D1 Integration, Dissemination and Execution	III 2016	July 2016	II 2020	June 2020	
D2 Science-policy-stakeholder interaction	III 2016	Aug. 2016	II 2020	June 2020	
D3 After-LIFE Communication plan	II 2020		II 2020	June 2020	
E1 Project Management	III 2016	July 2016	II 2020	June 2020	
E2 Monitoring of the project progress	III 2016	Sept. 2016	II 2020	June 2020	
E3 External audit	II 2020		II 2020	Deleted	According with new LIFE rules

MILESTONES	Foreseen due date	Achieved on	Notes
B1 - Planning of activities	15/07/2016	10/09/2016	During KO meeting.
B1 - Inter-calibration training course	30/09/2016	15/09/2019	Back to back to KO meeting to reduce travel costs.
B1 - Inter-comparison exercises, data validation and provision (visible injury, crown condition) to the EFDC & FISE	15/10/2016	07/07/2017	The inter-comparison exercise was carried out on 07/07/2017 (postponed back to back with 1st Progress Meeting to reduce the travel costs. A later inter-comparison exercise allowed a better understanding of actual issues and how to solve them). Impossibility to deliver dataset to EFDAC & FISE (see Report 3rd MV).
B1 Agro-meteorological and ozone station installed	01/11/2016	31/03/2017	For delays in purchasing the instruments and in accessing the sites (due to late snow and technical issues).
B1 - Verification of good functioning of the monitoring stations	01/12/2016	30/04/2017	Due to postponement of station set-up.
B2 - Building and update of database of B1	15/10 of each year (2016, 2017, 2018 2019)	01/07/2017 01/10/2017 01/10/2018 01/10/2019	Postponed in the first year due to delays in B1.
B2 - AOT40 & PODY values transferred to Action B3 for critical levels derivation	01/01 of each year (2017, 2018, 2019 and 2020)	31/01/2017 31/01/2018 31/01/2019 31/01/2020	In 2017 we selected values based on literature data. In 2018, 2019, 2019 calculation based on MOTTLES dataset. In February 2020, two soil parameters were available (after long lab analyses) allowing to calculate the final and correct value for all indexes in each year.
B2 - Provision of validated stomatal ozone fluxes to EFDAC and FISE	01/06/2018 and 01/06/2020	01/06/2018 Completed on 07/2020	Not completed due to the impossibility to contact EFDAC & FISE (see Report 3rd MV).

B3 - Critical levels values transferred to Action B4 for mapping	01/04 yearly (2017, 2018, 2019 and 2020)	01/04/2017 31/04/2018 31//04/2019 Expected for 20/04/2020	In 2017 based on literature data In 2018 completed for 2017 In 2019 completed for 2017+2018 In 2020 on track for 2017+2018+2019
B3 - Provision of validated critical levels to EFDC and FISE	01/06/2018 and 01/06/2020	01/06/2018 01/06/2020 but not completed	Due to the impossibility to contact (see Report 3rd MV).
B4 - Scenarios and configuration of simulation model	01/04/2017	01/04/2017	
B4 - Application of simulation model	01/05/2017	01/05/2017	
B4 - Results of data processing, Maps of CL exceedance	01/06 yearly (2017, 2018, 2019 and 2020)	01/06/2017 01/06/2018 01/04/2019 01/05/2020	In 2017 based on literature data In 2018 completed for 2017 In 2019 completed for 2017+2018 In 2020 completed for 2017+2018+2019
C1 - Impact of the project: initial situation	01/10/2016	01/10/2016 Revised on 04/2018	Revised after MTR Revision (delivered on 04/2019)
C1 - Impact of the project: in-progress situation	01/07/2018	01/07/2018 Revised on 01/03/2019	Updated to 03/2019 with questionnaire results and delivered on 04/2019.
C2 - Impact of the project: initial situation	01/10/2016	10/2016 Revised on 01/04/2019	Revised after MTR Revision (delivered in 04/2019)
C2 - Impact of the project: in-progress situation	01/07/2018	01/07/2018 Revised on 01/03/2019	Updated to 03/2019 with questionnaire results and delivered in 04/2019
C3 - Review of present forest management practices for adaptation to climate change	15/06/2017	15/06/2017	
C3 - Evaluation of ozone-oriented management strategies and discussions with the SIB and other relevant stakeholders	15/06/2019	15/06/2019	
D1 - Website operational and on-line	01/10/2016	15/10/2016	From 10/2016 to 10/2019 http://mottles.ipsp.cnr.it/ From 11/2019 https://mottles-project.wixsite.com/life
D1 - Notice boards set-up	01/10/2016	31/03/2017	To reduce travel costs the noticeboard setup was combined with agrometereological station installation
D1 - First distribution of leaflets and brochures	01/12/2016	01/10/2016	
D1 - Experts' workshop organised by CNR	01/03/2019	21-25/05/2018	
D1 - International workshop organised by INCDS	15/03/2020	18-22/09/2018	

D2 - 3 One-day meetings with stakeholders organised by CNR	15/12 yearly (2016-2018)	01/12/2016 01/12/2017 01/12/2018	
D2 - Decision-makers & Stakeholder-oriented workshop (coupled with the Expert workshop organised by CNR)	15/03/2019	21-25/05/2018	
D2 - Decision-makers & Stakeholder-oriented workshop (coupled with the International workshop organized by INCDS)	15/03/2020	18-22/09/2018	
D2 - Session in the final International workshop organised by INCDS: specific mechanism to transfer the guidelines to stakeholders	15/03/2020	19/09/2018	
D3 - Draft of the After-LIFE plan	15/06/2020	15/06/2020	
E1 - Kick-off meeting	15/07/2016	10/09/2016	
E1 - Implementation of SIB	01/11/2016	01/11/2016	
E1 - 1st Progress Meeting	01/07/2017	04-07/07/2017	
E1 - 2nd Progress Meeting	01/07/2018	18/09/2018	Back to back with the international workshop organized by INCDS to reduce travel costs.
E1 - 3rd Progress Meeting	01/07/2019	01-04/07/2019	
E1 - Final meeting	15/06/2020	25 May 2020	Completed, as telconf due to the coronavirus epidemic.
E1 - Progress with respect to performance indicators	15/06/2020	15/06/2020	
E2 - Annual dashboard 2016-2017	15/07/2016	01/09/2016 Revised on 01/05/2018	
E2 - Self-evaluation of the project viability	01/01/2017	01/10/2017	
E2 - Annual dashboard 2017-2018 & Periodic check of progress	15/07/2017	15/07/2017 Revised on 01/05/2018	
E2 - Annual dashboard 2018-2019 & Periodic check of progress	15/07/2018	18/09/2018	
E2 - Annual dashboard 2019-2020 & Periodic check of progress	15/07/2019	15/07/2019	
E2 - Final check of progress	15/06/2020	15/06/2020	

DELIVERABLES	Foreseen due date	Finalised in	Notes
B1 Mid-term report on the forest health status at each site: ozone data, crown condition, phytosociological and visible injury	01/07/2018	July 2018	
B1 Atlas of validated ozone visible foliar injury for European forest species (released with the Progress report)	01/07/2019	January 2019 (Revised then October 2019)	
B2 Report on species-specific parameterization of stomatal ozone flux (released with the Progress report)	01/07/2019	April 2019	
B3 Paper on “species-specific thresholds and critical levels” as provision/inputs for UNECE activities “Mapping Critical Levels for Vegetation"	01/01/2020	01/06/2020	Postponed to update it with 2019 results
B4 Guidelines book “how to assess the effectiveness of air pollution control strategies for ecosystem protection”: an overview for policy makers and practitioners	30/06/2020	20/06/2020	Completed with the help of an external assistance
C1 Inputs for the deliverable in Action C2 "Statement of project-related impacts"	30/06/2020	15/06/2020	
C2 Statement of project-related impacts on local economy, environment and population, including MOTTLES savings in CO2 equivalents as well as photochemical oxidant formation equivalents (LCA)	30/06/2020	30/06/2020	
C3 Integrated tool box of practices summarising the new knowledge for evaluating expected risks and benefits of adaptation/mitigation options and a summary for stakeholders in EN, IT, FR & RO	30/06/2020	20/06/2020	Completed with the help of an external assistance
D1 Website	01/10/2016	15/10/2016	
D1 Notice boards	01/10/2016	01/03/2017	
D1 Communication and dissemination plan	01/10/2016	March 2019	
D1 Layman’s report	30/06/2020	25/06/2020	Completed with the help of an external assistance
D2 Reports on existing and future science-policy interactions and needs (released with the progress report)	01/07/2019	April 2019	
D2 Guideline with recommendations and effective adaptation measures for sustainable forest management	30/06/2020	30/06/2020	
D3 After-LIFE Communication Plan	30/06/2020	20/06/2020	Completed with the help of an external assistance

6.3 Main deviations, problems and corrective actions implemented

Exceedance of travel budget

The travel budget was unfortunately halved at the time of the proposal revision, even though we specified that this was not suitable for a project with so much field and dissemination activities. As a corrective action, we did our best for co-financing MOTTLES travels by other projects and sources. The reallocation of the budget for covering the needed travel costs (and considering other unavoidable reallocations for the other items) **do not exceed the 20%** of the overall eligible costs i.e. 367,681€ (see art II.22 of the Grant Agreement) so that an amendment was not needed.

Nine months delay in site installation

Minor delays in purchasing the instruments (due to administrative constraints) and in accessing the sites (due to late snow and long agreements with site local manager) resulted in a slight postponement of data acquisition, so that the entire 2017 growing season is not available at a few sites. Therefore, we had to slightly change the milestones in actions B2 and B3.

Changing the reporting schedule

After approval by the EC (Annex E1.1), we changed the planning of reports suggested in our proposal. We realized that the reporting plan we proposed referred to the previous LIFE framework (LIFE+). More importantly, the first visit by the EMA (21/11/2016) and the planned first progress report (01/2017) were really very close to each other, while the mid-term report would be after 18 months, i.e. in July 2018. Submitting two very similar reports (to EMA and to the EC) at the very beginning of the project sounded not very fruitful. In fact, we were still implementing the monitoring stations and the monitoring activity actually started only in the 2017 growing season. Therefore, we did not have data to present yet, except our preparatory activities. We thus cancelled the first progress report and anticipated the mid-term report to October 2017. This option had the benefit for us to access the second instalment earlier. At that time, in fact, our partners planned to have spent 100% of the first financing. As we anticipated the mid-term report, we had also to anticipate the following progress report (April 2019) in order not to exceed 18 months in between two consecutive reports.

Unforeseen modification of the personnel

Three post-docs were hired as permanent staff by the partners CNR, ENEA and CREA. This unexpected change determined the need to revise the project budget (see paragraph 9.1).

The project manager assistant, Elisa Carrari, got a maternity period from June to October 2019, her role in the project was covered by other permanent CNR staff (Elena Paoletti and Roberto Bruno), and thus this did not affect the quality of the project. Moreover, E. Carrari terminated her contract on 29th February 2020 before the conclusion of the project; in consideration of this unforeseen issue, the consortium decided to ask for external support for the conclusion of the Actions she was responsible (actions C3 and E2) and for the realization of the Final report. From March 2020, the actions were led by the project coordinator E. Paoletti (CNR) without changes in the project activities and results, activities were successfully completed thanks to the external support of ARCHES-Conseils (action C3) and AISF (action E2 and final report).

Modification in the partnership

The associated beneficiary CREA-RPS changed its name in CREA-FL, as explained in 5.7. Such a change did not affect the quality and quantity of work carried out by CREA-FL in MOTTLES as well as the financial duties of CREA-FL in MOTTLES.

The associated partner ACRI-HE was replaced by ARGANS for cessation of activity, as explained in 5.7. However, the overall project objective, the expected results, and actions remain unchanged and the quality of the project was retained. ARGANS, as a replacement for ACRI-HE, took over from activities. ARGANS accepted to carry out the MOTTLES activities that were previously assigned to ACRI-HE, with exactly the same associated budget, in order to retain the main objectives of the project and the expected results. The maximum contribution of the European Commission and the budget per category, as stated in the approved proposal, were unchanged. ARGANS maintained the same personnel, structures and resources. The project was still managed by Pierre Sicard.

The CNR partner underwent a reorganization of its institutes. As a result, part of the MOTTLES staff of CNR moved from IPSP-CNR to a new Institute, IRET-CNR (Research Institute on Terrestrial Ecosystems of CNR). The administrative management of MOTTLES also moved to the new institute. Thus, the address and legal representative of the partner CNR changed, while VAT and PIC numbers did not. The external monitor informed the project coordinator that there was no need of an amendment (Annex 6). The overall project objectives, the expected results, and the actions remained unchanged.

6.4 Evaluation of project implementation

Table 8 - Project implementation

Action	Methodology evaluation	Foreseen in the revised proposal	Result achieved General Evaluation
B1	The new-generation monitoring system provided: -Data of good quality with limited necessity of gap filling; -During COVID-19 lockdown the active and remote management of the MOTTLES monitoring stations resulted particularly useful, allowing the continuation of data recording -Higher cost of installation for consumables and maintenance compared to the provisional budget -In comparison with the traditional monitoring system, the costs were lower after 5 years from economic, social and environmental points of view (in terms of CO_2 footprint)	Objectives: Set-up and maintenance of the integrated monitoring stations, collecting of plant-response indicators , harmonization of monitoring approaches and intercalibration training Expected results: -Set up of a permanent new-generation monitoring system for the ozone effects on EU forests -A comparable European-wide forest information and collection system at European level -Support the adoption of this new-generation monitoring system at pan-European scale -Concurrent monitoring of forest response indicators and ozone standards across Europe -Quantitative and qualitative data related to ozone pollution, climate change and biodiversity -Pooled database to clarify cause effect relationship between ozone, climate and forest responses -Provision of validated data to the EFDC & FISE of the EC -Better understanding of air pollution & climate change impacts on forests -An atlas of validated ozone visible foliar injury for European forest species -Lists of sensitive tree species for forest sustainable management	All the project objectives and expected results were achieved and action B1 was finalized on time. The network was successfully created (17 sites) and is working well. MOTTLES network collects 2.2 million data in real time per year, allowing the calculation of POD and AOT40. Data are validated, collected and stored, and are available upon request. Intercalibrated teams of surveyors carry out ozone damage detection on MOTTLES sites simultaneously. Field monitoring protocols are available. The atlas of validated species-specific ozone visible foliar injury for European forest species was realized. The complete dataset allows a better understanding of the relationships between pollution, climate change and forest indicators. The list of sensitive species is available. The MOTTLES network was included in the NEC networks of Italy and Romania, which is giving continuity and visibility to this forest information and collection system at European level.
B2	Partners elaborated a script for the calculation of the stomatal ozone uptake. This required longer time to be completed, but resulted in a fast and efficient method for indicators calculation. The script allows now to easily manage a large dataset and it works on a free programme.	Objectives: Calculate species-specific stomatal O_3 uptake by the DO3SE model for sites distributed in France, Romania and Italy, by using data on soil type, hourly meteorological data (air temperature, relative humidity, soil water content and solar radiation) and hourly O_3 concentrations obtained from monitoring stations Expected results: - Calculation of AOT40 and stomatal ozone uptake above different thresholds -Refining old parameterization and developing new parameterization for the major forest species in main forest biomes of Europe -Validation of DO3SE model by comparison between measured and modelled stomatal O_3 fluxes -Species-specific parameterization of DO3SE model across different EU environments -Selection of the best species-specific	All the project objectives and expected results were achieved and action B2 was finalized on time. Due to the delay in site installation the milestone "Building and update of database of data collected in B1" for the first year was postponed of 9 months, such deviation from the project proposal did not affect the achievement of final results of action B2: the calculation of AOT40 and PODY above different thresholds was delivered for the years 2017, 2018 and 2019. A DO3SE parameterization was developed or refined for a total of 11 European forest species. Anew parameterization was developed for two species that were missing in the literature (*Alnus glutinosa, Phillyrea angustifolia*) by comparing modelled PODY with measurements carried out at the ozone FACE facility.

		approach	Application of the DO3SE model was completed and published with species specific parametrizations, which allows selecting the best species-specific approach.
B 3	The methodology used for the calculation of flux-based critical levels (CLef) was defined during the project and applied. One-year dataset was not sufficient to derive optimal CLefs, hence only at the end of the project MOTTLES defined scientifically based CLefs. They were applied for 2017-2018-2019.	Objectives: Define the best criteria for the EU forest protection from O_3 in a changing climate, derive proper flux-based critical levels (CL) for forest protection and contribute to the UNECE activities Expected results: -Selection of the best effect parameter and O_3 metrics to derive the best and suitable species-specific critical levels -Suggestion of proper standards and critical levels as new policy for forest protection -Decision-support tool for European authorities. European legislation will adopt new criteria to assess ozone risks based on our new calculations -Provision of open-access data for incorporation into the EFDC & FISE -Support to future EU forest monitoring and management policies	All milestones and final deliverables were achieved, values of indicator of progresses respected always the expected values; therefore the action was concluded successfully. Visible foliar O_3 injury was selected as the best effect parameter to describe O_3 impacts on vegetation, and POD1 resulted to be the O_3 metric to be adopted to derive critical levels. We successfully derived Clef for forest protection against visible foliar O_3 injury. We recommend CLef of 12 and 5 mmol m^{-2} POD1 for broadleaved species and conifers, respectively. The calculation of stomatal fluxes is now recommended by the NEC directive. Guidelines for authorities and forest monitoring are available.
B 4	The models and methods selected were functional to achieve the objectives of the action. The costs incurred were in line with what was expected.	Objectives: i) identify ozone hot-spots; ii) assess large-scale mature forest injury by O_3; iii) define which threshold Y is the most biologically-based; and iv) define more consistent and realistic critical levels (CL) for forest protection across EU to support the elaboration of sustainable management strategies. Expected results: -Definition of regional vulnerability to climate change stressors by investigating N-S & E-W transects -Identification of ozone hot-spots -Assessment of large-scale mature forest injury by O_3 -Consistent, realistic and proper species-specific critical levels for forest protection against O_3 -Modelling & mapping of observed and projected changes in critical levels exceedances - Quantification of long-term changes in critical levels exceedances -Indicators supporting the impacts assessment of future policies at European/national levels -Support to the elaboration of effect-based abatement strategies in pollutant emissions -Management options for adaptation: an overview for policy makers and practitioners	All the project objectives and expected results were achieved and action B4 was finalized on time. Meteorological, AOT40, PODY, forest data and critical levels collected in actions B1-B3 were used for mapping. The maps of critical levels exceedances for AOT40 and POD1 2017, 2018 and 2019 were completed. Thanks to them regional vulnerability and European hot-spots were defined. The guidelines for transferring the MOTTLES new method to monitor and define limits of ozone pollution and protect European forests were defined and published. Modelling of projected changes (for the year 2100) showed that the expected reduction of O_3 precursors emissions will be compensated by climatic changes that stimulate the stomatal uptake of ozone and thus POD1-based risk to forests will remain high.

C 1	Action indicators allowed us to keep monitored the progress of the project. Performance indicators represented the best tool to keep updated and monitored the impacts of the projects. The action foresaw the use of questionnaires at the beginning and during the project, but we decided to postpone these by distributing them in progress and at the end of the project. This allowed us to create more adequate questionnaires and to verify the actual impact of the project on how the general public responds to and learns about environmental problems in general and about air pollution and climate change in particular. The costs of the action respected what was expected	Objectives: Define the project impacts in terms of population and local authorities' awareness, knowledge and sensitivity about risk related to air pollution and climate change. Expected results: Achievement of expected values for action-specific indicators Achievement the expected values for performance indicators	All milestones, final deliverables and expected results were successfully achieved. Expected values per each action were respected. Expected values of performance indicators were achieved. Evaluation of project impacts were conducted two times as scheduled. Results of questionnaires were useful to evaluate social impacts, included in action C2.
C 2	The total economic evaluation and the Life cycle assessment represented the best methods to measure economic and environmental impacts of the projects. Methodologies were slightly adapted to the specific cases, since applied to this type of case study for the first time. The derivation of new critical levels for forest protection were expanded to larger scale, in order to provide information helpful to make social analysis on food security on rice and wheat. Ex-ante evaluation was correctly conducted through questionnaires.	Objectives: Assess the impact of all project actions on the socio-economic conditions of the local populations and on ecosystem functions Expected results: - A study of the impacts of the project actions on local economy and population with a focus on wood production - A quantitative assessment (LCA) over the environmental impacts	All milestones, final deliverables and expected results were successfully achieved. The reports on the local economy and on environmental impacts were completed. Results supported the long-term sustainability of the monitoring system implemented by MOTTLES in terms of economic, social and environmental impacts. A significant impact of O_3 on Italian wood production (case study) i.e. 1.2B€ to 3.0B€ of capital value The questionnaires showed that a third of the respondents declared the willingness to pay 100€ yearly for the next 10 years to save forests from climate change and reduce European greenhouse gas emissions. These results are/will be of great support to the transfer, replication and continuation of MOTTLES monitoring practices

C 3	A deep bibliographic survey showed a low level of knowledge about current forest management practices for adaptation to climate change. It was insufficient to carry out a meta-analysis as originally proposed by MOTTLES. The meta-analysis was replaced by a detailed review and discussion with stakeholders, hence, the overall project objectives and the expected results remain unchanged.	Objectives: Summarize the new knowledge produced in MOTTLES for evaluating expected risks and benefits of adaptation/mitigation options, and transfer of scientifically-sound information to policy makers and the general public, so that MOTTLES results can last in the long term. Major aim is improved awareness about the benefits of an O_3-oriented management of forests. Expected results: -Which kind of forest age, density, structure, fertility is more tolerant of ozone pollution -Which species and species mixtures maximise the air quality benefits of forests -Which management is more appropriate for limiting the injury by disturbances in ozone-impacted forests -Which management is more appropriate to reduce ozone-induced wood loss -Which management is more appropriated to different policy settings in terms of forest protection from ozone	All milestones, final deliverables and expected results were achieved; therefore the action was concluded successfully. The detailed review contains the forest management options most appropriate to adapt natural forests, plantations and urban forests to an ozone-polluted environment. The options were discussed with the MOTTLES major stakeholders. An important result was the regional law of Tuscany (Italy) with indications for selecting urban tree species with low potential of ozone formation.
D 1	The dissemination activity included in the dissemination and communication plan was the best tool to increase awareness of the project among the public and stakeholders. Each foreseen tool was used to spread project results: gadgets, brochures, leaflets, noticeboards, scientific papers, journal articles, policy briefs, newsletters, website, social networks, participation in workshops and courses, announcements and conferences, organization of workshops, educational activities. The only exception was the use of CDs, replaced by a second brochure, due to the disposal of this type of tool in recent years.	Objectives: Synthesize key findings, collate, maintain and disseminate reliable information generated by MOTTLES, provide the basis of dissemination campaigns and results exploitation, prepare and conduct outreach activities with a wide range of stakeholders, create the basis for long-lived exploitation of MOTTLES results, help practitioners and decision makers to make use of the new knowledge generated by MOTTLES. Expected results: -Project website operational, on-line and regularly updated -17 notice boards implemented -More information and awareness-raising to reduce the air pollution impacts on forests -Better understanding of forest biodiversity in a context of climate change -Comparable Europe-wide forest information for a healthy and resilient forest structure -Creation of a network of European experts -Organisation of one experts' workshop -Transfer of know-how, best practices and methodology on the O_3 monitoring approach	The consortium carried out a broad dissemination activity, even managing in some cases to exceed what was foreseen by the project, however such activity was largely co-financed as the travel costs foreseen by the project were not enough to carry out a sufficient dissemination activity. Hence, all milestones, deliverables and expected results were successfully completed. The dissemination activity allowed stakeholders and the public to be aware of MOTTLES best practices to reduce air pollution impacts on forests and the role of forest biodiversity against climate change. The website received a total of 8869 visits, 17 notice boards were installed, one expert workshop was organized.

D 2	Interaction with foresters and site managers, oriented one day meetings with stakeholders, communication with policy makers and stakeholders at international levels, ONGs, oriented workshops organized by CNR and INCDS succeeded to efficiently transfer the project know-how among the main stakeholders.	Objectives: i) update forestry legislation to reflect current context and the requirement for improved forest management planning and monitoring; ii) propose to policy-makers: usable legislative standards and proper regional policies for forest protection; iii) propose to forest/park managers and other stakeholders a guideline that is proper and policy relevant with recommendations and effective options for a strengthening a sustainable forest management to ensure a healthy forest ecosystem and resilience to climate change challenges Expected results: -Active support and involvement of relevant stakeholders (multi-actor approach) -Decision-makers & Stakeholder-oriented workshop -Contributing to develop and broaden the dialogue among all levels of responsibility from EU to local level -Understanding of stakeholder perceptions and information improvement for EU policy making and evaluation -Report on existing and future science-policy interactions and needs -Recommendations for uptake of results in policy and management processes -Development of science-based strategies, methods and recommendations for policy-makers and managers -Usable, intelligible and policy-relevant guidelines & standards for forest protection/conservation -Guidelines with recommendations & effective adaptation options for a sustainable forest management: a healthy and resilient forest structure -Indicators supporting the elaboration of effect-based abatement strategies in pollutant emissions to assess the future policies -Efficient and effective integrated policies	The close interaction of MOTTLES with stakeholders at national and international level brought important legislative results such as the application of the new NEC directive and the new role of national expert for ozone within ICP-Forests for the MOTTLES coordinator E. Paoletti. Thanks to MOTTLES, the Tuscany Region was the first Italian region to apply a regulation on the management of urban forests in relation to atmospheric pollution. Furthermore, the action also assessed the stakeholders' perception regarding the improvement of European policies regarding air quality. The guidelines have also been completed, therefore the action was completed successfully and the expected results were achieved. it will ensure the adoption of the MOTTLES monitoring system by other bodies. If this spreads, it will give us environmental, social and economic savings.
D 3	The elaboration of the plan is an essential method for planning the future activity of the project and its sustainability in terms of continuation, replication and transfer	Objectives: To plan for project legacy through dissemination and maintenance of products as part of the project activities once project completion Expected results: An efficient After-LIFE plan	The plan was realized with the help of an external assistance with a broad experience in the frame of LIFE projects communication. It will ensure long-lasting results for the project.

E 1	The PMT was able to manage the project efficiently. The Management Plan was the basis of all management activities and generally respected. The relationship with the external NEEMO monitor was fundamental in the difficult moments of the project. The meetings between partners were very useful moments for planning activities.	Objectives: Establish an efficient management of interactions with EC and consortium regarding all administrative and contractual issues; efficient consortium coordination, ensuring all partners agree on common strategic, technical and scientific orientations and objectives; efficient project control, appropriate quality assurance, ensuring results are effective, available in time and within budget; proactive/reactive process, anticipating possible problems by performing risk assessments allowing making fast decisions and keeping project risks under control Expected results: -Definition of a well-organised team -Organization of MOTTLES Kick-off and Progress meeting -Elaboration of the Management plan -Evaluations of progresses with respect to performance indicators -Implementation of Stakeholder Involvement Board -Mid Term, Progress and Final Report including progress of performance indicators	Apart from some initial issues that emerged with the first monitoring visit, the project management proceeded efficiently, helped to provide a well-organized team, elaborated the management plan, crosschecked the project progress, liaised with the SIB, coordinated the reports, resolved administrative issues and successfully completed two amendments. The reports were positively evaluated by NEEMO and EASME.
E 2	The monitoring and working plan and the annual dashboards were a good tool to carry out the actions successfully.	Objectives: Ensure that the project is in compliance with the key contractual and remains in line with the Grant Agreement and detecting problems at an early stage where it is still possible to change aspects of the project and thus steer it towards a successful outcome Expected results: -Development and implementation of the monitoring protocol -Periodic checking of the advancement -A well-organised and efficient technical execution -An efficient project control ensuring that project results are effective, available in time	The monitoring of the project was carried out successfully, as demonstrated by the fact that the delays in milestones and deliverables were minor and that the project was able to successfully and timely conclude despite the health emergency situation linked to COVID-19.

7. Analysis of benefits

7.1 Environmental benefits

MOTTLES assessed its impacts on the environment in terms of savings in CO_2 equivalents (CO_2-eq) and other pollutants by a life cycle analysis, by comparing the MOTTLES practices (i.e. the active O_3 monitoring system implemented by MOTTLES) with the traditional passive approach in forest monitoring (Annex C2.1). The work was carried out under Action C2. The study considered a monitoring site at average distance from the control base, two forest types (deciduous and Mediterranean evergreen) and three time frames (5, 10 and 20 years). Results showed that the high installation costs of the active monitoring system are compensated over time by a reduction in the travel and personnel costs so that the MOTTLES system is more sustainable after 20 and 10 years for deciduous and Mediterranean forest types, respectively, than the traditional system. Considering only carbon, the MOTTLES system was more sustainable even after 5 years, leading to a **saving for the whole network of 102 tons CO_2-eq in case of deciduous forests and 194 tons CO_2-eq in case Mediterranean evergreen woods.** These savings increased over time up to **218** and **402 tons CO_2-eq in 10 years** and **450 and 819 tons CO_2-eq in 20 years** respectively for the two forest types.

The present evaluation will help practitioners in the decision process for the set-up of further long-term forest monitoring sites dedicated to the protection of forests from O_3.

KPI: 2.78 tons CO2 equiv. per ha per year at the end and after 5 years after the project end

7.2 Economic benefits

The impact of the project on the economy of the local population was assessed by **ex-ante/post-intervention evaluation** and with a **total economic evaluation on the risk of O_3 damages on forests**, as wood loss.

A questionnaire was submitted to the site managers and monitoring responsible of the three Countries (20 people) before and after the intervention, e.g. implementation of the new active MOTTLES monitoring method. The interview is available as Annex C2.4. It contained questions about specific costs, in terms of materials, personnel and travels, of the monitoring before the intervention (passive system) and after the intervention (active system). The responses were analysed to determine the total economic impact of the MOTTLES practice on the monitoring companies. We supposed 2 case studies (monitoring sites on deciduous forests and evergreen forests with different number of travels for data collection) and 3 time frames (5, 10 and 20 years of monitoring duration). Two types of sensors were evaluated as ex-ante situation (traditional system), i.e. OGAWA and IVL. The total cost of monitoring after 5, 10 and 20 years and in both types of forest, resulted lower in the situation post intervention. This result derives from the high travel and personnel costs related to the ex-ante situation (traditional monitoring), in fact, only after 5 years, the present value of the MOTTLES monitoring system for the monitoring in one site of the network is 19,271€, while with the pre-intervention situation (passive monitoring) the total cost would be 28,921€ (for deciduous forests), 43,929€ (for evergreen forests) where the OGAWA was implemented and 30,766€ (for deciduous forests) and 46,135€ (for evergreen forests) with IVL system. **We conclude that the**

project intervention led to savings of 45,431-50,301€ in the case of deciduous forests and 88,051-94,796€ in the case of an evergreen forest for site managers in 20 years, per site.

Moreover, the impact of the project on the economy was evaluated by a Total economic evaluation on the risk of damages by ozone on forests (Annex C2.1). MOTTLES developed a modelling approach for realistic estimates of the economic impacts of POD1-based wood losses, by using Italy as a case study. Among the many ecosystem services provided by forests, only wood losses have been estimated so far, because experimental dose-response relationships are available only for estimating biomass losses. The damage of ozone to forests was then estimated taking into account the reduction of forest increment. Two scenarios were compared: i) a Business as Usual scenario to quantify Forest Economic Value and forest surface with positive financial value with no ozone pollution and ii) a scenario based on POD1 limiting biomass production. The biomass reduction was attributed spatially to quadrats of 1 x 1 km. Results confirmed a significant impact of ozone on Italian forests, estimated as total potential damage from 1.2B€ to 3.0B€ of capital value (average from 382 to 949 €/ha). The annual damage ranges from **46.3M€ to 61.9M€** (average 15-19 €/ha y^{-1}). Italian regions were affected by ozone in different ways.

7.3 Social benefits

The social impacts of project actions were evaluated at local scale in terms of **costs of CO_2 equivalents**, while at global scale in terms of ozone **impacts on food security** (Annex C2.1).

Social benefits at local scale

In order to evaluate the social benefit at local scale we calculated the social benefits of adopting the active monitoring. These benefits are reported in terms of "Social Cost of Carbon" (SCC) avoided when using active monitoring instead of passive monitoring. The SCC represents the present value of future incremental damage caused by an additional ton of CO_2 emission today. Estimates of the SCC can be used by policy makers to evaluate climate change policies and cost-benefit analysis of GHG emission reduction. As we did for the monetary cost, we compared the present value of social costs of the annual CO_2 emissions caused by the management of the two monitoring systems (active MOTTLES system and passive traditional system). Literature supplies a strand of SCC values, depending on climate change projection damage modelling, we used the values developed by the US EPA[15] since are officially utilized by the US Federal Government for cost-benefit analysis, while equivalent guidelines at EU levels are not yet available. The SCC of passive system for a site at average distance from the control base resulted always higher than in the new method. With the traditional method the SCC related with the monitoring of the evergreen forests was ca. 50% higher than in deciduous forest regardless of the time frame. After 5 years the SCC of passive method was 2.2 times higher than the SCC for active system for deciduous forests and 3.25 times for evergreen forests. Such differences increased at 10 and 20 years until 2.5 for deciduous and 3.8 for evergreen forests.

Social benefits at global scale

[15] http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.686.7262&rep=rep1&type=pdf

MOTTLES scientists evaluated the social impact of ozone in terms of food security using the methodology developed in MOTTLES to assess the ozone impacts on two of the most important food species: wheat and rice.

Using a modelling method that accounts for the effects of soil moisture deficit and meteorological factors on the stomatal uptake of ozone, the study on the effect of ozone on **wheat** yield showed that ozone impacts are particularly large in humid rain-fed and irrigated areas of major wheat-producing countries (e.g. United States, France, India, China and Russia). In particular, averaged over 2010-2012, we estimated that ozone reduced wheat yield by a mean 9.9% in the northern hemisphere and 6.2% in the southern hemisphere, corresponding to some 85 Tg (million tonnes) of lost grain. Total production losses in developing countries receiving Official Development Assistance are 50% higher than those in developed countries, potentially reducing the possibility of achieving UN SDG2. Crucially, our analysis showed that ozone could reduce the potential yield benefits of increasing irrigation usage in response to climate change because added irrigation increases the uptake and subsequent negative effects of the pollutant. We showed that mitigation of air pollution in a changing climate could play a vital role in achieving the above-mentioned UN SDG, while also contributing to other SDGs related to human health and well-being, ecosystems and climate change.

The second case study was applied in China, because China's economic growth has significantly increased emissions of tropospheric ozone (O_3) precursors, resulting in increased regional O_3 pollution. We analyzed data from >1400 monitoring stations and estimated the exposure of population and vegetation (crops and forests) to O_3 pollution across China. Based on WHO metrics for human health protection, the current O_3 level leads to +0.9% premature mortality (59,844 additional cases a year) with 96% of populated areas showing O_3–induced premature death. For vegetation, O_3 reduces annual forest tree biomass growth by 11–13% and yield of rice and wheat by 8% and 6%, respectively, relative to conditions below the respective AOT40 critical levels (CL). These CLs are exceeded over 98%, 75% and 83% of the areas of forests, rice and wheat, respectively. Using O_3 exposure–response functions, we evaluated the costs of O_3-induced losses in rice (7.5 billion US$), wheat (11.1 billion US$) and forest production (52.2 billion US$) and SOMO35–based morbidity for respiratory diseases (690.9 billion US$) and non–accidental mortality (7.5 billion US$), i.e. a total O_3-related cost representing 7% of the China Gross Domestic Product in 2015.

7.4 Replicability, transferability, cooperation: Potential for technical and commercial application

Although the project has ended, several methods developed by the project will be further developed in other projects. Project results will be maintained in the medium and long term by **continuation,** i.e. the continued use of the monitoring stations by the project partners after the project ends, but also by replication and transfer. The monitoring stations will continue collection of O_3 and environmental data after the end of the project. Beyond July 2020, only data storage will be indispensable, and this does not need further co-financing. The analysis of the monitored data for estimating the critical levels as well as the mapping of the critical level exceedances will be carried out once a year as part of the partners' institutional activities, with the aim to assess the effectiveness of air pollution control strategies in the European Union.

Replication is how the solutions applied in MOTTLES are used again in the same way and for the same purposes by other entities/sectors during or after the project end. Thanks to the numerous targeted discussions with the SIB and other relevant stakeholders (IUFRO, EFI, EEA, SISEF, ICP veg, ICP Forests) and publications, MOTTLES practices are available to be applied by other entities. In particular the NEC Directive makes the "**Monitoring air pollution impacts**" mandatory. The funding of LIFE15 program to the MOTTLES project, allowed Italy, France and Romania to have an active monitoring network able to provide data on ozone damage according to the new directive. In order to reply to the NEC, other countries can replicate the MOTTLES monitoring system.

Transfer is how solutions applied in MOTTLES can be used in a different way or for a different environment, climate action or related governance and information purpose by the same or other sectors during or after the project ends. The validation of guidelines by MOTTLES allows the transfer of these innovative methodologies for a more coherent policy on forest protection in Europe, in response to the climate change challenges. The application of the MOTTLES method will make a positive contribution to the convergence and policy leading up to the effectiveness of forest monitoring by providing a framework for research and analysis. CNR obtained the financial support by the Italian Ministry of Environment (Annex D2.6) for establishing a new monitoring station in **Southern Italy** (Calabria), i.e. in an area at present not covered by the MOTTLES network. In the After-LIFE, MOTTLES plans to extend the network to **Lithuania** to cover Northern conditions and **Croatia**, a new country at high O_3 risk. The upgraded network will cover larger soil and climatic gradients, extending from the sclerophyll forests of the Mediterranean area to the mountainous beech forests of the Alpine region. A follow-up LIFE proposal was submitted with a major focus on **transfer to policy**. The main expected result is to bring EU directives towards a new standard, based on ozone stomatal flux, and the development of a **larger trans-European monitoring system of forests** responses to climatic changes by setting up national monitoring stations. Unfortunately the proposal did not pass the stage-2 evaluation, but it was revised and submitted again.

After completion of the project, major dissemination methods will be contacts with experts, through participation in conferences and meetings, publications and the internet. The website will be regularly updated and maintained for free by CNR for at least 5 years. Partners are active in the main forest networks and programmes i.e. SISEF, IUFRO, EFI, WGE, ICP Vegetation, ICP Modelling and Mapping, ICP Forests and can get financial support for experience-sharing. MOTTLES is policy relevant. The results will be transferred to ICPs for encouraging the adoption of this new monitoring approach at pan-European scale and beyond. We wish that our results may stimulate the development of similar networks all over the world, because only monitoring at forest sites is truly representative of the actual stomatal O_3 flux conditions.

7.5 Best Practice lessons

The **new-generation monitoring system** of O_3 effects on European forests is the main best practice implemented by MOTTLES. The upgraded MOTTLES network consists of 17 sites selected from existing European networks. The MOTTLES sites were equipped with new instrumentation in order to obtain for the first-time reliable data for the quantification of the Phytotoxic Ozone Dose (PODY).

PODY is a new and more effective metric proposed as a legislative **standard** rather than AOT40 which is based on estimation of the amount of O_3 entering stomata during a given time

period. The use of PODY in the O_3 risk assessment for forests is one of the main best practices proposed, tested and standardized by MOTTLES.

Plant response indicators of forest health and vitality were also assessed during the project and related to a range of different Y thresholds of PODY. Compared to radial growth and crown defoliation, the **visible foliar injury**, a specific **indicator of phytotoxic O_3 levels**, has resulted as the best plant response indicator of O_3 injury to forests.

MOTTLES evaluated also the health and vitality of trees thanks to the set-up of dendrometers, used to estimate seasonal stem growth increment and **tree phenology**, and provided best practice lessons for large-scale implementation of these approaches in forest monitoring networks.

We recommend **POD1-based critical levels: 12 and 5 mmol m^{-2}** for broadleaved species and conifers. Before to use PODY as a legislative standard in Europe, we recommend using the AOT40-based critical levels for ≥ 25% of crown defoliation in a plot: 17 and 19 ppm.h for conifers and broadleaved species.

A specific **atlas of visible foliar injury** was realized and made available online at the MOTTLES website https://mottles-project.wixsite.com/life.

A validation system was developed for non-validated visible foliar O_3 injury, by making use of an O_3 free-air controlled exposure (FACE) facility, and is available for continuation, replication and transfer.

All MOTTLES best practices are explained in detail in the deliverable: *Integrated tool box of practices summarizing the new knowledge for evaluating expected risks and benefits of adaptation and mitigation options* (Annex C3.5).

Table 9 - MOTTLES best practices, described by subtitle, subjects, surface area covered by MOTTLES and addressed issue.

Name of best practice	Subtitle	Subject	Area	Addressed issue
1. Innovative monitoring system of O_3 effects on European forests, based on active monitoring rather than passive monitoring.	1.1 A permanent new generation of active monitoring site. 1.2 Surveys for response indicators of forest health and vitality. 1.3 Real time data storage and management.	Pollution and climate change adaptation/mitigation. Sustainable forest management.	8.5 ha	Definition of new epidemiologically-validated critical levels for protecting forests against O_3 based on an long term network of remote sites.
2. Phytotoxic Ozone Dose (PODY) as tool to assess the risk for forests.	2.1 New parameterization of forest species using an O_3 FACE facility. 2.2 PODY calculation. 2.3 Consistent methodology to derive critical levels. 2.4 Recommendation of PODY critical levels for the National Emission Ceiling (NEC) Directive.	Pollution and climate change adaptation/mitigation.	8.5 ha	Production of new scientifically-sound critical levels based on stomatal fluxes as new legislative standards in Europe
3. Visible foliar O_3 injury as best plant-response to O_3.	3.1 Best measure of visible foliar injury: the percentage of symptomatic species at LESS. 3.2 Atlas of visible foliar O_3 injury. 3.3 Symptom validation using an O_3 FACE facility. 3.4 Recommendation of visible foliar O_3 injury for the National Emission Ceiling (NEC) Directive.	Pollution and climate change adaptation/mitigation Forest biodiversity Pollution and climate change adaptation/mitigation	8.5 ha	Definition of the best indicator to monitor for the protection of forests from O_3 under the new National Emission Ceiling (NEC) Directive
4. Monitoring of radial growth by using point dendrometers	4.1 Application of best approach for forest growth, phenology and water status.	Pollution and climate change adaptation/mitigation. Sustainable forest management.	8.5 ha	Estimating seasonal stem growth increment and tree phenology in forest subjected to O_3 pollution.
5. Assessment of economic impacts of O_3 on forests.	5.1 Application of Total Economic Value method (TEV).	Pollution and climate change adaptation/mitigation. Sustainable forest management.	8.5 ha	Estimating the wood biomass loss due to O_3 in the three MOTTLES countries, and valuating the economic impact resulting from wood loss.
6. Assessment of environmental impacts of O_3 on forests.	6.1. Life Cycle Analysis (LCA): passive versus active monitoring.	Pollution and climate change adaptation/mitigation. Sustainable forest management.	8.5 ha	Quantify the improvement in the environmental impacts of the new MOTTLES monitoring network compared with the traditional system.

7.6 Innovation and demonstration value

All the MOTTLES best practices described in chapter 7.5 and in Annex C3.5 are innovative and were practically tested and demonstrated during the project. In particular, the detailed description of how to develop a MOTTLES-type monitoring station, how to plan a MOTTLES-type monitoring network, how to assess the best plant response indicator suggested by MOTTLES i.e. the visible foliar O_3 injury, how to continuously measure the radial growth of trees as a proxy of their carbon acquisition capacity and tree phenology, how to validate field results by an ozone FACE, and how to test PODY-based critical levels for the protection of forests, are major pillars of the innovation and demonstration value of MOTTLES. Moreover, the active and remote management of the MOTTLES stations allows to record measures even without the possibility to access the sites; such innovation of our network compared with the passive traditional method, can be particularly useful when the site is not accessible, as verified during the lockdown of COVID-19 pandemic. Next, an innovation of our project is about the gap filling procedures applied for ozone concentrations. While those procedures are more common in the scientific field for the other weather variables, the reconstruction of the ozone measures was conceived and tested within the MOTTLES project thanks to the collaboration of technicians and scientists from CREA, CNR and INCDS. Also the automatic procedure to calculate ozone metrics represents an innovation of MOTTLES, since it was elaborated for the first time by INCDS for MOTTLES data. Such technical results will be extremely useful in the context of the monitoring of O_3 at forest sites.
Finally the results on the socio-economic-environmental sustainability of the MOTTLES approach are truly innovative and represent a cornerstone for the replicability and transfer capacity of the project because they show the major advantages of the active monitoring of O_3.

7.7 Policy implications

Following the revision of the **NEC Directive** (2016/2284 on the reduction of national emissions of certain atmospheric pollutants), the interest in calculating PODY based on site-specific monitoring is now increasing in Europe. This is the main output of the impact of the MOTTLES project on environmental policies. MOTTLES is **fully compliant** with requirements of NECD art. 9 by giving long-term information on air pollution impacts on forests and by using key indicators according to the NEC Annex 5 (visible foliar O_3 injury, exceedance of flux-based critical levels), hourly measurements (O_3 concentration, meteorology, radial growth) and the DO3SE model (CLRTAP). MOTTLES fulfills the art. 9 of NEC by ensuring that the Member States of Italy, France and Romania carry out long-term monitoring activities to provide risk assessment and long-term quantification for O_3 effects on forests. From 2019, and every 4 years, the monitoring data must be transferred to the EC and EEA. The exceedances of PODY critical levels and visible foliar O_3 injury are now recommended as indicators in the revised NEC Directive. The EU Member States shall monitor the impacts of air pollution (including O_3) upon ecosystems, based on a network of monitoring sites representative of their habitats. **MOTTLES, unique in Europe, is able to provide those data**, indeed sites of Italy and Romania are now included in the national lists of NEC sites and **the first set of data was provided in 2019 upon request by the national Ministries**.

The agreement with the Italian Ministry is available in Annex D2.6. The agreement with the Romanian Ministry is available in Annex D2.6. These agreements are the result of MOTTLES

dissemination, in particular the one-day meetings and the two MOTTLES events in Florence and Bucharest described in Action D2.

From flux-effect relationships, we derived flux-based critical levels (CLef) for forest protection against visible O_3 injury. We recommend POD1-based CLec: **12 and 5 mmol m^{-2}** for broadleaved species and conifers, respectively. Before to use PODY as a legislative standard in Europe, however, we recommend to still use the AOT40-based CLec for ≥ 25% of crown defoliation in a plot: 17 and 19 ppm.h for conifers and broadleaved species. These recommendations are a final result at the end of the project and will be disseminated to ICP-Vegetation decision makers during the After-LIFE.

The project results allowed to **promote best forest monitoring practices** (in terms of cost-effectiveness of plant-response indicators, species-specific critical level thresholds and reporting to the EU) (Annex D2.3) to be transferred into policy approaches. In addition, the project coordinator E. Paoletti participated as SISEF consultant to the long process of launching and implementing a new forest law in Italy (Testo Unico Forestale D.lgs n. 34/2018), and the MOTTLES scientist I. Popa participated in the work group for forests of the council of the European Union: "Establishing Strategic priorities on forests for the period 2019-2020 and the guidelines for a new European forestry strategy after 2020". Both MOTTLES scientists attended the United Nations Forum for Forests 2019 for proposing climate-smart forest management principles to policy-makers. The forest management principles were also transferred to foresters, site managers and forest decision makers during dedicated MOTTLES events.

Thanks to the interactions with Italian decision-makers, the MOTTLES coordinator E. Paoletti was nominated Italian **expert for ozone within ICP-Forests** (Annex D2.11). In addition, the MOTTLES scientist D. Silaghi was nominated Chair of the ICP-Forests Expert Panel on Ambient Air Quality (http://icp-forests.net/page/expert-panel-on-ambient-air). These new positions are an important MOTTLES result which will allow to consolidate the MOTTLES monitoring system standards within this stakeholder community and the UNECE Convention on Long-Range Transboundary Air Pollution. In detail, the Expert Panel has the task to further develop the harmonised monitoring methods in the field of ambient air quality and ozone visible injury assessment. The Expert Panel closely cooperates with the Programme Co-ordinating Centre and the data centres in order to contribute to the data evaluation and quality assurance.

MOTTLES dissemination allowed also to develop a collaboration with the Tuscany Region and develop the first "Guidelines for the **management of urban forests** aiming to improve air quality" available in Italy (Annex C3.4). Such guidelines commit the local urban authorities of Tuscany to select tree species from a list of most performing species, i.e. able to maximize the uptake of gaseous and particulate pollutants.

8. Key Project-level Indicators

In Table 10, we report the expected final values for each KPI as planned in the Grant Agreement, together with the actual values and values at 5 years from the project end (e.g. long-term indicators). Final actual values of the KPIs were introduced in the online KPI database (https://webgate.ec.europa.eu/eproposalWeb/kpi) considering the environmental, economic, and social benefits reported in the preceding section. All the other expected values were reached or even exceeded (**in bold**), except for the provision of forest data sets for the European Data Centre (*** in red**). The expected values were largely exceeded in particular for the raising awareness of the general public, knowledge exchange strategies and replication and transfer of results assuring the sustainability of project results, one of the main objectives of MOTTLES.

Table 10 - Expected vs. actual value of key project indicators (see also Annexes C1.5 and C1.7)

Numbers	Key indicators and parameters	Units	Value expected at the end of the project, as planned in the GA	Actual value, observed at the end of the project	Long-term indicators (value 5 years after the project end)
3	**Resource efficiency (incl. soil, forests and green circular economy)**				
3.2	**Implementation of the European Forest strategy**				
3.2.1	Area newly under sustainable forest management (17 sites each 0.5ha)	Hectare (ha)	8.5	8.5	11
3.2.2	Set up a permanent new-generation monitoring system for the ozone effects on EU forests	Number of systems	17	17	22
3.2.3	Provision of forest data sets for the European Data Centre	No. of data sets provided	4	**3** [1]	8
3.2.4	Usable guidelines book for a more coherent policy on EU forest protection	Number	1	2	2
3.2.5	Atlas of validated ozone visible foliar injury & list of sensitive tree species for the forest sustainable management	Number	2	2	2
3.2.6	Indicators to support future EU policies - AOT40 + POD1	Number	2	2	2
5	**Air**				
5.2	**Air pollutants - other than particulate matter**	Metric tons (per year per hectar)	Not planned	2.78 [2]	2.78

7	**Biodiversity** (Natural and semi-natural biodiversity and ecosystems)				
7.1	**Biogeographical area(s)**	Number	4	4	5
9.	**Adaptation**				
9.1	**Area potentially affected by climate change covered by adaptation measures**	Hectare (ha)	8.5	8.5	11
10	**Coverage / Range of the environmental / climate change impact**				
10.1	**Total human population to be affected by the project**	No. of individuals	8,500	8,500	9000
10.2	**Total area to be affected by the project**	Hectare (ha)	8.5	8.5	11
10.2.1	Total area covered by mapping of risk maps for vegetation	Hectare (ha)	8.5	8.5	11
11	**Governance**				
11.1	**Compliance/enforcement**				
11.1.3	Better governance - Risk-based compliance/enforcement system put in place	No. of systems	17	17	22
11.2	**Implication of NGO including interventions supporting EU environmental and/or climate change policies and other stakeholders**	Number	100	**243** [3]	300
11.3	**Better governance - Implication of stakeholder to improve stakeholder perceptions**	Number	6	**18** [3]	20
12	**Information and awareness**				
12.1	**General public reached and/ or made aware**				
12.1.1	Website - Average number of visitors per month	No. of individuals	50	**173**	175
12.1.2	Awareness-raising - Educational activities	No. of students	300	311	500
12.1.3	Raising awareness of the general public	No. of individuals	500	**3,979** [4]	5000

12.1.5	Raising awareness of the general public	No. of copies	1,950	**4,959** [5]	5500
12.1.4	Project notice boards	No. of notice boards	17	17	22
12.1.6	Surveys carried out regarding awareness of the environmental/climate problem addressed	No. of individuals reached	40	**155**	200
12.2	**Scientific community**				
12.2.1	Workshops, seminars and conferences with specialized audience (e.g. decision-makers)	No. of events	3	**24** [6]	40
12.2.2	Workshops, seminars and conferences with very specialized audience (e.g. experts, scientists)	No. of events	16	**36** [6]	50
12.2.3	Knowledge exchange strategy - Workshops, seminars and conferences	No. of experts & scientists expected/reached	1,000	**7,690** [6]	9000
13	**Capacity building**				
13.1	**Networking and other professional training or education**	No. of individuals trained	150	**340**	**490**
13.2	**Suitability for replication and transfer**	No. of events	5	**16** [7]	**20**
14	**Jobs**				
14.1	**Full-time equivalents (FTE)**	**per year**	2.3	2.3	1

[1] The provisions of validated data for the years 2017, 2018 and 2019 were carried out, while some data in 2020 were only partly validated and then submitted before the end of the project.

[2] One of the most important conclusions obtained from KPI analysis is the optimal results achieved in terms of CO_2 savings demonstrated with a LCA analysis, which were not foreseen at the beginning of the project. The MOTTLES active system allows saving 2.7 tons of CO_2 eq. per hectar per year.

[3] In MOTTLES we involved 17 stakeholders through the SIB (x 6) and stakeholder-oriented workshops. Finally, 243 local authorities (e.g. regional councils) and NGO (e.g. EFI, ICP Veg, ICP Forests, IUFRO, SISEF, and AISF) were reached.

[4] Approximately 4,000 people were reached and informed about MOTTLES thanks to 6 free guide sites tours and social media such as YouTube, Facebook and Twitter - After the end project we are expecting an increasing number of followers.

[5] During MOTTLES, we published and disseminated 500 Layman's reports, about 700 leaflets, 1,300 brochures, 500 guidelines and 2,000 e-newsletters.

[6] Due to large and efficient dissemination activities, about 7,700 experts and scientists were reached, by one-day stakeholders meetings in 2016, 2017 and 2018 (790 people reached), 22 international conferences with 25-75 participants each, 16 international conferences with more than 100 participants and 12 conferences at national/EU level with 75-100 participants.

[7] Regarding the replication and transfer activities, project partners attended 10 task force meetings and organized 6 events.

Thanks to the foreseen After-LIFE activity, we expect to expand the network to 5 new sites: 2 new sites in Croatia, 2 in Lithuania and one in Italy (CAL1). Accordingly, we expect an increment of the indicator values in the long-term, as reported in table 10. In particular, in the long-term, we expect 5 more datasets, consisting of AOT40 and POD1 distributions and exceedances maps, for a total of **8** *datasets* (2017-2024). The 5 new sites allow us to increase the *areas newly under sustainable forest management* up to **11 ha**, as well the *permanent new-generation monitoring system for the ozone effects on EU forests* to **22** sites. Moreover, the indicator "biogeographical areas" will become 5, because of 2 new sites in the boreal phytoclimate. The indicator *air pollutants* expressed as CO2 saving per ha per year keeps constant in the long-term, so that in the 5 years after the project ends, the MOTTLES active system will save **174 tons of CO_2** relative to the traditional passive system.
The project dissemination will be carried out through the Knowledge Exchange Strategy explained in the After-LIFE. Such activity will lead to an increment of awareness in the project audience, accordingly, to the increment of all indicator values in the long-term corresponding with the categories: *General public reached and/ or made aware*, *Scientific community* and *Capacity building*.