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Development of Technologies and Methods for the Application of Prescribed Fire for the Management of *Calluna vulgaris* Heathlands contaminated by Unexploded Ordnance (UXO)

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Abstract

Active and abandoned military training areas in Germany, some of them in use for more than a century, have been subjected to mechanical disturbances as consequence of movements of military vehicles and tanks, and the direct and indirect impacts of artillery shooting and bombing exercises, often associated with wildfires started by explosive ordnance. These training areas provide habitats and refugia for endangered species and open land ecosystems. Abandoned or reduced disturbances by military training have resulted in plant succession towards forest formation, resulting in losses of habitats for endangered species dependent on open land ecosystems, notably the *Calluna vulgaris* heathlands. In some areas the desired effects of meanwhile abandoned military activities and wildfires are substituted by targeted grazing, mechanical treatment or prescribed fire. However, within Germany a total area in the magnitude of tentatively 250,000 ha of high conservation value is contaminated with unexploded ordnance (UXO). While grazing alone cannot maintain openness in all cases, mechanical treatment and prescribed burning cannot always be considered as complementary measures due to the threat of UXO explosions. A concept and technologies have been developed in a R&D project in the Heidehof-Golmberg conservation area, an abandoned military training area in Brandenburg State, Germany, to safely apply prescribed fire by using converted military tanks as armored prescribed fire ignition vehicle and fire suppression apparatus. Prescribed burning operations are supported by unmanned aerial systems (UAS) for monitoring progress and decision support. The first experimental burns have been conducted in 2012 and 2013, followed by practical application, including wildfire suppression on UXO-contaminated terrain, between 2013 and 2015.

Keywords: Military training areas, succession, *Calluna vulgaris*, unexploded ordnance, prescribed fire, prescribed burning.

1 Introduction: Status of the use of prescribed fire in conservation and landscape management in Germany

Extended rural areas of temperate boreal Eurasia are affected by land use change and/or the abandonment of agricultural and pasture lands. This development is threatening the sustainability and survival of open cultural landscapes with their habitats of open space dependent species. Abandoned lands are undergoing rapid

succession. Substitution measures, which are practiced in some places to encounter succession and to maintain the open space habitats, are often highly subsidized in Western European countries. Mechanical measures or targeted grazing, however, are limited by the sheer magnitude of land area to be treated and by rapidly increasing costs. Since the 1990s the use of prescribed fire is investigated and applied in Germany in a number of pilot projects as a possible substitution in maintaining open landscape habitats (GOLDAMMER et al. 1997a, b, 2004, 2009, 2012, MEYER 2015). In particular in the following disturbance dependent ecosystems prescribed burning is an integral part of habitat management:

- Sub-Atlantic heathlands in Lunenburg Heath Nature Reserve (KEIENBURG & PRÜTER 2004),
- Atlantic *Calluna* dune heath in Schleswig-Holstein State (HOFFMANN 2004),
- Continental *Calluna* heath on abandoned military exercise areas without or cleared of unexploded ordnance (UXO) in Brandenburg, Rhineland-Palatinate und North Rhine-Westphalia States (BRUNN 2009a/b, GOLDAMMER et al. 2009, MAUSE 2009),
- Gras dominated open landscapes on former military training areas such as Münsingen (Baden-Württemberg State) (GOLDAMMER et al. 2009, NITTEL 2016),
- Slopes between viticulture terraces in the Kaiserstuhl, Baden-Württemberg State (PAGE & GOLDAMMER 2004, LANDSCHAFTSERHALTUNGSVERBAND EMMENDINGEN 2006, RIETZE 2009),
- Mountain meadows in the Black Forest, Baden-Württemberg State (GFMC TEAM & PAGE 2009), and
- Moorland habitats in Northwest Germany (NIEMEYER 2004).

In Germany Federal and State legislation, notably laws and bylaws regulating nature conservation and reduction of emissions, in general prohibit the use of fire in vegetation management, including the use of fire for disposal of agricultural residues and other organic materials. Exemptions from the general prohibition of fire application, however, are possible and are detailed by GOLDAMMER et al. (2012). In practice prescribed burning is conducted by authorized and trained personnel. In viticulture and open land management practice in Baden-Württemberg State, local farmers and wine growers are trained and certified for the application of prescribed fires and have to observe the annually published rules of exemption at county level. On active and abandoned military exercise and shooting ranges without UXO contamination, the local military fire services and the Federal German Forest Service take the responsibility for conducting prescribed burning operations based on individual rules of exemption (GOLDAMMER et al. 2012, GLOBAL FIRE MONITORING CENTER 2014).

The use of prescribed fire in the neighbouring countries of temperate boreal Eurasia is reflected by a number of informally connected activities under the „Eurasian Fire in Nature Conservation Network" (EFNCN) (GFMC 2004, 2009, EFNCN 2015). In the Euro-Mediterranean region, emphasis of prescribed fire application is on wildfire hazard reduction and the use of fire in wildfire suppression (suppression firing) (Fire Paradox 2010). The rationale, principles and postulates for the way ahead in the application of prescribed fire in the European biota have been manifested in the „White Paper on Use of Prescribed Fire in Land Management, Nature Conservation and Forestry in Temperate Boreal Eurasia" (GFMC & FIRE ECOLOGY RESEARCH GROUP 2009) and the monograph "Prescribed Burning in Russia and Neighbouring Temperate Boreal Eurasia" (GOLDAMMER 2013).

Fig. 1: *Calluna* heath subject to invasion and succession by birch and pine (left) and first prescribed burning tests in Zschorno Heath in the early 2000s (middle and right) (photos: project team).

Fig. 2: Recovery of the prescribed burning test sites in Zschorno Heath immediately after the fire left 4), one year (middle) and two years after the burn (right) (photos: project team).

2 Unexploded ordnance and vegetation fires in Germany

2.1 Introduction

Unexploded ordnance (UXO) include explosive ordnance (EO) (bombs, shells, grenades, land and sea mines, cluster ammunition, etc.) that did not explode when they were employed and still pose a risk of detonation, potentially up to several decades or even a century after they were used or discarded. In Germany UXO are found as remnants of war on former combat grounds and in or around urban and industrial sites subjected to aerial bombing during the World Wars. UXO and unused disposed am-

munition as remnants of armed conflicts and military training are found in vast areas of natural and cultural landscapes of Germany and neighbouring European countries. In conjunction with vegetation fires (land use fires and wildfires) UXO constitute a considerable threat to human health and security.

Active and abandoned military training areas of Germany have been inventoried, mapped and classified according to conservation value and included in the database "Nature Conservation and Military". According to the most recent update many of the 632 active and abandoned military areas, covering tentatively around 685,000 hectares (ha), have a high conservation value (NATURSTIFTUNG DAVID 2014, 2016). More than half of these areas are registered under the Natura 2000 network.

The information about the presence of explosive and other military ordnance on active and former military training and shooting ranges is scant. This refers especially to exercise sites dating back to the late 19th and early 20th Century and to the sites that had been used by the Soviet Army between 1945 and 1994. The available information, however, which could be derived from the database, indicates that around 250,000 ha of currently active and abandoned training areas, which have a high conservation value, are contaminated by UXO. This value, however, cannot be confirmed precisely due to lack of status of UXO contamination and UXO clearance (NATURSTIFTUNG DAVID 2016).

This database does not include the former combat theaters of the World Wars. In Brandenburg State – Germany's State with highest density of active and abandoned exercise areas (Fig. 3) – 89 % of the military training areas are abandoned today. The size of the military areas of high conservation value in Brandenburg of tentatively ca.195,000 ha (this value cannot be confirmed precisely, cf. NATURSTIFTUNG DAVID 2016) compares with ca. 400,000 ha former combat theaters and bombing target sites of World War II around Berlin with suspected UXO contamination (REINHARDT 2004).

Observations of the Explosive Ordnance Disposal (EOD) teams in Brandenburg State reveal that corroding UXO or disposed ammunition, especially cartridges and small caliber (< 20 mm) warheads, containing phosphorous and exposed to oxygen and high summer temperatures may lead to selfignition and cause wildfires (REINHARDT 2004). Vice-versa, wildfires burning on vegetated terrain, in which UXO are embedded in the soil surface layer, may elevate the temperatures of UXO containers and detonators to a critical point and trigger uncontrolled explosions, resulting in human injuries and fatalities. According to experimental observations of the Brandenburg State EOD teams, small arms cartridges located at the soil surface under vegetation cover explode after two to three minutes exposure to fire; caliber 2-3 cm grenades detonate after 10 to 15 minutes exposure of a slowly moving fire. Splinters released by 20-30 mm warheads are deadly up to a distance of ca. 100 m. UXO located below the surface of mineral soil is less exposed to heat generated by vegetation fire.

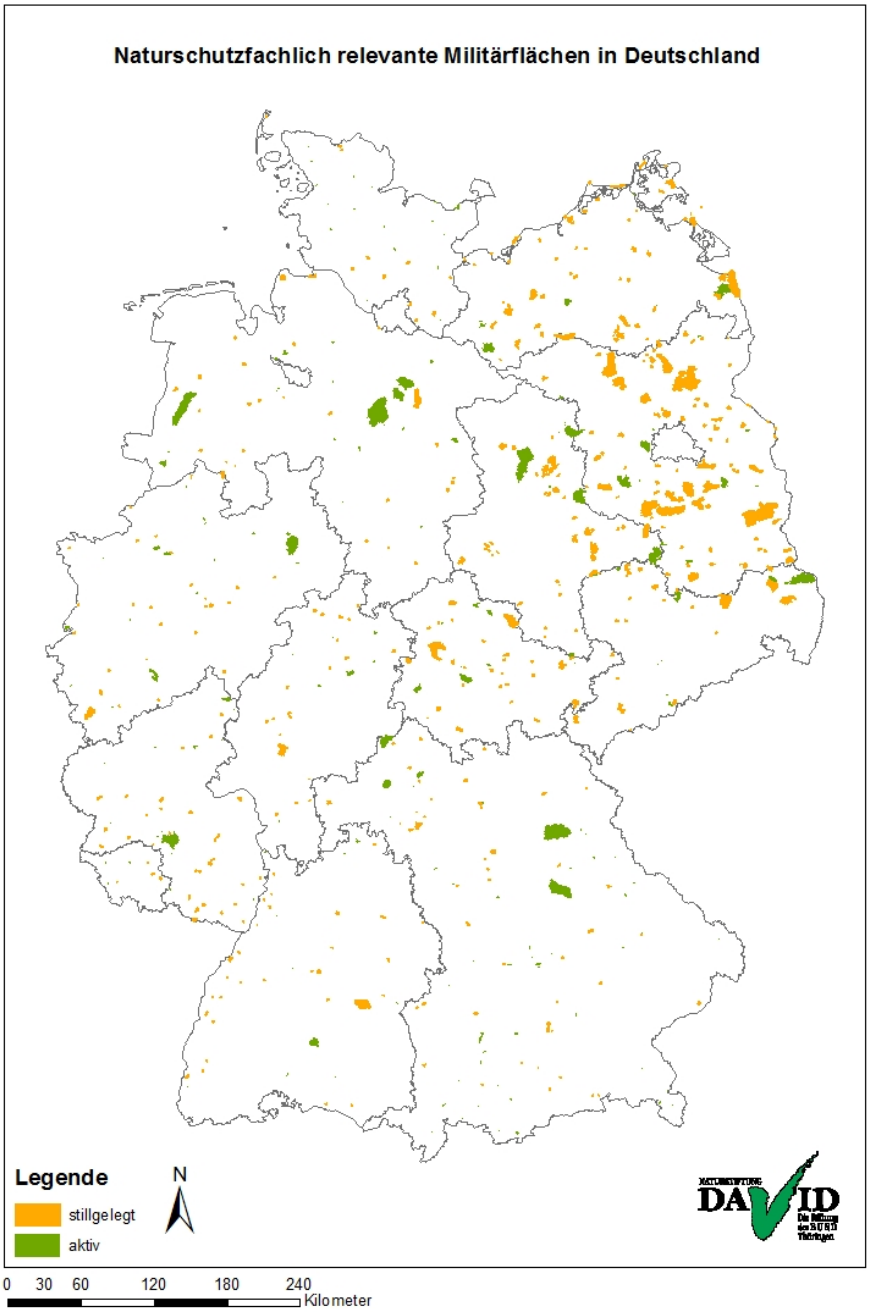

Fig. 3: Germany has about 685,000 ha active or former military exercise and shooting ranges with high conservation value. Tentatively 250,000 ha of these lands are contaminated with EO/UXO. Legend: Green – active military areas; ochre – abandoned military areas (source: NATURSTIFTUNG DAVID 2016).

However, the heat-insulating effect of the soil can be overcome by fires burning with a long residence time, e.g. burning windrows, wood piles or otherwise highly accumulated fuels (burnable organic matter). Such long-lasting fires may increase the temperatures of the soil and may lead to the heating of UXO up to the level of triggering detonation.

2.2 Fires burning on UXO-contaminated sites with high conservation value: Wildfire threats to human security and limitations for the use of prescribed fire

There are no standardized report procedures or statistics available for wildfires in forests and open lands on UXO-contaminated terrain in Germany. A report of the fire season of 2003 by the Fire Commissioner of Teltow-Fläming County (Brandenburg State) may serve as an example (HEINE 2004). Out of the total area of the county of ca. 200,000 ha about 49,000 ha are suspected UXO contaminated lands. In 2003 on 48 days the highest meteorological Fire Danger Index IV was reached. The total forested and open land vegetation affected by wildfire was 327 ha and thereof 275 ha UXO-contaminated sites.

Thus, wildfires burning during extremely dry and hot days during spring and summer bear a high risk of injuries and fatalities of firefighters and civilian populations. This is particularly the case in Brandenburg, the most contaminated State of Germany, where villages, farmsteads and other structures are located at the interface of or dispersed within contaminated lands. The public authorities therefore always prioritized the protection of human health and security once a wildfire occurred on areas of known or suspected UXO contamination. However, neither the professional or voluntary fires services nor the German Armed Forces (which may be activated in case of declared emergency situations) possess armored firefighting equipment, which provide protection of personnel against direct or remote impact of exploding ordnance. The last private aerial firefighting service of Germany, which operated fixed-wing firefighter planes (PZL Dromader) in Germany, closed business in August 2014.

Given the lack of appropriate equipment and in order to prioritize the protection of human lives several counties of Brandenburg State decided in 2012 to halt any fighting of wildfires on contaminated terrain and to concentrate on evacuations. The fire services are strictly advised to keep a minimum safety distance of 1000 m to any fire burning on UXO-contaminated or suspected sites. By following these rules, it is impossible to fight any wildfires burning on UXO-contaminated terrain. Since the safety distance of 1000 m is also applicable for the air space on top of UXO-contaminated sites, i.e. vertically, the use of manned aerial assets (helicopters, fixed-wing airplanes) for aerial firefighting is prohibitive because dropping of water or retardants including foam from altitudes > 1000 m above ground are inefficient.

The inherited UXO contamination, however, is not only a problem for the uncontrollable causes and the impossibility – not to say inability – of controlling wildfires, but also for the use of prescribed fire for maintaining or restoring open land ecosystem features.

As elaborated above many former military training areas are classified as high conservation value areas because of mechanical ecosystem disturbances caused by movements of tracked and non-tracked military vehicles including tanks, and explosions of ground and aerial ordnance. Fires caused by the training activities, notably on shooting ranges, are another characteristic disturbance factor and responsible for the genesis and dynamic maintenance of vegetation types such as *Calluna vulgaris* heathlands.

The potential threats and limitations respectively for the use of prescribed fire depend on the types of ammunition used on the specific shooting ranges and the accuracy of registration of ammunition used, including non-explosions of shot explosive ordnance.

Prescribed fire may be used relatively safely on ranges where the following types of ammunition were used:

- Small caliber exercise (practice) ammunition (blank cartridges)
- Exercise ammunition (grenades, rockets) with non-explosive exercise war heads (steel, concrete…)
- Exercise aerial bombs and land mines without explosives

Some areas in Germany, where explosive ordnance had been used, have been cleared up to a depth of several meters. Here the use of prescribed fire is without problems and limitations. Examples for low risk use of prescribed fire application have been documented in Brandenburg by BRUNN (2009a/b), Rhineland-Palatinate und North Rhineland-Westphalia States (GOLDAMMER et al. 2009, 2012, MAUSE 2009).

However, on many training shooting areas, in which explosive had been in use for more than a century, there is a lack of detailed inventories and maps of UXO. This is particularly the case on the shooting ranges of the former Soviet Armed Forces. On those areas, there is an imminent threat of explosions by these types of UXO:

- Live ammunition (grenades, rockets with unexploded warheads) including tracer ammunition containing phosphor
- Non-exploded bombs and land mines
- Any ammunition with non-activated propelling charge which were lost or disposed on the training areas

Control of wildfires or the use of prescribed fire on those terrains is possible only with technical equipment which provides safety of the personnel against impacts of detonations.

3 Prescribed burning on terrain contaminated by UXO: A pilot conducted in Brandenburg State, Germany

3.1 Introduction: The significance of *Calluna vulgaris* dwarf shrub heathlands in Brandenburg State for biodiversity conservation

With regards to the occurring Habitat Types (HT) of Annex I of the EU Habitat Directive the State of Brandenburg has a nation- and EU-wide significance, particularly with European dry heaths (HT Code 4030). Abandoned military training areas in Brandenburg State cover a total area of ca. 71,000 ha Natura 2000 sites consisting of 38 Special Areas of Conservation (SAC) and nine Special Protection Areas (SPA). More details are described by NATUR & TEXT (2007).

The main impediment to maintain or restore the abandoned dwarf shrub heathlands is the lack of knowledge on the degree and threats by UXO. This is one of the reasons why targeted measures are conducted only on a fraction of the conservation sites. The pilot project aimed at testing safe and efficient methods of the use of prescribed fire on UXO-contaminated terrain and selected the Natura 2000 site and nature reserve „Heidehof-Golmberg“ (GOLDAMMER et al. 2012) (Fig. 4).

Fig. 4: The Heidehof-Golmberg Nature Reserve is characterized by open dwarf shrub *Calluna vulgaris* cover, in which birch and pine trees are increasingly invading (left), and intermixed with open sand sites and dunes (right) (photos: project team).

3.2 Project goals and project partners

The project „Development and Tests of Methods for Heath Management on UXO-contaminated Sites by Prescribed Burning in Heidehof-Golmberg Nature Reserve (Teltow-Fläming County)“ was prepared since 2006 and implemented between 2010 and 2014[1]. The project was financed by the NaturschutzFonds Brandenburg (Brandenburg Nature Fund) and subsidies of the European Commission through the Landesamt für Ländliche Entwicklung, Landwirtschaft und Flurneuordnung (Brandenburg State Agency for Rural Development). The main goals of the project included:

- Development of principles for the safe, effective and efficient use of prescribed fire on UXO-contaminates areas of high conservation value to meet the Natura 2000 conservation obligations for highly endangered habitat types
- Studying the effects of prescribed fire on the regeneration of the subcontinental subtype of *Calluna vulgaris* heathlands and its fauna communities
- Integration of aspects of wildfire hazard reduction by fuel reduction using prescribed fire
- Development of pilot principles and techniques that would allow the replication of the developed methods and technologies on other contaminated sites to revitalize degenerated *Calluna vulgaris* heathlands
- Active public relations outreach for enhancing acceptance of the public, administrations and land owners for using prescribed fire as an alternative means of conservation measures
- Qualified accompanying research that would ensure efficiency and optimization of the use of prescribed fire in conservation sites

Furthermore, collateral synergies should be developed by the project by highlighting the significance and acceptance of the expected outcomes for gaining insight and further develop principles and methods for fire management on UXO-contaminated terrain, for UXO disposal after wildfires or using prescribed fires to detonate or expose UXO that were embedded and covered by vegetation cover und thus invisible. After the fire the UXO could be identified and disposed at low cost (Fig. 5).

The project consortium consisted of the administration of Teltow-Fläming County conservation authority (responsible for project coordination), the Fire Ecology Research Group (FERG)/Global Fire Monitoring Center (GFMC) (responsible for the prescribed burning activities), the RANA consulting company for nature conservation

[1] The full report of the project (PROJECT TEAM 2014) has been submitted to the financial sponsors NaturschutzFonds Brandenburg and the authorities of Brandenburg State and Tetow-Fläming County, respectively. The project peam is available to provide more details of the project results.

(responsible for monitoring and evaluation of the conservation related aspects) and DTF GmbH/Dienstleistungen im Brand- und Katastrophenschutzfall (DiBuKa) company (responsible for the development of the armored technologies), with technical and practical advisory support of Mr. Egbert Brunn (Federal German Forest Service, Lausitz District, Brandenburg State). The UAV drone component was contributed by the company Crvena tipka d.o.o. (Croatia). Local and State administrations responsible for conservation, land management, public health and security, land owners and civil-society interest groups participated in an advisory group, which accompanied the project by providing guidance and/or were also actively involved in the planning and implementation of the trials.

Fig. 5: Exempt of open sand sites: most of the UXO is embedded in vegetation or partially in the mineral soil. Some UXO will explode during the application of prescribed fire. Other non-detonated UXO will become visible after the fire and can be safely disposed by EOD teams after the burn (photos: project team).

3.3 Location and UXO contamination of the project area

The nature reserve and Natura 2000 site Heidehof-Golmberg is located 50 kilometers South of Berlin in Teltow-Fläming County and is a part of the abandoned military training area “Jüterbog Ost”. The project site is characterized by a continental climate with an average annual precipitation of 530 mm, average temperature of 8.7°C, relatively warm and dry summers and winters with persistent frost periods. The military use started in the 19th century. From 1945 until 1992 the site was used as an artillery and air force shooting range by the Soviet armed forces. The site includes also ammunition dumped at the end of World War II, including tracer ammunition containing phosphor that are now corroding and easily igniting by high summer daytime temperatures or by fire. The degree of contamination with unexploded ordnance is still unknown in extended areas. As part of the research and development project, the question had to be answered how the use of controlled fire for heathland management can be applied on UXO contaminated areas with sufficient safety.

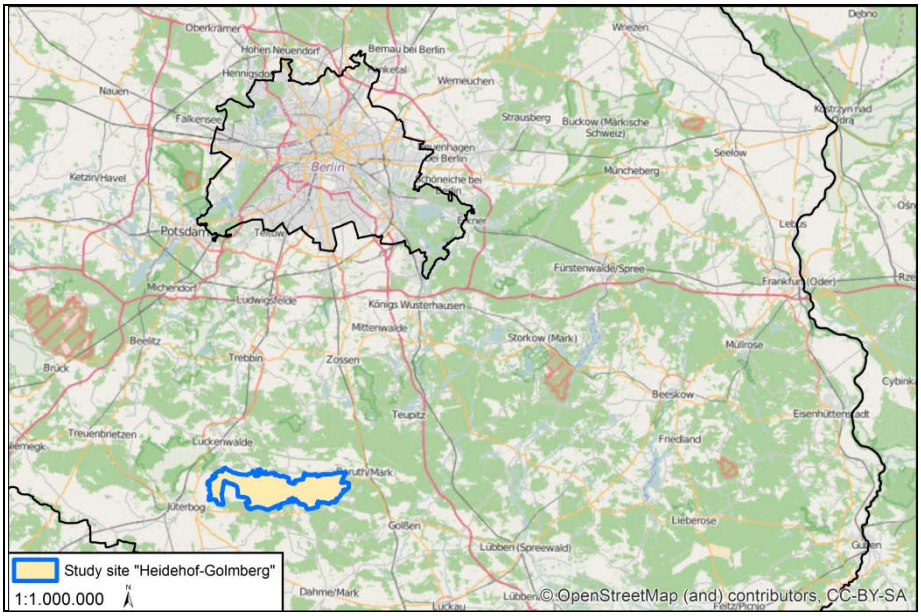

Fig. 6: Location of Heidehof-Golmberg Nature Reserve South of Berlin (source: RANA, based on ©Open Street Map).

Fig. 7: Prefire aerial photograph of test sites 10 (center) and 4 (upper right corner) in Heidehof-Golmberg Nature Reserve taken by the drone (photo: project team).

In order to explore the density of UXO contamination, a small test area of 0.5 ha was cleared from UXO between soil surface and 20 cm depth. In this case a total of 68 UXO were recovered on this site. Furthermore, the safety tracks serving as fire breaks and safe driving trails for the armoured vehicles were cleared on a total length of 2.2 km with a width of 7 m and a UXO clearing depth of 2 m, corresponding to an area cleared of 15,500 m^2; the cleared terrain included several demarcated 20x20 m plots established as vehicle turning/manoeuvring points (when turning tracked vehicles tend to exert fairly high pressure on the ground and break through the ground surface and may trigger UXO explosions under the tracks), command and monitoring points and UAV launching sites (3,000 m^2). On the total of ca. 1.85 ha cleared area 375 UXO and other ammunition parts were recovered. Typical types of UXO recovered are displayed in Fig. 8. The costs per unit area for securing safe prescribed burning by clearing safety trails and vehicle turning points depend on the length of trails and number of turning points and the size of the plot to be burned. An economic assessment of the project revealed that securing a plot of 25 ha would costs 340 €/ha.

Fig. 8: Typical UXO recovered during clearing of the 7 m wide train surrounding the test site 10: (a) 125 mm shaped charge grenades; (b) light case explosive bombs (70 kg) (photos: project team).

3.4 Safety prerequisites, technical concept and technological requirements for prescribed burning on UXO-contaminated terrain

The safety prerequisites and the technical concept involved the following considerations for safe and effective prescribed burning operations:

- All personnel involved in the ignition and containment of the prescribed fire would operate in armored vehicles; all other personnel had to keep a minimum safety distance of 1000 m.
- The personnel operating the armored fire ignition and suppression vehicles would be connected with the command by continuing wireless communication and have all around visibility/view.

- Detailed realtime monitoring of the progress of the operation would be obtained by an unmanned aerial system (UAS) and transmitted to the operations command post and further on to the operating armored vehicles.
- All prescribed burning procedures would observe/follow national and international standards including legal, technical and otherwise required laws and regulations.

The project was challenged to put in place and – if not yet available on the market – develop technologies and operating procedures that would meet the safety requirements and legal standards.[2]

3.4.1 Armored ignition technologies

A protected fire ignition vehicle needed to be designed and constructed. It was decided to use a decommissioned light non-armed command tank of type BMP OT-R5, which was procured by the DiBuKa on company costs. The BMP OT-R5 was manufactured as a command vehicle under license in former Czechoslovakia based on the design of BMP-1 floatable armored personnel carrier, a nimble, robust, and easy to maintain vehicle. The steel armor thickness between 12 and 20 mm is able to protect the personnel against shrapnel and bomb splinters. Pursuant to the German Foreign Trade Act (AWG) and the War Weapons Control Act, permission for the import and operations of the fully functional BMP OT-R5 had to be obtained (Fig. 9).

Fig. 9: The BMP OT-R5, decommissioned by the Armed Forces of the Czech Republic (left), was converted to an ignition tank by DiBuKa (photos: project team).

In order to improve the orientation of the crew of the BMP and providing view for observation of the fire while driving with closed hatches, four waterproof outdoor cameras were installed. With a resolution of 700 TV lines to the front and 420 TV lines to the rear and to the sides the realtime images are transferred to a high resolution

[2] Details about legal requirements and administrative procedures as well as public relation measures are summarized by GOLDAMMER et al. (2012).

flat screen to the tank commander's workplace. Image display can be changed with a touch screen function, e.g. choosing between a four image and a single image display (Fig. 10). Internal communication lines within the tank and external radio links to other vehicles (e.g., the fire suppression tank) as well as the incident command post ensure continuous exchange of information with all units involved in the operations.

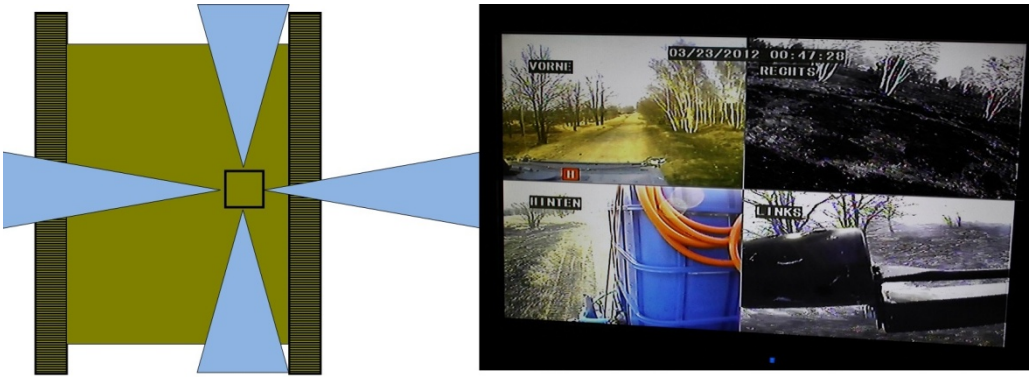

Fig. 10: Four cameras installed on the BMP provide view to the terrain from inside the tank while driving with closed hatch (graphic and photo: project team).

Two types of ignition technologies were tested and successfully applied:

1. Temporally and spatially delayed ignition: The BMP is equipped with a Pyroshot Green Dragon® (Fig. 11). The device is an automated ground launcher designed and engineered for use in forestry and wildfire management applications such as back burning or prescribed burning. As a CO_2-propelled, fully automatic fire ignition tool, the device offers a variable firing rate that can be adjusted for shooting more than 30 ignition spheres per minute up to 70 m away. The spheres made of high impact polystyrene plastic are filled with three grams of potassium permanganate. At the moment of firing, the spheres ethylene glycol is injected by a needle, which initiates an exothermic reaction. After a delay of approximately 30 seconds, combustion commences with white smoke being expelled from the needle hole followed by sphere ignition. Once ignited, the plastic shell is consumed as fuel. The total combustion time, following ignition, is about 80 seconds. The firing of the spheres is controlled by personnel inside the BMP. The time lapse between firing of the spheres and the vegetation ignition as well as the forward movement of the BMP results in building up of fire intensity and UXO explosion threat at a time when the BMP has reached a safe distance, i.e. outside of range of full direct impact of ordnance detonation.

2. Direct ignition: In addition, the BMP is equipped with an ATV drip torch, which is used to ignite prescribed fire or back burning from off-road vehicles and is also operated by personnel inside the BMP (Fig. 21). The Foxfire Trail-Blazer ATV Drip Torch has a 40 l tank with a diesel gasoline mixture and a 12 V fuel pump. The

torch can project a 0.5 to 5 m flame. Driving on UXO-cleared tracks surrounding an area to be burned the ignition by the ATV is efficient if the vegetation cover is within reach of ignition of the flame thrower.

Fig. 11: Pyroshot Green Dragon (left and center) and the Foxfire Trail-Blazer ATV Drip Torch (right) mounted on the converted BMP OT-R5 (photos: project team).

3.4.2 Armored fire suppression technique

With the firefighting tank SPOT 55, the DiBuKa provides a powerful armored firefighting technology that allows effective and safe firefighting on UXO-contaminated sites. SPOT 55 was designed and built in former Czechoslovakia on the basis of the medium size battle tank T 55 of the Warsaw Pact, which like the BMP is known to be exceptionally robust and relatively simple in construction.

The armoured hull of the SPOT 55 has remained complete and uncut which ensures an appropriate protection of personnel. The SPOT 55 has two water tanks with a total capacity of 11,000 l. For better penetration of water into the combustible material (dry fuels including duff layers and dead organic matter), a wetting/foaming agent can be injected (tank content for additives: 2000 l). At the front top, two rotatable high pressure water monitors are installed (Fig. 12). The pumping capacity is max. 1250 l/min and the water throwing distance is up to 60 m. In action against an intense fire, the SPOT 55 can be cooled by a water mist, which is generated by a number of nozzles on the surface of the vehicle. Also below the dozer blade are corresponding water jets. This provides a safe driving over low ground fire or piling burning material. The crew consists of the driver and the commander who also operates the water monitors. Like the BMP the SPOT 55 is driven with closed hatches and is equipped with video cameras as well as with internal and external communication.

Fig. 12: SPOT-55 in field operations during the 2012 trials. The aerial photograph taken by the UAV shows the control of a fire crossing the security trail (photos: project team).

3.4.3 Monitoring by Unmanned Aerial Systems (UAS)

During the preparatory phase of the field trials, the use of unmanned aerial vehicles/systems (UAV/UAS) for safely conducting, overseeing and monitoring of the prescribed burning operations was investigated. This was necessary in order to overcome the constraints of safe prescribed burning operations on UXO-contaminated terrain by observing (a) the safety distance of unprotected personnel of 1000 m to the fires, and (b) the dispersion of armored vehicles over several hectares and distance of several hundred meters under conditions of restricted visibility due to smoke. Three unmanned small monitoring platforms systems were tested – tethered balloon, helicopter and fixed-wing aircraft. During the 2012 field trials, the remotely controlled octocopter CT Bee 6B® provided still and video imagery (Fig. 13). Permission had to be obtained for the operation of the octocopter (see next section).

Fig. 13: The small octocopter drone type CT Bee 6B operated by project partner Crvena tipka d.o.o. (Croatia) provided realtime imagery (still photos and videos) of the prescribed burning operations allowing safe and precise ignition and suppression of escaping fire (photos: project team).

3.4.4 Prescribed burning techniques

The use of the specially designed assets for prescribed burning on contaminated terrain followed the generally applied methods and best practices, i.e.

- Observation of prescriptions for obtaining ecologically sound results for the regeneration of target species (burning during the late winter at times of vegetation and faunistic dormancy)
- State-of-the-art ignition techniques to secure confining the prescribed fire to the targeted terrain (see EuroFire Ignition Standards and Training Materials) (EUROFIRE 2015)
- Observation of rules of smoke management, i.e. observation of appropriate weather conditions and firing techniques to avoid smoke emissions to directly affect humans, critical infrastructure and smoke sensitive traffic

3.5 Legal and administrative provisions

The legal and administrative provisions that had to be observed for the prescribed burning operations have been detailed by GOLDAMMER et al. (2012). In summary the following federal and state regulations of Germany had to be observed and permissions obtained:

1. Exemption of the ban of using fire in conservation areas in Brandenburg State (Nature Conservation Law of Brandenburg State)
2. Exemption of the ban of using fire with regards to the emissions control law of Brandenburg State (Emissions Control Law of Brandenburg State)
3. Exemption of the ban of using fire inside or nearby forest in Brandenburg State (Forest Law of Brandenburg State)
4. Observation of regulations concerning safety on areas contaminated with UXO in Brandenburg State (Decree of Brandenburg State to Reduce Risks on Areas Contaminated with UXO)
5. Coordination with local/communal fire services (Law on Fire and Disaster Protection of Brandenburg State)
6. Import of weapons of war (with regards to importing the BMP from Czech Republic to Germany) (Federal Foreign Trade Act and Federal War Weapons Control Act)
7. Import of the Pyroshot Green Dragon and the ignition spheres containing potassium permanganate as a key substance to produce cocaine (permission required by the Federal German Opium Agency)

8. Transport of heavy vehicles like the SPOT 55 and the BMP on public roads (General Administrative Provisions on Public Traffic and Transport of Heavy Cargos)
9. Airspace safety with regards to possible explosions: Issue of permissions, navigations warning and Notice for Airmen (NOTAM) (procedures coordinated with the German Airspace Control [Deutsche Flugsicherung GmbH])
10. Airspace safety with regards to UAV operations (Federal Airspace Traffic Law and regulations by the Berlin-Brandenburg Air Traffic Control Authority)

The amount of permissions required to conduct prescribed burning in general, and in particular on UXO-contaminated terrain, reveals that a careful preparation of such operations is necessary. Apart of detailed briefings of the Federal and State authorities in the frame of application for permissions, it was also essential to inform the public. In the case of the experimental trials, the local community in which the prescribed burning site is located, as well as other communities bordering the former military training site, were closely involved and several round tables and public hearings held.

4 Technical summary of field tests in 2012 and 2013

Based on the developments of technologies described above and the permissions obtained, two experimental field trials were conducted in 2012 and 2013 at the project site. The lessons learned from the development and application of safe prescribed burning technologies and techniques on UXO-contaminated terrain are summarized as follows:

1. Principles, techniques and procedures of the application of prescribed fire for the maintenance and restoration of endangered *Calluna vulgaris* heathlands are applicable on terrain contaminated by UXO.
2. The creation of a public private partnership between public authorities (administrations), academia (research institutions) and private (commercial enterprises) enabled the project team to develop a coordinated approach towards the use of existing and the development of new technologies for safe and effective prescribed burning on contaminated terrain.
3. The development of an integrated system for safe armored ignition and fire suppression and the use of UAV/UAS for operations monitoring and decision support closed a critical gap.
4. The burning operations in 2012 and 2013 were conducted safely without any incident or injuries.
5. Economic assessments have been made for the use of the armored technologies for prescribed burning. Considering the costs for transport and operations of the heavy equipment, it is recommended to burn a minimum size of ca. 20-25 ha per operations day in order to reduce the costs per ha burned.

6. The spin-offs of the project resulted in the availability of technologies and procedures for managing UXO-contaminated terrain with regards to (a) Wildfire hazard reduction, (b) Safe and economic identification and disposal of post-fire remaining UXO and (c) Use of the technologies for safe wildfire suppression.

After initial controversial assessments and judgements by public administrations and discussions with civil society, it was possible to obtain a consent that the problem of conservation of UXO-contaminated Natura 2000 sites and other protected and non-protected terrain needed to be tackled and that the project provided a solution. The specific results related to the conservation objectives of the experimental trials are summarized in the following section. Visual impressions of the trials are provided in Figures 14 to 19.

Fig. 14: Progressing ignition with the ATV Drip Torch (photos: project team).

Fig. 15: Ground view of point ignitions with the Pyroshot Green Dragon (left) and aerial view of progressing ignition from the drone (right) (photos: project team).

Fig. 16: Aerial view from the drone: The SPOT 55 shows the control of a fire crossing the security trail (left) and monitoring of fire behavior and progress of the burn (right) (photos: project team).

Fig. 17: The fire intensities varied depending on fuel loads and burning techniques (photos: project team).

Fig. 18: Smoke management considerations determined the preferred weather and atmospheric conditions as well as the technique of the prescribed burn. A high intensity fire allowed the development of convective smoke plume and the vertical smoke export, thus avoiding near ground smoke pollution (photo: project team).

Fig. 19: The post-fire aerial and ground views of the test site reveal that it was possible to safely contain the prescribed fire by the armored vehicles (photos: project team).

5 Ecological monitoring

The use of fire as a means of habitat management was absent for many years on abandoned former military training sites. The loss of experienced staff and know-how after troop withdrawal led to a hiatus of the burning tradition. Among conservationists, fears on proper fire control were mixed with serious doubts concerning its positive effects on the heathland ecosystem or possible damages, especially on the fauna.

Hence, the current project was accompanied with an intense ecological monitoring programme consisting of the following parts:

- Analysis of biotope and vegetation structures including Natura 2000 habitat types
- Age structure of *Calluna vulgaris*
- Post-fire vegetative and reproductive regeneration of *Calluna vulgaris*
- Biomass storage and fire induced mass exports
- Nutrient element balance
- Mapping of key faunistic taxa, such as spiders, grasshoppers and birds
- Photo monitoring

The study design consisted of different plots covering burned as well as non-managed (reference) plots, where various parameters were measured and mapped before, during and after the use of fire (Fig. 20). The results are documented in the project report (PROJECT TEAM 2014). Results of monitoring birds, grasshoppers and ground beetles (Carabidae) (MEYER et al. 2016); further details will be published elsewhere in the near future.

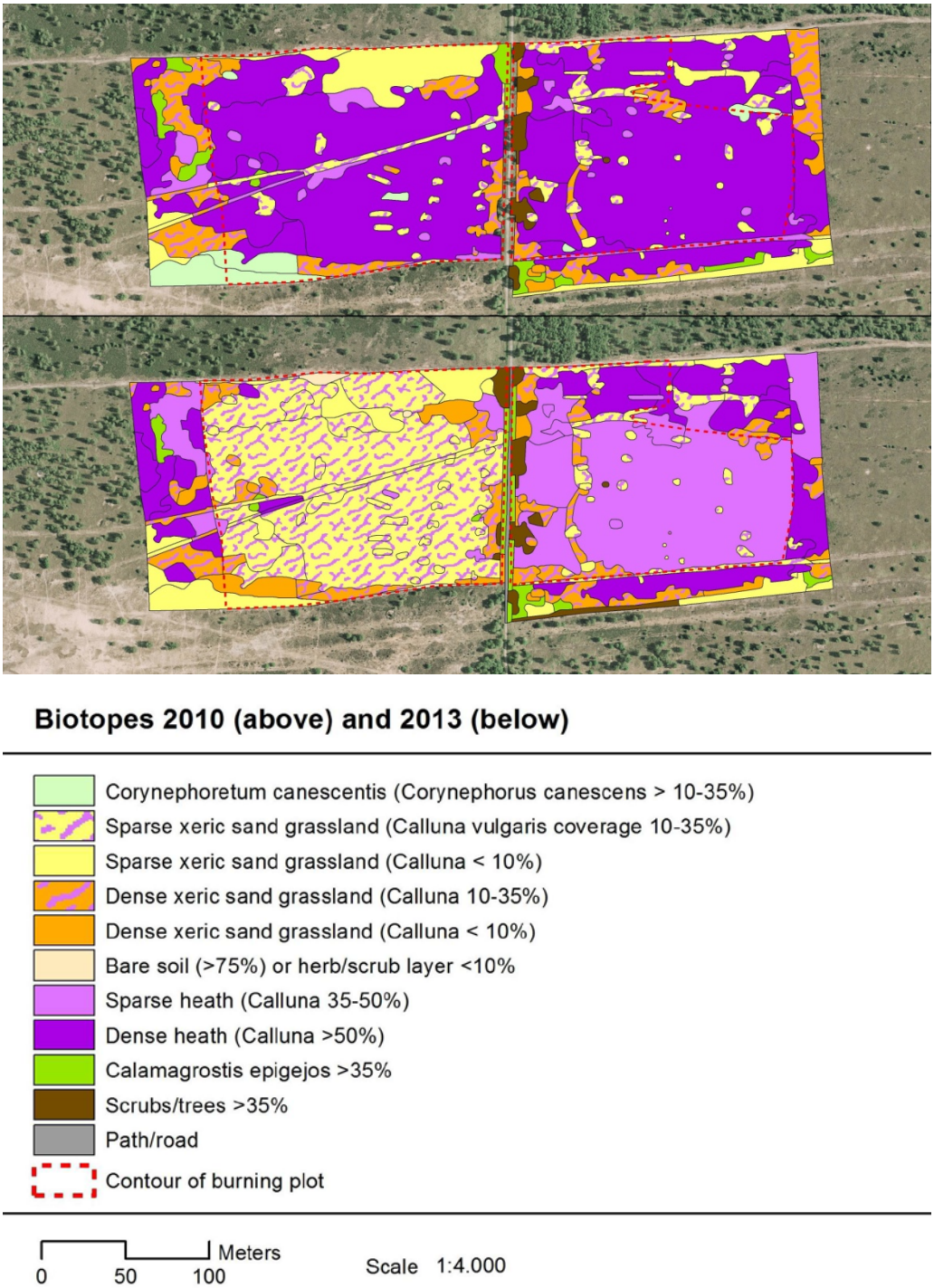

Fig. 20: Biotope structure of burnt plots before (2010) and after burning (2013) (source: RANA).

Here, we summarize some of the key findings and interpretations.

- *Calluna vulgaris* ages faster under subcontinental climatic conditions as compared to Atlantic climate conditions. Our analyses revealed a mean age of only 14.8 years when reaching the senescence phase of its life cycle, opposite to the life cycle of 30 to 40 years in the Lunenburg Heath (PETERSEN 1990). This shorter lifespan also means that shorter management cycles are required!
- Coverage of competing grasses, above all *Deschampsia flexuosa*, increases after burning and it is supposed that an effective suppression of such competing species can only be reached by high fire intensities. *Calamagrostis epigejos* did not show distinct changes in its frequency.
- A boost growth of trees and scrubs as a result of the increased bare soil ratio did not take place, so that the initial concerns are unwarranted.
- Prescribed burning led to the export of 15.2 to 25.7 tons of biomass per ha (mean of 21.2 t/ha or 76 % of biomass), which is consistent with published data of burnt 10- and 15-year old *Calluna* heath in the Lunenburg Heath (72 % or 84 % biomass export) (NIEMEYER et al. 2005).
- The amount of total nitrogen (N) was quantified as 209 or 193 kg/ha at two different plots. Here, the application of prescribed fire led to an export of 73 % of the original N amount, i.e. an average of 145 kg/ha. Assuming a 15-year management cycle, this amount is almost sufficient to compensate for more than half of the annual atmospheric N intake of 15 kg/ha, as determined for this part of Germany (GAUGER 2011). CHAPMAN (1967) published an even higher export of 95 % or 173 kg N/ha for heathlands in south England.
- Fire management, when practiced in late winter, has a very positive effect on invertebrate communities, especially on target species of *Calluna* heathlands and sand dunes that are often highly endangered. Recolonization of burnt plots can be recorded immediately after burning, often already within a few days. Development of species and individual numbers are almost indistinguishable between burnt and reference plots immediately after burning, but a higher increase is seen in the burnt sites subsequently. The resulting strong elevation of arthropod densities evidently benefits the prey supply for reptiles and birds.

6 Transfer from research & development to practice: Development of concepts on Integrated Fire Management (IFM) at landscape level

The overall aim of the R&D project was to provide innovative solutions for overcoming the unresolved problem of maintenance and restoration of endangered conservation species on UXO-contaminated Natura 2000 sites and other protected areas. While these specific goals have been obtained, there are spin-offs, which have created addi-

tional value und inspirations for future related developments.

The final phase of the project coincided with an increasing awareness on the complexity of fire related issues in Brandenburg State and the need for multiple interaction of stakeholders responsible for land management (forestry, conservation), environment and public security. At the end of the project a Round Table "Integrated Fire Management at State level in Germany – Brandenburg State" was held in which State agencies and civil society representatives (NGOs involved in conservation; entrepreneurs such as the project partner DiBuKa) concluded that the theme of fire management ranging from fire use in conservation to the prevention and control of fires burning on dangerous terrains would merit a coordinated and integrated approach at State level. In a concluding report, which was submitted to the government of Brandenburg State, it was proposed to take proactive measures to encounter the increasing threats of climate change and collateral damages caused by wildfires burning on contaminated terrain on the one side, and the options of using the benign effects of prescribed fire and some (controlled) wildfires for the benefit of conservation on the other side.

6.1 Spin-off I: A concept for an integrated system for the use of fire in heathland conservation and UXO clearing

During prescribed burning in the cold (winter) season the unexploded ammunition, which is typically embedded in vegetation cover and often invisible, is exposed and becomes visible (Fig. 21). Low soil and surface temperatures during the winter season are keeping the UXO in a state of cold temperatures. The heating effect of ammunition by prescribed winter fires, especially by fires spreading rapidly with the wind and with short residence times, is rather low and thus resulting in a lower rate of explosions as compared to fires occurring during the summer. During the hot summer season prescribed fires and wildfires lead to higher rates explosions because UXO had been preheated by elevated soil temperatures and solar irradiation.

Fig. 21: During prescribed burns in the cold winter season some of the UXO, which was previously embedded in vegetation cover, may not explode but is exposed and can be disposed by EOD teams easily and at low costs (photo: project team).

During the project extensive consultations were held with the EOD teams of Brandenburg State. Long term observations of EOD teams reveal that most of the UXO, which was initially buried subsurface, is moving gradually to the soil surface due to frost effect (pedoturbation). The time elapsed between surface clearing of UXO and the next "generation" of UXO appearing at the soil surface in general seems to be in the magnitude of 15 years. This period coincidentally matches with the scientific evidence that *Calluna vulgaris* heath requires a regeneration burn at least every 15 years.

The development of an integrated heath recovery and UXO clearing plan is proposed, which will require the use of prescribed fire for regeneration of *Calluna vulgaris* heath on UXO-contaminated sites in intervals of 15 years. After the fire the EOD teams would remove and dispose the exposed ammunition at low cost. An economic evaluation of the costs for using armored technologies for setting and controlling prescribed fires in practice concluded that an area of at least 20-25 ha should be treated in a one day operation in order to utilize best the personnel and the transport costs of the armored vehicles. In 2012 the costs were around 500 €/ha for such a scenario (without costs for a monitoring UAS/UAV and for the above mentioned costs for UXO clearance on the safety trails).

6.2 Spin-off II: A concept for the prevention of wildfires spreading from UXO-contaminated terrain

The magnitude of wildfire problems on UXO-contaminated terrain in Brandenburg State and other States in Germany on the one side, and the threats of explosions of UXO in wildfire situations on the other side are calling for solutions that are considering a number of aspects that need to be tackled in an integrated approach towards fire management at landscape level:

- Threat to local populations: In the most contaminated areas of Brandenburg State villages, farmsteads and other residential areas are located intermixed with or at the interface with forests, wilderness areas, conservation areas such as dwarf shrub heathlands, abandoned or otherwise access restricted active and former military areas. The threat of wildfires burning on UXO-contaminated terrain to human safety is extremely high.
- Safety regulations for firefighting and management of contaminated terrain: The above quoted safety regulations (paragraph 2.2) require firefighting forces to keep a safety distance of 1,000 m (on the ground and in the air) to a fire burning on UXO-contaminated terrain if not protected appropriately. This makes any firefighting with conventional equipment impossible.
- Safeguarding wilderness areas and adjoining lands: In various parts of Germany, including Brandenburg State, wilderness areas have been established, which are embedded in the cultural landscapes and in which natural succession is allowed and any forestry or land management activities are prohibited. Some of them include UXO-contaminated former military areas. Here the treat of dangerous wildfires is successively increasing over time due to the build-up of fuel loads – resulting in an increased wildfire hazard – in which UXO are embedded and impossible to be removed/disposed. In other words: The UXO-contaminated wilderness areas are posing an extremely high risk of severe and dangerous wildfires.
- Development of a “Let burn policy”: Considering the wildfire threats on the one side and the needs for fire to keep some protected areas – mainly abandoned military areas – in a healthy state on the other side, it is suggested to develop concepts that will allow letting burn wildfires. This concept would apply for areas where fire (a) is desired from a conservation point of view, (b) would not cause site degradation or destruction of ecologically and economically valuable vegetation resources, and (c) could burn out up the safe limits without endangering public safety.

Fig. 22: Fuel break (buffer zone) established in Zschorno Heath, German Federal Forest District Lausitz, Brandenburg State (photo: E. Brunn).

Experiences in the creation of fuel breaks (buffer zones) in former military areas by the Federal German Forest Service (Bundesanstalt für Immobilienaufgaben, Sparte Bundesforst) and around wilderness areas by Foundation Natural Landscapes (Stiftung Naturlandschaften Brandenburg) reveal that large fuel breaks may be planned in a combined effort of wildfire protection and establishment of high value conservation sites (Fig. 22).

In a follow-up of the project activities, a fuel break concept was designed, which includes the application of prescribed fire using armored ignition and control techniques for maintaining *Calluna vulgaris* corridors and prescribed undercanopy burning in pine stands (*Pinus sylvestris*) for reducing fuel loads and potential wildfire intensity/hazard (Fig. 23).

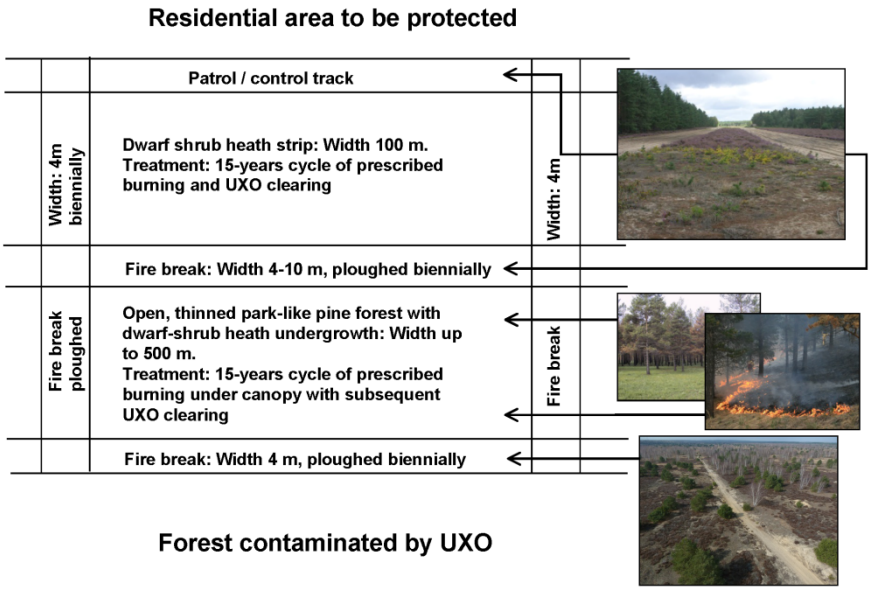

Fig. 23: Proposal for the design of a fuel break (source: project team).

6.3 Spin-off III: A concept for suppression of wildfires on UXO-contaminated terrain

In Germany the suppression of wildfires is the responsibility of the States and implemented by the voluntary fire and rescue services, which are organized, supervised and coordinated by the county fire commissioners. In case of larger fires assistance and reinforcement is provided by professional urban fire services, the local (voluntary) units of the Federal Agency for Disaster Relief (Bundesanstalt Technisches Hilfswerk) and – in case of declared disaster/emergency situations – the Armed Forces (Bundeswehr). None of the services or institutions is equipped and trained for controlling fires on UXO-contaminated terrain. In 2012 – during the project lifetime – several communities in Brandenburg State, enforced the rules and imposed strict bans to the fire and rescue services to approach any fire burning on contaminated terrain closer than the required safety distance of 1000 meters.

In the same year a wildfire on contaminated terrain prompted the authorities to call project partner DiBuKa to fight the fire (Fig. 24). Following the performance and success of the operation subsequent agreements were made between the county authorities and the project partner to provide services in support of the authorities to be available to fight these dangerous fires. In 2015 the agreement was followed by a joint interagency fire control exercise in Teltow-Fläming County (Fig. 24).

Fig. 24: In 2012 the Project Team Partner DiBuKa was called for the first time by the Brandenburg State authorities to fight a wildfire on UXO-contaminated terrain (left). The right photo shows an exercise of the public private partnership in training the preparedness for fighting fires on contaminated terrain in Brandenburg State in early 2015 (photos: project team and S. Gragert).

Capacity building of specialized personnel in using prescribed fire for conservation and applying suppression firing (counter fires, back fires) for fighting wildfires were on the agenda of project partners GFMC and German Federal Forest Service. A major training programme was implemented in Germany in 2014 to train Federal Forest Service personnel to conduct safe and effective use of fire in conservation (GFMC 2014).

6.4 Spin-off IV: International implications of the project

The advances in using prescribed fire and fighting wildfires on UXO-contaminated terrain were observed at international level. On 16 October 2013 a military exercise at the Marrangaroo Training Area near Lithgow, New South Wales (NSW), Australia, set off unexploded ordnance and grew into a massive fire that burned for more than a month. The unexploded ordnance made it too dangerous for firefighters to get close to the blaze and it was not declared extinguished until 20 November 2013. The fire destroyed five homes and covered more than 50,000 ha. Damages to the Zig Zag Railway installations were estimated at around $AUS 30 million. During the emergency, the GFMC offered support to the Fire Commissioner of NSW by liaising to DiBuKa for providing appropriate support. After the incident, a Commission of Inquiry into the role of the Defence Department in the fire was established by the State Coroner, Department of Justice in NSW, and called the Project Partner GFMC to support the hearing in 2016 by providing advice out of the expertise of the project.

In 2014 the Organization for Security and Cooperation in Europe (OSCE) commissioned a study to the Project Partner GFMC to investigate and report best practices and recommendations for wildfire suppression in contaminated areas, with focus on radioactive terrain. The study revealed that the technologies developed and experiences gained during the project are significant for the further development of state-of-the-art practice in fire management on contaminated terrain (GOLDAMMER et al. 2014).

Currently the GFMC is working with the Project Team and international partners to investigate the utility of using UAV for aerial ignition and firefighting, as well unmanned ground vehicles (UGV) for creating firebreaks in support of armored fire suppression vehicles (GOLDAMMER et al. 2014).

7 Summary and conclusions

The project has addressed multiple challenges of fire management in a landscape, which is representing conditions of other regions of Europe that are exposed to a high wildfire risk in general and especially with regards to wildfires burning on terrain contaminated with ammunition stemming from historic armed conflicts and military training activities. The concept of using prescribed fire in the maintenance and restoration of dwarf shrub heathlands is receiving increased acceptance by conservation authorities and by the public. By developing innovative technical and conceptual solutions the limitations of applying prescribed fire on contaminated terrain have been overcome. Understanding the principles and the threats of using prescribed fire in conservation on contaminated terrain is essential to develop abilities for managing dangerous wildfires for which no solutions had been in place so far. Targeted measures for the prevention of spread, the combat and the possibilities of letting burn wildfires under controlled conditions – if the impacts of these fires would be in line with land management/conservation objectives – have been proposed as spin-off products. The project team established a public private partnership (PPP) in which skills of fire and conservation science, fire and habitat management, public administration and private entrepreneurs developed the necessary synergies that could not have been created otherwise. At the end, solutions for Integrated Fire Management (IFM) at landscape level have been reached.

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