DARWIN INITIATIVE

POST-CLEARANCE MANAGEMENT METHODS FOR RESTORING NATURAL VEGETATION AND LIMITING REGROWTH OF INVASIVE ALIEN PLANT SPECIES ACACIA SALIGNA

THE CASE OF ACACIA SALIGNA IN CAPE PYLA, CYPRUS

DPLUS141:
Habitat restoration and wise use for Akrotiri and Cape Pyla

January 2022

BirdLife Cyprus

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This literature review on post-clearance management methods for restoring natural vegetation and limiting regrowth of invasive alien plant species A. saligna is part of a 3-year project (July 2021 – June 2024), funded by Darwin Plus "DPLUS141: Habitat restoration and wise use for Akrotiri and Cape Pyla".

Reference: Georgiou Panagiotis, Vayanou Phoebe, Annie Papadopoulou (2022). Post-clearance management methods for restoring natural vegetation and limiting regrowth of invasive alien plant species *Acacia saligna*. The case of *Acacia saligna* in Cape Pyla, Cyprus. Under Darwin Plus Project: "DPLUS141: Habitat restoration and wise use for Akrotiri and Cape Pyla". Birdlife Cyprus, Terra Cypria, Sovereign British Areas Administration Environment Department (SBBA ED), Royal Society for the Protection of Birds (RSPB).

Post-Clearance Management Methods for Restoring Natural Vegetation and Limiting Regrowth of Invasive Alien Plant Species *Acacia Saligna* – The Case of *Acacia saligna* in Cape Pyla, Cyprus.

Key words: Acacia saligna, invasive alien plant species, seed bank management, habitat restoration

1. INTRODUCTION

1.1. General Information on *Acacia saligna*

Approximately 1000 species of Acacia are native to Australia. One of them is *Acacia saligna* (Labill.) H. Wendl, also known as Port Jackson or Western Australian golden wattle, which is native to southwestern Western Australia, where it is a pioneer species, widespread and locally abundant.

A. saligna is a perennial, dense and multi-stemmed, thornless, spreading shrub or single stemmed small tree 2-6 m tall, but can also grow up to 10 m tall (Hadjisterkotis et al., 2002). The leaves are replaced by phyllodes (a flat expanded petiole), which are blue green changing to bright green, having a length of up to 200 mm and a width of 10-50 mm (Strydom et al., 2012). The characteristic yellow flowers appear in late winter through spring, in groups of up to ten bright yellow spherical flower heads. Seeds are formed in initially green pods which turn brown, with a hardened white margin as the legume matures. In the pod, dark brown seeds, 5-6 mm long, possess a small funicle which inspissates into a cream-coloured aril that is carried lengthways.

It has a substantial genetic diversity and grows rapidly in various environments, usually favouring more moist locations. The *A. saligna* altitudinal range stretches from sea level to 300 m. It prefers warm, sub-humid and humid climatic zones, but it can also be found in higher rainfall areas of the semi-arid zone. It is a fire-adapted tree, and it is adapted to a variety of soil types, particularly nutrient deficient and calcareous sands, as well as fairly dense clays. In its native distribution area, where water is scarce, it can also be found in semi-arid low woodlands, phrygana communities extending to heath communities and also can be present in eucalypt woodlands (Strydom et al., 2012).

A. saligna has been widely introduced to arid and semi-arid sites with tropical, subtropical, or Mediterranean climates throughout the world for soil conservation purposes, for fuelwood and fodder, for tannins and gums and as an ornamental. It has naturalized in many of these countries, notably in the Mediterranean basin, in South Africa and California, USA, and in some countries, like South Africa and Mediterranean countries, it is considered to be an invasive weed.

1.2. *Acacia saligna* in Cyprus

In Cyprus, *A. saligna* was introduced intentionally by the British at the beginning of the twentieth century for the production of firewood, as an ornamental, for soil erosion control and as fodder, with the aim of helping the protection of forests from overgrazing, which is still a serious problem in some parts of the island. Not only that but it is proposed that it was introduced to drain swamps as a method of controlling malaria at Larnaca and Limassol salt lakes and stabilising sand dunes a the city of Salamis (Christodoulou, 2003). *A. saligna* has naturalized in Cyprus and it is one of the most serious invasive species in Cyprus, threatening many natural habitats, invading forests, maquis, garigue, phrygana, marshy areas and agricultural land, becoming a serious weed (Hadjikyriakou and Hadjisterkotis, 2005). It can survive semi-desert environments where the annual rainfall is below 400 mm and the high temperatures of July and August, which can reach over 41°C in Cyprus. According to Hadjisterkotis et al., (2002), this species is associated with the elimination of the *Orchis papilionacea* in the Larnaca district, due to the dense cover created by wattle and the distribution of the mycorrhizal association of the *Orchis.* The Acacia genus has no indigenous representatives in Cyprus, but a few species are cultivated either as quick growing shrubs for fuel, or for their attractive scented flowers (Hadjisterkotis et al., 2002). In Cyprus, *Acacia farnesiana* and *Acacia redingotes* are also present, but not as widely distributed as the *A. saligna* (Hadjisterkotis et al., 2002). *A. saligna* is present and widespread on the island and in many areas has replaced the natural vegetation, creating wattle forests. For example, in some parts of Cape Greco it prevents the expansion of juniper. It invades fields neighbouring the forest if these are left uncultivated. *A. saligna* was planted extensively along highways to create green cover by the road and also to hold the soil from erosion. This leads to further spreading of the species and facilitates the spread to areas where it was not previously found. During the 1990's, this species was planted near Xylofagou village in areas which in the past were covered by *Juniper* maquis and the planting of wattle followed as a fast growth attraction.

Acacia saligna poses a serious threat to native flora by forming dense canopies and outcompeting other vegetation for nutrients, space, and sunlight. Charalambos Christodoulou, 2003, conducted a study on the impact of *Acacia saligna* invasion on the autochthonous communities of the highly ecologically valuable salt marshes in Aktoriti, Limassol. Results showed that the spread of the *A. saligna* has an adverse impact on the natural communities with the floristic transformation being largely dependent on the stage of the invasion. Species structure and composition have been altered by displacing sensitive species and reducing their abundance in lightly invaded areas with >50% canopy cover. Halophytic and wetland species were eliminated in densely invaded areas, with trees exceeding 2.5m in height and <70% canopy cover. It was concluded that specialised species, with specific habitat requirements such as salt marshes and other wetlands, are vulnerable to the *Acacia* invasion and annuals are more susceptible than perennial plants because of their sensitive short life cycles. Not only that but, the spread of the *Acacia saligna* facilitates fire by long and dry summers, and human disturbance, enabling the *Acacias* to spread thus displacing indigenous communities (Christodoulou, 2003).

Cyprus is a biodiversity hotspot and strategically situated on internationally important migratory routes for wild birds; many of which are of international importance. *Acacia saligna* is intentionally planted, creating small Acacia forests, by illegal bird trappers all over the island, in areas such as Ayia Napa and Paralimni, including Cape Pyla. Wattles attract songbirds, such as Blackcaps (*Sylvia atricapilla),* and are captured by non-selective trapping methods such as mist nets and lime sticks, sometimes supplemented by illegal bird calling devices, imitating the calls of birds. This is an illegal but lucrative practice, since the income of the trappers from selling these birds is very high. The trade of wild birds has been prohibited since 1974 under Cyprus legislation, by the introduction of the "Protection and Development of Game and Wild Birds Law of 1974 (39/1974)". The prohibition of illegal bird trapping was later reinforced by the 1979 Bern Convention on the Conservation of European Wildlife and Natural Habitats, with a list of birds being designated as protected, including the Blackcap (BirdLife Cyprus, 2010 - 2021). A surveillance programme has been ongoing since 2002 against illegal bird trapping with a systematic monitoring programme in Cyprus and is one of the key activities of BirdLife Cyprus. In collaboration with the RSPB (BirdLife in the UK), BirdLife Cyprus, in consultation with the Cyprus Game & Fauna Service and the British Sovereign Base Administration (SBAA) Police, a "Bird Trapping Monitoring Protocol" was developed, providing the longest record of field data, with long term trends, illustrating an overview of the bird trapping situation in Cyprus (BirdLife Cyprus, 2010 - 2021). By controlling the invasive *A. saligna,* and enforcing strict regulations, such as regular anti-trapping patrols, the use of covert surveillance such the use of hidden cameras, spot checks and large fines for illegal bird trappers, the natural vegetation would be enhanced, and bird trapping will be reduced. Cape Pyla represents the worst example in Cyprus of a natural area where *A.saligna* has been planted and maintained (including through irrigation) for the purposes of illegal bird trapping, with a significant impact on the local flora and habitat.

European Union has included *A. saligna* in the list of Invasive Alien Species of Union concern in Regulation (EU) 1143/2014 on invasive alien species (the IAS Regulation). The IAS Regulation provides for a set of measures to be taken across the EU in relation to invasive alien species included on the Union list, which follow an internationally agreed hierarchical approach to combatting IAS through **(1)** prevention, **(2)** early detection leading to rapid eradication and **(3)** management. In Cyprus, Law 120(I)/2019 regulates in a national level the implementation of EU IAS Regulation through the formulation of measures and action plans. Invasive plant species, such as *A. saligna, Ailanthus altissima,* and *Pennisetum setaceum,* are banned in all kinds of plantations, including those in inhabited areas and disturbed sites. Therefore, to address any additional intentional introductions and consequent spread, a ban on importing, keeping, breeding, growing, and selling at an EU level would be needed, as it is required under Article 7 of the EU IAS Regulation 1143/2014 (Giuseppe Brundu et al., 2018).

1.3. Aim and scope of the Literature Review

This literature review on post-clearance management methods for restoring natural vegetation and limiting regrowth of invasive alien plant species *A. saligna*, is part of a 3-year project (July 2021 – June 2024), funded by Darwin Plus. One of the project's work packages is the "Support for sustainable management of invasive *Acacia saligna*, with a focus on post clearance habitat restoration on Cape Pyla". The first step is a review of scientific and other published literature on approaches and methods for restoring natural vegetation and limiting regrowth of *Acacia saligna*, mainly by controlling the seed bank, following the clearance of invasive acacia bushes from scrubland habitat. Groundwork has already been carried out (pre-project) by the Sovereign British Administration (SBA) Environment Department team and this is expanded in order to arrive at a set of clear recommendations. Drawing on these recommendations, at least two specific restoration methods will be selected to be the subject of practical trials on the ground on Cape Pyla under the Darwin Plus project, in areas that have been cleared of acacia bushes by the SBA authorities in recent years.

Therefore, this report includes:

1) General introduction on *A. saligna* characteristics, its introduction and impacts in Cyprus.
2) Brief description of *A. saligna* invasive characteristics and impacts.
3) Cape Pyla protection designation, description and history of *A. saligna* in the project area in terms of introduction, uses and management.

4) Control methods examined, tested, and used for clearing and managing *A. saligna*.
5) Acacia management and control recommendations.

For this literature review, information has been drawn from online sources, as well as by liaising with experts from both abroad and Cyprus. Based on these recommendations, a minimum of two methods will be tested in the field for two years at selected trial plots. Important considerations taken for the proposed methods are effectiveness, biosecurity, soil protection, herbicide use, costs and potential risks. Field trial results will be written up in a relevant report, including clear assessments of trialled method efficacy and recommendations for replication for further work. This study's goals are primarily *Acacia* seed bed management, improving species assemblage and enhancing restoration potential of native habitats.

There have been numerous attempts at controlling adult *Acacias* in Cyprus, some of them successful. However, less effort has gone into post clearance management, such as controlling the seed bank. Little work has been conducted with *Acacia* forests and sometimes counter effective methods, such as isolated controlled burns have been used, without follow up treatments and a long-term post-clearance monitoring program. No information is available for *A. saligna* seed bank dynamics in Cyprus. Furthermore, an investigation of current seed bank status, as well as its distribution range in Cyprus, including potential seed bank management, have been neglected. This study hopes to provide more insight for effective *A. saligna* management, providing a wider picture on habitat restoration for areas taken over by invasive alien plant species (IAPS).

2. INVASIVENESS OF *ACACIA SALIGNA*

2.1. Reproduction

A. saligna reproduces almost entirely by seed and is an outcrossing species. The seeds *of A. saligna* can remain dormant in the soil for considerable periods of time. As the seed coat is water impermeable, dormancy can be broken by heat or seed scarification which will rupture the seed coat and allow water uptake; the seed will then germinate rapidly (Cronk and Fuller, 1995). *A. saligna* is capable of prolific seed production, often in the first year or two after germination depending on site; 1 m^2 of canopy can reportedly produce around 10,500 seeds per year (Cronk and Fuller, 1995), thus building an enormous seed bank overtime.

The species is also capable of regenerating by root suckers and coppices freely and a single tree is capable of forming a clump or small colony (Duke, 1983; Whibley and Symon, 1992). The seedlings are quite hardy and have an extensive root system (Cronk and Fuller, 1995). When established, therefore*, A. saligna* poses a serious threat to native flora by forming dense canopies and outcompeting other vegetation for nutrients, space and sunlight. As with the majority of *Acacias*, the *Acacia saligna* is relatively short-lived (10-20 years) but can survive longer in dry conditions.

2.2. Seed bank dynamics

The soil seed bank consists of all seeds, dormant and non-dormant, on top or below the soil surface or in the associated litter. The seed bank in an area may consist of propagules produced in the vicinity or from other localities. As seeds are continually added to the seed bank it represents both past and present plant communities. Seeds present in the seed bank have spatial and temporal dimensions. Dispersal from the parent plant onto the soil and movement of seed, thereafter, result in seeds having both a horizontal and vertical distribution. Usually, seeds reach the earth's surface in a dormant state. Propagules may require specific germination queues in order to break dormancy. Consequently, seed banks can be either transient, with seed persisting in the soil for less than a year, or persistent, which is the case of the *Acacia saligna*, with seeds lasting in the soil for a period greater than one year depending on their germination requirements. Seed bank input is a consequence of seed rain (Figure 2-1). Input can be either from a local or outlying seed source. Dispersal may occur through passive means such as mechanical ejection of seed or through fire, wind, water, and animals (zoochory). Seed bank loss results from seed germination, deep burial, decay, predation, fire, pathogens, failed germination and physiological death (Strydom et al., 2012).

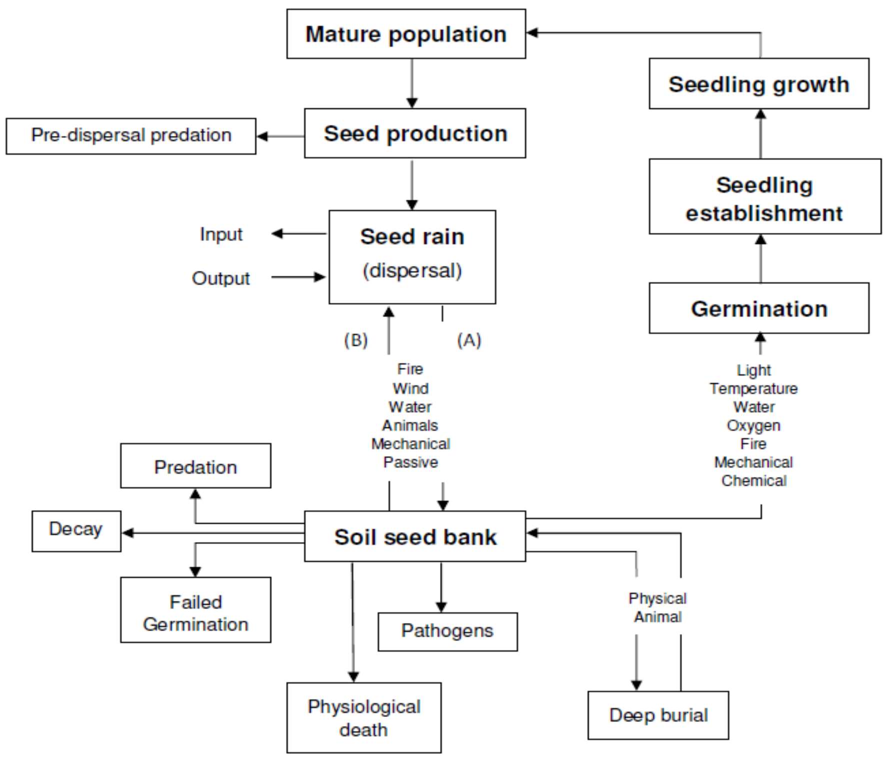

Figure 2-1: Simplistic model illustrating seed bank dynamics. (A) primary dispersal, (B) secondary dispersal (Strydom et al., 2012).

Many of the invasive plants – like *A. saligna*- possess a large persistent seed bank characterized by Physical dormant (PY) seeds, which is a major challenge to their effective and sustainable management. Physical dormancy is caused by water-impermeable seed coating, meaning that water absorption is not possible. As a result, from years of seed build up and the ability to stay dormant for years, a persistent seed bank is accumulated. The breaking of PY involves disruption of this structure, such as increase of temperature or damage to the coating (scarification), which acts as an environmental germination signal. According to

Cohen et al. 2018, the average soil temperature at a depth of 0.5 cm in the soil during a burn event, sufficient to break the PY seed dormancy was 60°C.

As mentioned above, the *A. saligna* tends to accumulate large and persistent seed banks. Persistent seed banks consist primarily of small sized, light-weight seeds. Seed bank density of the *A. saligna* has been measured to be 212 000 m^2 with the largest proportion of seeds situated in the top 10cm. The proportion of *A. saligna* seed in the soil that are unable to germinate is low (1.0%) and approximately 90% of the seeds in the seed bank will not germinate immediately, as a result of physical imposed dormancy. Previous studies determined that seed dormancy levels for the *A. saligna* are between 90.8 – 91.2%.

Seeds situated below 10cm have a smaller probability of germinating- but germination at a 15cm depth has been recorded before. Seeds occurring in such depths have optimal insulation and temperature conditions compared to the others on the top 10cm, therefore, these seeds have physical dormancy imposed on them for a longer period. The *A. saligna* seeds are primarily dispersed by ants and birds. Seeds buried by ants or seeds that pass though bird digestive systems can germinate because of increase of temperature or from acid scarification.

Long-term seed banks form an evolutionary memory, allowing for rapid adaptations in response to environmental fluctuations. The effect of a single year drift, as a consequence of an extreme change in conditions, will be smaller as the dormancy of seeds increase. In fire adapted systems, post-fire germination *en masse,* leads to the absence of a regenerative guard against local extinction for annuals or obligate-seeding shrubs or to strong environmental selection during seedling establishment. This factor adds to the persistence of *A.saligna* in habitats it invades.

2.3. Phenology

The growing season of *A. saligna* is influenced by water availability and temperature. Growth begins when the water in the soil available for use by plants is at a maximum (at field capacity, where the soil is fully saturated) and ends when available water is exhausted. Where water is not a limiting factor and available through the year, the end of the growth season is determined by temperature. Acacias are physiologically well adapted to warm dry climates. When phyllodes experience negative turgor pressure (lack of water content in cells) due to late summer drought, water use efficiency increases, and the photosynthetic rate is not influenced. In warm temperature climates, *Acacias* can sustain some growth throughout the year, giving them the ability to react to unseasonal increments in rainfall or temperatures. *Acacias* stop growing when temperatures drop to or under zero (Strydom et al., 2012).

2.4. Invasive characteristics

According to the European Union "Invasive Alien Species (IAS) are animals and plants that are introduced accidentally or deliberately into a natural environment where they are not normally found, with serious negative consequences for their new environment. They represent a major threat to native plants in Europe, causing damage worth billions of Euros to the European economy every year" (European Commission, 2022).

A. saligna has been characterised as and IAS on an EU level and is a significant threat to natural vegetation in Cyprus, as well as in many other countries. The key features and characteristics of *A. saligna* that qualify the species as an IAP species are the following;

- Widespread planting outside its native range
- Significant ability to adapt in a wide range of habitats and substrates
- High tolerance to pressures and disturbances, such as drought, fires, pollution, degraded areas e.g., urban areas and side roads' areas
- Rapid growth
- Nitrogen fixation
- Large quantity of seeds produced that can stay alive in the soil for up to 50 years
- Early reproductive maturity
- Ability of seeds to survive fire
- Ability to germinate after cutting or burning
- Extensive root system
- Taller growth (by more than 3 m in some places) than indigenous plants

The above characteristics that qualify *A. saligna* as an IAP species, have the following potential negative impacts to biodiversity and ecosystem services:

- Replace and outcompete natural vegetation, thus transforming ecosystems and large landscapes as a result, reducing local biodiversity
- Change of fire regimes and increasing fuel loads
- Altering soil chemistry
- Changes in hydrological characteristics
- Decrease aesthetic value of natural areas
- Financial implications due to costly control management
- Used as a cover for criminal activities, such as the illegal bird trapping.

3. CAPE PYLA

3.1. Special Area of Conservation

Cape Pyla has been designated as a Special Area of Conservation (SAC) under SBAA legislation and a Draft Management Plan for consultation purposes has been produced in July 2021 (Johnstone, 2021).

Cape Pyla SAC is situated in the Eastern Sovereign Base encompassing 1667.5ha of marine and terrestrial habitat. The majority of the terrestrial designation lies within the boundaries of Larnaca district, with a small portion within Famagusta district (5ha). The North-western corner of the designated area is approximately 9 km to the East of Dhekelia Station and 1 km south of the village of Xylofagou, below the Larnaca-Protaras motorway, and the Eastern extent reaching the boundary between the SBA and the Republic of Cyprus. The marine section of the site is proportionally larger than the terrestrial, extending from the SBA boundary in the East to the Xylofagou fishing shelter, in Vathia Laxia at the Western extent.

According to the site's geological characteristics, Cape Pyla belongs to the zone of the autochthonous sedimentary rocks of the island. This zone consists of bentonitic clays, volcaniclastics, melange, marls, chalks, cherts, limestones, calcarenites, evaporates and clastic sediments. The site is mostly covered by natural habitat types, with the exception of older forestations of alien, and in some cases invasive species, like *Acacia saligna*, Eucalyptus spp. and *Pinus pinea*. The natural habitat types are severely fragmented due to the extensive network of loose surface roads used for military and other activities. The most dominant vegetation at the site consists of garigue subshrubs, as well as taller maquis shrubs. Coniferous forest with Phoenician juniper trees is found at certain locations. The abundance of *Asphodelus aestivus* and *Drimia aphylla*, most commonly within garigue is due to grazing. The coastal zone of the site includes cliffs and rocky coasts dominated by plant taxa adapted to high salinity environments and rocky substrate.

Cape Pyla covers a rare coastal ecosystem, comprising a mosaic of habitats (including priority ones) listed in Schedule 1 to the Protection and Management of Nature and Wildlife Ordinance (Table 3-1 and Figure 3-1). The habitats support a variety of plant communities and the parts that are not affected by alien invasive species, have excellent floristic composition and are characterised, according to the relevant management plan (Johnstone, 2021) by satisfactory relative surfaces, conservation status and global assessment. The Vegetated sea-cliffs, thermo-Atlantic halophilous and Halo-nitrophilous shrubs, Embryonic shifting dunes, *Sarcopoterium spinosum phryganas*, Pseudo-steppes, Mediterranean temporary ponds and Arborescent matorral with *Juniperus phoenicea* in combination with the unique landscape character of the area, synthesize one of the most important coastal areas on island.

Table 3-1: Cape Pyla Habitat evaluation table (*Johnstone, 2021*)

Feature description	Marine (M) Terrestrial (T)	EU habitat code	PMNWO 2007[1]		Habitat Extent (Ha)	Habitat condition assessments		
			Schedule 1	Priority		IUCN[4]	EU article 17 report 2013-18[3]	Cape Pyla SAC (citation)[2]
Posidonia beds (*Posidonion oceanicae*)	M	1120	y	y	473	VU	Favourable	Not assessed
Reefs	M	1170	y		506	DD	Favourable	Not assessed
Submerged or partially submerged sea caves	M	8330	y		-	EN	Favourable	Not assessed
Annual vegetation of drift lines	T	1210	y		0.8	NT	Unfavourable bad (U2)	Not assessed
Vegetated sea cliffs of the Mediterranean coasts with endemic *Limonium spp.*	T	1240	y		13.8	LC	Unfavourable - inadequate (U1)	Excellent (A)
Mediterranean and thermo-Atlantic halophilous scrubs	T	1420	y		0.3	NT	Unfavourable bad (U2)	Not assessed
Halo-nitrophilous scrubs (*Pegano-Salsoletea*)	T	1430	y		1.8	LC	Unfavourable bad (U2)	Excellent (A)
Embryonic shifting dunes	T	2110	y		0.002	VU	Unfavourable bad (U2)	Average or reduced (C)
Mediterranean temporary ponds	T	3170	y	y	2.3	VU	Favourable	Not assessed
Arborescent matorral with *Juniperus phoenicea*	T	5212	y		26.2	LC	Favourable	Good (B)
Sarcopoterium spinosum phryganas	T	5420	y		147	LC	Unfavourable - inadequate (U1)	Good (B)
Pseudo-steppe with grasses and annuals of the *Thero-Brachypodietea*	T	6220	y	y	0.5	NT	Unfavourable - inadequate (U1)	Good (B)

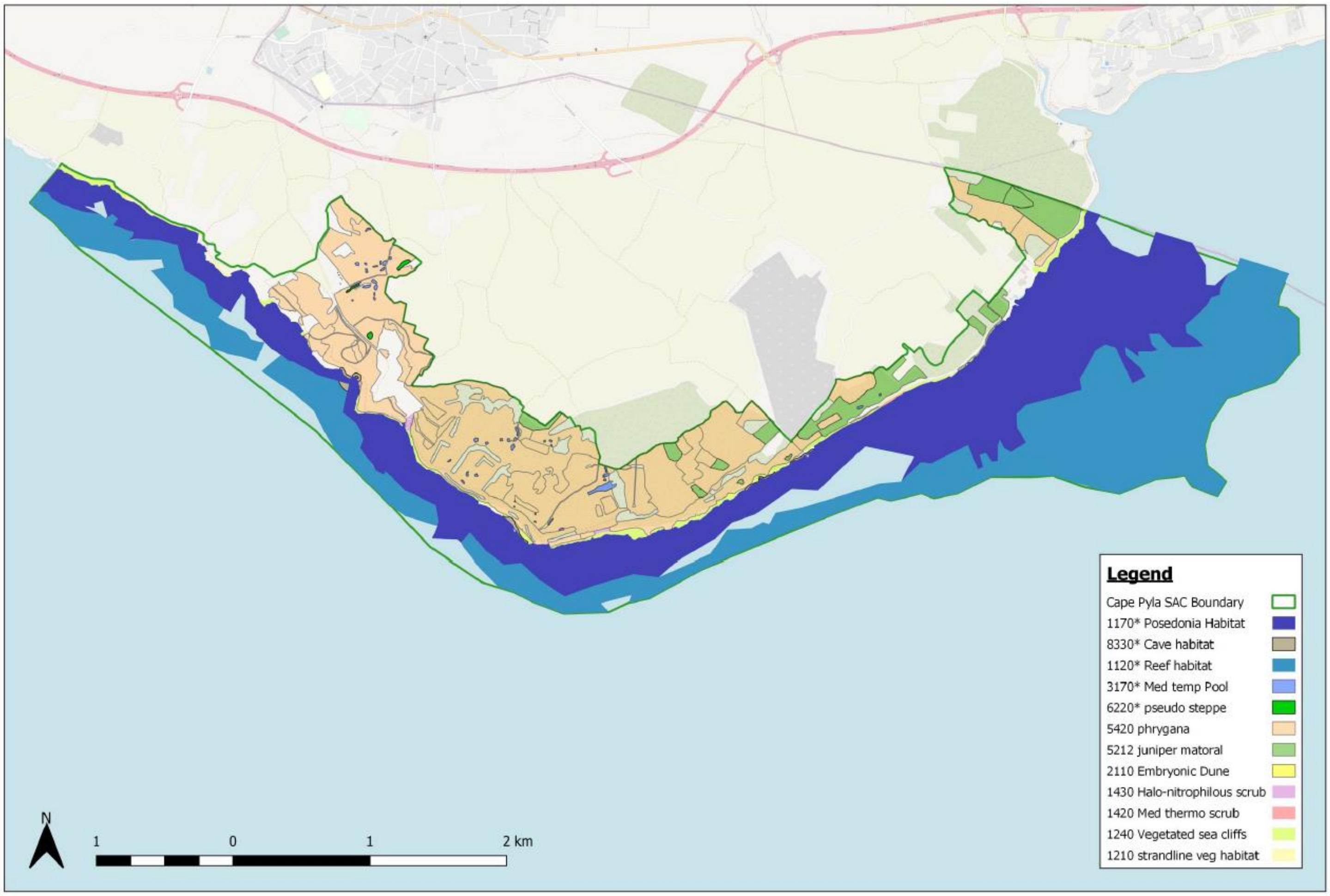

Figure 3-1: Cape Pyla SAC Habitat map (*Johnstone, 2021*)

In terms of flora and fauna species, these are summarised in Table 3-2. Most of the flora taxa found on site are common representatives of the flora of Cyprus and the eastern Mediterranean. The flora of the area includes many endemic species, orchids, as well as five Red Book plants.

Important mammals include the Monk seal (*Monachus monachus)*, which is a priority species, as well as bats, rodents, and shrews. Thirty-two bird species included in Schedule 1 to the Game and Wild Birds Ordinance have been recorded on site. 92 other important bird species, which are included in Annex III to the Bern Convention, are regularly found on site. It is worth noting here that bird species richness is probably underestimated, as the Cape was until relatively recently 'off limits' for bird-watchers, due to the presence of organised trappers. The fauna covers also important reptiles and invertebrates.

Table 3-2: Species evaluation for Cape Pyla SAC (*Johnstone, 2021*).

Feature description	Endemic species	PMNWO 2007[1]		Game and Wild Birds Ord. 2008	Bern Convention Appendix	CMS (Bonn) Annex	CITES appendix	Species condition assessments			
		Schedule	Sch. 2 priority					Site (SAC citation)	IUCN Cyprus Red list	IUCN Euro (EU report)	IUCN Global
Breeding birds (resident, occasional and migratory breeding) of terrestrial habitats	✓*			✓*	III*	II*	✓*	✓*	✓*	LC	LC
Non-breeding bird assemblage of terrestrial scrub and mosaic habitats	✓*			✓*	III*	I & II*	✓*	✓*	✓*	VU* - LC	LC
Bird assemblage of coastal/marine/wetland associated birds				✓*	III*	I & II*		✓*			
Monk Seals *Monachus monachus*		II	✓		II	I & II	I		EN	EN	EN
Assemblage of bat sp.		II*			II	✓*		✓*		NT*	NT*
Plants associated with coastal habitats	✓*						✓*	✓*	✓*		
Plants associated with terrestrial habitats	✓*						✓*	✓*	✓*		
Crepis pusilla		II			I				VU	VU	
Marine turtles (*Caretta caretta* and *Chelonia mydas*)		II	✓		II		I			EN*	
Assemblage of reptiles (terrestrial)		III*			III	✓*		✓*	✓*		
Trochoidea liebetruti	✓							R	NT		
Cyprian Marbled Bush-cricket *Eupholidoptera cypria*	✓							C	NT		
Cyprian Plump Bush-cricket *Isophya mavromoustakisi*	✓							R	EN		
Fan Mussel *Pinna nobilis*		III								CR	CR

Overall, it is an area with both a terrestrial and marine mosaic habitat, that supports a diverse and important species assemblage and it is an important site that functions as a high-quality component of an island-wide network of marine and terrestrial protected areas.

3.2. Acacia history on site

Acacia tree planting has taken place extensively across Cape Pyla. *Acacia saligna* was a useful tool for production of fodder, firewood and for stabilizing ground among other things. It has clearly been actively planted across the site and surrounding area, as indicated by the uniform plantations visible from satellite pictures (Figures 3-2 and 3-3). Its tenacious qualities and characteristics have been utilized also in the illegal bird trapping operations across the site.

Cape Pyla has been recognised as a 'hot-spot' for illegal bird trapping (Deberšek, 2016). It is a relatively undeveloped and unpopulated area and a promontory, and thus it provides a suitable migration staging area for migrating birds. As it is without lights in the night, it is further favoured during migration, allowing birds to avoid the bright lights of the major populated areas of Larnaka on one side and Ayia Napa on another side. Barren coastal landscape in Cape Pyla has been illegally managed for decades by trappers, planting, and irrigating *A. saligna* trees to create suitable habitats for trapping migratory birds with mist-nets. Trappers have illegally installed irrigation systems to encourage the rapid growth of acacias, which grow rich foliage to make them even more attractive to birds. Irrigation systems use water from illegal boreholes or water intended for agricultural activities, further depleting the already degraded aquifers. At the same time, as already being mentioned in the above paragraphs, *A. saligna* is an invasive alien plant species that overcomes the local vegetation, which mostly consists of garigue subshrubs, as well as taller maquis shrubs. Until 2016, an extensive irrigation system, supporting illegal and unauthorized areas of tree plantation was in operation.

Within 2014-16, management operations were undertaken for the invasive *Acacia* in Cape Pyla, reducing dense *Acacia* patches, with the aim of restoring the local habitat and controlling the illegal bird trapping by Sovereign Base Areas Administration (SBAA) in partnership with the Ministry of Defence (MOD) and the Republic of Cyprus (RoC). This operation also involved removal of illegal irrigation infrastructure (Figure 3-6).

The methodology used on controlling the Acacia is based on a guide by Invasive Alien Plant Expert Dr Dufour-Dror, which is currently also being used by the RoC Department of Forests. The guide is titled "Guide for the Control of Invasive Trees in Natural Areas in Cyprus: Strategies and Technical Aspects" designed by Dr Dufour-Dror and submitted to the RoC Department of Forests in the framework of the ecology consultation related to the restoration program of the abandoned Amiantos Asbestos mine, in the Troodos National Forest Park. This guide provides detailed technical guidelines for the control of *A. saligna*. The control techniques detailed in this work are all related to targeted chemical control methods (TCCM) and are based on the results of research, experiments and studies carried out by the author over 9 years in Israel and Cyprus.

The result of these operations to date has been a substantial reduction in Acacias and trapping activity at Cape Pyla (Figure 3-4). In addition, in the summers of 2019 and 2020 wildfires (Figure 3-5) occurred at Cape Pyla with most of the affected areas being predominantly phrygana habitat (5420) with Mediterranean temporary pool (3170*) habitat scattered within it, and a high density of *Acacia saligna*.

In the following Figures 3-2 to 3-6, the planting history, as well as the management efforts for *A. saligna*, through the removal of illegal irrigation networks and chemical control of Acacia plants, and the areas affected by wildfires in Cape Pyla, are depicted through satellite pictures from 2003 to 2021.

Figure 3-2: Acacia presence in <u>2003</u> in Cape Pyla. ***The arrows indicate areas with increase Acacia presence in the following years because of active planting (compared to 2013). The red lines are the SAC boundaries.***

Figure 3-3: Acacia presence in <u>2013</u> in Cape Pyla. ***The arrows indicate areas with increase Acacia presence because of active planting (compared to 2003). The red lines are the SAC boundaries.***

Figure 3-4: Acacia presence in <u>2015</u> in Cape Pyla. ***Circled areas indicate Acacia areas treated with chemical control methods by MoD. The red lines are the SAC boundaries.***

Figure 3-5: Acacia presence in 2021 in Cape Pyla, with areas affected from 2019, 2020 wildfires (in light blue lines). ***The red lines are the SAC boundaries.***

Figure 3-6: Acacia presence in 2021 with high density decline from MoD management efforts, as well as wildfires.

4. METHODS USED FOR MANAGEMENT ACACIA SALIGNA

In this section, the approaches and methodologies for the management of the invasive plant species *Acacia saligna* are presented. For each methodology, the relevant literature is being presented, as well as its effectiveness on managing the seeds in the seed bank or the plant regrowth.

4.1. Chemical Treatment

Chemical treatment or targeted chemical control method (TCCM) is when herbicides are used to control a specific plant selected to be controlled. This is an effective control method to protect sensitive areas from an invasive alien plant species without harming the native vegetation. The two main chemicals used to control the *Acacia saligna* are glyphosate (RoundUp) and triclopyr (Garlon) (Dufour-Dror, 2013), but Glyphosate is considered more environmentally friendly it is a more aggressive herbicide to *A. saligna*, but studies suggest that it is potentially carcinogenic in humans, increasing the risk of some cancers by more than 40% (Zhang et al., 2019). Glyphosate has currently been approved in the EU until the 15th of December 2022 as a substance for Plant Protection Product (PPP) (European Commission, 2022). According to Dufour-Dror, a newly developed herbicide now registered in Israel, Aminopyralid, is also an effective chemical (Personal Communication, November 2021) and could potentially be an alternative PPP if Glyphosates licence is not renewed.

TCCM have an average death rate of 80-95% success rate as a first treatment. Further follow up treatments are necessary to increase the rate to 100%. Follow ups should have 3 months to 1-year frame to treat the still viable plants. This is especially necessary where the aim is a complete eradication. In the event of sapling emergences, new individuals should be treated before they mature to produce seeds. This is especially crucial as the *A. saligna* can start seed production two years after it is germinated. Post-control monitoring should be 5 consecutive years since the initial treatment, or until no new individuals are spotted (Dufour-Dror, 2013., Giuseppe Brundu et al., 2018).

To control the invasive *Acacia saligna*, chemical treatment does not involve spraying treatments, but rather the direct application on the plant. TCCM does not address the exhaustion of the long-lived accumulation of the abundant seed banks directly, but rather indirectly as removing mature trees or seed-bearing trees is the first step of controlling the seed bank to stop replenishment and recruitment (Dufour-Dror, 2013). There are **six** common targeted chemical control methods: **(1)** Drill-Fill, **(2)** Cut-Stump, **(3)** Frilling, **(4)** Hack and squirt, which are recommended for the *A. saligna*, **(5)** Stem-Scrape and **(6)** Ringbarking which are application to vines or shrubs that do not reshoot when damaged. The main guide on how to perform these methods have been drawn by Dufour-Dror (2013), Guide on how to control the invasive trees in areas in Cyprus, submitted to the Department of Forests of the Republic of Cyprus. These methods have widely been used in Cyprus and implemented by the SBAA as a pre-treatment on the SAC in Cape Pyla. In the next paragraphs, methods **(1)** to **(4)** are briefly described, as they are presented in Guide by Dufour-Dror (2013).

(1) Drill-fill

This method involves drilling the tree and injecting the herbicide. It should be used for trees and saplings with base diameter greater than 5cm. Preferably an engine drill is necessary for drilling holes of 1 to 2cm diameter around the trunk (Figure 4-1). Since the sap flow ceases very quickly in the area where the plant tissue is damaged (drilled, cut, or frilled), it is crucial to apply the herbicide within 10 seconds of a drill being made. Therefore, to ensure maximum control efficiency, a pair of two workers is necessary with one worker drilling and the other injecting the herbicide. This way the time elapsing between the drill and the application of the herbicide is minimal. Holes are drilled into the lower part of the trunk, preferably close to the base and around the trunk, 5-10 cm apart. The holes are drilled with an angle of ca-45° the herbicide injected will not spill over from the trunk. It is necessary to drill as many holes as needed to inject the volume required for the targeted tree. When multi-stems trees need to be controlled it is necessary to drill each trunk individually. Small trunks should be treated with the frilling technique (see par. 3). The thinnest stems must be cut with a hand pruner and controlled with a few drops on the cut.

Figure 4-1: Drilling in tree prior the injection

Figure 4-2: Drill-fill in an *Ailanthus altissima* trunk in Cyprus.

A first returning control can be performed within 3 months after the first control in the unlikely event that absolutely no effects of the herbicide are detectable on the foliage of the targeted trees. Such a situation can happen if it turns out that the initial control was not performed properly, for example when the herbicide was injected with a delay exceeding the time lapse mentioned above (10-15 seconds).

The last step is the felling of dead trees once they have lost their vitality. It is recommended to wait until the end of the second blooming season, i.e., 14-15 months after the initial treatment, before felling the dead trees. It is always very tempting to remove the trees as soon as possible but the felling of trees at a too early stage might lead to root sucker development and eventually to the recovery to the treated individual. Therefore, it is wiser to wait until after the second blooming season before removing the dead trunks.

A second, and generally last, returning control should be performed one year after the initial treatment. Only the trees displaying signs of vitality, even if only to some degree, will have to be drill-filled again, according to the same procedure detailed above.

(2) Cut stump (or Cut-and-treat)

This method involves cutting down trunks of the tree, and the herbicide being applied on the stump. It should be used for trees and saplings with base diameter greater than 5cm. As opposed to drilling, the cutting and felling of the targeted trees is drastic wound that inevitably triggers resprouting reaction and root-sucker development. Therefore, one may prefer to use triclopyr (Garlon) which is considered somewhat more aggressive than glyphosate (Round-Up). Yet, trials performed in Cyprus with both herbicides in cut-stump did not show significant differences between the effects of the two products, so it can be concluded that they are interchangeable.

For the same reason explained earlier, the application of the herbicide within 10 seconds of the trunk being cut is crucial. Thus, it is recommended that the work is being conducted by a pair of workers, carrying out this process to ensure the proper implementation of this method (Figure 4-3). One will cut and the other will apply the herbicide. If the cutting takes longer than 30 seconds, use **(1)** Drill-fill instead.

When multi-stems trees need to be controlled it is necessary to apply herbicide on each trunk individually, including small trunks. The thinnest stems must be cut with a hand pruner and brushed like larger trunks, although with a minute amount of herbicide.

Similarly, to Drill-fill, the Cut-stump procedure should take place during growing season. Since trees are felled in the Cut-stump method it is crucial to ensure, prior to control, that targeted trees do not bear fruits. Felling trees with mature fruit may enhance dispersal of seeds. The seasons for the Cut-stump are similar to those recommended for Drill-fill operations: March-April for *Acacia saligna* and *Robinia pseudoacacia*.

A first returning control can be performed within 3 months after the first control if resprouting shoots or root suckers emerge. In that case, the returning control must be performed with **(1)** Drill-fill. If necessary, a **second** return control can be performed one year after the initial treatment. Only individuals which have developed root suckers and/or basal shoots will have to be Drill-filled again.

Figure 4-3: Cut-stump: a pair of workers is necessary to apply the herbicide with the brush (right) immediately after the trunk is cut (left).

Figure 4-4: The herbicide should be applied over the outer rim of the stump to be absorbed into the moist sapwood so it can circulate down to the roots.

(3) Frilling

This method involves frilling (stripping a part of the plant's bark) and applying herbicide. It is a highly effective method with 95% success rate and returning controls are generally limited to a few individuals. Frilling is used for young saplings and seedlings with base diameter less than 5cm. As previously mentioned, the two main herbicides recommended are glyphosate (RoundUp) or triclopyr (Garlon). *Acacia saligna, Ailanthus altissima, Robina psedoacacia* are all sensitive to glyphosate. For the same reasons previously detailed, it is crucial to apply the herbicide within 10 seconds of the frills being made.

Figure 4-5: The two main steps of frilling on a young sapling of *Acacia saligna* in Israel

Like drill-fill and cut-stump, frilling must be performed **when the sap flow is the most intense**, i.e., during the growing season, before the development of inflorescences, and preferably not during the hottest hours of the day when individuals experience some stress and reduce the speed of the sap flow.

Returning control is rarely needed when using frilling properly but the follow-up may reveal individuals that keep showing signs of vitality after the treatment. A first, and generally unique returning control, can be performed within 3 months after the initial treatment in the unlikely event that absolutely no effects of the herbicide are detectable on the foliage of the targeted saplings and seedlings. In the previous experiments carried out in Israel on young individuals of *Ailanthus altissima* and *Acacia saligna*, second returning control was never needed as 90 to 95% of the targeted saplings and seedlings died off after the initial treatment, and 100% after the first returning control.

Figure 4-6: Dead *Acacia saligna* sapling controlled by filling in Israel

(4) Hack and Squirt

Hack & squirt is a **(3)** Frilling variation, and it uses the same principle, for removing selected trees and large shrubs such as the *Acacia saligna*. Using a machete, axe or hatchet, chop into the trunk at chest height, making sure to penetrate the cambium layer below the bark. Then apply 1ml of herbicide, depending on label directions, inside the hacked openings, using a syringe or by spraying. Herbicide must be applied within 10 seconds of frilling; thus, a pair of workers is recommended for this method. Frill cuts should be approximately 2 inches long and spaced 1-2 inches apart.

4.2. Soil Solarization

Soil solarization (SH) or soil decontamination is a hydrothermal method that utilises solar power to disinfect the soil from weeds, pests, and many soil-borne plant pathogens. It is a non-chemical practice, widely used in agriculture and an effective method for controlling a variety of wild plants classified as weeds, such as creeping buttercup (*Rannunculus repens L.*), redroot pigweed (*Amaranthus retroflexus*) and the nettleleaf goosefoot (*Chenopodium murale*) (Cohen et al., 2008).

The procedure that is usually followed involves firstly the ploughing of the field and the removal of large obstacles, such as large rocks and tree stumps, because they could damage the plastic sheet. Then the exposed area is moderately moistened, and a plastic transparent polythene sheet covers the area to trap the heat. The combination of moisture and trapping the heat during the hot and dry season by the polythene sheets raises the soil temperature. As a result, the increase in temperature incudes germination and kills the seeds in the seed bank (Giuseppe Brundu et al., 2018). To improve results, recommended time for SH application in the Mediterranean is mid-June to mid-August (Cohen et al., 2019)

Nsikani et al. (2019), conducted a field study investigating the effects of applying fire as an *Acacia saligna* control method on secondary invasion in the South African Fynbos. Burn control methods included the “fell, stack and burn” method and collected data around burned areas for 3 years. According to this study, secondary invasion can persist for years after the initial clearance. Thereafter, methods are discussed on how to avoid secondary invasion and control methods are recommended, one of which is soil solarization and the use of solar heat to eradicate the seed bank (Nsikani et al., 2019).

Reducing Persistent Seed Banks of Invasive Plants by Soil Solarization- The Case of *Acacia saligna* (Cohen et al. 2008). Field and laboratory experiments have been conducted by Cohen et al. (2008), mid-summer in sandy-loam soil and mountainous clay soil in Israel, examining the temperature in the seed bank, using temperature loggers, in a 30-day period. Experiments were conducted in different depths with different polyethylene sheets, using 3 *Acacia* species: *A. saligna, A. murrayana* and *A. sclerosperma*. <u>Results indicated that under all SH treatments, there was a significant increase in soil temperature.</u> The highest temperature observed was under the SH treatment with Black polymer sprayed on the soil surface before mulching with polyethylene sheet, with a peak of 80°C on 3cm depth and 75°C on 12cm depth. The second highest treatment was when using Anti-drip sheets. In the SH treatment using standard polyethylene sheets, the highest temperature reached 52°C on 3cm and 46°C on 12cm depth. All soil temperatures observed were higher than their corresponding control treatments. The temperatures recorded in the 3cm depth are important as the highest *Acacia* seed density is on the top 3cm of the seed bank (Krupek et al., 2016). Highly intensive SH significantly reduced the seed viability, especially on the top layer of the seed bank were temperature increased the highest. The ability for seeds to germinate below 10cm is limited (Cohen et al., 2019).

Rain-based soil solarization for reducing the persistent seed banks of invasive plants in natural ecosystems – Acacia saligna as a model. (Cohen et al. 2019), conducted a field experiment, in an experimental agricultural farm on the east coast of Lake Kinneret, Israel, studying the possible use of moisture induced by last rainfall (Rain-based soil solarization) in the area, rather than pre-irrigating the soil. (Cohen et al., 2019). The study site has a semi-arid climate, sandy clay loam, with a maximum daily temperature of 30°C. Most of the significant rainfall occurring in the area is between October to April. Mature *A. saligna* trees were cut and removed from the experimental area by the Israeli Forest Department. The experimental plots were ploughed 2 days after the rain fall, mid-April 2016. Then, they were covered with transparent anti-fog 100μm polyethylene sheets, purchased by Politiv, in Israel, and then later removed in October to avoid next seasons rainfall. Although soil tillage was not applied in this study due to the specific conditions of the experimental site, it is usually applied prior to regular SH to remove the vegetation and pruned branches and to flatten the soil to prevent future tears on the sheets. It is a common view that seeds which penetrate to the deep soil layers due to tillage might escape the SH. However, Holmes and Moll (1990) demonstrated that in an untreated site, soil depth and seed burial duration significantly interacted in reducing the survival of *A. saligna* seeds. After 30 months of burial, ~75% of the seeds were viable at 1 cm soil depth, whereas only 9% survived at 15cm depth (Holmes and Moll, 1990). Therefore, even if seeds in the deep soil layer escape the SH, their survival rate is expected to be low, and it is likely that their germination would be followed by death.

Cohen et al. (2019) also produced laboratory analysis germination tests, to determine the *A. saligna* and natural vegetation density in the seed bank, at the start of the experiment and eleven months later. Results showed that compared to the corresponding control plot, the treated plots had no viable seeds and that the seed fraction was almost completely eradicated. They have also conducted a laboratory experiment, studying the changes in the seed dynamics after being exposed to three different temperatures at different moisture profiles. After 68h, results showed that there was a significant loss of viability occurring at 57°C with 20% soil moisture. The results for the field experiment yielded positive results as there were no seedlings at the treated plots, whereas *A. saligna* seedlings emerged from the seed bank in all 16 sampled controls within the first Spring. Not only that, but the experiment showed rain-based soil solarization maintained higher moisture levels (44%), compared to the control plots (14%). SH showed a high rate of depleting the natural seed bank of 76% *A. saligna* viability at 1-19cm soil and a reduction of 91% at 1-4cm depth (Cohen et al., 2019).

Richardson and Kluge (2008), produced a review article journal, reviewing information on major invaders, such as the *Acacia* in South Africa, where just like in Cyprus, numerous plants from the Fabaceae family invaded large habitats causing substantial impacts. They describe how organizations focus on clearing the Invasive Alien plants with methods such as chemical and mechanical means. Biological control such as the release of the gall-forming rust fungus *Uromycladium tepperianum* and the seed feeding Weevil (*Melanterium compactus)* have been cited as some of the most effective methods of controlling the *Acacias,* with impressive results. But it is mentioned that the importance of controlling the seed bank has not been recognized and could potentially compromise the success of millions of dollars' worth of efforts. (Biological Control option is covered more fully under section 4.8 further down). While discussing possible seed bank control methods such as fire, soil inversion and biological control, soil solarization has also been discussed. It is stated that this can be used to reduce seed viability, while stimulating germination and the successful application of Cohen et al. (2004) for *A. saligna* in Israel is being mentioned, thus recommending SH a suitable mean of controlling the seed bank in sensitive habitats (Richardson & Kluge, 2008).

Moist heat works especially well with SH rather than dry, because the heat conduction from the surface can reach lower layers of the seed bank (Shlevin et al., 2004). When *A. saligna* seeds were exposed to a dry heat of 80-100°C for less than 30 minutes, it led to an accelerated germination rate and to a low seed mortality rate of less than 20% (Cohen et al., 2008). Mass germination is not unexpected, and it depends on the temperature and duration to the heat exposure. Cohen et al. (2008) observed that when the *A. saligna* seed is exposed to temperatures between 40-60°C, germination can still be induced. Cohen et al. (2019) found, under laboratory conditions, that exposing the *A. saligna* seeds to moist heat higher than 57°C for 68h, results in an almost complete seed viability loss. Both moist and dry conditions can induce mass germination, but moist heat can increase the soil temperature higher. Not only that, but because the *Acacia* is a drought tolerant, fire adapted species, it has evolved and better adapted to germinate in dry conditions (Jeffrey D.J et al., 1987).

This is a valid control method for eradication of the seed bank of the *A. saligna,* as it leads to loss of seed viability, but also mass germination in the treated area, exposing the seeds left in the area seed bank. When SH follows the clearance of adult *Acacias,* new seeds cannot replenish the seed bank. Long-term post-monitoring treatments are imperative, to control the second-generation *Acacia* saplings, resulting in a complete eradication of the seed bank. SH is an alternative method for eradicating the *A. saligna* seed bank as it can cause the destruction of a significant part of the seed bank and mass germination of the seeds remaining.

This method can be improved when combined with other control methods (Cohen et al., 2008, 2018, 2019., Giuseppe Brundu et al., 2018; Richardson & Kluge, 2008). **Controlling the seed bank of the invasive plant *Acacia saligna:* comparison of the efficacy of prescribed burning, soil solarization, and their combination. Cohen et al (2018)**, concluded that when having a controlled fire as a pre-treatment for SH, it significantly reduces the *A. saligna* seed bank. When conducting SH and prescribed fire, it was concluded that in the experimental study area, the seed bank was almost completely eradicated within 2 consecutive years following the treatment, indicating that the combination of methods can yield better results. In situations were controlled burns cannot be prescribed, SH is still relatively effective (Cohen et al., 2018). According to Cohen et al. (2018), a plastic fence can provide an additional protection to the mulched area and can also be used for providing protection when active revegetation is planned following the solarization.

This method has some limitations. This is a relatively recent method for controlling the seed bank, first described by Katan in 1976 and has room for improvement (Katan J et al., 1976). **(1)** It is only suitable for controlling the seed bank and is not for mature *Acacias.* **(2)** The application of the polythene sheet could be problematic over large surfaces and in natural ecosystems. It can be applied in flat, non-stony soils such as dunes, shorelines, and wetlands. **(3)** SH requires irrigation and can be problematic where areas are inaccessible. **(4)** Soil composition can also affect the sheet mulching process because non-flat surfaces can damage the sheet. **(5)** Sheets can be damaged by natural hazards, such as strong winds and animals. **(6)** SH can cause mass germination and invite a re-introduction. This should be considered when planning a control plan, as post-treatment monitoring is crucial (Giuseppe Brundu et al., 2018; Richardson & Kluge, 2008). **(7)** This method is not species-specific and will eradicate all the seeds in the natural seed bank (Cohen et al., 2019), including those of native species that a restoration plan is aiming to encourage.

4.3. Sprayed Coating

Mulching (using sheet installation on the soil) is a way of preserving plants from soil diseases, retaining water and controlling weeds. Plastic material when used in a large area, e.g. in agricultural areas, such as in the frame of Soil Solarization, can generate large amounts of waste. As a way of tackling this issue, new environmentally friendly and sustainable alternatives are being developed, such as the use of biodegradable films and biodegradable sprayable coating as a way of replacing the use of plastic. This new method of sprayable coatings is receiving increased attention as it could be a potential more sustainable alternative (Adhikari et al., 2019; Chen et al., 2019; Sartore et al., 2018). Most of the studies focus on water retention and soil water evaporation, but this is potentially beneficial to controlling unwanted plants when combined with another method. For example, Adhikari et al. (2019), found that sprayable coatings when performance was assessed under laboratory and field conditions, delivered a significant reduction in soil evaporation. A 2-year field study by Braunack et al. (2021), showed that the sprayable coating demonstrated a reduction of crop emergence if applied after sowing because of growth suppression by limiting photosynthetically active radiation. But effectively, when compared to plastic mulching films, sprayable coatings cannot compete alone, in terms of increasing temperature.

Biodegradable films can be produced from starch, cellulose, chitosan, alginate, galactomannans, and other natural polymers, and sprayable coating can be made from natural polysaccharides which then can be sprayed on the soil, forming a thin geo-membrane (Vox et al., 2013). In a study, Santagata et al. (2014), described the use of biodegradable films and spray coatings, as an alternative to plastic polyethylene sheets.

This innovative method was field tested by Vox et al. (2013) at an experimental farm of the University of Bari, Italy, from 2001 to 2005. Biodegradable material was put to test by mechanical mulching and by spraying to test their field performance compared to polyethylene mulching films. The sprayable coating basic ingredient were polysaccharides as galactomannans (guar gum, locust bean gum), agarose and sodium alginate, chosen for its property to form water resistant coating (Santagata et al., 2014). After 9 months of continuous use, the biodegradable sheets kept their mulching effects, except from a few irregularities on the surface, where the irrigation system was delivered (Vox et al., 2013). The sprayable solutions lasted between 5 to 6 months but can be damaged by weather conditions, such as hail and heavy rain (Santagata et al., 2014). In addition to this, but according to Schettini et al. (2005), when sprayable coatings were tested for their tensile stress (stretching ability), this method showed a much lower value compared to commercial polyethylene and biodegradable starch-based films. This was indicated by cracks on the sprayed coating and hand weeding controls were necessary (Schettini et al., 2005).

Mormile et al. (2016) investigated the hybrid approach of combining a solar film and a biodegradable sprayable coating, to simulate a thermal solar panel, increasing the soil temperature. This approach is to improve the traditional hydrothermal mulching approach. Three trials were performed on four 2m X 3m plots, under greenhouse, lasting 30 days each between June, July, and September in the Ristallo farm, Italy. Two polyethylene sheets were tested for the hybrid approach investigation, one produced in Israel and one in Italy. The sheets produced in Israel outperformed the Italian sheets according to the spectral testing, results appealing for SH. Alginate based liquid with dissolved carbon black powder was sprayed at the end of the soil irrigation, before applying the polyethylene sheets. The black liquid was alginate based and black colour was given using carbon powder. The recipe for the black biodegradable liquids studied can be found within the report (Mormile et al., 2016). Temperatures were collected at different depths using temperature loggers. The results indicated that the hybrid approach produced higher temperature values compared to the traditional method of only using plastic sheets. These results correlate with the results produced by Cohen et al. (2008), were a combination of black polymer sprayed on the surface before the commercial polyethylene showed a significant temperature increase, compared to the traditional mulching method. According to the results, it is believed that this new method can be used to obtain better SH results in shorter time compared to the traditional mulching method (Mormile et al., 2016).

4.4. Controlled Fire

Fire management, such as controlled fire or prescribed burn, is the term used when a planned fire is set intentionally for habitat, forest, or hazard reduction management. It can control the invasion of undesired plants, improve the habitat, and even enhance poor grazing distributions. Implementing fire to control seedlings or mature plants is only moderately efficient (Morris, 1991). A permit is required for controlled fires and burns need to be overseen by authorities, such as the Fire or Forest Department for regulation control. Mild weather conditions are required to achieve a successful prescribed burn and to avoid further wildfires, such as mild suitable periods during early autumn (van Wilgen, 2013), though this season is very dry in Cyprus. The adoption of controlled fire is a relatively recent method in Europe, and it dates to 1980s. It requires skills and expertise to avoid negative impacts, thus experienced personnel are needed on the strategic development of a fire management. Proposing a fire management should be adaptive, based on desired goal and agreed upon objectives from the beginning. Boundaries should be described and a monitoring program implemented following the treatments, assessing the realistic set goals (van Wilgen, 2013).

According to van Wilgen, (2009), burning is a valid conservation tool used in South Africa and the species rich fynbos for more than 40 years. Fire is also a natural phenomenon that can be the principal driver, making them inevitable and necessary (van Wilgen, 2013). The use of fire management is more suitable in areas where the seed bank is shallow, and in areas where follow-ups are easily accessible (Richardson & Kluge, 2008). Fire management has the potential of drastically decreasing the seed bank according to Richardson and Kluge (2008), by either stimulating germination or destroying *Acacia* seed bank.

Accompanied by biological control methods such the release of seed-feeding weevils, fire management was successful with invasive species such as *Pinus* and *Hakea* plants, where mechanical clearing was limited (van Wilgen, 2013). According to Pieterse and Cairns (1986), the control of the *Hakea* plant was successful, but introduced another invasive alien plant, the *Acacia longifolia.* Like the *Acacia saligna,* the *A. longifolia* is another invasive plant infesting large areas of South Africa, having a large annual production of characterised PY (hard-coated) seeds and can dominate large areas by dormant seeds in the seed bank, germinating by an increase in temperature (Pieterse & Cairns, 1986). So, the *A. longifolia* infestation soon followed the *Hakea* fire management. While eradicating the *Hakea* seeds, *A. longifolia* germinated and established. This could have been avoided by post-treatment monitoring and adaptive management planning.

Pieterse and Cairns (1986) conducted a field study, examining the effect of fire on the *A. longifolia* seed bank in the south-western Cape. Two 20 X 30m plots and a control plot were used close to each other, in

Banhoem Valley, a heavily *A. longifolia* infested area. In plot 1, some trees (2-4m tall) were present and plot 2 was previously treated by cut and burn, prior to the study (trees felled in February and burned in May). Results showed that there was a high reduction in seed viability in the plot that was burned. It is worth mentioning that the seedlings emerging in the control plot were significantly lower compared to the burned plots, with an average of 75 seedlings in total, 12 weeks later. This was to be expected as an increase in temperature induces germination. An intensive fire was used to reduce the number of viable seeds by either stimulating germination or destroying seeds. Only 3% of the treated seeds managed to germinate and establish. It was thus recommended that the small number of plants established post-treatment, can annually be contained by regular follow-ups and controlled by weeding or the application of herbicides (Pieterse & Cairns, 1986). Post treatment weeding, chemical treatment or grazing following fire management is also being recommended by Richardson & Kluge. (2008) and Campbell et al. (1999, 2000).

Cohen et al. (2018), conducted a field experiment in the Palmachim San Dune Nature Reserve in Israel, with the use of prescribed fire, combined with SH, investigating the effect on the *Acacia murrayana, Acacia sclerosperma* and *Acacia saligna* seed bank. It is mentioned that burning is currently one of the most effective methods for reducing seeds characterized by physical dormancy (PY), such as the ones of the fire adapted *A. saligna* (Richardson & Kluge, 2008), but post-treatments are required for a total eradication. When using fire as a pre-treatment, the stimulation of seed dormancy release, increases the seed sensitivity to the hydrothermal effects of SH. For this experiment, four random blocks were set up in an area infested by *Acacias* investigating the difference between areas that were burned, soil solarized, a combination and a control. Prescribed burns took place in mid-June and temperature in different depths were recorded using temperature loggers. The temperature at the surface peaked to 500 °C 45 minutes after ignition and then dropped to 100 °C within the next 6 hours where plots were treated by burning. Within the first 3cm depth of the soil the temperature peaked at 100 °C after 6.5 hours. Both surface temperatures dropped to normal values during the night. Results indicated that burning had reduced the viable seed fraction along the 12cm seed bank to 56%, from the initial 98% and the remaining seeds were in a state of dormancy. This partial seed reduction can be explained by the fact that fire induced heat penetration to deeper layer is limited. They have concluded that burning is effective at raising the temperature in the top part of the seed bank, whereas SH at the whole layer profile (Cohen et al., 2018). Thus, in the study it was demonstrated that using prescribed burning further increases the solarization efficacy.

Tozer (1998) examined the distribution and the effect of fire on the *A. saligna* seedbank on the central coast of New South Wales, Australia. Field work was carried out in a sandy area used for mining minerals, now infested with *A. saligna.* Two 4 x 5m plots where used, including a control, to examine the differences in fire treatments with different intensities. Using a liquid propane gas torch, one plot was treated for a period of 2 minutes and the other for 4 minutes. A systematic movement was used on the surface to mimic the motion of a realistic low-medium intensity wildfire. Using temperature loggers, the maximum temperature recorded was 73°C at depth of 0.9cm, during the 4-minute treatment. The treatments were monitored for 8 weeks, because no more seedling emergences were expected. During that time, no seedlings emerged in the control plot, but new emergences did occur on treated plots. Results showed a total of 31 seedlings emerged from the 2-minute plot and 41 from the 4-minute plot, indicating a higher proportion of emergence during the more intense treatment. Most of the emerged seedlings were located between 1 cm and 2.5 cm. During seed distribution examinations, Tozer (1998), suggests that there is a higher seed density on the top (6 cm) layer of the seedbank making these results consistent with other studies (Cohen et al., 2018). The probability of a seedling reaching the surface from a 10 cm depth is low (Tozer, 1998). The results are positive as they correlate to a higher control of the seed bank, but follow-up control treatments are recommended to deplete the seedbank even further.

Prescribed burning raises several questions, such as whether burning can influence the duration of future fire regimes and the effects fire shifts on the local biodiversity (van Wilgen, 2013). Fire is not species-specific in its effects, meaning it can also deplete the natural seed bank, including the seeds of natural vegetation. Fire is suitable for fire adapted ecosystems such as the Mediterranean, but may not be suitable where biodiversity is the principle consideration of the project (Richardson & Kluge, 2008).

Developing post-fire application on control methods to prevent reinvasion is of a particular importance nowadays, since as global warming is being accelerated, the frequency of fire event is expected to rise in Mediterranean-climate regions (Cohen et al., 2018).

4.5. Essential Oils

Essential oils (EO) or ethereal oils is a concentrated, liquid form of plant chemical compounds. EO are more commonly used for medicine or for aromatherapy, but they can be used as pesticides because of their allelopathic properties, meaning they can inhibit the growth of another plant. This is a plant defence mechanism, reducing nearby competition and possible predators, thus increasing survival rates (Kruse et al., 2000). Due to this biological property, EO have been studied for their potential usage as a natural pesticide and an alternative solution to chemical pesticides. Plant species heavily researched include rose, lemon grass, lavender, thyme, peppermint, and eucalyptus. As the demand for environmentally friendly alternatives increases, so does the research on using EO as a control method for invasive alien species. Researchers investigated the effects of EO from plants from the sage family (*Lamiaceae*) and results indicated a reduction of seed germination of a range of species, depending on type and concentrations. (Atak et al., 2016).

Atak et al. (2016) conducted a laboratory study on the allelopathic effect of *Origanum onites L.* (Turkish oregano) and *Rosmarinus officinalis L.* (Rosemary) on bread wheat seeds and other seeds of the agricultural pest species *Avena sterilis* and *Sinapis arvensis*. Results indicated a significant interaction between the EO's and the seeds with both EO suppressing germination rated on tested seeds, thus demonstrating that the use of the two EO's have the potential to be used as herbicides (Atak et al., 2016).

Maccioni *et al*. (2019), conducted a novel study on the inhibitory effect of rosemary EO, on the germination of *Acacia saligna* seed. The focal EO used for the laboratory investigation was Rosemary (*Rosmarinus officinalis L*), loaded in liposomes, with the variability on seed germination evaluated. Rosemary is a flowering species native to the Mediterranean, belonging in the *Lamiaceae* family. Under controlled lights with constant temperature, Maccioni *et al*. (2019), examined the inhibitory effects using three different EO concentrations of 3.9, 7.8 and 15.6 mL/L and one with the commercial herbicide DICOTEX RTU as control. Results suggest that EO concentration at 15.6mL/L had the highest seed inhibition rates. It was concluded that EO concentrations had a highly significant effect on germination rates and no *A. saligna* seeds recovered when treated (Maccioni et al., 2019).

This is a novel method that could potentially address the control of invasive alien plants such as *A. saligna* but both studies recommend further laboratory or field experiments to provide more useful information (Atak et al., 2016).

4.6. Grazing Management

In Australia, the main agents responsible for the lack of regeneration of the *Acacia oswaldii* are introduced grazers, such as rabbits, goats, and domestic stock. In a study, Auld (1990) examined the survival of *Acacia oswaldii* seedling emergence under selective caging treatments in an arid climate at Kinchega National Park in western NSW, Australia, from 1987 to 1989. The climate at the Kinchega National Park is one of low erratic rainfall combined with high summer temperatures (>40°C) (Auld, 1990). Even though *Acacia saligna* and *Acacia oswaldii* are both *Acacia* species, they do have some major differences. *A. oswaldii* can reach up to 8 meters in height and commonly found in arid Australian regions. *A. oswaldii* does not produce suckers, unlike *A. saligna*, and relies on seedlings recruitment to maintain populations. Also, the *A. oswaldii* seedbank is short lived and seedling recruitment is expected after large rainfall events (Auld, 1990).

For the investigation, various animal cage excluders were used, to identify the main seedling predator. Results indicated that virtually all seedlings exposed to rabbit grazing did not survive. While most seedlings perished within 12 months of emergence, a few persisted for several years before dying. Such seedlings often re-shot after periods of grazing, but eventually died from continuous grazing pressure. It is worth mentioning that the rabbits in the area are wild and widespread. While rabbits were responsible for the regeneration limitation in the study, other grazers such as sheep, cattle and goats also contributed to the lack of plant regeneration. The impact of rabbit densities on the survival of young plants is also likely to vary between species in relation to palatability and proximity to rabbit warrens (tunnels). Field observations suggest that seedling losses to rabbits are greatest when rabbit numbers are high and little forage is available (during dry or drought periods) (Auld, 1990).

Lange and Graham (1983), describe two experiments concerning the effect of rabbit grazing on the Acacia seedling recruitment to populations in the South Australian arid zone.

In the first experiment, a series of observations concerning the role of rabbits versus sheep in the suppression of Acacia recruitment is examined. The following data found was concerning suppression from rabbit grazing. Field work was carried out on Middleback Station, South Africa. Selective guards were used for the plots examined, in ten of which only rabbits were allowed to enter. After 15 months, the control plots had an increase in vegetation, while all selective entrance plots had a decrease in vegetation due to grazing. Results indicated that rabbits could suppress the growth of Acacia seedlings. The seedlings that were exposed to rabbits alone via selective guard, were all grazed to some extent (Lange & Graham, 1983).

For the second experiment, seedlings from four Acacia species were transplanted into four 50x50m rabbit proof enclosures with 6 rabbits each. Seedlings were translocated when 3 months old, since there were no *Acacia* seedlings occurring naturally in the enclosures. The experiment started at 5 p.m. on 6 May 1981 and ran until 11 a.m. on the 14 May 1981, with readings taken every 12 h. Within the first 24h, half of the total seedling population had been grazed. In one of the enclosures, the seedlings were not grazed, indicating that a dense patch of grass can act as a buffer zone, reducing grazing pressure. Results demonstrated that rabbits have the capacity to rapidly eliminate *Acacia* seedlings. Over the experimental period, 92% of the seedlings in enclosures B, C and D were consumed, with 74% being eaten within the first 36h (Lange & Graham, 1983).

A study by Wimbish and Forrester (1988), investigated the effects of rabbit grazing and fire on a subalpine environment. The study focused on the effects of two low-intensity fires and/or grazing by rabbits and wombats on *Eucalyptus pauciflora* and *E. stellulata* trees between 1977 and 1984. The trial consisted of two treatments, one involved no fire and the other with two low-intensity fires 4 years apart. Each of the treatments was subjected to four grazing regimes, free-ranging rabbits and wombats, free-ranging rabbits only, rabbits enclosed at a known density and an ungrazed enclosure. The plots were 0.5 ha in area. The areas were inspected by foot, and all were found to contain large numbers of active rabbit warrens. It must be emphasised that the fire intensities were much lower than most hazard-reduction operations. Observations indicated that shoots induced from fire damage, were seen to be grazed by rabbits. Few to none of 2m or taller trees were destroyed during the first fire and at an early stage, rabbits had no significant effect. The first fire killed most of the sapling stems and shoots, but more shoots were stimulated alongside with mass seed germination. But after the second fire four years later, rabbits had killed a significant number of smaller trees on the burned plots by grazing the regenerating shoots. Rabbits did not only have an effect on young trees, but some of the adult trees by ring-barking. By April 1981, 25 trees on one plot had been completely ring barked and 14 of these were dead, their stems ranging from 16 to 59 mm diameter. It was concluded that as tree seed recruitment was inhibited by the fires, rabbits killed a significant number of large trees by first ring-barking the stem and then grazing on the regrowth (Wimbush & Forrester, 1988).

Tiver et al. (2001), conducted a field study surveying existing populations of prickly acacia *Acacia nilotica* to determine if the livestock species used for grazing influence the seedling survival and population density in four sites in central Queensland, Australia. The study areas are heavily grazed fields for the past >20 years. It was observed that there was a significantly lower frequency of <3m in height plants in areas grazed by sheep, indicating that browsing by sheep reduces regeneration. There was a higher loss of seedlings at areas grazed by sheep, compared to cattle grazed areas. These results support the assertion that the prickly acacia is regenerating with higher rates at cattle grazed areas, because cattle both disperse seeds and are not as effective as herbivores. Both sheep and cattle can eat acacia seed pods, but cattle chew seeds ineffectively compared to sheep, thus more viable seeds are dispersed through dung. According to the study, cattle pass about 81% of ingested seeds, whereas sheep only <1%. According to Brown and Archer (1987), cattle are responsible for dispersing seeds of mesquite *Prosopis* in North America, a known pest. Results indicated that prickly acacia seedling loss was higher in sheep-grazed areas, due to heavy grazing, trampling or by repeated browsing. Seedling losses at cattle-grazing areas were between 16-23%, whereas sheep-grazing sites of 88% (Tiver et al., 2001).

It is thus suggested by Tiver et al. (2001) that prickly acacia would be less of a management issue if sheep are used for grazing in the Mitchell grasslands.

It is recommended by Crisp and Lange (1976), that a combination of rabbits and sheep can prevent completely the reproduction of *Acacia burkittii* in a sheep grazing property in the southern arid zone of Australia. The effect of rabbits alone is to reduce reproduction greatly, but not completely (Crisp & Lange, 1976).

Goats are known to thrive in semi-arid regions of Botswana due to their ability to feed on different types of plant species. *Acacia fleckii* and *Acacia tortilis* are widespread in Botswana and goats manage to browse heavily on these species. Aganga et al. (1998) conducted a feeding study lasting 98 days using 12 yearling *Tswana* male goats fed on *Acacia fleckii* or *Acacia tortillis* as supplementary fodder to evaluate the feed value on goats in Bostwana, Africa. Fodder was provided in a dry form and average daily body weight was measured. Goats fed on *Acacia* species consumed the leaves, twigs and even the thorns leaving only the stalks (Aganga et al., 1998). Even though this proves that this goat species finds *Acacias* palatable, it might not be the case for all goats and more research must be done in the field. One of the reasons the British introduced *A. saligna* to Cyprus was to provide fodder for goats, so the species is known to be palatable to local goats.

Using grazing as a method has some limitations; **(1)** they might increase seed germination though gut passage and scarification of seeds **(2) they might increase** seed dispersal of *Acacia* or other plant species seeds to the controlled area or other areas, away from the mother tree **(3)** introduction of nutrients into the system through dung fertilisation (Pillay & Ward, 2021).

4.7. The use of native plants competitors (revegetation)

Acacia saligna is a shade-intolerant species, requiring full sun exposure. According to Smith and Shackleton (1988) reduced light levels under the canopies of trees plays a role in suppressing *Acacia* spp seedling establishment. Smith and Shackleton (1988) conducted a field study in Australia, examining the growth response of *Acacia tortilis* seedlings to reduced light availability. Examination of *A. tortilis* seedling germination and establishment relative to canopy cover of trees showed a greater proportion of newly germinated seeds per unit area, but a lower proportion of established seedlings, with light exposure as the main factor. Similar results for the *A. tortilis* have been observed in Australian and North American *Acacia* species, which demonstrate shade avoidance (Smith & Shackleton, 1988).

The suppression of *Acacia* spp seedling growth under shaded conditions may also play an important role in the interaction of grasses and woody vegetation in *Acacia* savannas. Brown and Brooysen (1967), found that seedling of *Acacia tortilis* and *Acacia karoo* rarely survived under closed canopies of grass. Seedlings grown in areas of grass cover were elongated with an absence of branching and had lower shoot biomass values as compared with individuals grown under open conditions (i.e., grass cover removed). According to Smith and Shackleton (1988), the removal of grass cover significantly increases the seedling establishment of *A. tortilis* and *A. nilotica.* Whether the reduction in seedling establishment in areas of high grass cover occurs because of competition of grasses for moisture in the topsoil following germination or because of the reduction in available light by shading has not been established.

Pillay and Ward (2021) conducted a study investigating the effects of fire, grass cover, cattle ingestion and dung on germination, seedling height and survival as well as on recruitment on *Acacia sieberiana* in a sub-humid grassland in KwaZulu-Natal, South Africa. About 8,000 seeds were planted in the fields in 48 plots of 1 x 2 m and monitoring of the experiment lasted for 1 year. They manipulated passage through grazing livestock, presence or absence of animal dung, competition with grasses and wire and tested their effects on seed germination, seedling height, seedling survival and recruitment.

Results suggest that removal of grass by grazing and/or fire had the most important effect on the *Acacia* recruitment in the savanna suggesting that grass competition is more important than fire and grazing for suppressing seedlings. Grass had the most negative effect on seedling survival that is probably because of strong competition between *Acacia* seedlings and grass during the dry season when water was scarce.

Invasive species such as the *A. saligna*, have greater phenotypic plasticity than co-occurring non-invasive species, yet non-invasives can maintain fitness homeostasis better than invasive species under limited resources or stressful conditions. Additionally, native species may undergo coevolution processes with invasives which make them potential competitors. According to Zahra et al., (2020) authorities in Baluran National Park, Indonesia, planted native grasses to restore a managed area invaded by *A. nilotica*, providing food for ungulates and shelter for animals in the dry season. Such grasses could be effective competitors of *A. nilotica* or help reduce its rate of spread in the park. (Zahra et al., 2020)

There is evidence that grasses and trees can outcompete *A. nilotica*. For example, as the prickly acacia seedlings are shade-intolerant (Tiver et al., 2001), particular shade tree species could be planted within the post-cleared area to prevent re-establishment. Seedlings of these shade trees should be planted in the nursery bed first and later transplanted in the field to ensure successful establishment. Planting these grasses as native competitors along with shade trees may accelerate control efforts or at a minimum slow its spread in some areas. A recent study shows that shade and grass competition reduce the germination rate, length of shoot, root, and number of leaves of *A. nilotica* seedlings (Ridwan 2018).

Cohen et al (2018), also recommends that active revegetation could be used as a method following Soil Solarization.

4.8. Biocontrol

Biological control or Biocontrol is a pest management strategy, and it is defined as the reduction of alien species or pest populations by natural enemies introduced by humans. This is based on the natural principle of utilising natural enemies to control, supress, maintain, or outcompete a certain species lacking a natural predator (suppressor) in a given area. Such methods include insects, mites, weeds, and various parasitic plant diseases. The introduction of a biological control on an established alien plant species is not a recent control strategy. This method has been used in the past with positive results, but overall impacts are still unclear.

One such story relates to the introduction of *Opuntia stricta* (prickly pear) in Australia around 1840. By the first two decades of the 20th century, the prickly pear had spread widely in Australia, eventually infesting 30 million hectares by 1930. After systematic insect research looking into prickly pear natural predators, the moth *Cactoblastis cactorum* was introduced to control the spread. Within less than 10 years, it is estimated that 1.5 billion tons of prickly pear was consumed by the introduced biocontrol agent (Osmond et al., 2008). This has been cited as a success story as it did not generate secondary damage. Substantial research must be undertaken prior the introduction of bio controls to avoid (1) direct attack on non-targets (2) indirect effects on non-targets (3) dispersal of a biocontrol agent to a new area (4) changed relationships between a control agent and a native species (Simberloff, 2012).

A famous unsuccessful biological control, lacking the necessary investigation, was the intentional introduction of the *Rhinella marina* (Cane toad) in Australia in 1935 to combat cane beetles that infested sugar cane crops. As a result, the toads completely failed at regulating the cane beetles, and instead turned their attention to other native insects. Since the initial release of 3,000 toads, cane toad populations in Australia number in the millions and their range continues to expand. (Gruber et al., 2017)

Acacia saligna has become naturalized and invasive in many parts of the world. Part of its invaded area is South Africa, where a lot of efforts go into controlling it. Management efforts include mechanical, chemical, and biological methods. Biological controls released on invasive Australian *Acacias* include five *Melanterius* spp. (seed feeding weevils), two *Trichilogaster* spp. (bud galling wasps), two *Dasineura* spp. (flower galling flies) and one *Uromycladium* spp. (gall rust fungus). According to Impson et al. (2011), the impact of these biological control agents on the seed production is described as extensive, with almost no seeds surviving, or considerable, with less than 50% of the seeds surviving (Impson et al., 2011).

Strydom et al. (2017), conducted a study investigating the size and relationship with stem diameter of *Acacia* in the presence of gall-forming biological control agents. Four *Acacia* species were investigated, *A. longifolia, A. mearnsii, A. pycnantha* and *A. saligna,* in six to seven monospecific sites in the Western Cape of South Africa. Seed bank sampling was conducted during July 2013. Results indicate that the *Acacia* seed banks are still large over their introduced area despite the long-term presence of the gall-forming control agents. It is thus recommended that long-term active management (mechanical), despite its higher cost is required to manage the seed banks of the *Acacias* (Strydom et al., 2017).

Biological controls have been cited by some researchers as some of the most successful methods for controlling the invasive *Acacias* and the only sustainable and cost-effective method for controlling *Acacia* invasions.

5. RECOMMENDATIONS

Cyprus is a fragile biodiversity hotspot and the bird epicentre of endemism in Europe, as well as for plant diversity (Hadjisterkotis et al., 2002). The Cypriot fauna and flora are at risk by human intervention, as it is the case of the invasive *Acacia saligna* being planted in Cyprus, causing impacts both environmentally and economically. In areas were the *A. saligna* has become widespread, such as in Cape Pyla, dense monospecific stands have been formed, preventing growth of native species and altering ecosystem processes, while also facilitating illegal bird killing practises.

The control management of the invasive *A. saligna* must integrate a management strategy for dense *Acacia* stands, the persistent seed bank, as well as long-term follow up to treatments. The management approach should be balanced by gathering data on both the impact of the invaders and the effect of the management methods on the local environment. Attention must be given on the native flora seed presence in the soil in the managed area, and the ability for the habitat to recover from the treatment, naturally or by supplementation.

The aim of this literature review is to conclude at a minimum of two management methods for restoring the natural vegetation and limiting the regrowth of the invasive *A. saligna* in Cape Pyla. Methods have been drawn by reviewing scientific and other published literature on various approaches, following the clearance of dense *Acacia* stands in Cape Pyla. The selected recommended methods for the management in Cape Pyla will be trialed in areas that have been cleared of *Acacia* stands by the SBA authorities and by natural wildfires. The recommended methods to be applied were selected based on their effectiveness in the field, their applicability on Cape Pyla habitat and their ability to manage dense seed banks. The methods recommended to be tested are the following:

- Soil solarization
- Chemical treatment
- Grazing management
- Revegetation

From the research conducted for the literature review, evidence suggest that the application of these methods alone, or in combination, would have effective results in controlling the *Acacia* seed bank and reducing future regrowth. The methods recommended have the potential to address the *Acacia* management problem, by managing the seeds in seed bank directly (soil solarization and variations of this method) and indirectly by controlling the regrowth (chemical treatment, grazing management, revegetation).

5.1. Direct Seed bank management for the restoration of the natural vegetation and limiting *Acacia Saligna* regrowth

For the direct seed bank management, Soil solarisation (SH) is recommended. Results from Cohen et al., (2008, 2019), van Wilgen, (2013) and Richardson and Kluge (2008) show that soil solarisation produced positive results on controlling *Acacia* seed bank, by either stimulating germination (and die off) or by destroying the *Acacia* seed bank. Cohen et al., (2018) produced a trial experiment by combining SH and prescribed burning, studying the effect on *Acacia* seed bank. For this experiment fire will not be used as it can potentially completely eradicate the natural vegetation, slowing down the habitat restoration. As SH has the potential to allow some natural seeds to survive and drastically manage the *Acacia* seeds in the seed bank, fire can negatively impact the treated area by completely halting the natural restoration. Intense fire has the potential to destroy subterranean propagules of indigenous species (Christodoulou, 2003).

Recommended treatments come by intensities: **High intensity** SH with double plastic sheets. **Medium intensity** SH. **Low intensity** SH excluding soil tillage.

Testing SH and variations of SH will allow us to investigate the effectiveness of SH, and the effectiveness of the intensity of variations of the method on the natural environment in Cape Pyla. The effectiveness of the direct seed bank management will be tested by monitoring seed viability, native vegetation, *Acacia* germination rates, and seed density before and after.

5.1. Indirect Seed Bank management for the restoration of the natural vegetation and limiting *Acacia Saligna* regrowth

For the indirect seed bank management, chemical treatment, grazing management and revegetation are recommended for trials. Results by Dufour-Dror, (2013), Lange and Graham, (1983), and Pillay & Ward, (2021) produced positive results on controlling *Acacia* and limiting other plant species regrowth. The recommended methods will investigate the effectiveness of grazing (with goats and sheep) in *Acacia* post-clearance management and the effectiveness of revegetation combined with chemical treatment follow ups. Revegetation with local native plants, has the potential to outcompete the *Acacia* samplings from sunlight, space, and water, thus accelerating the natural revegetation. The outcome of these methods can support the creation of a more diverse landscape mosaic of scrub/tall vegetation encouraging the restoration of the natural vegetation in the local area. These will be tested by evaluating native vegetation, *Acacia* germination rates, and seed density before and after.

5.2. Plot selection criteria

For the management of the *Acacia* seed bank and the control of regrowth, it is recommended that trial plots will be used in Cape Pyla within the SAC boundaries. The criteria of the selection of the plots are as follows:

- Homogeneous past coverage and history of Acacia in the area (as far as possible).
- Accessibility and easy access to the plot for workers and equipment.
- Soil substrate and presence of other plants. At the start of the experiment, trial plots have to be mostly clear of vegetation and obstacles such as rocks.
- The absence of mature *Acacia* trees and seed-bearing trees within and near the trial plots (i.e. focus on areas cleared of standing Acacia trees and bushes).

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