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Controlled Spectral Experiments and Biological Control of Cannabis sp.

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Prepared by

Titan Analysis Ltd.

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Controlled Spectral Experiments and Biological Control of *Cannabis* sp.

Part 1

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EXECUTIVE SUMMARY

The following report is a concise description of topics relating to the characteristics of *Cannabis* sp. (marijuana/marihuana) that Titan Analysis considers important in order to support the eradication efforts of law enforcement with the most efficient allocation of resources for British Columbia. A range of topics from the basic botanical description of the different *Cannabis* species and their use in propagation, a discussion of ecological characteristics to a summary of efforts to date using remote sensing technology to detect outdoor grow operations are presented. Assemblage of this compilation is the first step in the development of a series of tools aimed at both better detection of and subsequent control of illegal *Cannabis* grow operations. The intended long-term outcome of the integration of the information assembled here is similar to the effect adaptive management, in which changes from one scenario triggers a response from its counterpart furthering and improving development. The following topics are covered in this document:

- Botany, distribution and ecology
- Chemical constituents
- Genetics
- Spectral characteristics
- Seizures and trafficking

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1. Introduction

Information derived from research into the properties of *Cannabis* is available from a variety of sources specific to disciplines such as medicine, genetics, policy, crime analysis and botany. In addition, there is a significant amount of information from popular sources such as books published by growers or *Cannabis* enthusiasts as well as reports from sources such as the United Nations, the US Drug Enforcement Agency, the Bureau for International Narcotics and Law Enforcement Affairs, the National Drug Intelligence Center and the Treasury Board of Canada among others. However, there has not been a compilation of the most pertinent information from the variety of sources into one succinct report.

By summarizing the most relevant information from a variety of sources, the necessary background information is provided to facilitate a better allocation of resources for locating and eliminating illegal outdoor *Cannabis* grow operations. Aspects such as the biology, ecology, chemical composition, spectral properties, and statistics regarding product value and seizure reports are summarized. Recommendations are also included for future applications of this information such as the biological control of *Cannabis* to hinder the repeated use of sites by growers.

In this report we use the term *Cannabis* to refer to all species and strains of the plant (unless otherwise specified). For consistency, it is also used in place of the common term "marijuana" or "marihuana" as is used in some of the sources cited. In addition, the information is meant to be most relevant to plants selected or selectively bred for drug use (i.e. high THC content – see *Cannabis* chemistry section). In Canada the threshold for *Cannabis* plants to be considered "hemp" rather than drug producing plants is less than 0.3% THC in the leaves and flowering parts[1].

2. *Cannabis* botany, distribution and ecology

The genus *Cannabis* belongs to the family Cannabaceae. Currently, three species are of *Cannabis* are recognized: *C. sativa*, *C. indica* and *C. ruderalis* [2, 3]. Although there is still a controversy regarding the different species and varieties of *Cannabis* [2], for the present document we focus on the species *Cannabis sativa* L. (common name: marihuana or marijuana) and comment on *C. indica* and *C. ruderalis* because of their use

in breeding treatments for selecting desirable traits that can be specific to local environmental conditions or product requirements [3]. *C. sativa* differs morphologically from the other two recognized species of *Cannabis* (Table 1). At the plant level *C. sativa* is a tall plant averaging 4 to 15 feet (1 to 3 m) with long internodes between branches (3 to 6 inches) [3]. At the leaf level, leaves of *C. sativa* are pointy without markings and patterns, usually with 6 to 12 blades per leaf. All species of *Cannabis* are dioecious, meaning there are separate male and female plants. Table 1 illustrates the main differences between the *Cannabis* species.

Table 1. Main vegetative differences between three *Cannabis* species

Species	**Height**	**Nodes**	**Leaves**	**Blades**
C. sativa	Tall 1.2 – 4.5 m	Long internodes between branches 7.6 – 15 cm	Pointy leaves with no markings or patterns	Usually between 6 and 12 blades per leaf
C. indica	Small 15 cm – 1.2 m	Short internodes between branches 7.6 cm and less	Wide, short and rounded leaves, with marble-like patterns	Usually between 3 and 5 blades per leaf
C. ruderalis	Small 15 cm – 1.2 m	Very short internodes with much branching	Small and thick	Usually between 4 and 6 blades per leaf

Source:[3].

At the flower level male and female *Cannabis* plants are only distinguishable after blooming, although some preliminary genetic work has shown otherwise (see genetics section). Male flowers have 5 petals with very clear clustered stamens located in almost leafless branches. Female flowers are inconspicuous and crowded into dense clusters along with small leaflets at the base of larger leaves on different branches [2]. Because of the dioecious nature of the plant, *Cannabis* requires wind for pollination to occur. Differentiating between male and female plants is important because at harvest the female plants contain the levels of THC content required or desired by the growers.

According to [2] *Cannabis* originated either in the valleys of Central Asia or in northern South Asia along the foothills of the Himalayas but in modern times has a nearly

worldwide distribution and can grow naturally without human cultivation. In terms of the different species, pure *C. sativa* is typically found in warmer, lowland climates (Thailand, Mexico and South Africa, for example). *C. indica* likely originated in northern India and C. *ruderalis,* a more recently recognized species, can be found growing naturally in Central Asia [4]. Growers refer to "varieties" of *Cannabis* that may be pure plants from any of the species or crosses between the species. Common terms for the varieties are names of the location of origin such as Mexican, Colombian, Hawaiian, Southeast Asian, etc. Nevertheless, each variety shares several similar characteristics as detailed in this document.

Cannabis is an annual crop herb that can reproduce sexually (seed) or through vegetative propagation (cloning). Basic requirements for growth are good light conditions, well-drained soils, sufficient nutrients, and water. Ideal temperatures for its growth range between the 14 to 27°C, however it can survive short freezing periods. Although *Cannabis* can grow in a variety of soil types, it prefers loams rich in nitrogen, with a pH between 6 and 7 [4]. As many other herbs, after seed germination (3-7 days) juvenile plants increase biomass (leaves) with increasing day length [2]. This prepares the plants for the next stage of shorter days (less light availability) after the summer solstice. At this point the plants enter the flowering stage and seed development [5] which varies between 3 to 8 weeks [2]. Once seeds develop they can be dispersed naturally or harvested for additional production. In northern latitudes (30 to 60 degrees) seeds are usually planted between March and May, and if the plants are pure *C. sativa*, would produce flowers between September and November, in a six-month growth cycle [4]. However, this may not be optimal for most growers. Therefore, generally the plants used are varieties of *Cannabis* that are crossed with *C. indica*. Pure *C. indica* has a much shorter flowering period of 5-8 weeks[3]. Due to the option of vegetative propagation in *Cannabis*, seeds are not necessary to achieve a full life cycle under controlled conditions (light, soil and water). By prohibiting pollination, growers have been able to produce a new "type" of *Cannabis* product called "*sinsemilla*" (without seeds) with much higher THC content than what is derived from pollinated plants [2, 4].

On of the most important traits of *Cannabis* is its photoperiod sensitivity. By manipulating the number of hours of sunlight the plants receive, it is possible for the

growers to obtain two harvests in certain locations. If plants are exposed to eighteen hours or more of sunlight, they enter a vegetative phase where they will not progress to the flowering stage[2]. In addition, *Cannabis* does not require a dark period to complete its photosynthetic cycle[3]. If plants are exposed to only 12 or 13 hours of sunshine per day, they will be "forced" to flower [2, 3].

3. Chemical constituents of *Cannabis*

Cannabis plants have been found to contain 483 compounds, a portion of which are unique to these plants [6, 7]. The specific chemical constitution of *Cannabis* varies and is greatly influenced both by the genetics of the plant (mainly affects the cannabinoids) and the immediate environmental effects (mainly affects the terpenoids)[8]. Environmental effects can be as broad as a continent or as specific as a grow operation. However, *Cannabis* originating from different countries has also been shown to have unique differences in cannabinoids, indicating that the effects are a combination of both genetics and environment[8].

The unique differences in chemistry have led to the branch of research known as "*Cannabis* profiling" or "*Cannabis* fingerprinting". Following a multivariate analysis of the chemical compounds [8] found that twenty-two of the indicator compounds are terpenes, sixteen are cannabinoids, two are hydrocarbons, two are non-cannabinoid phenols, three are fatty acid esters and one is an aromatic compound.

In a comparison of indoor and outdoor grown (in ground and in pots with commercial potting soil) plants originating from Jamaica, the chemical constituents of the indoor plants were differentiated without error from both outdoor groups[8]. Differences were also observed between the outdoor groups, even though there was some error. These results indicate that while light and temperature may be the key drivers of chemical composition, soil can also be a factor. The expression of these differences in the chemical composition of *Cannabis* in its spectral signature is yet to be determined. [9] found differences in the spectral signature of canopy reflectance from *Cannabis* growing in two different geographical locations within British Columbia, Canada. The *Cannabis* was not profiled to identify its genetic origin, however, the growing conditions in terms

of elevation, aspect, rainfall and hours of sunshine were different between the sites. In a second experiment involving daughter plants from a variety of origins [8] found that even though genetic relationships do affect the chemical profile of the plants, the environment plays a greater role. [8] also found that plant age in an important influence on the chemical profile of the *Cannabis*.

3.1 Cannabinoids

The sixty-six cannabinoids are thus far found solely in the *Cannabis* plants. The terpenes, the most abundant class of compounds, 140 in total, can be found elsewhere in other plants as well [6, 7, 10], although in different combinations and abundances. "Cannabinoid" refers to a group of organic compounds with the basic C_{21} terpenophenolic structure and are subdivided into ten groups, of which the four main ones are[6, 11]:

- Cannabigerol (CBG)
- Cannabichromene (CBC)
- Cannabidiol (CBD)
- Δ^9-Tetrahydrocannabinol (THC)

CBG was the first cannibinoid to be identified and six cannabinoids are part of this class [6]. Five compounds form the CBC class, and seven form the CBD class. CBD compounds are the most prevalent in *Cannabis* plants grown for hemp and are a trade-off with the THC compounds as it is the biosynthetic precursor to THC[4] (Table 2). Nine compounds constitute the THC class. Δ^9-Tetrahydrocannabinol is the main psychoactive compound, but the precursory THC acids, though still classified in the same group due to their structure are not psychoactive.

Other classes of compounds include: Δ^8-Tetrahydrocannabinol (Δ^8-THC is similar to Δ^9-THC but is less potent), Cannabicyclol, Cannabielsoin, Cannabinol and Cannabinodiol (their concentrations in the plant depend on the age and storage conditions because they are the oxidation artifacts of THC and CBD), Cannabitriol and Miscellaneous (eleven compounds with unusual structures form this group)[6].

Table 2. Traditional gene pools for *Cannabis* [2]

Traditional *Cannabis* Gene Pool	**THC Content**	**CBD Content**	**Uses**
C. sativa: Russia, Mediterranean, Far East	Low	Medium – High	Fiber/Seed
C. sativa: South Asia, Southeast Asia, Africa, New World	High	Low	Marijuana
C. sativa: North India, Nepal, Middle East, North Africa	High	Low – Medium	Hashish
C. indica: Afghanistan, Pakistan	High	Low-High	Hashish

3.2 Terpenoids

The distinctive odour of *Cannabis* plants is due to the terpenoids (140 in total). Terpenoids can have a range of structures depending on substitutions of various groups such as alcohols, ethers, ketones and esters onto the main hydrocarbon skeleton. The main structure of the terpenoids is formed by isoprene units (C_5H_8) that make monoterpenoids (C_{10} skeleton), sesquiterpenoids (C_{15} skeleton), diterpenoids (C_{20} skeleton) or triterpenoids (C_{30} skeleton)[6]. The yield of terpoenoids depends on the type of *Cannabis* (grown for drug vs hemp), harvest time, pollination, gender, age of plants at harvest, cultivation type (indoor or outdoor), drying and storage conditions[6, 12]. The amount of terpenoids decreases with time following harvest. For example [12] found that freshly harvested outdoor grown *Cannabis* can produce on average 1.3L/ton or 10L/ha. The same study found that non-pollinated "*sinsemilla*" *Cannabis* produced 18L/ha versus 8L/ha for pollinated *Cannabis*. The constituents vary between indoor and outdoor grown *Cannabis* (Table 3).

Table 3. Breakdown of constituents from terpenoids in outdoor and indoor grown *Cannabis*

Terpenoid	**Indoor grown**	**Outdoor grown**
Monoterpenes	92%	47.9-92.1%
Sesquiterpenes	7%	5.2-48.6%
Others	1%	N/A

Compounds from the THC class of cannabinoids do not contribute significantly to the essential oils of *Cannabis*, even in the varieties of *Cannabis* grown specifically for

high THC content, for example, [12] found only a concentration of 0.08% of THC in the essential oils of drug *Cannabis*. The main terpenes from the outdoor grown plants were found to be: β-myrcene, *trans*-caryophyllene, α-pinene, *trans*-ocimene and α-terpinolene [6]. In a study of five cultivars from Europe, the concentrations of the dominant terpenes are listed in Table 4, while others were found in trace amounts [12]:

Table 4. Concentration ranges of dominant terpenoids

Terpene	**Concentration**
myrcene	21.1-35.0%
α-pinene	7.1-14.6%
α-terpinolene	7-16.6%
trans-caryophyllene	12.2-18.9%
α-humulene	6.1-8.7%

3.3 Other compounds

Cannabis also contains a broad range of other compounds: hydrocarbons (50), Nitrogen-containing compounds (70+), carbohydrates, flavinoids, fatty acids, non-cannabinoid phenols, alcohols, aldehydes, esters, ketones, acids, lactones, phytosterols, etc.[6] The only vitamin reported thus far is vitamin K. The plants also contain the common plant compounds such as chlorophyll (a and b) and accessory pigments such as carotenes and xanthophylls (all of which are of importance in remote sensing applications) [13-15]. In addition, eighteen elements have also been reported (Na, K, Ca, Mg, Fe, Cu, Mn, Zn, Hg, etc.) [6] some of which are common to plants whereas others less so. Increased nitrogen-containing compounds are also of interest to remote sensing because of the effect of nitrogen concentration on reflectance (see spectral response section)[16]. The relative effect of the other compounds unique to *Cannabis* on its spectral response is yet to be determined.

3.4 Trends in THC

THC concentrations have been increasing[6, 17]. In an analysis of over 7,000 tons of *Cannabis* in the United States between 1980 – 1997, mean THC concentration has increased from less than 1.5% to 4.2% with maximum values in *sinsemilla* varieties of 29.9-33.1%. In Canada, THC content was below 1% in the early 1980s, but had reached

and average of 6% in the 1990s [4]. Samples with very high THC contents (>20%) are still rare in Canada, but are increasing (Fig 1).

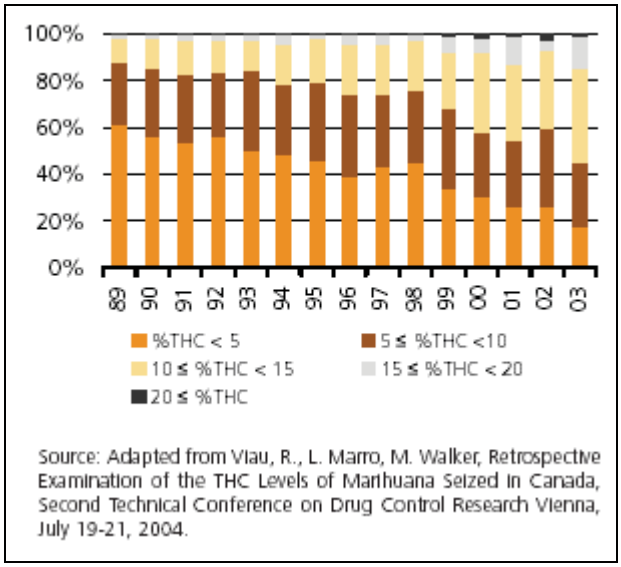

Figure 1. Trends in THC content from Canadian samples [4].

Early in the life cycle of the plants, males have a higher concentration of THC, whereas in mature plants ready for harvest female plants have a much higher concentration of THC, especially if they are unpollinated (i.e. *sinsemilla*) [4]. Unsubstantiated reports have listed the quality of *Cannabis* grown in British Columbia (also known as BC Bud) to be of exceptionally high THC content with level surpassing 25%. Wild *Cannabis* has been documented to reach THC contents nearing in the 47-52.9% range[3, 6].

4. Genetics

Cannabis (family, Cannabaceae) is an ancient cultivated plant with three major species: *Cannabis sativa, Cannabis indica* and *Cannabis ruderalis* [18]. *Cannabis* has two separate sexes (dioecious) determined by the XY sex determination system quite similar to that of humans. Male plant possesses the heterogametic (XY) chromosomes while the female bears the homogametic (XX)[19]. In psycho-active cultivars, female

plants possess the psycho-active compound Delta 9-tetrahydrocannabinol (THC)[20]. The sex of the plant is almost impossible to determine visually until the plant reaches reproductive maturity which occurs in a late stage of plant development, therefore considerable genetic work was necessary to characterize DNA markers associated with the male sex [19, 21-23]. A large number of genetic markers have been characterized to distinguish the three species of *Cannabis* which help drug enforcement units to determine the geographic source and the type of cultivar. Random Amplified Polymorphic DNA (RAPD) were the earliest genetic markers to explore the genetic variation in *Cannabis* [24, 25]. The advent of the Amplified Fragment Length Polymorphism (AFLP) technique enabled higher resolution genetic fingerprinting with reproducible results [23, 26, 27]. Microsatellite DNA markers have also been developed for *Cannabis*[28]. *Cannabis* demonstrates an exceptional capacity for clonal propagation and therefore, genetic markers can trace entirely clonally produced plant material.

5. Spectral characteristics of *Cannabis*

The studies examining the spectral signature of *Cannabis* are limited and often contradictory in nature regarding the actual separability of *Cannabis* from other vegetation. In general all healthy green vegetation has the same general spectral properties (i.e. shape as defined by the location of absorption features or reflective peaks) (Figure 3).

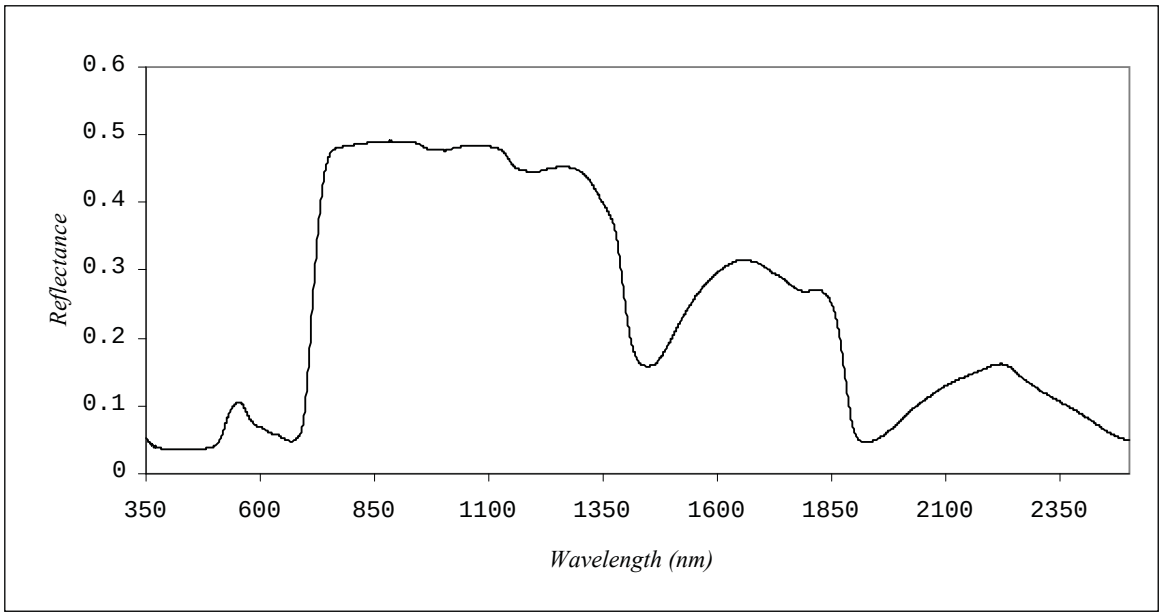

Figure 3. The general shape of the spectral response of healthy green vegetation. Reflectance is reported as a unit-less ratio where 0.5 corresponds to 50% of incident radiation being reflected.

The region centered around 550nm is known as the *green peak* in vegetation spectra and is representative of photosynthetic pigments such as chlorophylls a and b and photoprotection pigments associated with the xanthophyll cycle [13, 29-31]. Healthy, green vegetation has strong absorption in the red wavelengths (620-700nm) and high reflectance in the near infrared. The inflection point between the two is referred to as the *red-edge* and can be related to foliar nitrogen and chlorophyll content [16]. The plateau in the near infrared region is also a characteristic of vegetation reflectance spectra[32]; it is predominantly controlled by internal structure at the leaf level [14, 32] and is also influenced by leaf area index (total leaf area per ground area), water content, plant physiology and stress at the canopy level [14].

One of the earliest publication examining the spectral properties of *Cannabis* is [33]. In that study, the reflectance and transmittance of leaves from several varieties of *C. sativa* was compared to the reflectance and transmittance of other vegetation native to the East coast of the United States. Both sides of the leaves were measured along with the effect of the application of nitrogen fertilizer. The wavelengths with the greatest differences through time (i.e. plant growth) were reported to be around 700nm and 550-

600nm. Similar wavelengths were also reported to be influenced by the nitrogen fertilization. Differences between strains of *Cannabis* were centered around 550nm and near 720nm but were found to be minimal. The methodology used to assess differences between spectra in this study constituted subtracting one spectrum from another. This however, does not take into account the unusual properties of such hyperdimensional data[34]. In comparison to the leaf spectra of seven tree species and eight herbaceous species the greatest difference was observed in the 550 and 720nm regions of the spectrum. The greatest similarity was found between *Cannabis* and herbaceous vegetation in comparison to *Cannabis* and tree reflectance.

Other more recent studies examine the spectral signatures of *Cannabis* both at the ground level and from airborne hyperspectral imagery [9, 35, 36]. Though findings were inconclusive, [36] illustrate a potential unique feature in the second derivative of the reflectance spectra at 695nm of *Cannabis* in comparison to other vegetation from airborne imagery (19 band CASI data). Upon further analysis [36] determined however, that the feature was not unique to *Cannabis*. Data analysis by [36] was conducted on radiance data, not calibrated reflectance.

In comparison, [35] illustrate that the most likely reason for the unique "hazy emerald-green" reflectance of *Cannabis* reported by trained spotters is due to specular reflectance from the waxy cuticle layer of the leaves and from scattering due to microscopic structures on the leaf surfaces. The scattering of blue sky-light was hypothesized to add to the green reflectance (i.e. green peak) inherent in green vegetation to create an emerald-green quality to the spectral signature of *Cannabis*. Thus, [35] state that in clear conditions, the blue component of the reflectance will be stronger than under cloudy conditions where green reflectance and internal leaf elements would be dominant. The contrast of the "emerald-green" appearance of the *Cannabis* may be enhanced by the introduction of fertilizer and elimination of water stress especially if other vegetation is stressed due to a lack of water, nutrients or is subject to other conditions such as pests. The canopy architecture of *Cannabis* was hypothesized to the cause of the "hazy" effect when the plants are seen from a distance. In contrast to [33], no significant differences were observed between the leaf reflectance of different strains/varieties, leading to the conclusion by [35] that THC content has little effect on reflectance. Interviews

conducted with spotters indicated that *Cannabis* may have a unique directional reflectance feature. Photographs of maximum and minimum polarized reflectance indicated that the waxy cuticle may in certain cases have a strong enough reflectance for the leaves to appear white. Examination of cold-stage electron micrographs indicated that the leaves are covered with patches of aligned rods, only a fraction of a visible wavelength of light in diameter and multiple wavelength dimensions long. In addition, the orientation of the rods in adjacent patches was found to be different. A waxy substrate was also seen beneath the rods. The contribution of the rods and the waxy substrate were found to contribute to the preferential scattering of blue light[35]. Using 16 band airborne imagery, [35] concluded that the sixteen bands from the visible through near infrared wavelengths were insufficient for discriminating *Cannabis* from other vegetation types. The analysis methodology of the airborne imagery consisted of conventional supervised and unsupervised classification across the entire airborne scene. The Mahalanobis supervised classification provided the best results using various combinations of the bands at 780, 800, 850, 880, 990nm. Many classification errors led to the conclusion that the method was not successful at discriminating *Cannabis* from the imagery.

In a recent study [9] examine the spectral reflectance of *Cannabis* at the leaf level and from airborne and satellite imagery in British Columbia. Using a combination of feature selection and pattern classification (machine learning)[37] perfect separability was achieved with ten wavelengths (bands) at the leaf level. The areas of greatest separability at the leaf level included the blue wavelengths and the region between 630-680nm. The 550nm region previously reported was not found to be useful in separating the reflectance of *Cannabis* from other herbaceous vegetation (Figure 4).

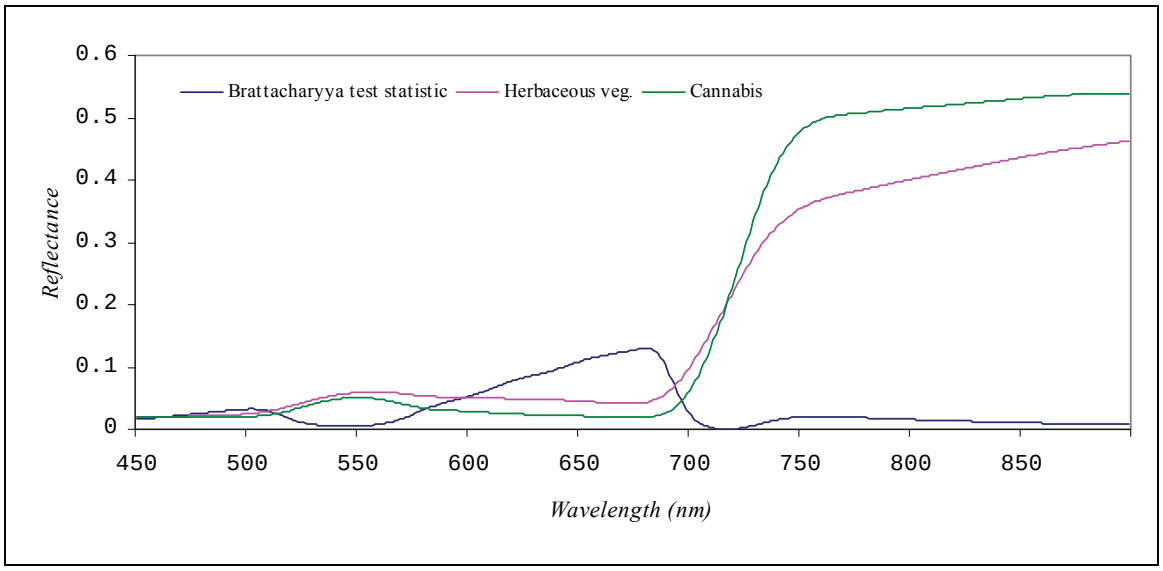

Figure 4. Differences were also seen between the spectra between *Cannabis* growing in two geographic regions investigated by [9].

The airborne imagery investigated in this study was the same as used by [36], converted to reflectance. Results from the in-situ study were used to guide the examination of the separability of the pixels indicated to represent known grow-ops. Using an n-dimensional visualization of the spectra and a measure of the spectral angle locations were highlighted as having the spectral signature the most similar to the known sites of *Cannabis*. In addition, an assessment of high resolution satellite imagery illustrated a potential for locating large grow operations but due to the limited spectral resolution [9] concluded that hyperspectral imagery provided the greatest separability.

In ongoing surveys, the United Nations Office on Drugs and Crime (UNODC) has been using satellite imagery to monitor the growth of illicit crops such as *Cannabis*, opium and coca[38-44]. Currently, methodologies employed in the surveys conducted in the different countries are not standardized, but follow similar principles of exploiting the phonological differences between the crops and other vegetation. Multispectral imagery (i.e. SPOT, IKONOS, Quickbird), containing only a few bands sensitive to radiation spanning from the blue to shortwave infrared wavelengths, is the type of imagery most often used in the UNODC surveys due to its relatively low cost and high repeat acquisition. The illicit crop plantations in these countries are generally large in size and limited efforts have been made to hide them in comparison to plantations in North

America which are considerably smaller and in many cases significant efforts have been made by the growers to make their sites difficult to locate; posing a more difficult detection problem.

As has been shown by [45], environmental factors greatly affect the spectral signature of vegetation and as [8] found, specifically for *Cannabis*, the chemical composition of the plant is affected. It is not currently known how these changes are manifested in the spectral response of *Cannabis* but would need to be investigated in order for region insensitive models to be developed.

6. Seizures and trafficking

6.1 Seizures and product value

In 2001, production of *Cannabis* was estimated at 800 metric tons [46, 47], no details are given however, regarding the number of seizures or the breakdown between indoor and outdoor operations. The United Nations 2006 world drug report [48] indicates that for the year 2004 herbal *Cannabis* seizures in Canada were a total of 33,777.4kg, where herbal *Cannabis* refers to the product containing the flowers and small leaves of the plants. In the same year, Operation SABOT, a Department of Defense and RCMP collaborative effort reports 177,767 plants were seized from outdoor operations resulting in 51 arrests [49]; this figure does not include the plants seized by municipal police departments.

For British Columbia specifically, the primary growing region in the country [47] statistics have been compiled for the period spanning 1997-2000 [50]. Between 1997 and 2000, the number of plants seized from outdoor operations in the province steadily increased from 12,134 to 39,790 (total of 115, 027). The same report also indicates an increase in size of outdoor operations of 76% over the period of 1997-2000 with a concentration of operations in the Kootenay, Vancouver Island/ Coastal region, Thompson/Okanagan and North Coast areas. The weight of the seized harvested *Cannabis* ranged from 114kg (1997) to 146kg (1999) and 125kg in 2000 with a total of 525kg over the four years.

Overall in Canada, the retail price for herbal *Cannabis*, *Cannabis* oil and *Cannabis* resin were as follows for 2004 ($US)[48] (Table 5):

Table 5. Value of herbal *Cannabis*, oil and resin at retail and wholesale prices in Canada for 2004

Product	Typical Retail (/g)	Retail Range (/g)	Typical Wholesale (/kg)	Wholesale Range (/kg)
Herbal *Cannabis*	7.50	7.50-18.70	2,969.50	2,242.20 – 4.484.30
Cannabis oil	18.70	15.00-37.40	5,979.10	5,979.10-8,968.50
Cannabis resin	7.50	7.50-18.70	7,473.90	6,726.50-8,968.60

For British Columbia, the average price over the 1997-2000 period the price of marketable *Cannabis* with the assumption of 100g of product per plant ($CAD) [50] is (Table 6):

Table 6. Retail and wholesale prices of marketable *Cannabis* for British Columbia (1997-2000)

Product	Retail range (/kg)	Wholesale range (/kg)
Marketable *Cannabis*	3,500-9,000	3,500-7,5000

From the estimates of [50], in 2000 alone the seized *Cannabis* was worth between $172 million and $466 million. The product seized between 1997-2000 in British Columbia was estimated to be worth $462 million - $1.25 billion.

In a conservative estimate of 400g/m^2 of product [2] with a planting density of 0.625plants/m^2[9], the 177,767 outdoor plants seized in 2004 would have occupied an area of 284,427m^2 and produced 113,771kg of marketable product. At the typical wholesale price of herbal *Cannabis*, the value of seized plants would be $US337.8 million with a range of $US 255 million - $US 510.2 million. Prices of the same product smuggled into United States can quadruple in major metropolitan areas[47].

6.2 Canada-US Trafficking

It has been estimated that fifty to sixty percent of *Cannabis* produced in Canada is trafficked into the United States[51]. The amount of seizures along the Canada-US border increased from 0.35 metric tons (1999) to 3.25 metric tons in 2000 [51] with major points of entry between British Columbia and Washington state, Detroit-Windsor and Buffalo,

and the Quebec and Ontario borders with New York, Vermont and Maine [47] (Figure 5) for a higher profit margin or trade for handguns or other drugs such as cocaine[47]. Facilitated by networks of organized criminal groups, *Cannabis* distribution within Canada and increased trafficking to the United States is expected [47, 51].

Figure 5. Cross border trafficking of *Cannabis* in North America [51].

7. Conclusions and future work

- Although the acceptance of different species of *Cannabis* is still controversial, three main varieties have been shown: *C. sativa*, *C. indica, C. ruderalis*, and are actively being used in breeding programs to produce news strains with specific desired characteristics.

- From an ecological perspective, *Cannabis* is a relatively hardy plant. However, it does have specific needs and characteristics that are exploited by growers, but could also be employed to optimize searches for grow operations.

- Breeders are selectively choosing plants to maximize THC content. As a result, THC content has been steadily increasing over the years. Specific strains of *Cannabis* maximize THC content and by knowing their characteristics and environmental requirements, they can be more effectively located.

- *Cannabis* plants contain several unique chemical compounds which may be responsible for their unique spectral characteristics. It has also been shown that both age and environment affect the chemical composition of the plants, allowing for the development of chemical fingerprints for *Cannabis*. Additional research is needed to examine the effect of plant age and environment on their spectral signatures to maximize the success of detection efforts.

- The area of *Cannabis* genetics is a relatively new area of research but is expanding as breeders seek to exploit the most desired traits in their plants.

- By understanding the drivers behind the unique spectral signature of *Cannabis*, remote sensing technology could be better exploited to locate the outdoor grow operations in North America which present a more difficult problem in comparison to the very large operations elsewhere due to their size and the efforts made to hide them within a large landmass (salt and pepper effect).

- A more efficient application of remote sensing technology with the combination of GIS modeling will enhance the detection capability of eradication efforts.

- The location of illegal outdoor *Cannabis* requires a multidisciplinary effort with integration into policy and the court system.

- Future work includes the integration of the topics presented in this report into a series of recommendations for biological control to hinder the repeated use of sites by growers as well as an in-depth examination of specific characteristics of strains that would facilitate their detection.

- Future work also includes the examination of the changes of the spectral signature of *Cannabis* as it matures as well as an examination of the environmental effects on the spectral response to develop a region insensitive detection model.

Titan Analysis welcomes feedback regarding the information presented in this report in order to narrow the focus to the characteristics *Cannabis* and topics deemed most relevant in order to synthesize the most efficient set of detection tools and methodologies.

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