SPATIAL DISTRIBUTION AND HISTORICAL DYNAMICS OF THREATENED CONIFERS OF THE DALAT PLATEAU, VIETNAM

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The undersigned, appointed by the dean of the Graduate School,

have examined the thesis entitled

SPATIAL DISTRIBUTION AND HISTORICAL DYNAMICS OF THREATENED CONIFERS OF THE DALAT PLATEAU, VIETNAM

Presented by Trang Thi Thu Tran

A candidate for the degree of

Master of Arts of Geography

And hereby certify that, in their opinion, it is worthy of acceptance.

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ABSTRACT

The Dalat Plateau is one of several biodiversity hotspots in Vietnam. It is considered to be one of five centers of plant diversity and one of three endemic bird areas in the country. Almost half of the conifer species known to occur in Vietnam are found in this area. Among the 14 species of conifers found here, six have been evaluated in the 2004 IUCN Global Red List of Threatened Species: *Pinus krempfii* (VU B1+2c), *Pinus dalatensis* (VU B1+2c*), Pinus latter*i (NT), *Fokienia hodginsii* (NT), *Calocedrus macrolepis* (VU B1 + 2b), *and Cephalotaxus mannii* (VU A1d). *Pinus krempfii* and *Pinus dalatensis* are endemic and rare species in this area. However, due to the remoteness of the mountains where these conifers grow, there is very limited information on the ecology, habitat, distribution, population characteristics or historical disturbances for these species. This research examines selected aspects of conifer biogeography in Bidoup-Nui Ba national park to determine their distribution and relationship to topography, size class structure, and disturbances between the 1970s – 2000s. A combination of field work, remote sensing and GIS was used to determine these patterns.

Analyses were conducted at spatial scales ranging from individual stands to the full landscape of BiDoup-Nui Ba National Park a total of 36 genera and 21 families were identified. Among the seven conifer species sampled, three were classified as threatened. Of the nine general land cover types in the study area, these conifer species occurred in the mixed forest and the coniferous forests, from 1,000 – 2,200 m asl. Results show that the stand structures for these conifer species were unimodal and decreasing. Age-class distribution of *Pinus krempfii* showed its population to be the oldest. This study suggests

that the decreasing number of threatened conifers, especially the old age stands, are vulnerable.

CHAPTER 1

LITERATURE REVIEW

1. Overview of Vietnamese forest

Vietnam is endowed with diverse natural resources and complex geographical patterns including a wide range of natural features such as rivers, plains, mountains, highlands and islands, all contributing to a high biodiversity. The term biodiversity (biological diversity) describes „the sum total of living resources on the planet which includes all plants and animals: It is the diversity and variety within the world‟s numerous species and the differing ecosystem that they inhabit‟ (IUCN 2007, Mac *et al*. 1998). In short, this definition has three parts: genetic diversity, species diversity and ecosystem diversity. Vietnam is considered one of the most biodiverse countries in the world and is classified as a high priority for global conservation (An 2001, DeKonick 1999, IUCN 2007). Conservation of Vietnam‟s biological richness is focused on maintaining known species and discovering of new species of global significance (IUCN 2007). It is home to approximately 1,500 animals including mammals, reptiles, amphibians, and birds. Vietnam has a high number of plant species, estimated at more than 12,000 species (of which around 7,000 plant species have been identified, and 40% are believed to be endemic) (IUCN 2007). Additionally, the national Red List recorded that more than 700 flora and fauna species are vulnerable and threatened and 310 of these are currently listed in the Global Red List (IUCN 2006).

Vietnam is situated along the southeast margin of the Indochina peninsula between 8°30‟-23°22‟ N, and 102°10‟-109°24‟ E (see Figure 1). It is bordered on the north by China, on the south by the Gulf of Thailand, and on the west by Laos and Cambodia. This elongated, S-shaped country has a total area of 331,123km^2 divided into three core economic and ecological regions: the North, the South, and the Central- ranging from mountainous regions to marine. Three quarters of Vietnam is predominantly hilly or mountainous with an average altitude of over 1000 meters (IUCN 2007, Jong *et al.* 2006). The mountainous areas are composed mainly of granite, gneiss, shale, schist, and sandstone. The highest mountain, in the Hoang Lien Son mountain range, in the North, is around 3143 m. The main geological character of the Central is Truong Son Mountain (Annam Highlands) and is considered to be the backbone of Vietnam. This mountain range is divided into the Northern and the Southern Truong Son by the Hai Van pass. The Dalat Plateau (or Central Highlands) is at the Southern part of the Central region and is located between Cambodia and the South China Sea. The main geographical feature of the South is the Mekong River.

Vietnam‟s weather is influenced by a tropical climate, and it is quite varied due to the vast range of latitudes and altitudes in the country. The nation can be divided into three major zones: Northern climate – from the boundary between Vietnam and China to the Ca River, Central climate – from the Ca River along the Truong Son Range to Mui Dinh, and Southern climate – including the South Delta, the Central Highlands, and the Edge of Southern Truong Son Range. Exposure to sunlight varies from the North to the South. The South receives around 2000-3000 hrs of sunshine regime (160 Kcal/cm^2 year), meanwhile the North gets 1400-2000 hrs of sunlight (110-140 Kcal/ cm^2 year; toan 1998,

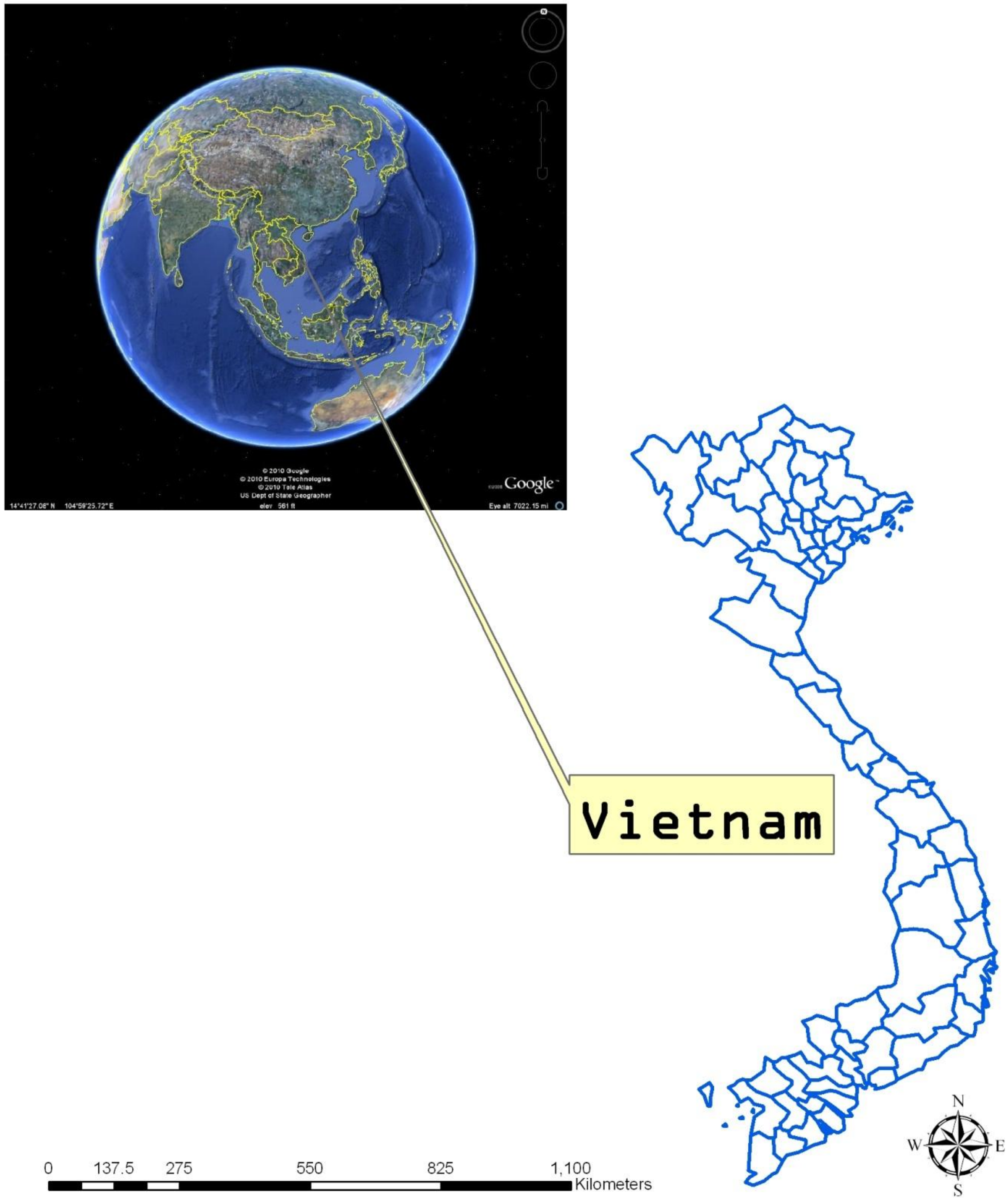

Figure 1 Location of Vietnam

Lap 1999). The average temperature in the North is about 21°C (70°F); and in the South 27°C (81°F). The temperature drops about 0.5°C for every 100m in altitude (IUCN 1994). Humidity and rainfall are both high.

Average rainfall in the rainy season comprises about 70%-80% of the precipitation of the whole year. Annual rainfall averages about 2,000mm with over 3,000mm in some central areas, but it can be as low as around 500mm on the southeast coast. Humidity averages about 80-85% in the north and 78-83% in the south (Trung 1998, Lap 1999).

The hot, humid, and rainy weather in Vietnam is controlled by three main monsoons, with typhoons from the East Sea affecting the whole country from July to November which often brings strong winds, heavy rain fall and flooding along the coast. The winter monsoon occurs mainly in the North in two time periods. From September to April, the winter monsoon originates from Siberia, bringing dry and cold winds. From December to January, this monsoon blows through the East Sea and becomes humid (Trung 1998). The Southwest Pacific Monsoon blows through Cambodia, and Laos. In Vietnam, it meets the Western Truong Son slope causing a heavy rain fall, but dry and hot on the other side of the mountainside. The other monsoon, the Southeast, comes from the East Sea is considered to be cool and rainy in the entire country (Trung 1998, Lap 1999).

Vietnam‟s abundant forest vegetation is a mix of plant species which emigrated from the Himalaya-Yunnam-Guizhou flora in the northwest, the India-Myanmar flora in the west, and the Malaysia-Indonesian flora in the south and southeast (Trung 1998). Scientific references to Vietnamese plant life have been found since the early 20th century

(Lecomte 1921, 1924, Chevalier 1944, De Ferré, 1948, Buchholz 1951). Several authors have developed classification systems to describe this vegetation. Duong (2004) categorized it into eight types: closed evergreen broadleaf forest, open evergreen broadleaf forest, broadleaf deciduous forest, coniferous forest, mangrove forest, shrub, grassland, and grassy wetland. Averyanov *et al.*(2003) classified Vietnam‟s vegetation into seven main types: evegreen broadleaf plateau forests on alkaline soils, evergreen and semi-deciduous forest on limestone mountains, evergreen lowland forests on acidic substrate between sea level and 1000m, evergreen montane and highlands forests on acidic substrates between 1000 and 3000m, semi-deciduous and deciduous dry lowland forest from sea level up to 500 (700) m, coastal vegetation, lowland wetlands and mangrove, and secondary and agriculture plant communities. Elevationally-zoned forest types, following the *International Classification and Mapping of Vegetation* (UNESCO, 1973), Thai Van Trung (1998), with modified altitudinal ranges as accepted by the *National Atlas of Vietnam* (Nguyen Van Chien, 1997) include:

0 to 600-700 m a.s.l. – lowland forest;

600-700 to 1500-1600 m – submontane forest;

1500-1600 to 2600 m – montane forest,

2600 to 3143 m – subalpine forest.

The characteristics of these Vietnamese forest vegetation types are as follows (Chien 1997, Trung 2000, Averyanov *et al.* 2003):

1) Tropical evergreen broad-leaved forest

This kind of forest occurs widely throughout the country at elevations below 700 m in the North and below 1000 m in the South (Chan & Dung 1992, Trung 1998). The mean annual temperature in these vegetation types is between 20°C -25°C, and the annual precipitation is more than 1200mm (Trung 1998). The forest structure is complex with a high diversity of tree, vine, epiphyte and shrub species. The strata comprise from 2-5 layers including a layer of emergent, the main canopy, the subcanopy, the shrub understory, and the forest floor layer.

2) Tropical semi-deciduous broad-leaved forest

This vegetation type is found mostly in the North and the Central Highland at the same elevation as the tropical evergreen broad-leaved forest (Chan & Dung 1992, Trung 1998). The mean annual temperature in these areas ranges from 20-25°C, with the coldest month from 15-20°C. Annual rainfall is higher than in the tropical evergreen broad-leaved forest, from 1200-2500mm, but the dry season my last from 4-6 months and one month usually has no rain (Trung 1998). The forest structure is also complex and diverse with deciduous trees dominating from 25-75% of the timber (Chan & Dung 1992).

3) Tropical deciduous broad-leaved forest

This forest type occurs at an elevation of less than 700 m in the North and below 1000 m in the South. The annual rainfall is about 600mm, and the dry season is from 4-6 months with at least one month without rain (Trung 1998). The forest structure is simple with two main layers of trees that are up to 75% deciduous (Chan & Dung 1992).

4) Subtropical evergreen forest

This type of forest is distributed at high elevations, above 700m in the North and 1000m in the South (Chan & Dung 1992, Trung 1998). The mean annual temperature ranges from 15-20°C and the annual rainfall is high, from 1200 to 2500mm. The forest structure is composed of two main layers of trees (Chan & Dung 1992).

5) Limestone forest

This forest occurs on limestone substrates in the North and middle-North of Vietnam. It is approximately 5.4% of total forested land (Phon *et al.* 2001). The forest structure is simple with 1-2 layers of slow-growing trees.

6) Coniferous forest

This forest is found in the North and Central Highlands, at elevations of over 1000m. The annual precipitation is only from 600-1200mm (Chan & Dung 1996). The dry season is long, from 4-6 months, with one month without rain (Trung 1998). The forest structure is simple with two species dominant in the area (*Pinus merkusii and P. kesiya*; Chan & Dung 1992).

7) Mangrove forest

The occurrence of this forest type is along the coast of the country, mainly in the South. The forest structure is simple with often one layer (Chan & Dung 1992).

8) Bamboo forest

These kinds of forests are distributed throughout the country and emerge after disturbance, such as harvesting the natural forest, or slash and burn cultivation (Chan & Dung 1992).

The rate of biodiversity degradation is more rapid in Vietnam than in other countries across the region (Figure 2). Furthermore, the loss of biodiversity has caused Vietnam to be considered a biologically-impoverished nation. Flora and fauna populations decrease with each passing year, especially rare and endangered species, resulting in an alarming number of threatened species found in the National and International Red Data book. It is clear that this loss is closely connected to the degradation of Vietnam"s forest during the last century. Jong *et al.* (2006) defined forest degradation as a "process that leads to a loss of forest structure, native species diversity, the ecological processes that characterize natural forest, and productivity." Although estimates of Vietnam forest losses vary, most authors recognized that forest cover fell from nearly 50 percent of total land area in 1945 (Vo Quy 1996, MOF 1991, Sam 1994, Quy & Can 1994, can & Quy 1994) to about 27 percent (Sam 1994) or as low as 16 percent in 1993 (WCMC 1996). Biodiversity conservation and protection of natural ecosystems are some of Vietnam"s most important challenges.

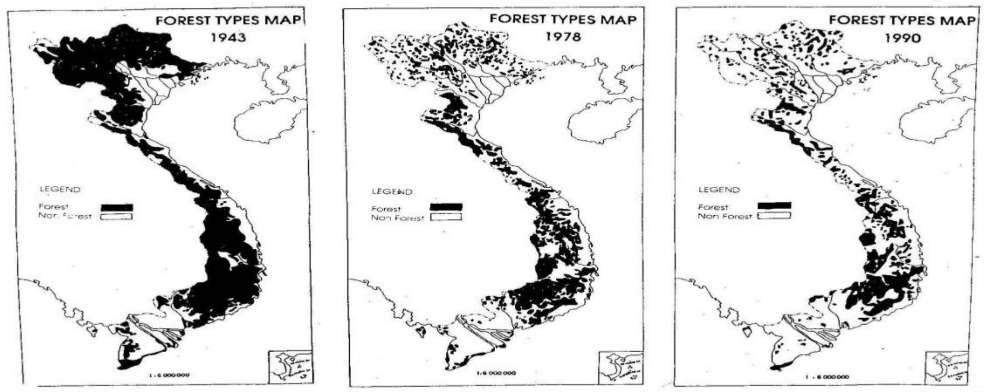

Figure 2 Vietnamese forest cover in 1943, 1978, and in 1990 (Maurand 1943, FIPI 1978 and 1995)

Vietnam has developed a number of national and international programs and policies since the late 1980s to preserve biodiversity (Hiep *et al.* 2005, Farjon *et al.* 2004). A system of forest protection was established with the aim of preserving the remaining natural areas in the country, as well as to conserving the threatened and endemic species of flora and fauna. Furthermore, Vietnam government reforestation programs have increased forest cover to around 39 percent (12.9 million ha) of the total area by 2006. The overall quality and quantity of Vietnam‟s forest however, has decreased rapidly due to military conflict and social preogress.

The rise of deforestation began with the last wars between 1945 and 1975. Therefore it devastated much of the countryside due to the use of herbicides (Egler 1968, Tschirley 1974, Orians & Pfeiffer 1970, Norman 1974, DeKoninck 1998). Along with the wars, a high rate of population growth (approximately 2% in 1990s), high population density (about 257 inhabitants/ km^2, 85 million inhabitants on 330,000 km^2 in 2006) and rural poverty are recognized as the truly fundamental causes of deforestation (Boyle 2003, DeKonick 1998). Vietnam is a highly populated, developing country. These factors have resulted in a lack of arable land, large-scale logging, and unsustainable collections of non-timber forest products, agricultural encroachments, fire, and infrastructure developments (Nguyen Tien Hiep *et al.* 2005, Nguyen Duc To Luu and Thomas 2004). In addition, a lack of understanding among resource managers has caused much of Vietnam"s deforestation. Scientists and biodiversity managers have provided scarce knowledge about the status of important species and ecosystems (Nguyen Tien Hiep *et al.* 2005). The lack of success of the Forest Land Allocation Program due to lack of knowledge and technical understanding of the nature of the actual farming system (Gomiero *et al.* 2000) is one example. Among other factors, prevailing national economic growth at a very fast pace without proper regard for habitat and biodiversity and excessive reliance on forest resources are other major problems (DeKonick 1998).

2. Vietnamese conifers

Conifers are one of three different orders of the Gymnosperms, a group of vascular plants whose seeds are not enclosed by a ripened ovary („naked seeds"). They are easily distinguished from angiosperms (flowering plants), which have seeds enclosed in carpels, forming fruit. Conifers stand out as a group due to their needle-like leaves, woody cones, dependence upon wind-pollination, long life-span, wide ecological amplitudes and high fecundity. Male and female organs develop on separate strobili (cones). The young cones have only one sex, either male or female. The fruit of the conifer is the mature female cone that produces seed. In evergreen forests, trees of conifers normally reach 25-30m, and frequently dominate the canopy. The conifers include the oldest and largest individuals in the plant kingdom. The sugar pine, *Pinus lambertiana*, reaches a height of about 70m (230 ft.), a basal diameter of about 3.3m (11ft.) that may reach an age of 500 years (Mirov 1967). Rocky Mountain Tree-Ring Research Institute (2007) published a database of ancient trees and their age recognized oldest individual is a conifer; according to this research, *Pinus longaeva* has been recorded as old as 4844 years. Conifers play major ecological and economic roles. Ecologically, conifer-dominated forests provide habitat for animals, control erosion and mediate the climate (Anderson and Lhoir 2006). Economically, conifer forests are extensively utilized as a source of forest products due to their high grade timber which is converted into lumber, furniture and non-timber products such as pulp for paper, bark, resin and oil for medicinal or commercial uses. In many gardens, conifer species are used for hedging or shelter plants (Rushforth 1987) and are frequently planted in reforestation projects. Conifer bark is also used extensively as garden mulch. In some countries, conifers have cultural meanings that include spiritual well-being (Hiep *et al.* 2005).

Coniferales is the largest group among the gymnosperms, with new species and genera still being discovered. Saxton‟s (1913) classification of Conifers included five families, Araucaceae, Podocarpaceae, Pinaceae, Cupressaceae, and Taxaceae. Buchholz‟ (1948) classification of the Coniferales includes 50 genera and approximately 550 species. Keng (1975) recognized more than 560 living species comprising 8 families of conifers (Phyllocladaceae, Taxaceae, Podocarpaceae, Cephalotaceae, Araucariaceae, Pinaceae, Taxodiaceae, and Cupressaceae). Rushforth (1987) and Miller (1982, 1988) identified seven families, containing some 48 genera, and over 600 species. Farjon (2001) reported 630 species of conifer belonging to 70 genera and eight families. Based on the classification schemes by Keng (1975) and Thomas *et al.* (2001), Anderson and Lhoir (2006) accepted the currently known diversity at approximately 7 families, 53 genera and 620 living species.

Although there is a little agreement on the number and classification of species, conifers are recognized for their worldwide distribution, with extensive latitudinal and longitudinal ranges. Pines exhibit broad geographic ranges, from the northern to the southern hemisphere (Buchholz 1949, Li 1953, Seward 1959, Mirov 1967, Keng 1975, Farjon 2005, Anderson and Lhoir 2006) in many habitats (Li 1953). At least 60% of the living genera occur in the Northern Hemisphere (Chamberlain, 1934, Buchholz 1949, Li 1953, and Anderson and Lhoir 2006).

The evolutionary pathways of ancient conifers have been subject to considerable debate amongst biologists since the early 20th century. Evidence from the fossil record, living species and plate tectonics show that toward the end of the Carboniferous, Pangaea - the super-continent that existed during the Paleozoic era - had separated out into two supercontinents: Gondawana to the south and Laurasia to the north. This event divided conifers into two groups, one northern and one southern (Thomas and Spicer 1959, Anderson and Lhoir 2006). Buchholz (1959) held that most modern conifer families originated in the Mesozoic era, including Pinaceae, Taxodiaceae, and Podocarpaceae.

Miller‟s (1982) brief review of the occurrence of major conifer taxa in geologic time showed that several modern families have been contemporaneous with their presumed ancestor (*Voltziaceae)* such as Pinaceae, Taxaceae, Taxodiaceae, Cupressaceae, and Araucaceae that have been documented to appear in the Triassic (Araucaceae), and middle Jurassic (Miller 1982). Pinaceae fossils were discovered growing in the Triassic primarily in Northern Hemisphere; the family has since been introduced to a variety of places in the world (Mirov 1967, Mirov and Hasbrouck 1976, Miller 1976). Podocarpaceae are documented to date from the Triassic and are native to the southern hemisphere (Buhholz 1959, Li 1953, Thomas and Spicer 1987). The Araucaceae also originated in the southern hemisphere, where all living genera of this prominent family now occur. The appearance of the Cupressaceae in southeast Africa resulted from the migration from western Asia down the East African coast during late Tertiary epoch (Anderssion and Lhoir 2001). Families with northern hemisphere origins include the Cephalotaceae, Taxodicaceae, and Taxaceae (Thomas and Spicer 1986, Anderssion and Lhoir 2001).

Pinaceae are one of the largest and most dominant components of the vegetation over large parts of the Northern hemisphere. The earliest fossils have been described from the early Mesozoic era (Miller 1976, Miller 1982, Mirov and Hasbrouck 1976). It is generally believed that Pinaceae originated in the north, where their Cretaceous-age fossils are abundant. Two large groups of Pinaceae - hard pines and white pines - separated during the Cretaceous period. During the Tertiary, pines expanded over large parts of the world along with angiosperms, spreading for instance, from the Great Basin to upland Mexico and to Nicaragua. Some pines also migrated northward from Southeast

Asia during the late Tertiary (Mirov 1967, Mirov and Hasbrouck 1976). From the north, pine migrated to Southeast Asia no earlier than the Tertiary (Mirov 1967). According to Farjon (2001), pines fossils found in Mexico and Southeast Asia are no older than Pleistocene.

The present Vietnamese conifers represent a commingling of conifer migrations from northward and southward during the late Tertiary (Nguyen Duc To Luu & Thomas, 2004). In the north and west of the Indochina peninsula, conifers mainly from Europe and North America emigrated across the Himalaya-Yunnam-Guizhou and India-Myanmar paths. Pine genera and *Glyptostrobus* are examples of Vietnamese conifers originating from the northern hemisphere. From the south, migrations taking place from Australia crossed the equator to reach the Indochina region via „stepping stones" along the Malaysian peninsula and Indonesian islands (Mirov 1967, Werner 1997). *Nageia wallichiana, Podocarpus neriifolius* and *Dacrycarpus imbricatus* are conifers with these tropical origins, and are found distributed throughout the moister, mountainous areas of Vietnam.

Present conifer distribution in Vietnam is concentrated in four areas of species richness through the country: North and Northeast zone, Hoang Lien Son Mountain range, the Northwest, and Central Highland areas (Figure 3; Luu & Thomas, 2004, Hiep *et al*. 2004).

1) *The Northeastern Zone* shares boundaries with the Hoang Lien Son Range and the east of the Red River. This region is formed mainly of low mountains alternating with hills, valleys and plains. The upper ridges are generally composed of highly eroded solid crystalline white limestone karst communities. The primary climatic influence is the

1. *The Northeastern Zone*
2. *Hoang Lien Son Mountain range*
3. *Northwest*
4. *Central Highland areas*

Figure 3. Main distribution zones of the conifers in Vietnam (Nguyen Duc To Luu and Thomas, 2004)

winter monsoon from China: cold and dry winters and summer rains. This type of geography and climate increases the favorablity of containing the highest conifer diversity in Vietnam (Hiep *et al.* 2005). *Xanthocyparis vietnamensis, Tsuga chinensis, Pseudotsuga sinensis, Keteleeria davidiana, Cupressus* cf *tonkinensis* and *Amentotaxus hatuyenensis* are example of the locally common species. Several species that are known to have their main distribution in China are also found in this region, such as *Amentotaxus yunnanensis*, *Podocarpus pilgeri*, and *Nageia fleuryi* (Nguyen Duc To Luu and Thomas 2004, Hiep *et al.* 2005).

2) *Hoang Lien Son Mountain range:* this highest part of the country is composed of granite and other silicate rocks. This area has a wet and cool climate. *Fokienia hodginsii* comprises a large stands and becomes the most widespread conifer, along with the

dominant northern temperate angiosperm families such as *Fagaceae* and *Lauraceae* (Nguyen Duc To Luu and Thomas 2004, Hiep *et al.* 2005).

3) *Northwest:* The topography is very complex ranging from steep mountains to valleys and hollows but the mean altitude tends to be lower than in the Hoang Lien massif, and the climate is generally drier. The geography is composed of silicate and limestone. This is home of the most widespread conifer, *Keteleeria evelyniana*. *Fokienia hodginsii*, *Cunninghamia konishii* , *Calocedrus*, and *Pinus latteri* occur here (Nguyen Duc To Luu and Thomas 2004, Hiep et al. 2005).

4) *Central Highlands:* This area shares boundaries with Laos and Cambodia in the west and the Southern Truong Son Range in the east. Geologic formations are composed of granite and other silicate rocks. The altitude ranges from lowest of 500m to more than 2000m. This is the second richest area for conifers in Vietnam. Conifer species distributions vary by altitude with changes in local climate. Lower altitude (600 -1600m) with lower rainfall is favorable for *Pinus kesiya, P. merkusii,* and *Keteleeria evelyniana; Calocedrus macrolepis, Cephalotaxus mannii* and *Taxus wallichiana* are more rare and restricted to moister areas. At altitudes higher than 1600m, *Fokienia hodginsii, Pinus dalatensis, P. krempfii* and *Dacrydium elatum* can be found. *Amentotaxus poilanei* is rare to the northern part of the Central Highlands while *Glyptostrobus pensilis* is only discovered in two small populations in Dak Lak province.

Currently, 33 conifer species have been discovered within Vietnam, belonging to about 27% of the total of around 50 conifer genera and eight families of conifers that have been found (Peterson 1980, Nguyen Duc To Luu & Thomas, 2004). Twenty-two of these species are globally threatened (Hiep *et al.* 2005: Table 1).

Table 1. Vietnamese conifer species and their status (Hiep *et.al.* 2004)

CONSERVATION STATUS		
FAMILY/SPECIES	**GLOBAL**	**NATIONAL**
CEPHALOTAXACEAE		
Cephalotaxus mannii	VULNERABLE A1d	RARE[1]
CUPRESSACEAE		
Calocedrus macrolepis	VULNERABLE B1+2b	ENDANGERED
Calocedrus rupestris	NOT EVALUATED [ENDANGERED A2cd, C1]	NOT EVALUATED
Cunninghamia konishii	VULNERABLE A1c	RARE
Cupressus sp.	NOT EVALUATED	RARE[2]
Fokienia hodginsii	NEAR-THREATENED	INSUFFICIENTLY KNOWN
Glyptostrobus pensilis	DATA DEFICIENT [ENDANGERED B1ab(i,iv), B2ab (i,iv), D]	ENDANGERED
Taiwania cryptomerioides	VULNERABLE A1d	NOT EVALUATED
Xanthocyparis vietnamensis	CRITICALLY ENDANGERED B2ab(v) [CRITICALLY ENDANGERED B1ab(ii-v), 2ab(ii-v)]	NOT EVALUATED
PINACEAE		

CONSERVATION STATUS		
FAMILY/SPECIES	**GLOBAL**	**NATIONAL**
Abies delavayi	LEAST CONCERN	RARE
Keteleeria davidiana	LEAST CONCERN	ENDANGERED
Keteleeria evelyniana	LEAST CONCERN	VULNERABLE
Pinus dalatensis	VULNERABLE B1+2c	RARE
Pinus kesiya	NOT EVALUATED	NOT EVALUATED
Pinus krempfii	VULNERABLE B1+2c [VULNERABLE B1ab(i-iii), 2ab(i-iii)]	RARE
Pinus kwangtungensis	NEAR-THREATENED[3]	VULNERABLE
Pinus latteri	NEAR-THREATENED	NOT EVALUATED
Pinus wangii	ENDANGERED B1+2bd	NOT EVALUATED
Pseudotsuga sinensis	VULNERABLE B1+2c	NOT EVALUATED
Tsuga chinensis	LEAST CONCERN	NOT EVALUATED
Tsuga dumosa	LEAST CONCERN	RARE
PODOCARPACEAE		
Dacrycarpus imbricatus	LEAST CONCERN	NOT EVALUATED
Dacrydium elatum	LEAST CONCERN	NOT EVALUATED
Nageia fleuryi	DATA DEFICIENT	VULNERABLE
Nageia wallichiana	LEAST CONCERN	VULNERABLE

CONSERVATION STATUS		
FAMILY/SPECIES	**GLOBAL**	**NATIONAL**
Podocarpus neriifolius	LEAST CONCERN	NOT EVALUATED
Podocarpus pilgeri	NOT EVALUATED	RARE
TAXACEAE		
Amentotaxus argotaenia	VULNERABLE A1c	RARE
Amentotaxus hatuyenensis	ENDANGERED A2c	RARE
Amentotaxus poilanei	VULNERABLE A2c	THREATENED
Amentotaxus yunnanensis	ENDANGERED A1c	THREATENED
Taxus chinensis	NOT EVALUATED [LEAST CONCERN]	RARE
Taxus wallichiana	DATA DEFICIENT [LEAST CONCERN]	RARE

Vietnamese conifers have attracted the attention of various scientists due to their rarity and since the discovery of a number of new species. Discovery of conifers in Vietnam has been carried out since the first quarter of the 20th century. The first puzzling localized endemic, with a restricted distribution in the southern part of the Central highlands (Farjon *et al.* 2004), was described by Lecomte (1921) as *Pinus krempfii*. *Pinus dalatensis* is also considered to be endemic to Vietnam. In recent years, more conifers have been added to the Flora of Vietnam, such as *Pinus kwangtungensis* (reported by Phan Ke Loc in 1984), *Amentotaxus hatuyenensis* (by Nguyen Tien Hiep & Vidal in 1996), *Pseudotsuga sinensis* and *Tsuga chinensis* (by Nguyen Tien Hiep *et al*. in 2000), *Keteleeria davidiana* (by Phan Ke Loc *et al.* 2002), and *Calocedrus rupestris* (by Averyanov *et al.* in 2004). Among the new finds, *Xanthocyparis vietnamensis* has attracted global attention since it is described as a new genus to science. More recent works (Hiep *et al.* 2002) reported a small population of the monotypic genus *Taiwania cryptomerioides* with a total of around 100 individuals distributed in Lao Cai province, which was only previously known from Taiwan, Yunnan and north east Myanmar. Another genus, *Glyptostrobus pensilis* was found in two small populations in Dac Lac province. This monotypic genus is considered one of the few remaining natural stands, which is also known from stands in southern China (Hiep *et al.* 2005). Another ancient genus with only two species was found in Thanh Hoa, Nghe An (Phan Ke Loc & Nguyen Tien Hiep 1999). Two of six known species of *Amentotaxus* found in Vietnam are localized endemics (Hiep *et al.* 2005).

Protection of these unique conifers and their natural ecosystems are one of Vietnam‟s most important conservation challenges. Due to their significance and threatened status, Vietnamese conifer species have become a greater focus of scientific research. Biological conservation was poorly developed in Vietnam and other Indochinese countries until the 1990s (Thomas 2007), but has rapidly become a subject of a number of research projects. Vietnam has been party to the Convention on Biological Diversity since 1994, and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) in 1994. The main goals of these programs are to provide recommendations for conservation policies, the improvement of management of protected areas, the identification of priorities, and improved dissemination of biodiversity knowledge. During the past decade, national and international scientists have paid particular attention to Vietnamese conifers. The first project, *Preservation, rehabilitation and utilization of Vietnamese montane forests* (162/10/017) was supported by the Department of Environment, Fisheries and Agriculture (DEFRA, United Kingdom). The second was *Community-based conservation of the Hoang Lien Son Mountain Ecosystem* hold by FFI Vietnam.

The primary focus of research on Vietnam conifers has been botanical classification. Taxonomy, morphology and classification of conifers were the early dominant paradigms in the Vietnamese plant literature. Although discovered by a French botanist at the beginning of the twenty century, the taxonomy of *Pinus krempfii* has been one of the most problematic since its discovery. Chevalier (1944) proposed this species as a new genus, *Ducampopinus,* based on several morphological and wood anatomical features. Other authors have suggested that the taxon represents a link between the genus *Pinus* and other genera such as *Keteleeria* and *Pseudolarix* (De Ferré 1948, 1953, Ickert-Bond 1997). More recently, researchers have applied many modern technological methods to infer plant phylogenies, including those of a number of gymnosperms. Secondary product chemistry, nuclear ribosomal DNA and chloroplast DNA sequences have been used extensively to contribute different types of information on the taxonomic position of some endemic and unique Vietnamese conifers (Erdtman *et al.* 1966, Liston *et al.*1999, Wang *et al.* 2000). These authors indicate that *Pinus krempfii* should be considered a member of subgenus *Strobus*. The new genus *Xanthocyparis vietnamensis* has been a main topic of discussion during the first decade of the 21st century. Previous research in taxonomy and classification has been carried out by various scientists. Xiang and Farjon (2003) compared the micromorphology of leaf cuticles with other members of the Cupressaceae. However, comparison of characters in the leaf epidermis alone cannot resolve the relationship of this species with its relatives. Little *et al.* (2004) used molecular techniques to combine with other informative morphological characters to test the taxonomic relation between *Chamaecyparis* and *Xanthocyparis.* Their study indicated that these species are closely related, and should be recognized as a single genus rather than two monotypic sister genera (Little *et al.* 2004).

This survey of conifer research in Vietnam to date reflects the primary focus on taxonomic classification. While this is one of the first important steps in plant study, Vietnamese conifers need to be understood more broadly with information from perspectives such as biogeography and ecology. The most prominent publications that have begun to address this gap are *Conifers of Vietnam* (Nguyen Duc To Luu & Thomas, 2004) and *Vietnam conifers: Conservation status review* (Hiep *et al.* 2005). The latter publication is an addition to the existing series of Vietnamese conservation status reviews produced by Fauna & Flora International. These references provide general information on Vietnamese conifers including general descriptions of morphology, distribution, ecology, uses, threats, protected area status, current conservation measure and recommended conservation measures. According to Hiep *et al*. (2004), these books "make significant contributions to national and international biodiversity conservation commitments made by the Government of Vietnam, including the national Biodiversity Action Plan, the Convention on Biological Diversity and its Global Strategy for Plant Conservation, and the Convention on International Trade in Endangered Species of Wild

Fauna & Flora." These reports offer significant information for long-term conservation of these species, but do not provide ecological information such as population structures, distribution of taxa, population sizes or stand dynamics. The conifer data, according to authors, was gathered from many years of botanical fieldwork and herbarium studies (Hiep *et al.*2004) and from national research institute publications (Nguyen Duc To Luu & Thomas, 2004). More detailed information on several „flagship species‟ has been compiled in reports by Farjon *et al.* (2004) and Regalado *et al.* (2006). Each conifer has been described by habitat, population size and conservation status. On the other hand, these papers are still preliminary findings and lacking in both the quality and quantity of scientific knowledge (Hiep *et al.* 2005). For instance, the age of these conifers has been reported to reach 800 years (Averyanov *et al.* 2005) or 2,000 years (Schmid 1974) although „no tree-ring counts has been published‟ (Farjon *et al.* 2004). The area of occupancy of conifers is also estimated in these reports. For example, the area of occupancy of *Pinus krempfii* is approximately less than 2,000 km^2 and *Xanthocyparis* population is reported "290 individuals scattered over a series of narrow ridges an area of 20.3 km^2" (Farjon *et al.* 2004). This work, therefore, is limited in supporting the quantitative analysis required for plant science. At present, there is no definitive study on the age structure of conifer populations in Vietnam.

A promising understanding of *Fokienia hodginsii* will be completed by the „Preparation and Implementation of a strategy for the management of *Fokienia hodginsii* in Vietnam by 2008‟ project (Osborn 2004). This project will conduct detailed research on both the economic status and plant science status of the species by assessing trade statistics from logging companies, assessing the volume of *Fokienia* standing wood through the use of remote sensing and ground truthing and conducting detailed research into its ecology and regeneration strategy. Hopefully this initial work will provide a strong knowledge for conservation this species.

This survey of the principal papers published on Vietnamese conifers reveals the limits of understanding of the current status on the ecology and population biology of conifer species. The dearth of biological and ecological knowledge about Vietnamese conifers is an urgent gap that needs to be filled. Data on variations in species distribution due to climate and soil conditions, dendrochronology (Hiep *et al.* 2004), and the relationship of species to historical disturbances is needed.

3. Coniferous forest dynamics

a. Disturbance and stand structure

A comprehensive review of disturbances has been provided by many ecological researchers, and a number of varying definitions have been proposed (Hobbs & Huenneke 1992). Grime (1979) defines disturbance as a process removing or damaging biomass, thereby altering subsequent population dynamics. Sousa (1984) describes disturbance as “a discrete, punctuated killing, displacement, or damaging of one or more individuals that directly or indirectly creates an opportunity for new individuals to become established.” White and Pickett (1985) expand the definition to “any relative discrete event in time that disrupts ecosystem, community, or population structure, and changes resources, substrate availability, or the physical environment.” Disturbance is also defined as “a process that alters the birth and death rates of individuals present in the patch" (Petraitis *et al.* 1989). Pickett *et al.* (1989) view disturbance as causing a change in structure due to factors external to the hierarchical level of the system of interest. Runkle (1985) defines disturbance in forest vegetation as a force that kill at least one canopy forest tree. Although there are many definitions of disturbance all agree that it is a very important component of many ecosystems since it effects community structure and functioning (Pickett & White 1985).

Studies have shown the important role of disturbance to the ecosystems, species diversity, especially in shaping forest structure and function. Forests depend on disturbance for maintenance and regeneration (Sakio 1997) across a range of spatial and temporal scales. Physical disturbances kill and remove existing trees above the forest vegetation, as well as reallocate resources such as light and water, and thus often releasing open forest space and nutrients that support recruitment. They may also promote invasions of non-native and weedy plant species (Ewel 1986, Hobbs 1989, 1991). Disturbance is often considered a primary mechanism underlying the maintenance of species diversity, particularly in species-rich ecosystem such as tropical forests (Connell 1978, Huston 1979, Petraitis *et al.* 1989).

The impact of disturbance on a forest landscape depends on a combination of biotic factors (stand composition, canopy structure, size, age and vigor), abiotic factors (severity, soil and site properties, etc.), and the nature of the disturbance agent itself. Disturbances vary in type, severity, frequency, magnitude, size, and intensity (Saiko 1997). The causes of disturbance are also varied, including fires, storms, floods, winds, droughts, pest/disease and human disturbance such as cutting and agriculture (Hobbs & Huenneke 1992). Canopy fires kill large trees and may consume varying quantities of organic material. Often only the largest trees can survive catastrophic wildfire, but most of the smaller trees are consumed (Franklin *et al.* 2002). Windthrow changes overstory trees to logs and debris on the forest floor. It creates forest canopy openings and a decrease in standing biomass. Vegetation composition may not change much under windthrow (Cooper-Ellis *et al.* 1999). Clear-cutting removes nearly all overstory trees and prevents the accumulation of coarse woody debris.

The time interval between successive disturbances provides opportunities for species recruitment; meanwhile the rate of competitive exclusion sets the pace of species extinctions within patches. The patches may approach maturity and be dominated by only a few species if the disturbances are too mild or too rare. On the other hand, if the disturbance is too intense or common, only a few species that are resistant to this disruption will persist (Petraitis *et al.* 1989). In this case, a second disturbance occurring before the species community reaches reproductive maturity stage may affect the availability of propagules (Hobbs and Huenneke 1992).

Forest structure is described by patterns such as density, height, diameter, and stratification of the trees (Brubb *et al.* 1963). One widely-cited conceptual model of forest structure in the ecological literature was created by Oliver and Larson (1990); it describes four developmental stages of forest structure: 1) stand initiation; 2) stem exclusion; 3) understory re-initiation; and 4) old growth or complex structure. The forest stand is defined as a unit of trees that is relatively homogeneous in age, structure, composition, and physical environment (Oliver and Larson 1990).

Stand initiation is the first stage of the forest stand"s development. This stage occurs after a major disturbance eliminates the former overstory and develops stems from pre-existing stumps and roots, buried or newly dispersed seeds, and advance regeneration. Stem exclusion is the second stage following a major disturbance; characterized by high tree mortality, tree canopy formation and closure, and a precipitous drop in understory biomass due to growing resource limitations (e.g., light). New stems therefore, do not become established and the existing stems develop vertical stratification by species. Understory re-initiation follows, wherein seedlings and advanced regeneration colonize the understory; during this stage canopy gaps begin to occur as canopy trees mature and die. The old-growth stage occurs when recruitment is principally derived from gap-phase replacement (Oliver and Larson 1996).

Recently, Franklin *et al.* (2002) classified structural attributes of forest stands to include "both the variety of individual structures, such as trees, snags, and logs of various sizes and conditions, and the spatial arrangement of these structures, such as whether they are uniformly spaced or clumped." Individual structural elements include live trees, large-diameter live trees, large-diameter branches, lower canopy tree community, ground community, standing dead trees (snags), large woody debris (logs), uproots (root wads and holes), and organic layer. Spatial pattern includes vertical distribution of foliage/canopy, horizon distribution of structures, and gaps and anti-gaps (Table 2).

Table 2. Some structural features of forest stands including individual structural elements and spatial patterns of structural elements (Franklin *et al.* 2002)

Important attributes	
Individual structures	
Live trees	Species, density, mean diameter, range in diameter, height, canopy depth
Large-diameter live trees	Species, density, decadence (including presence of decay columns), crown condition, bark characteristics
Large-diameter branches	Species, density, size, individual or arrays, presence of arboreal "soil"
Lower-canopy tree community	Composition, density, height
Ground community	Composition, density, deciduous/evergreen
Standing dead trees (snags)	Species, size, decay state, density
Large woody debris (logs)	Species, density, decay state, volume, mass
Uproots (root wads and holes)	Density, size, age
Organic layers	Depth, chemical and physical properties, biota
Spatial patterns	
Vertical distribution of foliage/canopy	Depth, continuity, cumulative distribution
Horizontal distribution of structures	Spatial pattern (e.g. random, dispersed, or aggregated)
Gaps and anti-gaps	Size, shape, density

Kershaw (1973) proposed three components describing the structure of vegetation. 1) the vertical arrangement of species; 2) the horizontal arrangement of species; and 3) the abundance of each species. The stratification of vegetation ranges from two layers to more complicated arrangements such as in the tropical forest. Generally, the tropical forest is divided into five layers A, B, C, D, and E. The first layer is the top stratum that comprised from all of the tallest trees, the B and C layers form two layers of the canopy, layer D is formed by shrub, and E is the lowest stratum described as the ground or field layer. The forest strata are also applied to exemplify the relationship between topography and the distribution of individual species (Kershaw, 1973).

The concept of forest stand structure aggregates a variety of individual plant measures (e.g., density, tree diameter at breast height distribution) into an overall „physical and temporal distribution of trees in a stand" (Oliver and Larson 1990). Beyond vertical and horizontal spatial pattern, species composition, size and age of trees are integral to defining stand structure which is a reflection of ecological conditions and historical disturbance. The terms „even-aged", „uneven-aged" and „multi-aged" refer to the age structure of stems within a stand (Cumming *et al*. 2000). An even-aged stand includes trees that have all germinated (or been planted) at the same time or within a short period of each other, often dating to a major disturbance event. Uneven-aged stands contain trees of a diversity of ages, and are often considered typical of Oliver and Larson"s (1990) old-growth stage. Multi-aged stands are intermediate between even- and uneven-aged stands. There is a distinction between two or more age or species groups within the stand, although the boundaries may not be clearly defined (Oliver and Larson 1990).

Diameter and age distributions have been used extensively to characterize forest stand structure (Nelson 1964). Distributions and differences in sizes between species in a stand are often significant to studying the successional status of species (Whipple and Dix 1979). Both size and age class distribution provide useful information for the interpretation of past population dynamics, and the relative importance of disturbance in different environmental settings (Stewart 1986, Parker 1992). The shape of a population"s age or size distribution results from the interaction of many factors: differences in regeneration requirements of early *vs*. successional species (Grubb 1977, Pickett 1980), differences in disturbance history that are considered in the context of physical and biological disturbance to the forest (Stewart 1986; Christensen 1989, Vale 1989; Westoby *et al.*1989), and differences in environmental setting (Whipple and Dix 1979; Kavanaugh & Kellman 1986). Ecologists have recorded many factors that promote variation in the size of plant population. They include seed or seedling size, relative growth rate, the time of germination, and correlations between plant performance and distance to close neighbors (Brown and Hutchings 1997).

There are five age and diameter forms commonly used to characterize population structure (Fig. 4 and 5): (1) inverse-J, (2) bimodal, (3) decreasing, (4) unimodal, and (5) random (Whipple and Dix 1979). The inverse-J structure suggests the balance of continuous recruitment and mortality, therefore persistence of a species in the stand over time. This stand structure possesses relatively high sapling density, as well as a relatively smaller number of large/old individuals. Forest ecologists have long identified this inverse-J pattern with „shade tolerant" species that can recruit an abundance of small stems beneath a closed forest canopy, and presumably dominate mid- to late-successional sites in the absence of stand-destroying disturbance (Despain 1983; Parker 1986; Parker 1992). The inverse-J distribution of Engelmann spruce in British Columbia has been described as a result of the destruction of a stand by fire. Spruce and lodgepole dominated the canopy, which prevented further spruce recruitment until lodgepole began to die out and open the canopy somewhat. As a result, one of the age distributions changed from a decreasing to a bimodal and finally to an inverse-J shape. The entire process took about 350 years after a fire (Day 1972). Inverse-J type and decreasing age class distribution are similar. However, decreasing type indicates a recent decrease in the rate of reproduction and decline in densities of all ages. It is suggested that the drop in recruitment of decreasing population may be temporary and the stand actually self-perpetuating. The unimodal curve has a peak of densities in one age class and a lack of recruitment which indicates that the population is not self-replacing. The random curve indicates a population that has no regular pattern of reproduction. The bimodal age type has peaks in younger and older age classes which indicate pulses of recruitment (Whipple and Dix 1979). A unimodal diameter distribution exhibits lack of seedlings and small saplings in which stands form with rapid canopy closure and a dense overstory of relatively small diameter stems (Parker 1993). Decreasing and bimodal distribution indicate irregular recruitment (Whipple and Dix 1979) in which the population structure has low density of saplings (Ziegler 1995). Random distribution is typical of adult tree population in the absence of a regeneration layer (Parker *et al*. 2001).

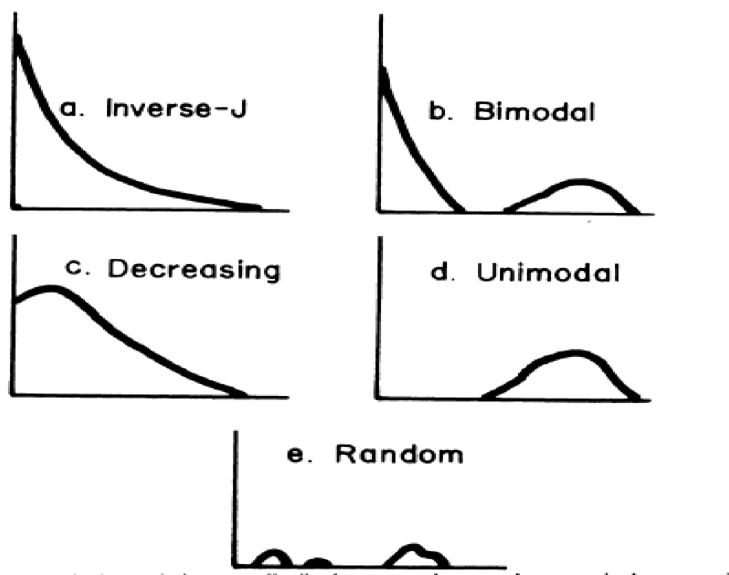

Figure 4. Idealized population age/size class distribution types (Whipple and Dix 1979)

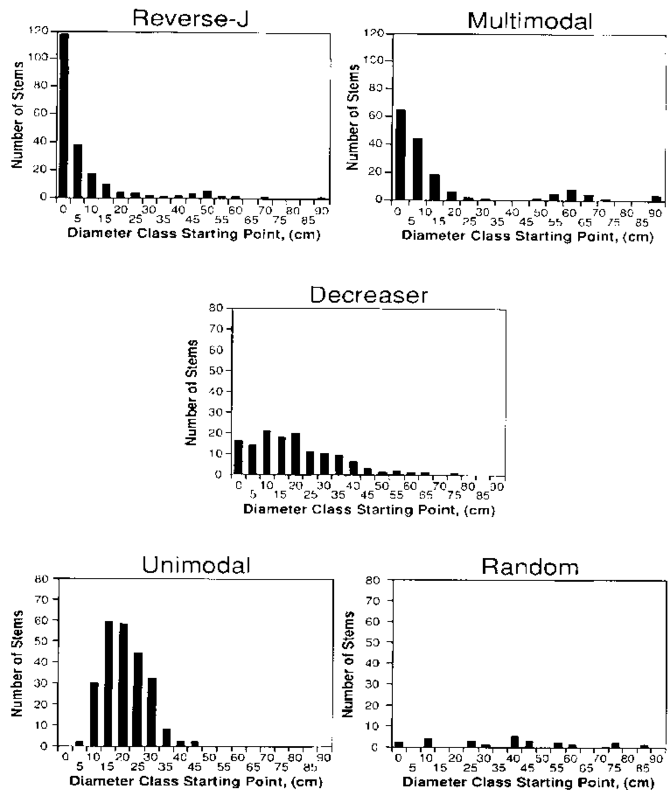

Figure 5. Representative diameter class distribution for each of the five diameter forms used to characterize structure (Parker 1992)

b. Boreal forest dynamics

The boreal forest includes the subarctic latitudes of Eurasia, Canada and Alaska which contain a great belt of coniferous forest (Hare 1950, Syrjanen *et al.* 1994). The boreal forest is dominated by white spruce (*Picea glauca*), black spruce (*P. mariana*), white cedar (*Thuja occidentalis*), white pine (*Pinus strobus*), red pine (*P. resinosa*), and jack pine (*P. banksiana*), with some hardwoods such as black ash (*Fraxinus nigra*), yellow birch (*Betula lutea*), and bigtooth aspen (*Populus grandidentata*).

In boreal forests of North America, Canada, and western Russia, most fires are generally characterized by crown fires that have high intensity and severity. Crown fires are generally stand-replacing fires, and the most dominant tree species have developed numerous adaptations to resist fire or colonize immediately after burns (Bergeron 2000). This phenomenon is typical of coniferous species which propagate their seeds as serotinous or semi-serotinous cones such as black spruce and jack pine, as well as develop root systems that survive fire such as paper birch (*Betula papyrifera*) and aspen (*Populus tremuloides*; Turner and Romme 1994, Bergeron 2000), or provide a thick bark (*Pinus* spp.). In addition, shade intolerance and a high growth rate are also the principal adaptations contributing to pine establishment following forest burn (Syrjanen *et al.* 1994). Dynamics of these individual species are also explained as being controlled by species shade tolerance and their means of regeneration (Bergeron 2000). The post-fire recruitment of some coniferous species such as white spruce and balsam fir is slower from 5 to 10 years than deciduous species (Begeron 2000).

Studying the stand dynamics in the mixed woods of Quebec‟s southern boreal forest, Bergeron (2000) found that deciduous tree species are able to invade burnt sites better than coniferous species. His study shows that pin cherry recruited during the first 20 years following fire while conifer species recruitment is constant and lower. These deciduous species however did not occur in mature stands and thus they are not dominant after fire events. White spruce recruited after the initial peak in recruitment with a decreasing age structure. Balsam fir (*Abies balsamea*) had a random distribution since it is constantly and abundantly recruited with important peaks centered 10, 75, 125, and 170 years following fire. Aspen and white birch had the same age distribution structure (bimodal) which indicates that they may be caused by similar disturbances. Root suckers of aspen and birch grow extensively after fire. Aspen roots suckers are denser than birch, and thus seedlings of birch are also abundant and dominate in the absence of aspen. White cedar is unimodal form of age distribution structure which increased between 70 and 130 years after fire and declining afterward. As a result, pin cherry, willow, aspen, and white birch are decreasing in recruitment after fire. Balsam fir and white cedar on the other hand constantly and abundantly recruited and established. Regeneration of all stands is dominated by balsam fir. Although less abundant than balsam fir, white spruce also displayed similar regeneration patterns (Bergeron 2000).

In Northwestern Ontario, most of the forests tend to be young stands and are composed of species quickly regenerating after forest fires (Syrjanen 1994). Many of these stands are dominated by *Picea mariana,* which displays a reverse- J shape on both upland and lowland sites. The abundance of black spruce decreased steadily following dense establishment of saplings, and this recruitment ended 50 – 60 years after stand initiation. *Pinus banksiana*, *Thuja occidentalis*, *Abies balsamea*, *Populus tremuloides* recruited sporadically and stooped after 50 years. Density of black spruce seedlings could indicate the broken canopy at the beginning. This is suggested by frequent vestiges of forest burn before they start to decline (Syrjanen *et al.* 1994).

In the Russian taiga, *Picea abies*, *Pinus sylvestris* are the most important species; *Abies sibirica* is less abundant in this coniferous forest. Repeated fires also shape stand dynamics in this region, especially *Pinus* forest structures which are burned by low-intensity fires (Syrjanen *et al.* 1994). *Pinus* spp. posess thick bark at the lower half of the trunk which supports their survival after fire and enables them to set seed for future regeneration. Frequent fires in dry sites occur in a cycle of 30 to 50 years which assists the maintenance of their general structure for centuries.

The literature documenting how disturbance regimes cause the fluctuation of coniferous species‟ recruitment has grown during the last two decades. At landscape scales, a short fire rotation, together with the large and severe fires favor fire-adapted species such as jack pine, red pine, and black spruce (Cogbill 1985, Sirois and Payette 1989, Bergeron and Brisson 1990). In contrast, long fire cycles, together with less severe and smaller fires favor shade tolerant conifers such as balsam fire, whit spruce, and white cedar (Bergeron and Dubuc 1989, Frelich and Reich 1995, Bergeron 2000, Lesieur *et al.* 2002). At a stand scale, fire cycles changes the class distribution after several decades (Bergeron *et al.* 2004). Structure of a stand is an indicator of the intensity of individual fires affecting that burned areas (Bergeron and Brisson 1990). Stands with dominant-tree cohorts result from post-fire establishment. Small surviving stems may suggest that areas were not affected by a particular fire (Bergeron and Brisson 1990). A sudden increase or decrease of a clump tree indicates fire was not severe enough to create a large opening or to produce scars (Wade and Johansen 1986). High intensity fires kill enough trees to create open habitats and provide a sufficient condition for post–fire regeneration. As a result, forest structures maintain an open, uneven-aged stand. On the other hand, the ability of surviving pine trees is higher and the canopy inhabit as close, even-aged stand and post-fire regeneration of shade-intolerant in the lower frequency of burned areas (Bergeron and Brisson 1990). High frequency of lethal fires provide high temperature enough to open the serotinous cones, meanwhile serotinous cones have more opportunity to disperse and ensure regeneration in nonlethal and lower fire intensity areas (Gauthier *et al.* 1996).

Studying the differences in age structures of jack pine population between two landscapes in Quebec, Gauthier *et al.* (1996) found that they are a result of differences in fire regimes. Red pine (*Pinus resinose*) and jack pine (*Pinus banksiana*) stands are known as uneven aged as a result of the occurrence of nonlethal fires (Bergeron and Brisson 1990). Fire intervals shorter than the average life time of *Pinus banksiana* are required to release seeds and allow regeneration, therefore perpetuating their populations. Fire circle length controls the species‟ presence locally as long as the proportion of young stands is high and determines it distribution (Parisien and Sirois 2003). Flannigan and Bergeron (1998) stated that fire regime is a key factor in the distribution and abundance of *Pinus resinosa*. In Quebec, spruce forest exhibits gap dynamics due to fire infrequency. This species is generally late-successional and could remain dominance in a combination of close proximity to metapopulation, favourable conditions, and a long fire cycle (Bergeron 2000, Parisien and Sirois 2003).

In summary, boreal forests are typically uneven-aged stands composed of early sucessional, fire-adapted tree species such as lodgepole pine, jack pine, black spruce. In western North America, Douglas-fir dominated forests display a complex age structure at both the stand and the landscape scale due to the combination of less frequent fires patterns and extended regeneration periods (Perry *et al.* 2008).

c. Mid-latitude coniferous forest dynamics

Outside of the boreal forest, the most studied coniferous forests are those of the southeastern United States where large expanses of longleaf pine (*Pinus palustris*) savannas and woodlands originally dominated the southeastern Coastal Plain. Longleaf pine is not vulnerable to summer fires so they dominated vast areas of presettlement forest under a natural regime of frequent, low-intensity summer fires, forming practically pure stands of this single species. These longleaf pine sites do not support growth of hardwood species, which lack fire resistant bark (Chapman 1932).

Analysis of longleaf pine populations on the remnant Wade Tract indicated that they tend to be uneven aged, with individuals spatially dispersed in small clusters of trees of even and size (Platt *et al.* 1988). Recruitment has occurred frequently but episodically over the past 250 years. The limited recruitment in such areas were suggested by the accumulation of incendiary fuel beneath large pine produced by combustion of dried needles at the base of large pine during fires and killed small trees. Lack of local recruitment for some time suggests the presence of large openings essentially devoid of seedlings or saplings.

Glitzenstein *et al.* (1995) analyzed the different influence of fire on two populations of longleaf pine in sandhills and flatwood areas. Burning frequency appeared to have only minor impact on growth of sandhill pine, pine recruitment or temporal changes in pine densities and basal areas due to the low-intensity fires (Nash 1985). However, fire frequency effects on flatwoods pine showed lower growth in biennially burned than in annually burned areas. Juvenile growth rates are much lower in the flatwoods than sandhills due to more stress under a frequent fire regime. Therefore, longleaf pine trees in flatwoods are not able to reach a fire-resistant size before being killed.

Explaining the juxtaposition of scrub and sandhill vegetation in the Florida sandhills, Myers (1985) documented that they were results of fire patterns (Figure 6). Vegetation which infrequently burns likely supports scrub instead of sandhill pine. The widespread distribution of sandhill vegetation possesses few impediments to fire spread (Myers 1985).

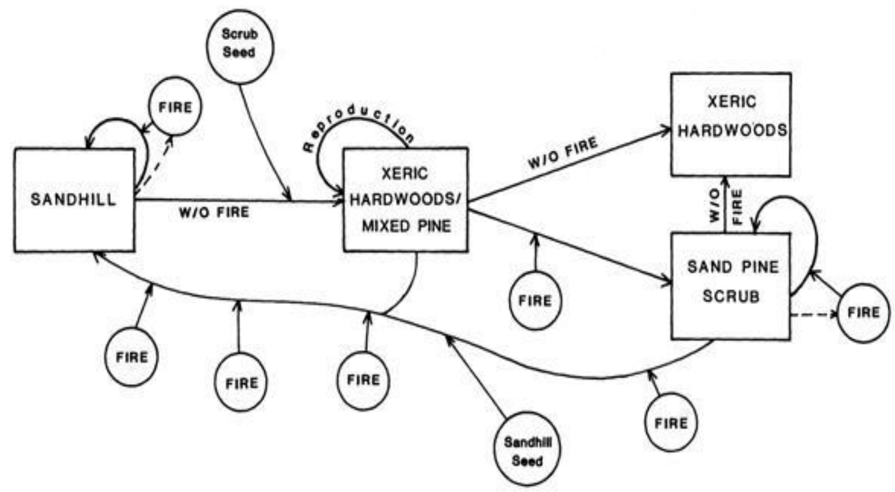

Figure 6. Qualitative model of the interaction of fire and vegetation in the development and maintenance of sandhill, sand pine scrub, and xeric hardwood communities where sandhill and scrub are contiguous and a mesic hardwood seed source is absent (Myers, 1985).

4. Research question

As shown in this literature review, there has been considerable study of the dynamics of conifers in the boreal forest and mid-latitude coniferous forests, and many of the processes are fairly well understood. However, "most (Vietnamese) conifers are poorly understood, and research into their ecology should be a priority" (Luu and Thomas 2004). For this reason, this study will focus on the geography and ecology of the endemic and endangered conifer species in the Central Highland in Vietnam at macro- and micro- scales. The objectives of this study are to: 1) map conifer distribution within the Dalat Plateau using remote sensing, 2) analyze size-class characteristics within the population of each pine species, and 3) interpret patterns of size structure related to disturbance history. The following questions will be addressed:

1. What is the distribution of threatened conifer trees within the Bidoup-NuiBa National Park?
2. Is the spatial distribution of these species related to topography?
3. How does size class structure vary for these species, and what does this indicate about the relationship of these species to disturbance?

These results will be used to contribute to understanding of the spatial distribution and ecology of some of the threatened Vietnamese conifer populations in order to develop appropriate conservation plans for them. The technical and analytical methodologies developed for data collection and vegetation analysis are described in detail in the following chapter.

CHAPTER 2

METHODS AND MATERIALS

1. Study area

a. Location

This study examines conifers of the Dalat Plateau, which is an important region contributing to Vietnam‟s designation as one of the top ten global conifer conservation "hotspots" (IUCN 2004). The Dalat Plateau is found in the south-central interior of Vietnam, and is an excellent example of the hill- and mountain-evergreen forest ecosystem. It is one of five centers of plant diversity and one of three endemic bird areas in Vietnam. The Dalat Plateau is one of the highest blocks of the southern portion of the Truong Son (or Annamite) Range in Vietnam. The Truong Son Range extends for nearly 1200 km from north to south along the Vietnamese border with Laos and Cambodia and includes the southern plateau areas of southern Vietnam (Averyanov *et al.* 2003).

Among the 14 species of conifers found in this region, six were evaluated in the 2004 IUCN Global Red List of Threatened Species. They are *Pinus krempfii* (VU B1+2c)[1], *Pinus dalatensis* (VU B1+2c), *Pinus latteri* (NT), *Fokienia hodginsii* (NT), *Calocedrus macrolepis* (VU B1 + 2b), and *Cephalotaxus mannii* (VU A1d). *Pinus krempfii* and *Pinus dalatensis* are endemic and rare species in this area (Nguyen Tien

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[1] IUCN Conservation Status Categories: VU =Vulnerable; NT=Near Threatened

Hiep et al. 2005, Nguyen Duc To Luu and Thomas 2004). This area has experience a turbulent historical period over the past 150 years (Déry 2000). Along with troubles facing the entire country, the Dalat Plateau is pressured by the acceleration of spontaneous migration. Human occupation, population expansion, agricultural production and the development of road infrastructure in the region represent primary threats to the coniferous forest. The protection and management of this area requires understanding of its natural ecology and techniques for forest monitoring. The study area focuses on the conifers within the Bi Dup-Nui Ba National Park in Lam Dong province, one of 28 protected areas in Vietnam (Figure 7).

b. Physical setting

BiDoup-Nui Ba National Park (hereafter BD-NB NP) is located in the south Central Highlands of Vietnam. The park occupies a total area of 64,800 ha. The topography of the Bi Doup- Nui Ba National Park is a mountainous range which inclines toward the northwest (Figure 8). In fact, the whole area of the Park is in fact a variety of mountain peaks, which are commonly referred to as Bi Doup – Nui Ba (the highest peak, Mount Bi Doup, at 2287 m). The other high mountain peaks are Mt. Hon Giao (2062 m), Mt. Gia Rick (1923 m), Mt. Chu yen Du (2075 m), and Lang Bian (2163 m). Vegetation of this area is dominated by montane evergreen forest, with small patches of coniferous forest and mixed broadleaf-coniferous forest. Ninety-nine percent of the park is forested, including old-growth forests.

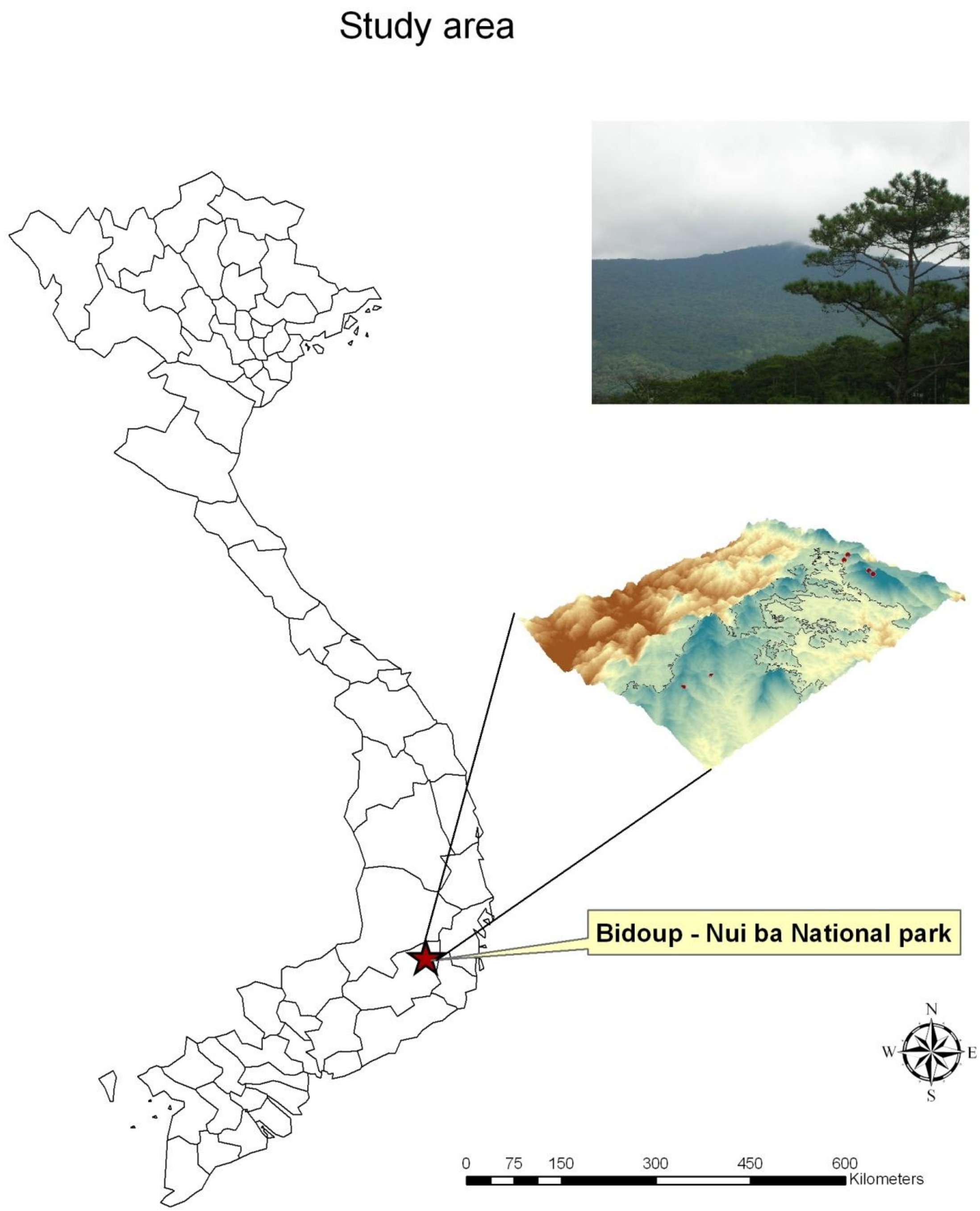

Figure 7 Location of the study area, Bidoup-Nui Ba National Park in Vietnam

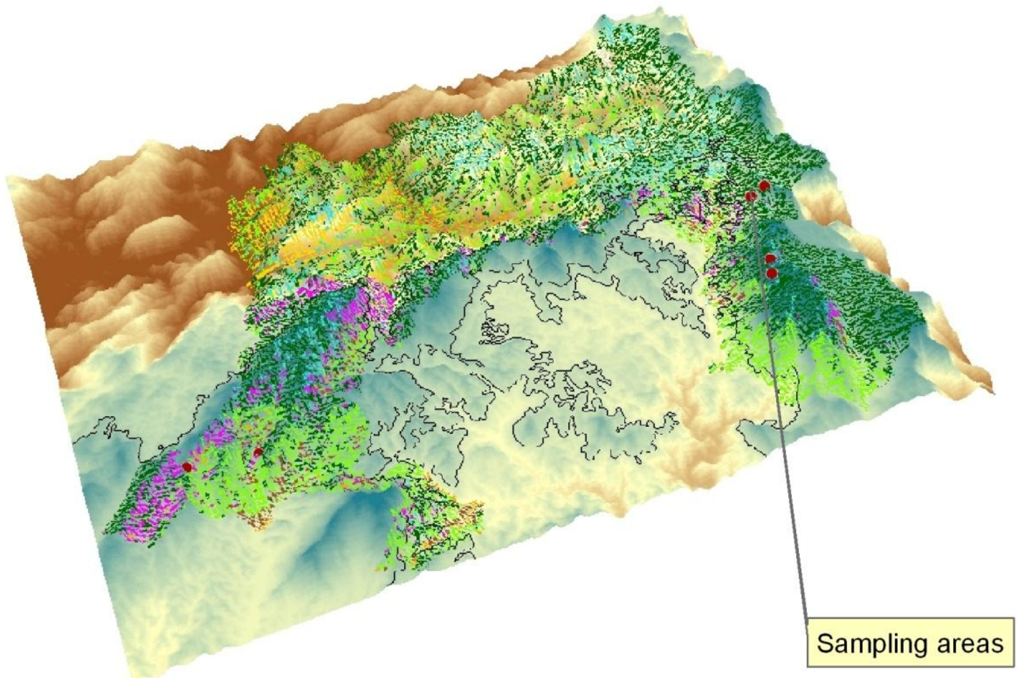

Figure 8 Physical setting of the Bidoup – Nui Ba National Park

c. Geology

The physiographic structure of the Annamite Range is complicated, resulting from a long history of multiple folds of marine sediments and metamorphic rocks, uplifted basement rocks, and later volcanic activity with extensive basalt flows. The south portion of Truong Son Range is ancient crystalline platform Precambrian gneiss. The highest points of this region, including Biduop peak, are granites. The Lang Bian mountains are composed of dacites.

d. Climate

The climate of the Central highland is characterized by a dry, cool season from December to April, and a warm, wet monsoon season from May to November. Mean annual temperature is 18° C (64.4° F) and mean annual rainfall is approximately 1800 mm (Van et al. 2000, Brodribb and Field, 2008; Figure 9). The low temperature is – 0.1° C and the high is 31.5° C. The humidity ranges from 80 – 85%, and it is typically cloudy in the highest mountains.

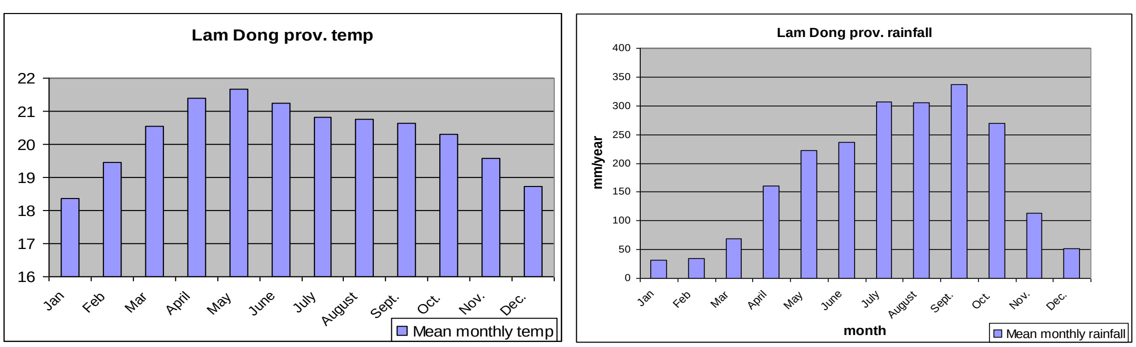

Figure 9. Mean patterns of monthly temperature and rainfall at Lam Dong

2. Data

a. Satellite image database

The study area could be fully covered by two Landsat scenes. This study utilized two sets of Landsat imagery. One is the Landsat Multispectral Scanner (MSS) acquired on 03-13-1975 (path/row: 133/51) and another on 01-01-1973 (path/row: 133/52) with spatial resolution 57 meters (4 bands). The other set is Landsat Enhanced Thematic Mapper plus (ETM^+) dated 03-04-2000 (path/row: 124/51) and 01-05-2001 (path/row: 124/52) with spatial resolution 28.5 meters (6 bands; Figure 11). These images were obtained from the US Geological Survey website (http://www.usgs.gov). Digital maps were provided by the National Park and Birdlife International. Ground control points were collected in the field using a handheld Global Positioning System (GPS) with the Universal Transverse Mercator (UTM) projection zone 48 North.

b. Field database

Before starting the main investigation, and after consulting with villagers, park officials, topographic maps, and previous field experience of rangers, transects were used in each survey site following the foot trails and pathways through the forest. Six plots were established in October 2008. Distance sampling on transects was based on the sighting of conifers. A team of observers walked along the 2 km transect and carefully looked for conifers. 50x50m plots were established on each side along the transect where

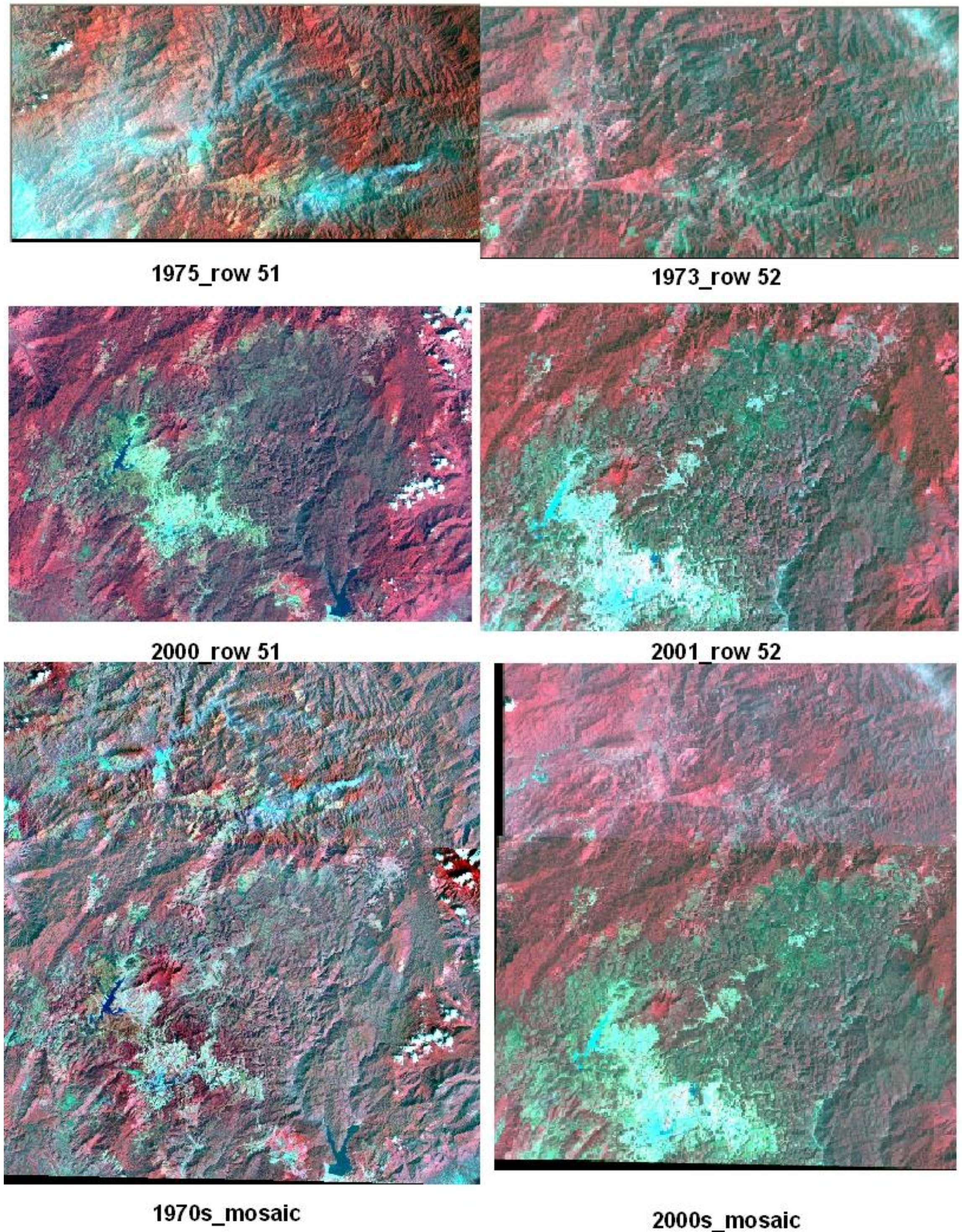

Figure 10 Landsat MSS (1970s) image and ETM (2000s) image of the path/ row 24/51-52

conifers were found. For each plot, altitude, longitude and latitude were measured by using a GPS receiver. Diameter at breast height (dbh, 1.4 m from above ground) was recorded for all coniferous trees in the plot using calipers. Total numbers of conifers were counted, and the height of each individual tree was measured. Cores were removed by the increment borer from approximate breast height of the tree trunk. Tree cores were immediately placed into plastic straws that were sealed and labeled in the field. Biological and ecological factors such as: habitat location, forest type, forest strata, and disturbance were recorded as well. The broadly defined forest type were recorded at the location of the point count defined as deciduous, evergreen or mixed depending on the dominance were recorded.

c. Data analysis

To answer the first research question about the distribution of these threatened pine trees within the National Park, satellite images of the study area were classified combined with field data as ground control points using ERDAS software. Image processing was carried out using ERDAS, version 9.0. In this study, totally, nine classes were extracted from satellite images: coniferous forests, water/shadow, broadleaf forests, grass/shrubs, sparse *Pinus kesyia* and broadleaf trees, anthropogenic (roads, open lands, agriculture areas, etc.), mixed broadleaf/conifer forests, clouds, and bamboo forests. Detailed description of these land cover classes is presented in table 3. The general procedure for creating the land cover data set, as illustrated in Figure 11. (1) PCT (Principle component transformation) and image Radiometric calibration; (2) subset and overlay images; (3) unsupervised/supervised hybrid classification; and (4) Mosaic and accuracy assessment.

Table 3 Land cover classification scheme

Land cover classes	**Description**
Grass/shrubs	Areas consisting of short, sparse vegetations or grass
Mixed broadleaf and coniferous forests	Mixed forest with deciduous and conifers trees
Bamboo forests	Bamboo forests with high density of bamboo species
Anthropogenic	Transportation, agriculture areas, bare soils, etc
Broadleaf forests	Deciduous forests, mixed forest with higher density of deciduous trees (up to 75%)
Sparse *Pinus kesyia* and broadleaf trees	Areas consisting of deciduous trees and *Pinus kesyia*
Water	River, lake
Clouds	Clouds
Coniferous	Coniferous forests in which dominated by pine species

Pre-processing of Landsat data:

The Landsat images have been geometrically corrected, therefore geometric correction method is not mentioned in this chapter. Atmospheric and radiometric distortion can improve classification results. Radiometric and atmospheric distortion was corrected by using 5S methods. Image contrast enhancement was applied in order to find a good appearance of the image. Then, the 1970s scenes were matched in x- and y- to 2000s scenes through second order polynomial co-registration technique. PCT method is based on the approach of the detection of non-vegetation and grassland area in band 2.

TM bands 1 and 2 also produced the best discrimination of the open land boundary in the study areas. Total of the non-vegetation areas were inverse highlight compared to the vegetation areas. The PCT image was used to classified open land and grass land.

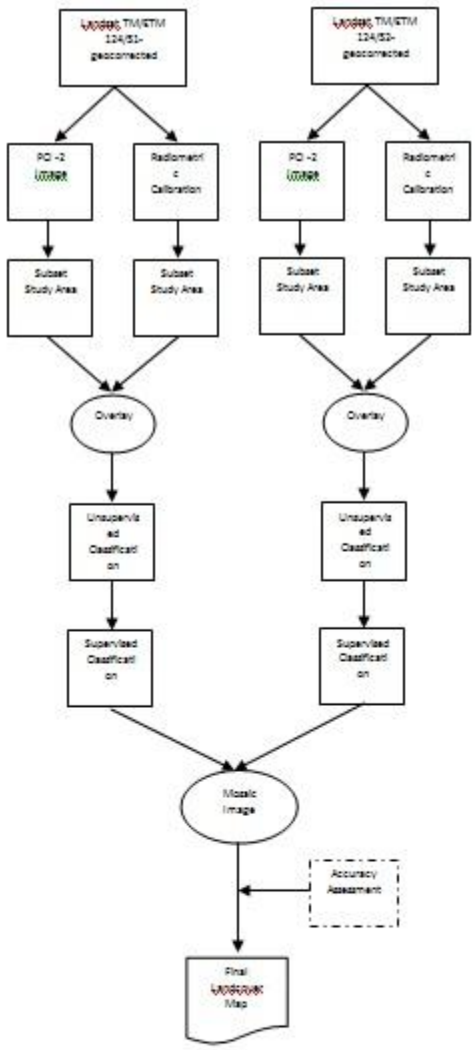

Figure 11 Satellite image classification process

Classification:

A hybrid classification method was used to classify land cover, a combination between supervised and unsupervised classification utilizing a Maximum Likehood Classification (MLC) algorithm to generate a classification map of the study areas. Unsupervised training is generally used when less is known about the data before classification since it is more computer-automated (Jensen 2005, Wang *et al.* 2010). Supervised training was carried out using selected pixels that represent pattern or land cover features that were recognized with help from ground truth data, maps, and field experience. Initially, 40 clusters were classified by using ISODATA clustering. In this case, the initial tests showed that 40 classes could distinguish forest from non-vegetation and grassland. Subsequently, forested areas were clustered again into 40 classes and labeled into seven classes i.e., deciduous forest, conifer forest, mixed forest, grass/shrubs, bamboo forest, sparse *Pinus kesyia* and broadleaf trees, and anthropogenic.

The accuracy of the classification is summarized through an error matrix and Kappa statistic, in which omission and commission errors were calculated by comparing satellite based land use/land cover categories with ground truth. This report calculated area and percentages of each land class incorporated in a maximum likelihood classification. The accuracy is essentially a measure of how many ground truth pixels were classified correctly.

Vegetation analysis:

In order to understand the relationship between spatial distributions of these species to topography, ArcGIS 9.3 was used to create geodatabases to store datasets.

Contours were converted from a Digital Elevation Model (DEM), and compiled DEM and LULC datasets to calculate the abundance of each land use category for each 250m elevation range from 550-2300m.

Tree diameter measurements from the field plots were analyzed to develop size-class distribution patterns for each species within the study area. Field data were analyzed in Excel spreadsheets to create histograms. Diameter class distribution were constructed for all species on each site, with 5 cm intervals ranging from 0- 5 to 125-130 cm dbh, following the approach of Parker (1993). Age structures were visually determined from rings counts of each individual. Cores were dried at the room temperature for about a week before they were glued each core into a groove on a slat. Cores were mounted, and sanded to prepare for examination under binocular microscope.

CHAPTER 3

RESULTS

1. Accuracy of classification land cover patterns

a. Accuracy of classification

This research attempted to classify the 1970s image to look at changes in LULC between two time periods (1970 and 2000). The overall accuracy of this image classification was, however, very poor – less than 50% – therefore, information from the 1970s image classification was not considered in this report. Instead, the research used the Landsat ETM plus. Its overall classification accuracy was estimated to be 72% (62.9% of the closed-canopy coniferous forests and 87.8% of broadleaf forests were classified correctly; Table 4).

Accuracy assessment is most reliable when using a random sampling approach of ground truth points, but obtaining such a data set is not always feasible. Although these levels of accuracy are within the range that can be considered acceptable, they definitely suggest some limitations when using classified maps. Several types of error contribute to these accuracy levels. The images were especially difficult to classify due to a number of factors: the satellite imagery used in this study consisted of mostly cloudy-scenes from

Table 4. Accuracy assessment for classification of Landsat ETM 2000

	Coniferous	Water	Broadleaf	Grass	Sparse *Kesyia*	Anthrop.	Mixed	Clouds	bamboo	Total	Users accuracy (%)
Coniferous	22	1	5	0	2	0	0	0	0	30	73.3
Water	2	4	0	0	2	0	0	0	0	8	50.0
Broadleaf	5	3	36	0	1	1	0	0	0	46	69.2
Grass	1	1	0	6	1	3	0	0	0	12	50.0
Sparse Kesyia	2	1	0	0	19	1	0	0	0	23	79.1
Anthrop.	0	0	0	0	1	2	0	0	0	3	50.0
Mixed	0	0	0	0	0	0	1	0	0	1	100.0
Clouds	0	0	0	0	0	0	0	0	0	0	---
Bamboo	0	0	0	0	0	0	0	0	0	0	---
Total	35	12	41	6	26	7	1	0	0	123	
Producers accuracy (%)	63.0	33.3	87.8	85.7	61.2	22.2	100.	---	---		
Overall Accuracy = 72.0% ; Kappa coefficient = 64.4%											

ETM 2000, the low number of coincident satellites, limited ground observations, and a real time comparison. One feature clearly visible in satellite images is the different „color" of the row 51 compared to row 52 (see Figure 10). It should be also noted that the satellite images were 28.5m (2000s) resolution. These resolutions are not the highest for detailed classifications, especially in the tropical forest where most of the forest types were evergreen forests. In addition, if the time periods in which the satellite images were acquired were different, gaps and duplicates in the data can be found at the edge where the two image subsets were mosaiced. In this case, inaccessibility of some areas and the causes by limiting GPS record recorded inhabited the manual collection of a randomly distributed set of points.

b. Land cover patterns

Nine land cover types classified in this project included: coniferous forests, water/shadow, broadleaf forests, grass/shrubs, sparse *Pinus kesyia* and broadleaf trees, anthropogenic (roads, open lands, agriculture areas, etc.), mixed broadleaf/conifer forests, clouds, and bamboo forests. Six study sites were found in the mixed broadleaf/conifer forests and coniferous forests (Figure 12).

In 2000, mixed broadleaf and coniferous forest was the dominant land cover (51.7%; Table 5). Sparse *Pinus kesyia* and broadleaf forest (22.4%) and broadleaf forest were the two most important components. Conifer forests covered a small percentage of the study area (4.7%). The geographic distribution of land cover (Figure 12) shows that mixed broadleaf/ conifer forests were mainly on the east side of the park. They are also scattered over the northwest part of the park. Sparse *Pinus kesyia* and broadleaf trees are found mostly in the southern and middle parts of the park, adjacent to broadleaf forests. Conifer forests were found from the southeast to southwest in areas where grass/shrubs and anthropogenic types were also common (Figure 12).

Table 5. Land use/land cover in 2000

Land cover class	Area (ha)	Percentage (%)
Coniferous forests	3,015.56	4.7
Water/shadow	0.00	0.0
Broadleaf forests	8,585.00	13.4
Grass/shrubs	1,270.52	2.0
Sparse *Pinus kesyia* and broadleaf trees	14,392.34	22.4
Anthropogenic (roads, open lands, etc)	984.28	1.5
Mixed broadlead and coniferous forests	33,171.97	51.7
Clouds	172.44	0.3
Bamboo forest	2,547.13	4.0
TOTAL	64,139.24	100.0

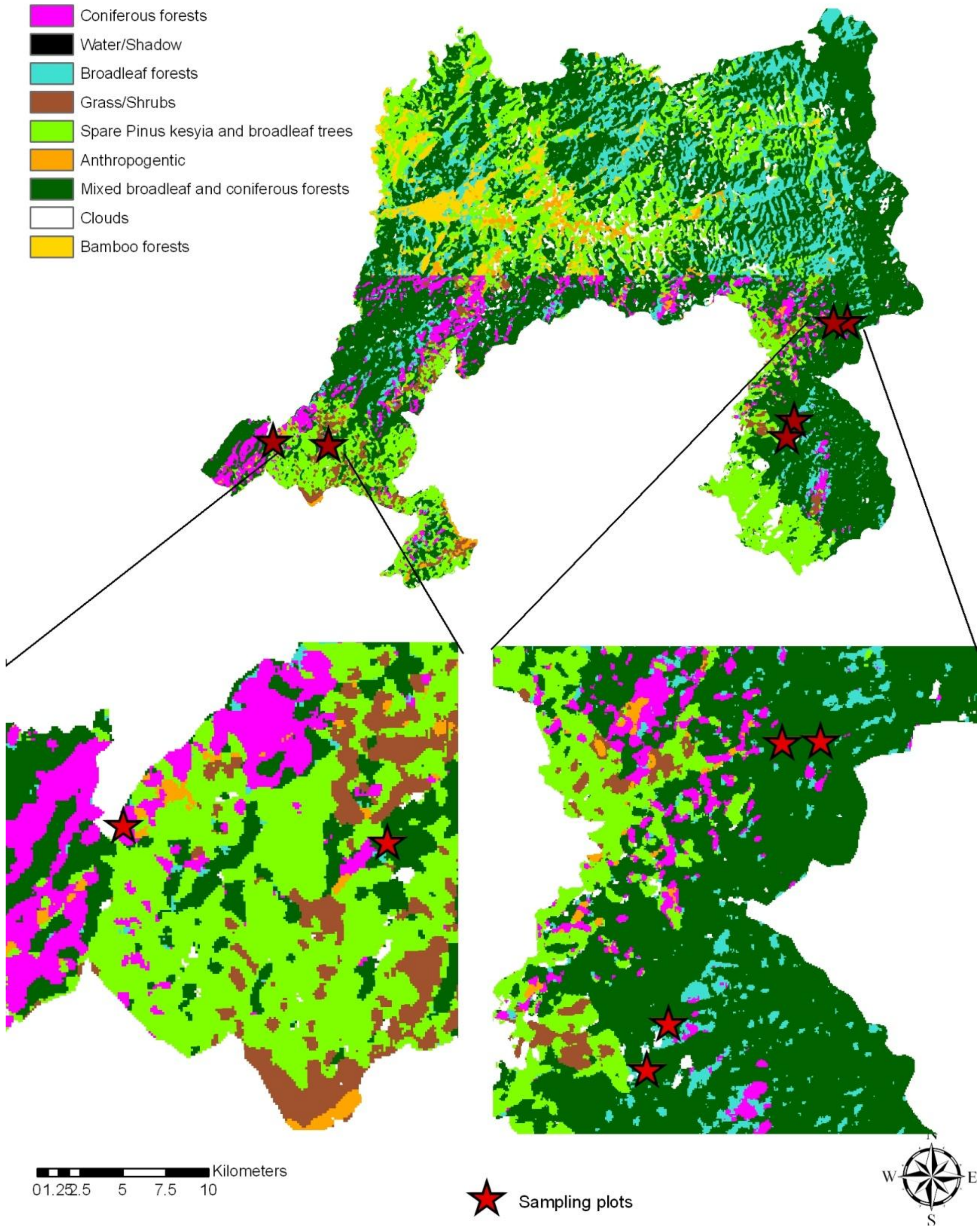

Figure 12. The classification of land use/land cover in Bidoup–Nui Ba National Park in 2000

2. Spatial distribution of conifer species

A comparison of the LULC classification to elevation patterns in the study area showed that coniferous forests occurred primarily between 1,000 and 2,200 m asl (see Figures 13 and 14). These forests peaked in abundance between 1550-1,800 m asl in the 2000 classification. Mixed broadleaf and coniferous forests were found at a somewhat higher elevation range, 1,300 - 2,000 m. *Pinus kesyia* and broadleaf trees favor elevations less than 1,800 m, particularly between 1,050-1,300 m.

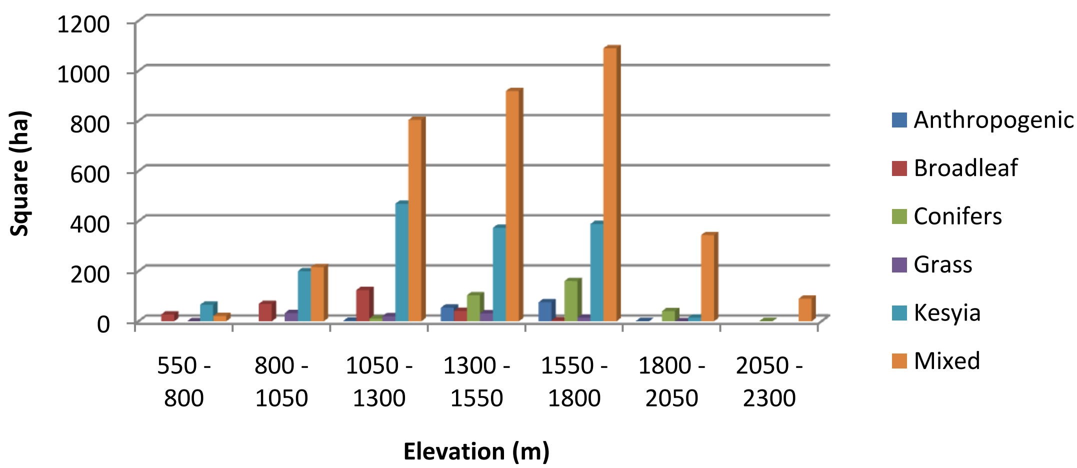

Figure 13. The distribution of major landforms LULC classes according to elevation

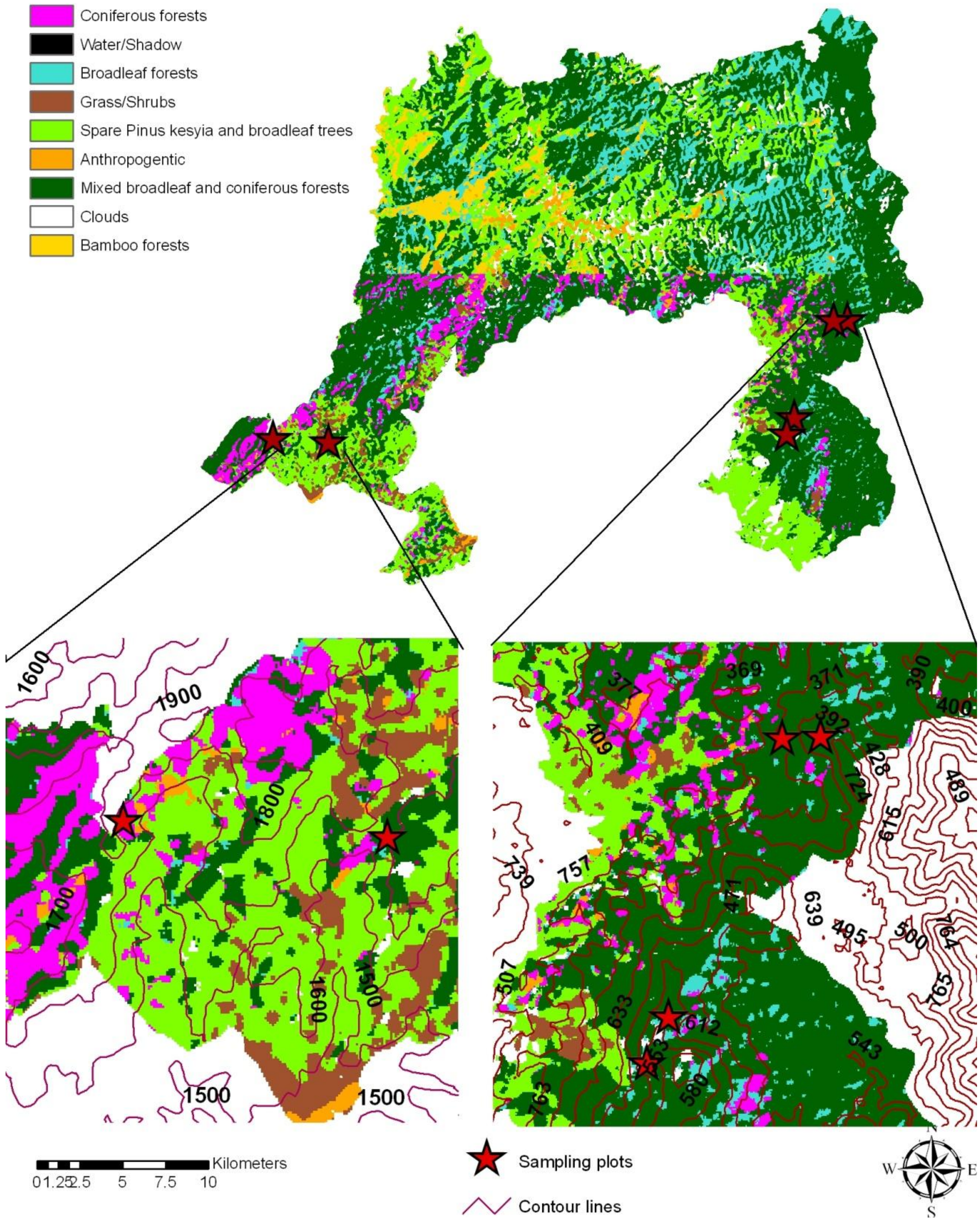

Figure 14 . Land use/ land cover (2000) according to elevation within the study area

3. Forest structure

Sampled stands, which were targeted around the presence of conifers, showed relatively low abundance and importance of conifer species relative to other taxa, although these conifer stems tended to be among the largest in the stand.

A total number of 1,446 trees with dbh ≥ 10cm were recorded in the six 50 x 50m plots (1.5 ha total sample area); 89 of these individuals were conifers (Table 5). In total, 21 families and 36 genera were identified (Appendix A provides a full list of the observed taxa with their scientific and common Vietnamese names). Among the three coniferous families present, the Podocarpaceae were most abundantly represented: 38 individuals of both *Dacrydium elatum*, *D. imbricatus*, and *Podocarpus neriifolius*; the number of *Pinus dalatensis, P. kremfii, and Fokienia hodginsii* sampled were 14, 14, and 13 trees respectively.

The overall stand density (all species) was calculated at 964 trees/ha; conifer species comprised nearly 60 trees/ha (6%) of this total. The total stand basal area is 53.3 m^2/ha; for conifers it is 10.3 (19%), as the diameters of conifers (especially *Fokienia hodginsii and Pinus krempfii)* tended to be well above the size of other stems in these stands. Mean dbh of non-conifer species was 21.3 cm, while for all conifer species it was much higher 35.3 cm. The overall importance value for conifer species in these stands was 12.8% when measured as the average of relative density and relative dominance; it was 10.6% if the relative frequency was factored in (Table 6).

Table 5 Aggregated stand characteristics and composition

Species	Individuals in sample	Mean dbh (cm)	Frequency (n quadrats)	Density (trees /ha)	Basal area (m^2 /ha)	% Importance value (DD)	% Importance value (DDF)
Fokienia hodginsii	13	51.4	4	8.7	2.6	2.9	2.6
Pinus dalatensis	14	33.9	1	9.3	1.0	1.5	1.1
Pinus kesyia	3	36.4	1	2.0	0.2	0.3	0.4
Pinus krempfii	14	59.7	3	9.3	4.2	4.5	3.4
Dacrycapus imbricatus	1	13.1	1	0.7	0.0	0.0	0.2
Dacrydium elatum	38	28.8	1	25.3	2.1	3.3	2.3
Podocarpus neriifolius	6	16.2	2	4.0	0.1	0.3	0.5
Total conifer	**89**	**35.3**	**6**	**59.3**	**10.3**	**12.8**	**10.6**
Non-conifer	1,357	21.3	6	904.7	43.0	87.2	89.4
Stand Total	**1,446**	**21.9**		**964.0**	**53.3**	**100.0**	**100.0**

Among the six sites, *Pinus krempfii* and *Fokienia hodginsii* were found in most of the study sites; *Dacrydium, Dacrycapus*, and *Podocarpus* were only found in sites three and five; meanwhile *Pinus dalatensis* and *Pinus kesyia* were only found at site three (Table 7). Site three had the most abundant conifers, with six among 28 total taxa. The diameter distributions of the conifers and non-conifers species are shown in Figure 15. Conifer species in six sites are described by the reverse-J shaped frequency distribution. Site six has a discontinuous diameter distribution with a relative lack of saplings and young trees. Although some of the primary non-conifer species have large diameters such as *Eleaeocarpus bidoupensis* (74cm) or *Magnolia candollei* (50cm), conifer species had

Table 6. Composition of sampled stands

		mean dbh (cm)	Density (trees /ha)	Basal area (m2 /ha)	Importance value % (DD)	Importance rank
Site 1	***Conifers (2 taxa)***					
	Pinus krempfii	86.9	24	18.8	15.3	1
	Fokienia hodginsii	57.6	8	3.7	3.2	12
	Primary non-conifers (36 total taxa)					
	Craibiodendron heryi	22.4	168	8.0	14.8	2
	Rhodoleia championii	36.1	76	9.3	11.0	3
	Syzygium zeylanicum	26.8	88	5.6	8.8	4
	Elaeocarpus lanceifolius	21.4	68	2.8	5.7	5
	Stand total	24.2	948	67.1	100	
Site 2	***Conifers (1 taxon)***					
	Fokienia hodginsii	77.3	8	5.5	6.8	5
	Primary non-conifers (32 total taxa)					
	Lithocarpus microspermus	23.5	92	5.2	11.8	1
	Lithocarpus silvicolarum	24.3	92	5.2	11.8	2
	Craibiodendron vietnamense	19.9	84	3.8	9.7	3
	Machilus parviflora	17.5	96	2.9	9.4	4
	Stand total	22.2	792	43.4	100	
Site 3	***Conifers (6 taxa)***					
	Dacrydium elatum	28.8	152	12.6	23.3	1
	Pinus dalatensis	33.9	56	6.2	10.1	3

	Pinus krempfii	22.6	24	1.0	2.3	11
	Pinus kesyia	36.4	12	1.4	2.2	12
	Podocarpus neriifolius	14.2	16	0.3	1.1	16
	Dacrycapus imbricatus	13.1	4	0.1	0.2	28
	Primary non-conifers (22 total taxa)					
	Craibiodendron heryi	16.5	268	6.2	19.8	2
	Quercus langbianensis	14.3	80	1.4	5.3	4
	Anneslea fragrans	14.2	80	1.3	5.3	5
	Stand total	22.4	1100	41.0	100	
Site 4	***Conifers (1 taxon)***					
	Fokienia hodginsii	35.6	16	2.0	3.3	11
	Primary non-conifers (39 total taxa)					
	Triginobalanus verticillata	22.6	124	5.5	11.9	1
	Vaccinium sprengelii	17.5	136	3.7	9.8	2
	Castanopsis pseudoserrata	19.1	116	4.0	9.5	3
	Calophyllum rugosum	13.5	152	2.3	8.6	4
	Symplocos poilanei	16.2	60	1.4	4.0	5
	Stand total	21.2	1360	38.0	100	
Site 5	***Conifers (2 taxa)***					
	Fokienia hodginsii	48.1	20	4.4	4.9	8
	Podocarpus neriifolius	20.1	8	0.3	0.7	31
	Primary non-conifers (36 total taxa)					
	Illicium parviflorum	17.7	104	2.8	8.3	1
	Magnolia candollei	50.0	32	7.0	7.8	2

	Litsea cambodiana	28.1	56	4.0	6.6	3
	Lithocarpus silvicolarum	35.0	36	5.3	6.5	4
	Actinodaphne utilis	27.2	48	3.2	5.5	5
	Stand total	20.4	868	59.6	100	
Site 6	***Conifers (1 taxon)***					
	Pinus krempfii	89.6	8	5.6	4.5	6
	Primary non-conifers (31 total taxa)					
	Lithocarpus microspermus	29.8	120	10.3	15.7	1
	Elaeocarpus bidoupensis	74.0	28	13.5	11.5	2
	Illicium parviflorum	18.4	120	3.3	10.7	3
	Lithocarpus truncatus	44.9	40	7.2	7.9	4
	Craibiodendron heryi	45.1	36	7.3	7.7	5
	Stand total	19.7	716	70.8	100	

the largest diameter with mean dbh of 20.1 cm for the smallest tree (*Podocarpus nerifolius*) and 89.6 cm for the largest tree (*Pinus krempfii).* The frequency distribution of adult conifers at six sites taken separately was normally distributed most of the conifers peaked in the largest diameter classes. Only one of the six sites, site three, had a continuous diameter distribution with relatively high amount of young species. *Dacrydium elatum* dominated site three with a density of 152 trees/ha. *Pinus dalatensis* also had a high mean density of 56 trees/ha. Stand densities of conifer species were an order of magnitude less with respective mean densities of 32 (948) –site one, 8 (792)-site two, 264 (1100)-site three, 16 (1360)-site four, 28 (868)-site five, and 8 (716)-site six

(Table 7). Of the six species all but *Pinus krempfii* had individuals with the largest average diameters > 89.6 cm. *Fokienia hodginsii* was not the dominant species at any site, but its diameter is large compared to most stems in the other sites with mean dbh > 77 cm (site two), 57.6 cm (site 1), 48.1 cm (site five), and 35.6 cm (site four). *Dacrydium, Dacrycapus*, and *Podocarpus* had a mean dbh ranking from 13 (Dacrycarous) to 29 cm (*Dacrydium*). *Pinus kesyia* was 36.4 cm of diameter in site three.

Diameter growth of trees varied among species and size classes. Diameter distribution for the conifer species (Figures 15 and 16) indicated that a variety of curve types were present in the study area. An examination of all the population histograms revealed two main types: (1) unimodal and (2) decreasing. *Pinus krempfii* and *Podocarpus nerifolius* had a decreasing shaped frequency distribution. The frequency distributions for *P. dalatensis* and *D. imbricatus* were approximately unimodal. Frequency distribution of trunk diameters from all seven conifer species consistently showed that larger stems had lower frequency in diameter (Figure 15).

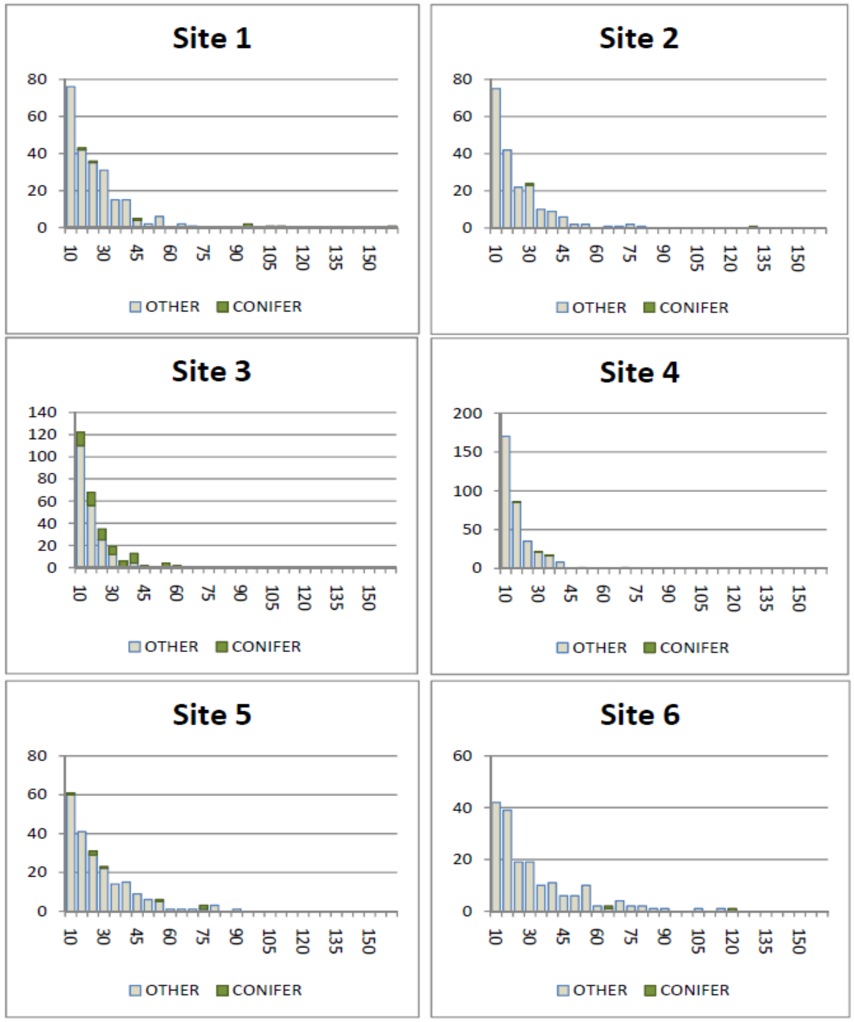

Figure 15. Size structure of conifers in the six sampled stands

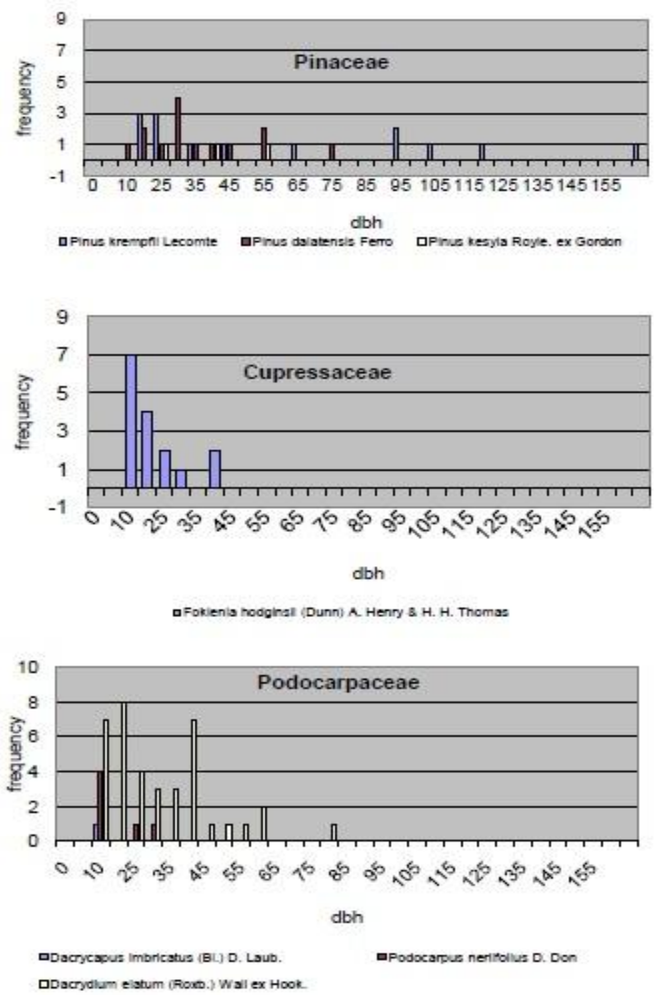

Figure 16 Diameter – class distribution for coniferous species

The study recorded age structures of *Pinus dalatensis*, *P. krempfii*, and *F. hodginsii* (Table 8). *F. hodginsii* was the oldest species, with some of the individuals more than 350 years old. *P.krempfii* were younger than *F. hodginsii* although there were individuals which had been established since 1700s. *P. dalatensis* was recorded as the youngest stand in which most of the individuals were established after the 1800s (Fig. 17).

Table 7 Tree core measurements

Sample No.	Species	No. of rings	circumference	Oldest ring	center
	F. hodginsii	110	70	1863	
110	*F. hodginsii*	78	340		
218	*F. hodginsii*	109	297		Hollow
	F. hodginsii	78	340	1900	
431	*F. hodginsii*	6	315	1683+	
246	*F. hodginsii*	138	110		
	F. hodginsii	16	327	1741	
476	*F. hodginsii*	125	407		
	F. hodginsii	232	210	1791	
	F. hodginsii	330	86	1881	
112	*F. hodginsii*	367	98		
	F. hodginsii	329	53	1797	
	F. hodginsii	5	163	1802	
179	*F. hodginsii*	21	230		
184	*F. hodginsii*	8	63		
	F. hodginsii	25	75	1843	
210	*F. hodginsii*	16	224		
	F. hodginsii	**?**	**?**	**1863**	
112	*P. dalatensis*	267	56		
	P. dalatensis	103	37	1955	
	P. dalatensis	78	230	1763	
168	*P. dalatensis*	255	109		
	P. dalatensis	150	105	1775	

133	*P. dalatensis*	93	172		
	P. dalatensis	133	127	1829	
138	*P. dalatensis*	271	87		
	P. dalatensis	189	71	1973	
	P. dalatensis	3	158	1858	
75	*P. dalatensis*	146	128	1923	
	P. dalatensis	46	92	1844	
47	*P. dalatensis*	179	89		
	P. krempfii	14	54	1862	
163	*P. krempfii*	20	315		Hollow
336	*P. krempfii*	160	546		
335	*P. krempfii*	138	291		center
	P. krempfii	208	70	1928	
not clear	*P. krempfii*	127	59		
83	*P. krempfii*	89	68		
	P. krempfii	280	60	1853	
148	*P. krempfii*	159	105		
	P. krempfii	32	373	1825	
	P. krempfii	6	190	1761	

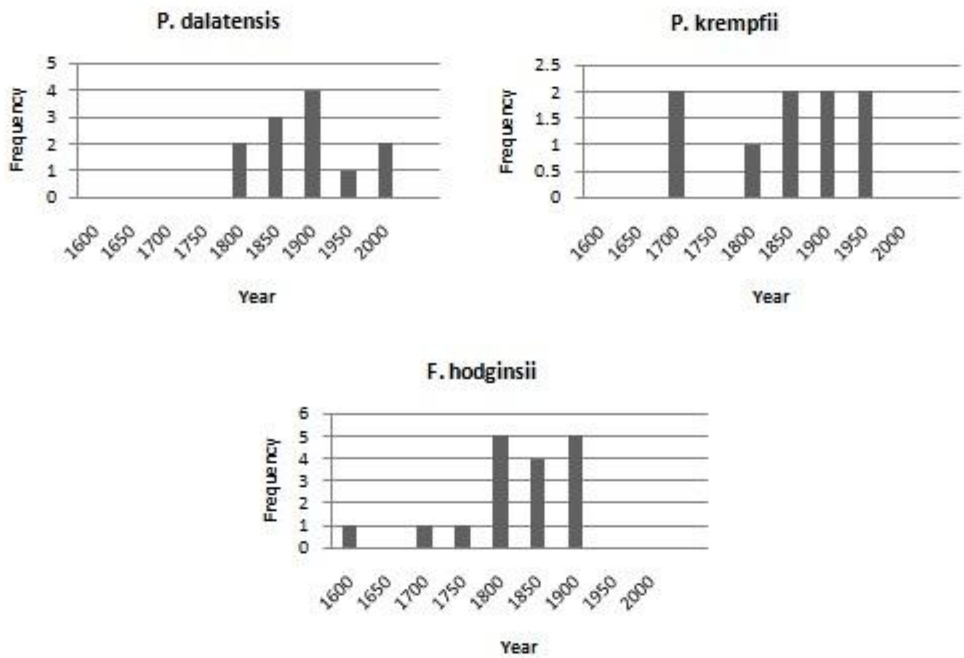

Figure 17. Age-class distributions for coniferous species

CHAPTER 4

DISCUSSION

1. Disturbance histories

The literature which documents the effects of past changes on disturbances in the study area, whether by natural or human ignitions is sparse. Much of the Da Lat Plateau was originally characterized by high-altitude moist forest formations (Trung 1998). However, extensive areas of secondary scrub and bamboo suggest forest clearance and disturbances. Eames (1995) believed that human intervention led to the replacement of much of this forest by a fire-climax forest dominated by *Pinus kesiya*, bamboo forests, and shrubs. We recorded vestiges of burning charcoal in the study areas (Figure 18).

Figure 18. Charcoal areas

Three different threats to conifer populations were recorded during our field work. First, a lack of understanding associated with the value of these species. Local people often chop the seedlings unintentionally on their way to collect non-timber forest products. They simply ignore young conifer stands mixed with other trees along the paths. Second, habitat disturbance: construction of a new national road in the middle of the forest threatens long-term sustainability (Figure 19). Third, logging: the biggest threat for conifers in the Plateau. The wood is extremely valuable. Legal logging in the past and illegal cutting in the present are serious problems in the study area (Fig. 20). In addition, controlled fires which are set by the forest park officers each year, and conifer-oil collecting were also considered (Fig. 21).

Figure 19. Road construction

Figure 20 Logging

Figure 21 Fire and Dead tree due to conifer oil collection

In Vietnam, *Fokienia hodginsii* is prized for its special qualities, and has a large economic value for local residents. At the local level, their timber is most often used for construction purposes, such as house building. The Government of Vietnam has introduced many laws to protect and limit use of this species of timber such as currently no international import (or export) of and these threatened conifer species (Osborn 2006, Truyen and Osborn 2006). Although known to occur in protected areas, illegal harvest and transport of these conifers occur „through little used routes, often under cover of darkness, to processing shops or trades houses‟ (Osborn 2006).

2. Historical disturbance analysis

Seedlings and saplings of *F.* hodginsii were found in some stands (Fig. 22), however, subsequent establishment tends to be sparse, which indicates that the population is old. The populations of *P. dalatensis* and *P. krempfii* are similar. Once trees are established, recruitment is controlled by differential growth rates among the species (Bergeron 2000). Many factors could be responsible for the lack of recruitment, including low seed production at the time of disturbance, and inadequate seedbeds during the first few years after disturbances. A concentration of trees ~200 yr old (Fig. 18) and the lack of young individuals suggests that most of the trees were recruited during an episode from 1800-1850. *F. hodginsii*, *P. dalatenesis*, and *P. krempfii* were successfully recruiting then to now dominate the canopy layers. This characteristic indicates that past disturbances then might have left large openings sufficient to recruit a new cohort of conifers. The decreasing number of *P. krempfii*, *F. hodginsii*, and *P. krempfii* suggest that they are being successionally replaced by deciduous species. In fact, after ~200 yr, although old stands still contain dominant conifer individuals, limited reproduction is causing the stand composition to change. In the context of these decreases, these conifer stands may become older and more vulnerable.

Figure 22. Seedlings of various conifer species in the sampled stands.

CHAPTER 5

CONCLUSIONS

The primary objective of this study was to describe the distribution of conifers at BiDoup-Nui Ba national park within the Dalat Plateau and the stand characteristics from which these populations occur. It is thought that structural/functional analysis of vegetation at the species level represented those plant responses which appeared to be adaptation of the plant to its environment (Parker 1982). Therefore, analyzing the distribution of landcover and forest types, as well as individual tree species distributions made it possible to better understand the factors related to forest development in the region.

The project mapped the distribution of landcover and forest types of the Bidoup-Nui Ba National Park. These forest types were correlated to topography, with the stands containing conifer species occurring mostly in the mixed broadleaf and coniferous forests which favored elevations at about 1,000-1,800 m asl. Stand structures of *Pinus dalatensis*, *P. krempfii*, and *F. hodginsii* were recorded with many of these individuals established 250 or more years ago. This region has been extensively logged and current structure and composition of these stands is likely reflect these anthropogenic impacts (Osborn 2008). The analysis was not performed on enough study sites to be statistically significant, but the findings of this project offer some testable assumptions for future research.

Based on the results, several future research directions are noted. More remote sensing analysis needs to be conducted in conjunction with field surveys to determine tree densities in various forest types at different altitudes, in order to better document the landscape settings of conifer populations. Further study on the impact of selective logging on these threatened conifer stands, and the region‟s forest ecosystems in general, would help to assess the role of human impacts. Finally, studies to develop comprehensive up-to-date distribution maps of their coverage, especially through using remote sensing techniques, could make it possible to predict the locations of other conifer populations of conservation value throughout the region.

The project is the only in-situ conservation initiative for these threatened conifer species. Based on the above results, the project would like to recommend some conservation and awareness rising for the Bidoup-Nui Ba National Park to improve the protection of these threatened conifers. These include:

1. Monitoring of the threatened populations. The monitoring has to include changed in land use, logging, and community attitudes. There should be understanding of the changes during 1970 to 2000.
2. Conservation and awareness raising. There should be some professional/academic training to park managers, forest rangers, and local people for some basic knowledge of clarifying the significance of conservation biodiversity loss and conifers‟ threatened situation.

3. Community consultations prove to be very valuable to discuss specific conservation activities with the local community. They are essential for the success for the community based conservation strategy which largely depends on self-imposed control. It clear the long term in situ conservation in the studied area could be supported by local communities. Some environmental education for the park could also be organized to provide such knowledge as forest dynamics, threatened species in the parks, and species concern of logging.

Appendix A

Association of species' Latin names with common Vietnamese name

Family	Scientific name	Vietnamese name
Aceraceae	*Acer laevigatum Wall.*	Thích láng
Aceraceae	*Acer laurinum Hassk.*	Thích lá quế
Aceraceae	*Acer laevigatum Wall.*	Thích láng
Annonaceae	*Polyalthia cerasoides (Roxb.) Bedd.*	Nhọc
Aquifoliaceae	*Ilex cochinchinensis (Lour.) Loesen.*	Nhựa ruồi
Araliaceae	*Schefflera octophylla (Lour.) Harm*	Chân chim
Burseraceae	*Garruga pierrei Guill.*	Cóc tai
Clusiaceae	*Garcinia poilanei Gagn.*	Bứa rừng
Clusiaceae	*Garcinia poilanei Gagn.*	Bứa rừng
Clusiaceae	*Calophyllum rugosum P. F. Stevens.*	Còng nhám
Clusiaceae	*Calophyllum dryobalanoides Pierre*	Còng trắng
Cupressaceae	*Fokienia hodginsii (Dunn) A. Henry & H. H. Thomas*	Pơ mu
Ebenaceae	*Diospyros apiculata Hieron.*	Nhọ nồi
Elaeocarpaceae	*Elaeocarpus coactilus Gagn.*	Cẩm nhung
Elaeocarpaceae	*Elaeocarpus coactilus Gagn.*	Côm nhung
Elaeocarpaceae	*Elaeocarpus bidoupensis Gagn.*	Côm Bidoup
Elaeocarpaceae	*Elaeocarpus lanceifolius Roxb.*	Côm cuống dài
Elaeocarpaceae	*Elaeocarpus varunua Ham.*	Côm láng
Elaeocarpaceae	*Elaeocarpus coactilus Gagn.*	Côm nhung
Elaeocarpaceae	*Elaeocarpus floribundus Blume*	Côm trâu
Ericaceae	Craibiodendron heryi W.W.Smith var bidoupensis Smith&Phamh.	Cáp mộc Bìdoup
Ericaceae	Craibiodendron scleranthum (Dop) Judd.	Cáp mộc Hòn bà
Ericaceae	Craibiodendron vietnamense Judd.	Cáp mộc Việt Nam
Ericaceae	*Rhododendron klossii Ridl.*	Đỗ quyên Kloss
Ericaceae	*Rhododendron irroratum Fr.*	Đỗ quyên Langbian
Ericaceae	*Vaccinium sprengelii G. Don*	Sơn trâm
Ericaceae	*Vaccinium sprengelii G. Don*	Sơn trâm
Euphorbiaceae	*Antidesma ghasembila Gaertn.*	Chòi mòi
Fagaceae	*Triginobalanus verticillata Forman*	Dẻ ba cạnh

Fagaceae	*Lithocarpus truncatus (King ex Hook.f.) Rehd.*	Dẻ bằng
Fagaceae	*Lithocarpus campylotropis A. Cam.*	Dẻ biến vẩy
Fagaceae	*Lithocarpus stenopus (Hickel & A.Camus) A. Camus*	Dẻ cọng mãnh
Fagaceae	*Lithocarpus microspermus A.Cam. var. mekongensis A.Cam.*	Dẻ Mêkông
Fagaceae	*Lithocarpus silvicolarum (Hance) Chun.*	Dẻ rừng
Fagaceae	*Lithocarpus annamensis (Hickel & A. Camus) Barnett*	Dẻ Trung bộ
Fagaceae	*Lithocarpus microspermus A.Cam. var. mekongensis A.Cam.*	Giổi mêkông
Fagaceae	*Castanopsis pseudoserrata Hick. & Cam.*	Kha thụ nguyên
Fagaceae	*Castanopsis echidnocarpa Miq.*	Kha Thụ Nhím
Fagaceae	*Quercus braianensis A. Cam*	Sồi Braian
Fagaceae	*Quercus langbianensis Hickel & A. Camus*	Sồi Lang Bian
Fagaceae	*Quercus braianensis A. Cam*	Sồi Braian
Fagaceae	*Quercus langbianensis Hickel & A. Camus*	Sồi Langbian
Fagaceae	*Quercus poilanei Hick. & Cam.*	Sồi Poilane
Hamamelidaceae	*Symingtonia populnea (Griff.) van Steenis*	Chấp tay
Hamamelidaceae	*Rhodoleia championii Hook.f.*	Hồng quang
Illiciaceae	*Illicium parviflorum Merr.*	Tiểu hồi
Juglandaceae	*Engelhardtia roxburghiana var. brevilata Mann.*	Chẹo tía
Lauraceae	*Litsea cambodiana Lec.*	Bời lời
Lauraceae	*Litsea grandifolia Lec.*	Bời lời lá to
Lauraceae	*Actinodaphne utilis Kosterm.*	Bộp
Lauraceae	*Dehaasia cuneata (Blume) Blume*	Cà đuối
Lauraceae	*Machilus parviflora Meissn.*	Kháu
Lauraceae	*Cinnamomum cassia Nees & Eberth.*	Quế bì
Lauraceae	*Cinnamomum iners Reinw. ex Blume*	Quế rừng

Lauraceae	*Cinnamomum glaucescens (Buch. – Hamilt.) Drury.*	Re hương
Lauraceae	*Cinnamomum glaucescens (Buch. – Hamilt.) Drury.*	Re hương
Lauraceae	*Cinnamomum glaucescens (Buch. – Hamilt.) Drury.*	Re hương
Lauraceae	*Cinnamomum cassia Nees & Eberth.*	Vớ bì
Lauraceae	*Cinnamomum parthenoxylum (Jack) Meisn.*	Xá xị
Magnoliaceae	*Magnolia hodgsonii (Hook.f.& Thommps.)Keng.*	Giổi đá
Magnoliaceae	*Magnolia candollei (Bl.) Keng var. candollei*	Giổi Nha trang
Magnoliaceae	*Magnolia annamensis Dandy*	Giổi Trung bộ
Magnoliaceae	*Michelia aenea Dandy*	Sứ đồng
Mimosaceae	*Archidedron robinsonii (Gagn.) Niels.*	Cứt ngựa
Moraceae	Artocarpus rigidus ssp. Asperulus (Gagnep.) Jarr.	Mít rừng
Myrtaceae	*Baeckea frutescens L.*	Chổi sể
Myrtaceae	*Syzygium wightianum Wall. Ex Wight et Arn.*	Trâm trắng
Myrtaceae	*Syzygium zeylanicum (L.) DC.*	Trâm vỏ đỏ
Pinaceae	*Pinus krempfii Lecomte*	Thông 2 lá dẹt
Pinaceae	*Pinus kesyia Royle. ex Gordon*	Thông 3 lá
Pinaceae	*Pinus dalatensis Ferro*	Thông 5 lá
Podocarpaceae	*Dacrycapus imbricatus* (Bl.) D. Laub.	Bạch tùng
Podocarpaceae	*Dacrydium elatum (Roxb.) Wall ex Hook.*	Hồng tùng
Podocarpaceae	*Nageia wallichiana (Presl.) O.Ktze.*	Kim giao
Podocarpaceae	*Podocarpus neriifolius D. Don*	Thông tre
Proteaceae	*Helicia petiolaris Benn.*	Mạc sưa
Proteaceae	*Heliciopsis terminalis (Kurz.) Sleumer*	Song quắn

Rhizophoraceae	*Carallia brachiata (Lour.) Merr.*	Săn mã trẻ
Rhizophoraceae	*Carallia brachiata (Lour.) Merr.*	Xăng mã chẻ
Rosaceae	*Malus doumeri (Bois) A. Chev.*	Bom rừng
Rosaceae	*Eriobotrya poilanei J. E. Vidal*	Sơn trà
Rosaceae	*Eriobotrya angustissima Hook.f.*	Sơn trà hẹp
Rubiaceae	*Wendlandia glabrata DC.*	Gạc nai
Rubiaceae	*Wendlandia sp.*	Huân lang
Sabiaceae	*Meliosma lepidota Bl. subsp. dumicola (W.W.Sm.) Beus.*	Mật sa
Sapotaceae	*Madhuca alpinia (Chev.) Chev.*	Sến núi
Symplocaceae	*Symplocos poilanei Guillaum.*	Dung đen
Symplocaceae	*Symplocos poilanei Guillaum.*	Dung đen
Theaceae	*Schima wallichii (DC.) Korth.*	Chò sót
Theaceae	*Gordonia bidoupensis Gagnep.*	Gò đồng Bidoup
Theaceae	*Gordonia axillaris (Roxb.) Dietr.*	Gò đồng nách
Theaceae	*Gordonia axillaris (Roxb.) Dietr.*	Gò đồng nách
Theaceae	*Anneslea fragrans Wall.*	Luống xương
Theaceae	*Aidinandra dongnaiensis Gagnep.*	Súng Đồng Nai
Theaceae	*Pyrenaria jonqueriana Pierre*	Thạch châu

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