CHAPTER 2

LITERATURE REVIEW

This chapter reviewed the characteristics of two-needle pine or Merkus pine tree (*Pinus merkusii* Jungh. & de Vriese), characteristics of pine caterpillar (*Dendrolimus punctatus* Walker), factors effecting and controlling insect pest population, and the methodology to predict the pest outbreak and the damages caused by the pests.

2.1 Merkus Pine tree: Description and uses

2.1.1 Taxonomic notes

Scientific Name: *Pinus merkusii* Jungh. & de Vriese

Family: PINACEAE

Synonyms: *P. sumatrana*, *P. merkusiana* (Jensen, 1995). *P. merkiana* Gordon; *P. sumatrana* Jungh (Farjon, 1984 cited in Christopher, 2002), *P. finlaysoniana* Wall. ex Blume; *P. latteri* Mason, (Farjon, 1998 cited in Christopher, 2002).

Common names: Merkus pine, Two-leaf pine, two-needled pine, Mondoro pine, Sumatran pine (English); damar batu, damar bunga, uyam (Indonesian); tapulau (Philippines); son-song-bai, son-haang-maa, kai-plueak-dam (Thai); Thong nhua, Thong hai la (Vietnamese) (Jensen, 1995; FIPI, 1996)

2.1.2 Description of the pine tree

Merkus pine tree is a big tree species, which can reach up to 70 m high and 140 cm in diameter at breast height. The shape of the open crown changes from conical to round as the tree ages with somewhat pyramidal crown in young specimens (Christopher, 2002). The bole is generally straight, and tapering from the foot to the top of the tree. It is about 30 m long from the foot to the first branch. At the lower part of the tree, the bark is thick, rough, gray-brown or reddish-brown, and deeply fissured which forms small round plates; the bark on the upper part of the tree, on the other hand, is thin and flaky. The branches area bit thick and heavy, and sometimes they are found in horizontal position. The leaves are needle-shaped, 15 to 25 cm long slender but rather hard**.** The leaves grow in pairs and last about two years together with their sheaths. Dried leaves weight 60 - 90 milligrams per fascicle. The flowers are purple. The fruits come out singly or in pairs, which are about five cm wide and 10 cm long, maturing after two years. Mature cone is cylindrical or long ovate in shape, with one cm long pedicel. It is propagated by seeds and flowers and its reproduction period is from November to March. Its seeds are small, ovate-shaped and slightly flat, with thin wings (Jensen, 1995; FIPI, 1996).

2.1.3 The uses of the Merkus pine tree

Merkus pine is considered a valuable tree as it can produce good quality crude resin. The resin can be extracted by tapping and injuring the sapwood and cambium of living standing pine trees. The tree contains a high content of resin and each tree can produce three to four kg of resin per year on average (FIPI, 1996). For normal pine trees, high quality resin contains about 160 to 170 kind of acids. The merkus, however, contains over 190 kinds of acids, in which some are rare resin acid (FAO, 1995). Crude resin is thick, sticky, and in fluid form. The fluid resin will be transformed into brittle solid form, called "rosin", after being processed under steam distillation. The resin is used in different field including commerce and industry. Manufacture of adhesives, paper-sizing agents, printer inks, solders and fluxes, surface coatings and synthetic rubber are some of the commercial applications of the resin. In electronic industry, it is as the main material to produce insulating products. It is also the material for making chewing gums, producing the products used for health care such as soaps and detergents (FAO, 1995; Jensen, 1995). Turpentine, also in liquid form, is produced after the resin is distillated. Turpentine has sharp and strong odor and bitter taste. It is used to produce paint, varnish, fragrances, flavors, vitamins, adhesives, and disinfectants. Merkus pine is also of an important ingredient of wax, which is used in batik fabric industry (FAO, 1995). Timber of Merkus pine is used for civil construction; it is suitable to make strong posts and pile. The timber is also specially used making pulp and producing paper. The wood of Merkus is hard and heavy. It is used in construction, used for making matches, toothpicks, paper pulp, domestic furniture, pit props, electronic poles, ships and vehicle-building (Christopher, 2002). It helps maintain the ecological balance in nature and freshen the air in the area. This species has been successfully grown in an agroforestry system, which intercropped pine trees and Irish potatoes in Indonesia (Jensen, 1995). It is a useful species for soil conservation or restoration of degraded areas (FIPI, 1996). In some Christian countries in Asia, pine trees are used during Christmas season as Christmas trees (FAO, 1995).

2.1.4 Distribution and habitat

Merkus pine tree is naturally growing in eastern Myanmar, Indo-China, southern China, northern Thailand and western Luzon and Mindoro of the Philippines, Sumatra (Aceh, Tapanuli region, Kerinci mountain) (FAO, 1995). It is planted mainly in Southeast Asia (Christopher, 2002). In Vietnam, it is found in large stands or in small groups at Lai Chau, Son La, Lang Son, Bac Thai, Ha Bac, Quang Ninh, Thanh Hoa, Nghe An, Ha Tinh, Quang Binh and Thua Thien Hue provinces (FIPI, 1996). It naturally grows in Mindoro, (Philippines) at the altitude below 1000 m and at 60 m a.m.s.l. At up to 2000 m altitude, it occurs in Sumatra, Indonesia (Jensen, 1995). It is found at elevations of between 800 - 2000 m, usually in open, savannah-like areas where the trees are frequently burned by native peoples, but it can also grow in tropical broadleaf forest. The best-developed forests of the trees have been found around Lake Toba in northern Sumatra (Christopher, 2002). It occurs in the areas where the average annual rainfall is 1000 - 3500 mm, and the average temperature is 19 - 28°C annually, the average maximum temperature in the hottest months is 24 - 35^0C, the average minimum temperature in the coldest months is five to 24^0C, and the absolute minimum temperature is greater than two degree Celsius.

It is a pioneer species, light demanding, heat and drought resistant tree, growing well on sandy and red soils. In Northern Vietnam, this species is one of the principal species, which is planted on bare or bushy hills, in order to protects land and minimize soil erosion and land-deformation. Young trees grow slowly during the first five years; their growth rate then increases. The 15 years old or older trees can produce resin. Natural regeneration is good, especially on open lands. Its flowers can be found in May - June; and the cones get mature in October - November of the following year (FIPI, 1996).

This species is vulnerable to many kinds of insects and diseases. At the seedling and young tree stages, it can be destroyed by ants, crickets, mole crickets, grasshoppers, cutworms, and other insect pests. At the mature stage, defoliation (caterpillars, sawflies) or borers (foliage, seed, and wood) are the major destroyers to the species. The common pests are such as *Milionia basilis, Pineus pini, Evetria duplana, Gilpinia murshalli, Dendrolimus kikuchii, D. puntatus,* etc (Duc, 2000; Loanh, 1989) and some common diseases are *Mycosphaerella pini, Cercospora pini-densiflorae, Lophodermium pinastri, Cladosporium hebarum,* etc (Mao, 1992; Dien, 1997).

2.2 The life cycle of Pine caterpillar and its effect

2.2.1 Taxonomic notes

Scientific Name: *Dendrolimus punctatus* Walker

Family: LASIOCAMPIDAE

Common names: pine caterpillar, Masson pine moth, Lappet moth (English), sau rom thong (Vietnamese).

2.2.2 Description of pine caterpillar life cycle

Eggs (Figure 2.1 a): Eggs of the pine caterpillar are oval in shape, 1.8 - 1.9 mm long, and 1.0 - 1.2 mm wide with light blue color and become light pink, and dark brown before hatching. Parasitical eggs are black or dark purple (Loanh, 1989). The eggs are laid in rows on the leaves of the pine trees, which are older than five years. They are distributed equally throughout the leaf canopy (Dien, 1997). The duration of egg stage is about 5 - 10 days depending on climate, especially temperature (Thuong, 1987).

Larvae (Figure 2.1 b, c, d): There are five or six instar larvae stages depending on different sub-species and the fluctuation of weather (temperature). The duration of each instar larvae and total larvae stage depends on the temperature. For example, if the temperature is 28^0C, 30^0C, or 32^0C the duration of larvae stage will be 32, 26, or 24 days respectively (Loanh *et al.*, 1992). Generally, the duration of larvae stage is about 25 - 40 days (Thuong, 1987). The larvae are dark brown or silver-dark brown on its body with some scatter white dots. It consists of 12 abdominal segments (Dien, 1997). It is necessary to take the larva with caution because its hairs contain an urticaceous toxin, which may cause itches. Some people may be immune from the toxin. Its form is different at different instar larvae stages. The length increases from two to three cm at the early instar larvae to five to six cm at the mature larvae. At all stages, fungus (*Beauveria bassiana*), or bacteria (*Bacillus thuringgiensis*) are the common parasites on the larvae (Loanh, 1989). A special biological feature of the larvae is that it can spit out its silk while moving for self-defense. From the second instar larvae, it starts to crawl from the one to other places along the tree branches. It can move between different trees along the intersection of leaf canopy (Dien, 1997). Haft a day after hatching the larvae start feeding on pine leaf. At the first and second instar larvae, it gnaws pine leaves and which forms serratiform leaves**.** From the third stage it destroys the leaves by eating half or two-third of the leaves normally. If the density of the larvae is high the situation will be more serious because it can eat whole leaves. At the fifth and sixth instar larvae, it slows down its activities, usually sprawl gets ready to make cocoon (Dien, 1997).

Pupae (Figure 2.1 e): Pupae have black-brown or reddish-brown color and different obviously segments. Their abdomen has seven pairs of outlets on both sides. The pupae live in silk cocoons covered by silks and poisonous hairs. The cocoons are white-gray, 32 - 37 mm long, and 10 - 13 mm wide (Loanh, 1989). The duration of pupa stage is about 7 - 10 days (Thuong, 1987).

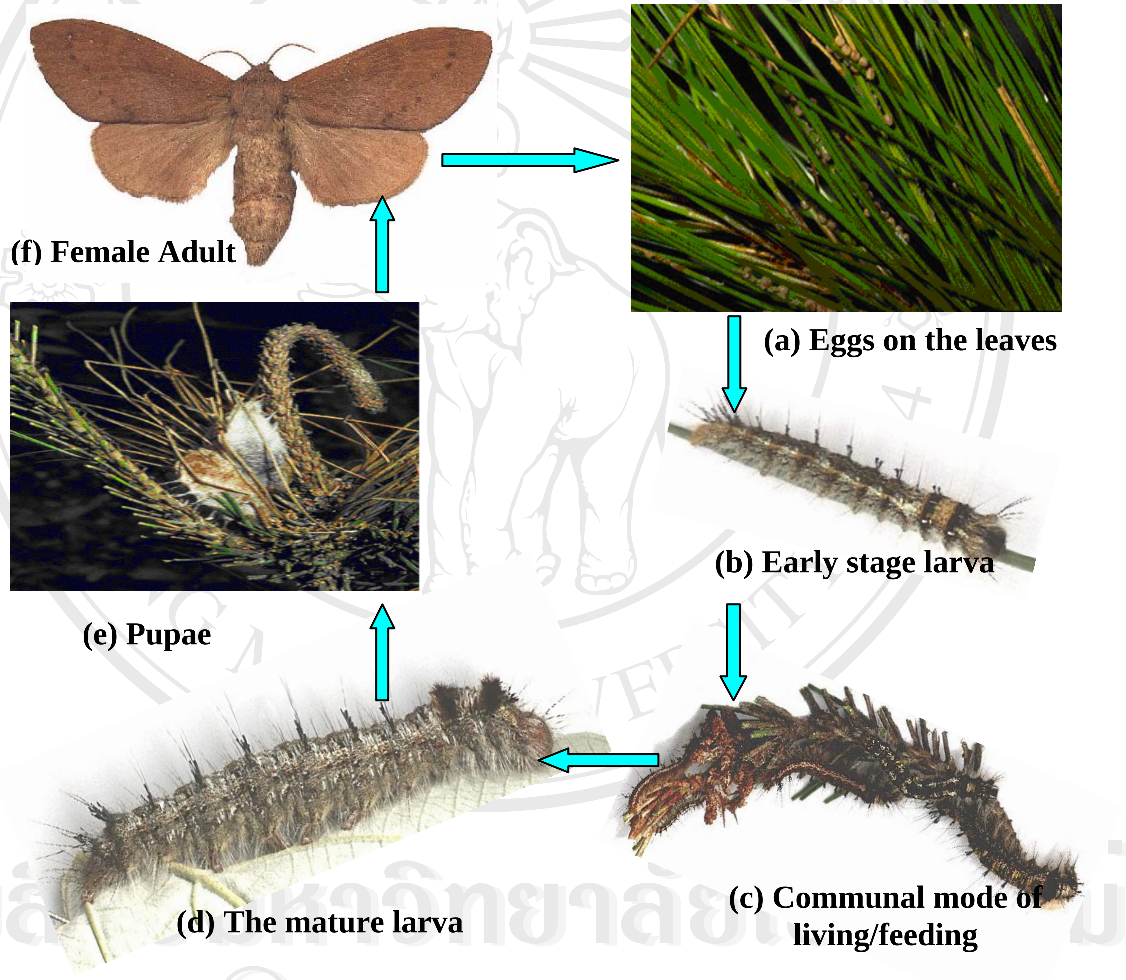

Figure 2.1: The life cycle of pine caterpillar (*Dendrolimus punctatus* Walker).
(Source: taken from field survey, and William, 2003).

Adults (Figure 2.1 f): In rest position, the female moths are between 25 and 35mm long. Their wingspan is about 50 to 70 mm. Male moths are smaller than females (Dien, 1997). Their color changed depending on different time of the year.

The antennae of the female moths are thin (single), and those of male moths are feathery. Their front wings are larger than the rear ones. In the middle of the front wings, there are small white dots. There are four darker stripes located from the foot to the edge of the front wings. Especially, at the edge of wings there are eight black dots, which arrange in number 3 shape (Loanh *et al.*, 1992). Generally, the male moths leave their cocoons one to two days earlier than the females. Four to five hours after getting out the cocoons, female moths start to copulate. The copulation may last 10 - 12 hours. After copulation, the adult female moths can lay eggs immediately. The eggs are laid in rows on the leaves (Loanh, 1989). An adult female moth can deliver about 300 - 500 eggs in one event. Egg-laying duration may take two to three days (Dien, 1997). The duration of adult stage is about 5 - 10 days (Thuong, 1987).

2.2.3 The occurrence calendar of pine caterpillar

Depending upon latitude, *D. punctatus* in China completes one to five generations per year (Zhang *et al.*, 2002). However, in Thua Thien Hue province, there are four generations of pine caterpillar in a year (Table 2.1). The density of each stage of pine caterpillar is different at different time in a year. At larvae stage, the high density is found in the period from October to February, when the fourth generation is produced in the year (Dien, 1997). In China, however, the over-wintering generation of the pine caterpillar develops into adults in late June. The first generation of moths reaches a peak in early to mid-August (Zhang *et al.*, 2002). In Thua Thien Hue province, from May to September, the density of larvae is lower because of higher temperature and lower humidity in this province during this time (PIAWFR, 1994). In addition, since the average temperature in the province in winter season is mild (20.2^0C - 25.8^0C) for the larvae needs to have hibernation period. This is quite contrary with what happen in Northern Vietnam where pine caterpillars have to hibernate in winter season, and the high larvae density is from June to August (Dien, 1997). During the winter season in Thua Thien Hue province, the pine caterpillar is sometimes too serious that may cause "forest - fires" which is called "a forest fire without smoke" (PIAWFR, 1994).

Table 2.1: The occurrence calendar of pine caterpillar in Thua Thien Hue province.

Generation \ Month	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
I		-----	-----									
			ooo	oo								
			+++	++								
			*	**								
II				--	-----	--						
					o	oo	o					
						++	+					
						**	*					
III							--	------	------	--		
								o	oo			
								+	++			
									**			
IV	-----	-----	-							-----	-----	-----
	ooo	oo								o	ooooo	ooooo
	++	+									++	+++
	**	*								**	**	**

(Source: Dien, 1997; PIAWFR, 1994).

Note: ----- Larvae stage ooo Pupa stage +++ Adult stage *** Egg stage

2.3 Factors effecting and controlling insect

At the first glance, insects are normally blamed for the break of ecological interrelationships. In facts, there many other factors make pest outbreaks happen. It is often difficult to distinguish between proximate causes and the ultimate causes. The main causes of outbreaks include (1) dramatic changes in the physical environment; (2) changes in the genetic composition of the pest population; (3) the qualitative changes in host plants caused by environmental stresses; (4) life history strategies characteristic of the species (Nair, 2001). The outbreak of the insect has been influenced by many factors, especially weather factors. Being cold-blooded species, insects are sensitive to outdoor temperatures (Loanh, 1989). According to Csóka (1995), climate conditions can have significant affects on the fluctuations of forest insects' population. The impacts can either be direct or indirect. The mortality decreased because the mild winters, and larval survivorship was higher because of the rainless period during the development. In addition, tree resistance was decreased by water deficiency. The joint impact of these factors resulted an expansion of areas damaged by several forest insects. Meshkova (2002) has recorded the correlation coefficients between climatic indices such as air temperature, rainfall, hydrothermal coefficients, winter severity, dates of late spring and early autumn frosts, dates of stable transition of air temperature over and below different limits (0, 5, 10, and 15°C) and the indices effecting the outbreaks of foliage - browsing insects, the probability of outbreaks, annual average effected area, and specific annual effected area for each of the main species. For *Tortrix viridana*, the species hibernate during the egg stage, she concluded that there was a close correlation between the probability of its outbreaks and latitude, longitude, continents. She also found that the outbreaks of the insects occurred more often in the regions where air temperature is high and the rainfall is low during the vegetation period. The integrated influence of temperature and rainfall on the insect outbreaks has been proved. The probability of *T. viridana* outbreaks is higher in regions where experience more early springs and shorter periods of larval feeding. There is a positive correlation between the density of gypsy moth foci and air temperature. It is claimed that warm autumns present the favorable conditions for the development and growth of the month and the most populated area of the moth often occur during the time. Warm autumns also provide the best environment for eggs to finish forming embryos and start diapausing stage. The highest probability of gypsy moth outbreaks is found during the time between May and September, and it is lower in October. There is a negative correlation between annual rainfall during the period when temperature is above zero and the pests' outbreak. It was proved that the lower the rainfall is, the higher probability of pests' outbreaks. Moreover, the probability of gypsy moth outbreaks is high when the air temperature stabilizes over 10°C in the spring. This means that an early spring is favorable for development of gypsy moth outbreaks (Meshkova, 2002). The study also calculated the correlation coefficients between the climate indices and other groups such as the species hibernating during larvae stage (such as *Dendrolimus pini, Euproctis chrysorrhoea*); hibernating during pupae stage (such as *Panolis flamea, Bupalus piniarius*); hibernating during enonymphs (*Diprion pini).* The results showed that the dynamics of insects' population depends on the peculiarities of seasonal development the insects and in particular, on weather conditions in the region. The results also showed the probability of outbreak depend on the biological features of insect species. For example for the insect species hibernating in the egg stage, the initiation of outbreaks occurs more often in a year when larval starts feeding early; for the species hibernating in larval stage, the outbreaks often happen at the end of the summer when the weather is dry and hot and young larvae are feeding; the outbreaks of the insect species that hibernating in the pupal stage occur in the years when early springs or dry and hot Junes are present and the outbreaks are associated with conditions supporting the rapid development of young larvae. The occurrence of outbreaks of insect species of which feeding takes place at the end of the spring season is also associated with warm and dry weather which promotes both the completion of their seasonal development and the completion of the period of vegetation by the host tree. In addition, the relative correlation between the course of annual temperature and the dissemination of foliage browsing insects in different regions of the Ukraine has provided evidences to support a suggested phenological theory of population dynamics (Meshkova, 2002). Volney and Fleming (2000) have studied on three defoliators, namely; spruce budworm (*Choristoneura fumiferana* Clem.), jack pine budworm (*C. pinus* Freeman), and forest tent caterpillar (*Malacosoma disstria* Hübner). They concluded that the populations of the three defoliators on the major forest tree species of the western boreal forest of Canada are all sensitive to climatic affects. The success of the insects in establishing feeding sites in the spring depends on both their development and the buds of their hosts. This indirect affect of climate appears to be critical in initiating outbreaks of all three species. The collapses of outbreaks often come together with heavy losses of foliage for these insects which is normally caused by spring frosts. For the two budworms, the normal collapse of the outbreak in the host's core range is associated with mortality driven by natural enemies at the late period in the larval stage. According to Loanh (1989), the proportion of hatching egg of pine caterpillar (*D. punctatus)* was about 54% if the temperature was greater than 32^{0}C. In addition, if the temperature was 28^{0}C, 30^{0}C, or 32^{0}C the duration of larvae stage was 32, 26, or 24 days respectively. Moreover, when the air humidity was over 75%, the hatching rate was greater than 90%. However, when the humidity decreased to 11% the hatching rate was 10% only. The larvae can only well develop in the environment where the humidity is over 75%. If the humidity is below 50%, the larvae cannot complete their development stage. Tiansheng (1995) had cut down 160 pine trees damaged by the pine caterpillar (*D. punctatus)* in different stands to analyze the affects of pests on volume growth of the trees. The results of stepwise regression showed that the age of the tree was the most important factor effecting the pests' outbreaks, followed by soil condition, meteorological factors, and forest density. The damage of caterpillar was simulated by artificial defoliation of the pine trees at different age in two kinds of soil conditions and under four seasonal periods. According to Dien (1997), the pine caterpillar (*D. punctatus*) outbreak has a strong relation to some climatic factors such as monthly average temperature, average humidity, and monthly total rainfall. It also has relation to the age of pine forests. The pine caterpillar outbreak usually occurred in the forests age from seven to 16 years, especially at the age of 12. The damages are not serious in the forests which are younger than seven or older than 17 years of age. At these ages, the forests are normally slightly affected by the pest, which causes no damage or a small damaged area. The outbreak of pine caterpillar usually occurs during October to March coinciding with the rainy season in Thua Thien Hue province. Roland (2002) examined the influence of forest diversity and other environmental factors including winter temperature, spring degree-days, and elevation on duration of pest outbreaks. Of these, forest diversity is the strongest predictor of the number of years of defoliation**.** The role of climatic perturbations in outbreaks remains unclear, but it may be discovered through the studies at larger or smaller spatial scales (Roland, 2002). The effect of plant age and weather factors on species richness and fluctuation of defoliator Lepidoptera populations was investigated in a *Eucalyptus grandis* plantation forest that was studied by Guedes *et al.* (2000). The study found that the lowest numbers of individuals were obtained in July and highest numbers were obtained in late December. In addition, the obtained results suggest that high populations of the main defoliator Lepidoptera species presenting in the area are more likely to occur in plants age older than five years and especially during the rainy season (October to March) (Guedes *et al.*, 2000). The study conducted by PIAWFR (1994) showed that the outbreak of pine caterpillar (*D. punctatus*) in the Northern Central region of Vietnam depended on the weather factors. In northern part, from December to February when the average temperature is about 18-19^{o}C, the larvae population is smaller and they are in slow activities. In Thua Thien Hue province, from May to September, the temperature is high and the humidity is low that cause larvae less developed or dead. It is difficult to find out larvae during this time in the year. In addition, during the first and second instar larvae, if the monthly total rainfall is greater than 500 mm, or daily rainfall is greater than 100 mm the density of the larvae then will reduce. Rubtsov and Utkina (2002) found that the larvae at both older and younger ages of the green oak leaf roller, *Tortrix viridana* L., are not very active and they move within a crown only if their food sources are not available. The laziness, predators and entomophases are the main factors caused about 90% of larvae deaths. A considerable portion of the larval population was killed by diseases caused by entomopathogens. However the disease has not ever caused serious decrease in larvae population. The study also showed that the development of *Tortrix viridana* L. outbreaks depends significantly on the survival rate in the larval, pupal stages and consequently on weather conditions, the condition of the host tree, and biotic factors. A delay in the development of larvae and pupae due to unfavorable conditions results of an increase in larvae death and it is, therefore, an important factor in the population dynamics of this species.

To control pest outbreak, Price *et al.* (1997) provided details of a technique using trap trees as a control measure. This consisted of cutting healthy trees at specified intervals. After the trees have been attacked by beetles, they were burned to eliminate the brood. In addition to direct control measures, he recommended thinning and sanitation measures to prevent attack. He also suggested that careless logging as well as weather and soil conditions may predispose stands to be attacked. A practical and effective method of disrupting expanding beetle infestations known as cut-and-leave was applied instead of the previously-used chemical control and pile-and-burn methods. Prompting the detection of new infestations followed by cut-and-leave treatment effectively minimized resource losses during the recent beetle outbreaks. Despite a greater number of initial infestations per year during the latter period, affected area has reduced from 14 ha per infestation on average to 0.4 ha per infestation by using cut-and-leave. Overall, total timber losses have reduced from 10,175 ha to 405 ha (Billings *et al.*, 1995). Augmentative biological control is a process designed to increase the efficiency of natural enemies already in place. Mass release of *Trichogramma dendrolimi*, an indigenous egg parasitoid of the defoliator *D. punctatus* in pine plantations in China is an example of this tactic. Another biological control tactic is use of biological insecticides such as bacterial agent, *Bacillus thuringiensis* (Bt), nuclear polyhedrosis viruses or fungal preparations to control insects. Bt is widely used to control lepidopterous defoliators in both natural and plantation forests. In China and Vietnam, a fungus, *Beauvaria bassiana*, is used to control the pine caterpillar, *D. punctatus* (FAO, 2001). To control the teak defoliator, *Hyblaea puera* Cramer, the aerial application of the bacterium, *Bacillus thuringiensis* Berliner var. kurstaki, was tried in Thailand as a substitute for the ground fogging method. Because ground spraying is inadequate for its control due to the very high feeding rate of the larvae and the fact that ground fogging can cover only a small area of extensive plantations. It is concluded that aerial spraying of commercially available *Bacillus thuringiensis* can be successfully employed for teak defoliator control (Hutacharern *et al.*, 1995). Another method was suggested in India to control the teak defoliator, *Hyblaea puera*, by using a crude preparation of a naturally occurring Nuclear Polyhedrosis Virus (NPV). One-time foliar application of NPV at the rate of 1×10^5 PIB/ml of the spray fluid, at the earliest sign of infestation, gave 70 to 75% protection during the first two infestations and 25 to 40% protection during the third and fourth infestations. The reduced effectiveness of NPV in the latter case was attributable to occurrence of rain, which may have caused wash off of the spray fluid. Methods were also standardized for monitoring the pest populations to facilitate timely application of control measures. The results showed that it is feasible to use NPV to control teak defoliator infestations (Sudheendrakumar *et al*., 1995).

2.4 Methodologies to predict the pest outbreak and its damage

A variety of methods is used to predict when a pest insect is at a susceptible stage. Using degree-days is more accurate in predicting insect emergence, but this method requires calculation or at least entering daily high and low temperatures into a calculator or computer program. Nixon suggested using plant phenology to predict the insect outbreak. Plant phenology is the process of associating a plant event, such as blooming, with the presence of a susceptible stage for pests. This is a very practical method because this method makes landscapers or nursery laborers enable to observe the daily happenings of the plants and realize the signs indicating the potenatial effects of insects at different stages. Phenology should be used to help determine when to scout for an insect, and not as a stand-alone insect control guide. As with any system, the presence, number, and potential damage of an insect must be verified before insect pest management is undertaken (Nixon, no date). Franklin *et al.* (1995) have used logistic regression techniques to develop models for predicting forest susceptibility (degree of defoliation observed) and vulnerability (impact of defoliation observed) and to assess the accuracy of the susceptibility and vulnerability forecasts. The result showed that when compared with the unaffected areas, the susceptible stands were younger and had lower basal area and lower tree density, but higher leaf area index. Vulnerable areas were older, had lower growth indices (stem-wood growth per unit of leaf area) and also displayed the highest near infrared reflectance values. Those models produced classification with accuracies of 81, 67, and 78% for predicting susceptibility and pre- and post-outbreak vulnerability, respectively. To determine the probability of outbreak, Meshkova (2002) has calculated the correlation coefficients between climatic indices and the probability of outbreaks. The result showed that there was a strong relation between these factors. In addition, the probability of outbreaks depended on insect species. Rubtsov and Utkina (2002) have developed a mathematical model of the development of *Tortrix viridana* L. populations. The model is non-linear, non-stationary, having alternating structure and dimensions, and reflects the results of a series of complex interactions within the modeled system. The mathematical model can be used to describe the dynamics of *Tortrix viridana* L. populations. It can also be used to estimate the following parameters: the density, survival rate, fecundity, and propagation coefficient of the population in each generation; defoliation and refoliation of crowns in a stand; value and loss of stem increment, and some other parameters. The model demonstrates that weather has a relative impact on the development of larvae and that the level of crown defoliation decreases at higher population densities; if the population continues to increase, i.e. a significant over-population occurs, the importance of weather factors again increases (Rubtsov and Utkina, 2002). The multiple regression models were developed to assess the relative importance of plant age and weather factors (temperature, relative humidity, and rainfall) affecting species richness and fluctuation of Lepidoptera populations. The obtained results found that plant age and average temperature were the main weather factors affecting species richness and abundance of total individuals of the species *Stenalcidia grosica*. Older plants (six to seven years old) and lower temperatures (18^0C) seem to favor species richness and higher populations of Lepidoptera. In contrast, plant age and rainfall were the main factors affecting the fluctuation of *Glena unipennaria* populations that presented higher incidence in older plants (six to seven years old) and higher rainfall (400 mm) (Guedes *et al.*, 2000). According to Guo *et al.* (2003), the relationship between population of the pests (*D. punctatus*) and their hosts' wood-loss is a linear one with a correlation coefficient (R) of 0.80. This study also found that a young tree is much more sensitive to the pest attack than the mature one and the pest attacking from March will do much larger damage to their host than one from September. By using simulation studies on the relation between the extent of damage caused by the pine caterpillar and wood volume losses were carried out in Southeast of China, Tiansheng (1995) concluded that the relationship was not a simple linear, but rather a curved regression or polynomial regression. A formula was developed to predict volume loss caused by the pine caterpillar, and therefore, an evaluation of the impact of the pest on *Pinus massoniana*. Dongliang and Bingli (1995) used multiple regression analysis and established a model to simulate the epidemic as; Y = 1.911 + 0.66X1 + 0.052X2 + 4.60X3, (where Y is the density of infected *D. punctatus* per square meter, X1 is the density of *D. punctatus* per square meter, X2 is the amount of *Beauveria bassiana* spore per scope, and X3 is the moisture content of the needle). The results provide a theoretical basis for forecasting the epidemic of *Beauveria bassiana* in Masson-pine forests and suggest principles for use of the fungus to control the Masson-pine caterpillar. For quantifying pine beauty moth (*Panolis flammea* Schiff.) populations in pine stands of Southern part of Lithuania, Žiogas (2002) has evaluated different methodologies. Evaluations were conducted in selected pine stands by assessing the following elements: number of pupae in the litter; number of larvae falling from trees after chemical knock down; and number of adult insects using pheromone traps. Analysis of evaluation methods indicated that the populations could be assessed most accurately by using the method of counting larvae. This method is used when outbreaks occur or aerial spraying of insecticides is needed. Count of pupae in the spring is the most accurate method for forecasting current densities of pine beauty moth. This was the most suitable method for silvicultural purposes; the use of pheromone traps is less precise than the other two methods. However pheromone traps, at best, are suitable only to determine the periodicity and intensity of flying adult males and for convenience, they can be placed at the height of three to four m (Žiogas, 2002). Dien (1997) suggested to use some indicators to predict the outbreak of pine caterpillar (*D. punctatus*) such as basing on the cocoon density, and sexual ratio and the age of forest; if healthy cocoon density is four to five cocoons per tree found in the forest age 7 – 10 years old, or six to eight cocoons per tree in the forest age 11 - 15 years old then the outbreak may be occurred during the next life cycle. Another indicator is based on egg density. This method shows that if egg density is 900 - 1,100 eggs per tree and 1,300 - 1,700 eggs per tree found in the forest age 7 - 10 and 11 - 15 years old, respectively, and at the same time if the egg parasite ratio is less than 75%, the outbreak will occur at the end of that cycle life.

According to Duc (1996), the potential damages of pine caterpillar (*D. punctatus*) can be predicted based on the density of larvae, or pupae, or egg and the pine tree age. The relation is shown in Table 2.2. The results of PIAWFR (1994) suggested the economical and preventive thresholds for pine caterpillar in North Central of Vietnam based on the density of egg, or larvae, or female pupae as presenting in Table 2.3.

Table 2.2: Damage potential of pine caterpillar base on density in each stage.

Indicators	Pine tree age (years)			Damage potential
	7 – 10	11 – 15	> 15	
Fifth or sixth instar larvae (larvae/tree)	10-15	16-25	>25	Heavy at following generation
First instar larvae (larvae/tree)	600	>600	600	Heavy at mature instar larva
Healthy female pupae (pupae/tree)	4-5	6-8	>8	Heavy at following generation
Egg (low parasitical ratio) (egg/tree)	900-1100	1200-1700	>1700	Heavy at current generation

(Source: Duc, 1996).

Table 2.3: Economical and preventive thresholds for pine caterpillar in North Central of Vietnam (for pine forest which age from 10 to 15 years old).

Indicators	Healthy egg	Instar larvae		Healthy female pupae
		2, 3, 4	5, 6	
	--Eggs/tree--	---Healthy larvae/tree---		---Pupae/tree---
Preventive threshold	900	600	90	6
Economical threshold	2,000	1,000	200	12

(Source: PIAWFR, 1994).

Traditionally, predictive modeling and decision support on control options have been the most important activities in forest pest management. When the concept of forest pest management is expanded to cover ecosystem-based health management, emphasis has been shifted to monitoring and diagnosis. Also a new predictive modeling has to be different from the present one; static model which is not driven by environmental factors need to be replaced by a more dynamic one (Saarenmaa *et al.*, 1993). Park and Reid (2002) have developed the Incidence Function Models (IFMs), a method to predict insect movement. IFMs estimate the probability of insect colonization based on patch size and isolation from other populations. IFMs have great potential for forest management since they can include a variety of ecological attributes, such as dispersal behavior and variation in habitat. Scientists in the Canadian Forest Service in Victoria have developed decision support tools called MPB-SELES, a Spatially Explicit Landscape Event Simulator, is a system that facilitates the specification and execution of landscape simulation models. Several large -scale operational level projects have been undertaken using the MPB-SELES model to examine the differential effects of management scenarios on spread and impact of mountain pine beetle (Shore and Riel, 2002). For insects, weather conditions are the controlling factors. Scientists at the Laurentian Forestry Centre (Canadian Forest Service, 2003) have developed another simulation model to predict different stages of insect development during the growing season, called BioSIM, which can be used to monitor or manage insect pest populations in outdoor situations. The package is generic, in the sense that it can help predict the development of populations of any insect or plant pathogen, provided that a simulation model for the organism is available. BioSIM also provides general-purpose simple or multi-stage degree-day summation models. Models are available for Spruce budworm, Gypsy moth, Hemlock looper, Jack pine budworm, and Yellow-headed spruce sawfly. By linking meteorological data to information on how temperature affects a given species, BioSIM predicts the timing of specific stages in an insect's life cycle (egg, larva, adult). With sufficient information on the pest's biology and local climate conditions, BioSIM can gives predictions for specific locations. Moreover, pest development predictions can be mapped for the entire region. The maps can be used in planning forest management activities that optimize pest control methods (prevention and intervention) and use of resources according to the risk level (Canadian Forest Service, 2003).