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Article 7: Biodiversity Conservation & Management Studies in New Zealand

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Abstract

This article firstly gives the full review of biodiversity conservation & management practices, mainly selecting plantation management, control of mammal pest, biological control of insect pests as the representative success in NZ biodiversity conservation. However, the original advice for future improvement has been discussed finally.

Key words: Biodiversity Conservation and Management, Plantation Conservation, Mammal Pest Management, Biological Control of Insect Pest.

1. Biodiversity Conservation of Plantations in NZ

1.1. Significance of plantation conservation

The biodiversity conservation should be recognized and provided in plantation forests due to its several crucial roles with respect to indigenous species, such as provision of essential habitats for indigenous species, connectivity between indigenous remnants, and buffering function (Lindenmayer & Franklin, 2000).

Therefore, it is necessary to conserve biodiversity within plantation forests, especially when plantation forests have occupied a significant proportion (more than 20%) of total forest areas in New Zealand. However, most of management practices taken in plantation forests paid the greatest attention to the maximization of timber production rather than integration of biodiversity conservation (Hartley, 2002).

1.2. Conservation value of plantation forests

1.2.1. Populations of indigenous species within exotic stands

If the plantation forests are well managed, they will become the areas that provide suitable habitats for diverse indigenous flora and fauna species (including threatened species), rather than 'biological desert'. For example, in Central North Island, the plantation forests were developed into important habitats for some rare species, such as kiwi, bats, and falcon. According to the subsequent investigation, there was no significant difference in kiwi populations between exotic stands and indigenous stands, which reflected the conservation value of plantation forests. Similarly, a wide range of indigenous plant species can form diverse understorey layers within plantation forests, which support a number of indigenous invertebrates and microorganisms (Lindenmayer & Franklin, 2000; Maunder, Shaw, & Pierce, 2005). However, both species richness and structure composition of indigenous plants are usually related to stand age. Odgen et al., (1997) reported that species richness increased with the increase of stand age, especially in the first 11 years.

1.2.2. Connectivity and buffering functions in plantation forests

Plantation forests will facilitate the movement of indigenous species between suitable habitat patches. Habitat fragmentation, which tends to isolate and/or subdivide populations, is one of the major threats for the wildlife conservation in temperate forests around the world. Consequently, the connectivity function of plantation forests is considered to be of significance for the conservation of these fragmented reserves. Particularly, those species that disperse randomly rather than movement using corridors may largely rely on this connectivity function of plantation forests. Therefore, well-managed plantation forests may enhance the population distribution of indigenous species, which eliminates the risks that an entire population can be extinct in the catastrophic events (such as wildfire) (Lindenmayer & Franklin, 2000)

In most regions, there are some small or medium-sized indigenous remnants within plantation forests, which may contain representative or rare species in their ecological districts. The edge areas between these indigenous remnants and their surrounding environment, which are typically warmer, windier, and drier than interior areas, are usually dominated by plants and animals of disturbed sites which threaten the biodiversity within indigenous remnants. In this case, plantation forests may provide buffering zones which reduce this edge effect in adjacent indigenous remnants, and hence can be considered to be significant in conservation management (David & Judith, 2004; Lindenmayer & Franklin, 2000).

1.3.Conservation management in plantation forests

1.3.1.Retention of essential areas for indigenous species

As mentioned above, there are usually some indigenous remnants within plantation forests, which are the key habitats for many indigenous species. Permanent retention of these indigenous remnants is crucial for the biodiversity conservation within plantation forests (Dyck, 2000). Protection of other sensitive areas such as wetlands, riparian zones, and lake margins is of significance for the conservation of an array of aquatic taxa. Harvesting operation which is closed to or within these areas will increase sediments and change microclimate (such as radiation availability and temperature regimes), which may negatively influence the stream populations. Hence harvesting in these sensitive areas should be prevented (Lindenmayer & Franklin, 2000; Metzeling, Doeg, & O'Conner, 1995). Especially, retention of these indigenous remnants is regulated by legislations in New Zealand (such as the Forests Amendment Act 1993 and the NZ Forest Accord), which enforce the managers of plantation forest to comply.

Retention of dead logs on the forest ground during harvesting process can be crucial for some non-autotrophic species. For example, retention of dead logs within plantation forests provides the key habitats for diverse fungi species (Niemela, Renvall, & Penttila, 1995). In Europe, a large proportion of saproxylic beetles (approximately 42-56%) rely on the dead woods, which plays an important role in decomposition and nutrient cycling in natural boreal forests (Kaila, Martikainen, & Puntilla, 1997). The retention of logs also provides important travel routes for small mammals to disperse through disturbed areas. In addition, stands on geologically and edaphically unstable areas such as steep terrain must be protected for the prevention of soil erosion (Lindenmayer & Franklin, 2000). Harvesting operation should also ensure that the important indigenous understorey vegetation will be relatively intact during harvesting (Lindenmayer & Pope, 2000). Usually, retention of these dead logs and understorey structures does not significantly increase economic cost during timber harvesting.

1.3.2.Maintaining the connectivity and buffering function

Management of plantation forests should enhance the connectivity function for the movement of indigenous species between habitat patches. There are a number of management practices to enhance this connectivity function. Firstly, establishment of wildlife corridors between suitable habitats, which prevents dispersal through open areas, can be valuable for some taxa (Lindenmayer & Franklin, 2000; Norton, 1998).

Secondly, the plantation design should ensure there are always continuous mature forests between indigenous remnants, which contribute to the dispersal of indigenous fauna species (especially for native birds). Another advantage of this design is that the younger plantation areas are connected with mature forests, which facilitates the re-colonization of new planting areas for indigenous species (Norton, 1998). Usually, this design of rotational sequence may not negatively influence the yields of timber production.

However, for those species that disperse randomly, corridor strategy may not be effective. In this case, permanent retention of some large stands (such as stands over 10 cm diameter and above 2 m height with at least one hollow) within harvesting areas will be helpful, which allow animals to disperse through these disturbed areas and re-colonize the new revegetation areas (Smyth, MacNally, & Lamb, 2002; Thomas et al., 1990). Nevertheless, this retention strategy sometimes led to declines in the yield of production forests, which hence might not be easily accepted by plantation forest managers (Hansen et al., 1995).

Especially, the planning of transportation networks in plantation forests should carefully consider that these roads may become the dispersal barriers across streamlines or ridge-tops. In addition, harvesting adjacent to the indigenous remnants should ensure that there are always a large proportion of mature forests surrounding the indigenous remnants, which maintains sufficiently buffering function (Lindenmayer & Franklin, 2000).

1.3.3.Habitat restoration for indigenous species

It is possible to restore the suitable habitats for indigenous species while maintaining timber production. Usually, the habitats for indigenous species (especially for native birds) in plantation forests will benefit from multi-aged stands and diverse plant species, which can be achieved by rotation design and planting multiple vegetation species (Lindenmayer & Franklin, 2000). Multiple-species planting may be preferable by plantation managers in those forests with poor-nutrient soil, mainly because mixtures usually lead to more yields than monoculture in poor soils (especially in boreal and temperate forests). Further more, mixed stands eliminate the risk of pest outbreaks by increasing the resistance to pests. However, in forests with high quality soils, pure stands of a productive species usually have obvious advantage in timber production, compared with mixtures (Hartley, 2002). Hence the acceptability of multiple-species planting is depended on the growing conditions in the plantation forests.

Usually, planting species should be selected on the basis of both economic and conservation value. It is often suggested that planting native plant species is preferable for biodiversity conservation, partly because a wide range of indigenous invertebrates and microorganisms may only adapt to native plants (Sedjo & Botkin, 1997). In New Zealand, Tane's Tree Trust launched a national program of native plantations (such as beech, Kauri, Totara, etc.), whose economic value has been proven in the timber market. However, Clout (1984) argued that exotic plant species are also able to provide food sources (such as nectar and fruit) for indigenous fauna species (especially native birds), which is one of the main considerations in restoration plan. It is suggested that at least a mixture of 20% indigenous species and 20% exotic species should be selected for conservation purpose in plantation forests. In some cases, planting of indigenous species (such as mountain beech) is cheaper than some alternative exotic species that requires longer rotation duration (such as Douglas-fur), and hence can be preferable (Lindenmayer & Franklin, 2000; Rosoman, 1994). Nevertheless, during species selection, the conservation value of plant species sometimes may not be consistent with its economic value, which tends to reduce the profit of timber production, to some extent.

However, the spatial arrangement of stands can be more important for the habitat restoration than the amount of indigenous stands in plantation forests. For example, plants that are selected for habitat restoration should be planted adjacent to the indigenous remnants, rather than away from them (Lindenmayer & Franklin, 2000). Optimizing spatial arrangement can be achieved by spatial modeling at a relatively low cost. In addition, planting diverse tree species along roads and streams, which provide additional habitats, can be helpful for indigenous birds (Norton, 1998).

1.3.4.Improvement of harvesting process

The harvesting operation usually leads to the major adverse impact on the biodiversity conservation in plantation forests. As mentioned previously, the greater indigenous biodiversity usually exists within old exotic stands, and hence the increase of rotation length may be a beneficial way to enhance the natural biodiversity in plantation forests. Firstly, the lengthened rotation schedule increases the time available for indigenous species to re-colonize the revegetation areas. Especially, this is crucial for some important habitats that take a longer duration to re-establish. The increase of rotation length also broadens the range of stand age classes within plantation forests, which contributes to the landscape heterogeneity. However, the increase of rotation length is currently considered to be uneconomic in New Zealand. The financial profitability starts to decrease above a certain stand age, which may become an obstacle for the implementation of longer rotation strategy (Lindenmayer & Franklin, 2000; Norton, 1998).

In order to retain the originally old and large stands at a site (as discussed above), small group or single tree harvesting has to be implemented instead of clear-felling. However, the main obstacle for this application is its uneconomical value. It is expected that small group harvesting can be gradually accepted as the timber price of high value species goes up (Norton, 1998). On the other hand, Eycott et al., (2006) argued that clear-felling is preferable for the conservation management in those forests that were planted on former open areas such as heaths, because the conservation management on these areas should focus on earlier succession species rather than old-growth species.

1.3.5.Protection of natural soil process

Protection of natural soil process, which contributes to the stream health within plantation areas, will improve the conservation of indigenous plant species and aquatic communities, which is highlighted in New Zealand Forest Accord (1991). Before planting, site preparation should avoid soil erosion, nutrient leaching, and loss of coarse woody debris. Compared with other plant species, *radiate pine* is a good soil quality improver, which increases soil porosity, soil nutrient, and organic matters (Dyck, 2000).

1.3.6.Conservation of understorey structure

Understorey vegetation is usually one of the most important elements of biodiversity within plantation forests, which provides key habitats for a wide range of indigenous animals. Stimulation of understorey vegetation diversity can be achieved by earlier and heavy thinning of young stands. Reduction of herbicide application also prevents biodiversity loss in understorey layers. However, the competition between understorey species and exotic planting species which may reduce timber yield usually becomes the obstacle of understorey conservation, although some models demonstrated that understorey structure diversity can be improved by thinning without significant effects on timber yield (Hartley, 2002).

1.3.7.Management of invasive species

Invasive pests are one of the major threats in New Zealand ecosystem, which has to be taken into account in the conservation management in plantation forests. The successful control of invasive pests usually significantly improves the health of terrestrial ecosystem in New Zealand. For example, Dilks et al., (2003) reported that kaka (a native bird in NZ) breeding success and juvenile survival rates were significantly increased by the large scale control of stoats in Eglinton Valley. Elsewhere other scientists frequently suggested that the nest success rates of kukupa, New Zealand pigeon, and kiwi birds could be largely increased by the mammal pest control program (John et al., 2004; Kelly et al., 2005; Robertson et al., 1999). However, control of invasive species not only contributes to the biodiversity conservation within plantation forests, but also increases the timber yields. Therefore, it is expected that part of revenue from timber trade should be returned to the pest control program in plantation forests.

2. Biodiversity Conservation: Mammal Pest Management in NZ

2.1. Mammal Pest Management in NZ islands

New Zealand islands show the relatively isolated nature in earth terrestrial ecosystem, and consequently the exotic species may easily evolve into invasive pest species in this unique ecosystem. This article takes an example of mammal pest management in Wenderholm Park, Auckland Region, to comprehensively discuss the biodiversity conservation strategies in this island.

In Wenderholm Park, there are a number of invasive mammal pests, including brushtail possums, ship and Norway rats, house mice, rabbits, hedgehogs, feral cats, stoats, ferrets, weasels, and red deer. These invasive mammals destroy the forest vegetation and reduce the amount of native fauna species, which was the major threat to biodiversity in this area. The successful control of invasive mammal pests usually significantly improves the health of ecosystem in New Zealand. For example, Dilks et al., (2003) reported that kaka (a native bird in NZ) breeding success and juvenile survival rates were significantly increased by the large scale control of stoats in Eglinton Valley. Elsewhere other scientists frequently suggested that the nest success rates of kukupa, New Zealand pigeon, and kiwi birds could be largely increased by the mammal pest control program (John et al., 2004; Kelly et al., 2005; Robertson et al., 1999).

One of the main objectives for ecological restoration in Wenderholm Park is to develop an open sanctuary for the reintroduction of locally extinct fauna species. Mammal pest control in conjunction with replanting is the main way to achieve this objective (Auckland Regional Council, 2002). However, the ideal geography in Wenderholm Park becomes an advantage for mammal pest control. Wenderholm area is a peninsula, and is partly separated from the main land by a state highway, which reduces the risk of mammal pest reinvasion. An extensive pest-control program has been undertaken in Wenderholm Park since the early 1990s, e.g. for the possum control, both toxin poisoning (including sodium monofluoroacetate (1080) and anticoagulant) and trapping were used; the control of rodents mainly relied on toxins (Talon 50 WB pellets and Storm Rodenticide) with species-specific bait stations, while the control of mustelids mainly relied on kill traps; feral cats and rabbits were controlled by shooting and cage trapping; most of the headlands were fenced to prevent sheep and cattle grazing. Consequently, habitats for the native bird species were significantly improved. Then robins, which had been locally extinct for at least a century, were reintroduced, and their breeding success rates were high. However, the annual pest control program will be continued to maintain the low levels of mammal pest populations (Lovegrove et al., 2002).

2.2.Integrated Pest Management (IPM)

Integrated pest management that combines multiple target species, objectives, technologies, and strategies has been proven to be the most effective way for the mammal pest control in New Zealand. In the integrated pest management, the multiple objectives are usually established, e.g. in Wenderholm Park, control of invasive mammal pests not only aims to improve the forest vegetation, but also aims to contribute to the reintroduction of locally extinct fauna species and other missing flora in local area (J. Coleman, 1993; Lovegrove et al., 2002). Usually, control of multiple species is concurrently undertaken in the same area, e.g. in Wenderholm Park, possums, rodents, mustelids, rats, and feral cats have been identified as the key vertebrate pests (Lovegrove et al., 2002). The advantages of multiple-species projects may facilitate the advocacy and education for the public, and contribute to the ecological restoration as a whole (Ross, Emma, & Kenneth, 2004). In integrated pest management, the multiple technologies and strategies are normally concurrently used, including physical, chemical, biological, and cultural control measures (Coleman, 1993).

2.3.Effects on the non-target species

In Wenderholm Park, the main chemicals involved in mammal pest control are toxin 1080 and anticoagulant (brodifacoum), which have been proven to be effective and contribute to the nest success rates of many bird species (Eason et al., 1993; Powlesland et al., 1999). However, in this case, the toxin effects on the non-target fauna species will be paid great attention, which have been demonstrated by a number of scientists. Powlesland et al., (2000) reported that the application of aerial 1080 poison with carrot baits resulted in 79% mortality of tomtits mainly through direct poisoning in the possum control area. Elsewhere Wright et al., (2002) suggested that the aerial 1080 application did not significantly pose toxic risk to the resident leaf litter invertebrates, but did posed a risk to those invertebrates closed to the baits on the ground. However, this toxic risk to invertebrates might indirectly become a threat to the insectivores through secondary poisoning, especially including the native birds that feed on the ground, e.g., tomtit (*Petroica macrocephala*) and robin (*P. australis*) (Gillies & Pierce, 1999). This secondary risk was further supported by Lloyd and McQueen (2000), who reported that a mean concentration of 57 mu g g super(-1) was found in arthropods collected around toxic bait stations after possum control operation in Central North Island, New Zealand. This was a high risk to tomtit birds, because only approximately 1.32 g of arthropods containing this concentration of 1080 could become median lethal dose for the adult tomitit, and this amount of arthropods only accounted for 14.7% of daily food intake for adult tomtit.

Therefore, a number of newly developed technologies aim to reduce the toxin risk to non-target species. Westbrooke and Powlesland (2005) suggested that native birds (e.g. tomtit) were significantly less susceptible to 1080 poison operation when cereal baits were used, compared with carrot baits. Their results showed that there were little immediate toxin impacts on tomtit populations when cereal bait operations were applied with low sowing rates and large bait size. Morgan (1999) reported that the cholecalciferol in a gel matrix considerably reduced impacts on the non-target species than 1080 poison, which was less toxic and unattractive to many non-target species.

2.4.Resistance and learned avoidance behavior

Toxin resistance is one of the main considerations for the chemical control program, which largely decreases the effectiveness of toxin application. Usually, the common method of resistance prevention is to alternate different toxins. In Wenderholm Park, toxins of Talon 50WB and Storm Rodenticide were alternately applied for the rodent control program. Similarly, for the possum control, the sodium monofluoroacetate (1080) and Talon 20P anticoagulant (brodifacoum) were alternated in this area (Lovegrove et al., 2002). I think the resistance prevention method should be continued in the annual possum and rodent control plan in Wenderholm Park.

However, the effectiveness of toxin application can also be reduced by the learned avoidance behavior (termed ‘aversion’). Aversion behavior of mammal pests can be induced by sublethal dosing. There are two types of aversion: firstly, the toxin doses targeting the more susceptible species (such as rodent) can sublethally poison the less susceptible species (such as possum), so that the effectiveness of this toxin that is subsequently applied to these more susceptible species will be reduced (termed cross-species aversion); in some other cases, the aversion induced by one toxin bait (such as cyanide paste) can reduce the effectiveness of other toxins (such as 1080), and this is normally called cross-toxin aversion (Hickling, Henderson, & Thomas, 1999).

For the prevention of aversion, pre-feeding is an effective way, which means that a pest population is pre-fed with the baits that are similar to the toxic baits (Hickling et al., 1999). Coleman et al., (2007) recently further demonstrated the reasonably economic value of pre-feeding method using cost-benefit analysis.

2.5.Trapping methods

In the Wenderholm Park pest management plan, the camouflaged traps with leaf litter, which aim to reduce the visibility for non-target species, were installed for the mustelid control (Lovegrove et al., 2002). However, Dilks et al., (1996) suggested that these camouflaged traps were less effective than the wooden and visible traps, which were faster and easier to check in the field, and hence saved the labor cost. It was also suggested that the broken and hard boiled eggs were the most effective and practical lures for the mustelids.

The current kill traps used for the control of possums, rodents, mustelids, and feral cats in Wenderholm Park were leg-hold traps (Lovegrove et al., 2002). However, Warburton and Orchard (1996) reported that most of kill traps currently used in New Zealand could not meet the International Trap Standards, after they carried out three testing stages for five common traps in NZ, including sequential mechanical testing, pen testing with free-moving possums, and field testing. Nevertheless, LDL 101 trap was the only one of five traps to succeed in all the three testing stages, which was much more effective than leg-hold traps.

2.6. Secondary poisoning

In addition to the adverse effects on non-target species, secondary poisoning can also contribute to the multiple-species control program. It is suggested that the control of carnivore pests (such as mustelids and cats) can benefit from secondary poisoning, which has been highlighted by several mainland conservation managers. In this process, rats, which are the important component of the diet for cats and stoats living in New Zealand forests, are the key vectors of toxins for the carnivore pests (Brown et al., 1998; Murphy et al., 1999).

However, in some cases, the secondary poisoning may not be effective for the carnivore pest control. Gillies and Pierce (1999) assessed the effectiveness of a common baiting strategy for possum control, which was the initial application of 1080 toxin followed by the secondary poisoning using brodifacoum. According to their investigation, the effectiveness of secondary poisoning was considerably reduced under the continuous baiting strategy, which might allow the carnivore pest populations to recover. This might be due to insufficient toxic prey. Therefore, it was important to identify the key prey species and predict if their densities were sufficient enough to achieve a satisfied incidental kill in carnivore pests, while relying on the secondary poisoning (Alterio, 1996; Gillies & Pierce, 1999).

2.7.Biological control

In the future, biological control may be applied to mammal pest management, which is environmentally friendly and less cost. Several potentially biological control tools have been identified, e.g. biological control for possums by inhibiting fertilization

(Jolly, 1993); aleutian disease virus, mink enteritis virus, and canine distemper virus as potential biocontrol agents targeting stoats (McDonald & Lariviere, 2001).

3. Biodiversity Conservation: Insect Pest Management in NZ

3.1. Biological control of insect pest

This article takes an example of biodiversity conservation success in insect pest control, with specific emphasis on the biological control, the environmental friendly one. The grass grub, *costelytra zealandica*, is one of the most destructive pasture pests in New Zealand, has been investigated for more than 50 years. Biological control, which is environmentally friendly, has become an ideal alternative method. Population surveys showed that the grass grub populations often collapsed significantly due to the amber disease caused by *S.entomophila*.

3.2.The Chemical Control VS. Biological control.

In the past, the control of grass grub mainly relied on the chemicals, despite some reasonable culture control methods, for example, rolling and cleansing crops in rotation, were applied as well (Wightman, J.A, 1972). However, chemicals have lead to some negative influence. The main effects are:

- Chemicals contaminate the environment and lead to accumulation of residues in the soil.
- Chemicals can attack non-target species, especially including beneficial species, which may also lead to pest resurgence.
- The grass grub has developed resistance against many chemicals.
- Chemicals require repeated treatment, which causes the cost of chemicals to be expensive (Launch Campaign, 2003/4).

Compared with the chemicals, biological control product of 'bioshield' grass grub can contribute largely both to the conservation of environment and saving of cost.

- Bioshield grass grub is highly specific to New Zealand grass grub and safe to other organisms.
- Bioshield grass grub does not leave any residues in the pasture.
- Bioshield has a long-term suppressive effect on grass grub, which reduces the cost of control (Launch Campaign, 2003/4).

3.3.Amber disease caused by *Serratia entomophila*

Population surveys showed that the grass grub populations often collapsed significantly due to the amber disease caused by *S.entomophila*. The invasion of bacteria was only shown at the final stage of infection. *S.entomophila* mainly attack the larvae stage of grass grub. The investigation both in laboratory conditions and field trials showed that the amber disease caused by *S.entomophila*, which was widespread without geographical limitations, could become epidemic and therefore lead to high levels of control (Jackson. T.A, eg, 2006).

3.4.Strain selection for pathogenicity

S.entomophila have several strains, which can be divided into both pathogenic and non-pathogenic forms. Strain selection should ensure the pathogenicity against grass grub. The pathogenicity of *S.entomophila* is required to pass on to the next generation without loss. The principle of the pathogenicity of *S.entomophila* has been determined at the molecular level. Scientists tested the single cell clones of cultures both before and after large scale fermentation. In laboratory conditions, loss of pathogenicity of *S.entomophila* infrequently occured. It is considered to connect with the resistance to antibiotics because strains that were selected for *kanamycin* resistance frequently lost pathogenicity. This study will try to fully clarify the stability of pathogenicity at the molecular level (Jackson. T.A, eg, 2006).

3.5.Specificity of *Serratia entomophila*

Specificity to target species is an important factor measuring the success of microbes for control of soil pests, which is supported by molecular studies. This specific interaction between the insect pests and pathogens is involved in a long process of co-evolution. In this process, resistance development can match to development of pathogenicity as a spiral interaction. This relationship contributes to microbial control by pathogens (Jackson T.A., 1999).

S.entomophila only infects the grass grub larval stage. The non-target species test must be carried out before registration. The first step of test was to determine the effect on small mammals and no negative effects of *S.entomophila* treatment were found. In further stages of registration, the tests should be taken on a broad range of non-target species tests, environmental monitoring, and efficiency of application. In 1989, the registration process for the bacteria was promoted. The aim was to allow limited sales and the application to be fully registered (Jackson. T.A, eg, 2006).

3.6.Competence in environment

The soil is considered as the most important environment factor for microbial control. Large amount of fungi, bacteria, actinomytetes, algae and virus survives as competitors with each other. These microbia vary in mineral composition, texture and structure. It is estimated that 10^5-10^8 bacteria, 10^6-10^7 actinomycetes and 10^5-10^6 fungal colony forming units can survive in a gram of fertile soil. Approximately 3000 species of microbia can be found in a fertile pasture soil (Jackson T.A., 1999).

One of the soil factors influencing the formulation of *S.entomophila* is soil moisture. Recent research (Callaghan, M.O., Gerard, E.M., Johnson, V.W., Townsend, R.J., and Jackson, T.A., 2002) has determined the effect of soil moisture on the application of *S.entomophila*. The results have shown that the speed of establishment increased with the increase of soil moisture. This indicated that application of water is essential for the inoculum of *S.entomophila*.

Another important factor is soil type. Jackson, Macnab, and Garnham launched a research (1989) to exam the effects of soil type on the efficacy of *S.entomophila*. Larvae from 27 sites of New Zealand were collected. On the other hand, scientists also collected soil samples from the same site, which were divided into eight groups, and determined their effect on pathogenicity of *S.entomophila*. According to the results, *S.entomophila* has still shown effective pathogenicity against grass grub regardless of soil origins.

3.7.Persistence of *S.entomophila*

In the soil, persistence of *S.entomophila* in intensively competitive condition is a major challenge, mainly because the grass grub in some life stages is sedentary or non-susceptible (Gurr,G., Wratten, S.2001). However, discrimination of persistence strains is difficult, because it can only be tested after field application and it is difficult to distinguish applied strains from similar natural strains in the soil (Jackson T.A., 1999).

Recent research (Calleghan, M.O, and Gerard, E.M, 2005) has assessed the persistence of *S. entomophila* after the granular formulation application, which has been designed and applied to prolong the shelf-life of *S. entomophila.* In this research, scientists assessed the bacterial establishment and survival, which were released from the granular and liquid formulations. Dilution of bacteria was plated into *S.entomophila* selective agar in order to be integrated. *S.entomophila* populations, which were inoculated with granules. The *S.entomophila* can be kept stable in soil for up to five months in different soil moisture conditions. The results have shown that bacterial numbers decreased faster as the soil was inoculated with the liquid formulation. However, high amount of bacteria still survived in the granules in the whole experiment, which indicated that the duplicate release of inoculum after the application of the biopesticide granules is required for an epizootic disease.

3.8.Fermentation

Microbial control products need to be released with sufficient propagule densities to cause an epizootic disease. According to field trials, it is suggested that a level of $>4\times10^{13}$ bacteria/ha is required for causing an epizootic. In the early large-scale trials, bacteria production reached a level of 2×10^{9} bacteria/ml and 20 liter of product was required for per ha in field trials. The outcome of these fermentation scale trials has contributed to the industrial process of mass production (Jackson. T.A, eg, 2006).

In addition, at present, there are two stages in the industrial production process. In the first stage, bacteria are incorporated into matrix. Then these matrixes are produced into granule containing zeolite and coat (Launch Campaign, 2003/4).

3.9.Storage and distribution

The first product of *S.entomosohila* can only survive three weeks in shelf storage. Therefore, the short longevity of *S.entomosohila* in storage is a thorny issue facing producers, despite an apparent improvement of shelf life is more than three months at

<4°C. Producers solved this problem by incorporating the distribution, storage, and application together. In this process, products, which are packed in 30 bags per pallet with each bag weight of 30kg, are produced by ordering and delivered by contractor/distributor who has specialist license and cool storage facilities. The contractors store and apply the bacterial products by using the application schedule (Jackson. T.A, eg, 2006). In the distribution process, the specific records of stock rotation and movement should be collected for supervision (Launch Campaign, 2003/4).

Recently, scientists have developed a novel method for thermostable storage. In this process, the bacterium can be stable in form of a biopolymer matrix. Then it can be produced into clay-based granules. At ambient temperatures of approximately 15~25 °C, the products after formulation can still be kept stable for relatively long periods of two months (Johnson, V.W, Pearson, J.F and Jackson. T.A, 2001).

3.10.Application on the field

S.entomophila is sensitive to UV light, which required prevention from exposure to UV light in application. Among several attempts, surface application of liquid or granules by using seed drill has shown the best effectiveness. Most larvae feed in 20-50 mm zone below the ground. Therefore, more than 70% of the bacteria were placed into the feeding space in this method (Jackson. T.A, eg, 2006).

There are two types of the microbial bio-insecticide application. The first one is inoculation, which can be defined as the small number release of natural enemies in the early crop cycle. The other one is inundation, which means natural enemies are released in mass and sometimes several times during the crop cycle (Van Driesche, R.G and Bellows, T.S, 1996). Combination of the two application methods can be more effective on biological control.

4. Improvement for Future Biodiversity Conservation

In addition to the content structure organized above, which is originally outlined, there are some original viewpoints presented below published in my previous articles of this journal:

For the biodiversity conservation in plantation, a novel matrix is designed for the assessment on spatial and functional heterogeneity in a ecosystem, which is discussed in the other article of this journal (Liu Huan, 2021 c). Consequently, it is advised to apply this matrix on the design of plantations for biodiversity conservation in forest management. For the plantation of habitat restoration for the endangered animal species, the yield component of food production would be the important selection criterion, improving the environmental adaptiveness of habitat vegetation under adverse environmental conditions such as drought tolerance of habitat vegetation (Liu Huan, 2021 a).

For the improvement of biological control in insect pests, there are some improvements for future research: firstly, the competence of bacteria *S.entomophila*, should NOT be isolated from the environment, which should be considered as a microbial community competence. Consequently, the inter-specific association of different bacteria populations is analyzed around *S.entomophila* to distinguish other bacteria families with interdependence relation or competition relation, and the methods is discussed in another article (Liu et al., 2015). The competence establishment of bacteria *S.entomophila* population should be conducted together with other interdependent bacteria families, and with the elimination of competing bacteria families. This improvement is supported by the results reported by Chen et al.,(2005), who has revealed that the establishment of pathogen competence is performed as microbial community rather than a population of single species by analyzing the correlation between the airborne microbes and pathology; secondly, a novel methodology of classifying and identifying the microbes is presented by me in the metabolomics test article and in another article of calculating the weighted averages based on the environmental gradient of gene expression on enzyme species (other than unweighted pair group method with averages) (Liu Huan, 2021 a, d), which facilitates the selection of bacteria families in biological control; thirdly, the evolution of insect resistance to bacteria *S.entomophila* displayed a spiral interaction, as discussed above. Consequently, this article advises that this DNA shaping evolution is determined by natural selection so that the sustainable diversity of genetics in *S.entomophila* population is essential for passing on the sets of gene expressed as pathogenicity to the next generations. Particularly, the systematic metabolomics test reveals the specificity of invasion-host interaction at molecular level, enhancing the pathogenicity of bacteria by 'training' the memory regulating the gene expression (Liu Huan, 2021b). The methods of training the memory of cells, aiming to the increase of pathogenicity of bacteria (such as persistence), have been pointed out in the other article of this journal, although this cultivation methods usually lead to lower reproduction rate in bacteria fermentation.

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