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Bio-agents (Pathogens, Parasitoid and Predators) of Gypsy moth *Lymantria obfuscata* Walker (Lepidoptera: Lymantriidae) and their mechanism of action and Natural mortality

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Abstract
The gypsy moth, *Lymantria* spp. (Lepidoptera: Lymantriidae), is one of the distinguished pest species feeding on forest trees and the caterpillars prefer oaks, birches, poplars and willows, causing huge defoliation, growth loss and tree mortality. Softwoods like hemlocks and pines are more likely to die after a single defoliation than hardwoods. A number of parasitoids have been released for classical biological control of the destructive this forest insect gypsy moth, however the pathogens especially *Entomophaga maimaiga* and the nucleo-polyhedrovirus have been found to give promising results. The parasitoids attacking on larval or pupal stages of gypsy moth have also been observed and evaluated by researchers. The infections due to *Entomophaga maimaiga* and LdMNPV can occur in all larval stages but are usually most profound in late instars. In Ladakh region a number of predators and parasitoids have been observed to feed on this pest. Generally, in Ladakh region infestation is huge and once enormous numbers of tiny caterpillars are present, a few become so entangled in their own webbing that they are unable to escape out of the web network and this results in their mortality in a natural way. During the whole infestation season (active larval season) almost 10-40 per cent population die because of this undesirable complexity in and around silken webs that had a considerable control over population build up.

Keywords: gypsy moth, defoliation, fungus, virus, caterpillars, damage

Introduction
The insect pest has diverse species worldwide, and even for any particular crop the diversity of insect varies (Dar *et al*. 2015a) [6] with different damaging impacts on agricultural/horticulture production. Pests either feed on foliage, fruits e. g Fruit fly (Mir *et al.* 2017) [20], brinjal (Dar *et al*. 2015b) [12], stem or whole plant causing an everlasting effect on production and productivity. The Indian gypsy moth, *L. obfuscata* Walker 1865 (Lepidoptera: Lymantriidae), is one of the serious foliage feeder on various fruit trees and forest trees, distribution mainly in northern India (Jammu and Kashmir, Himachal Pradesh, Uttar Pradesh, and Punjab), northern Pakistan, and Afghanistan. Gypsy moth been first observed in the regions of south western Himalayas, West Pakistan and USA and Canada, causing frequent and severe defoliation on social forestry trees. In India the pest has been documented from Kashmir, Himachal Pradesh, Tamil Nadu, Dehradun, Uttar Pradesh, Karnataka and Varanasi on different host plants. Gypsy moth is an outbreak pest and remain at low levels for several years and numbers rise every few years. However if the areas are not actively monitored even moderate gypsy moth populations can exist unnoticed. Although these cycles are influenced by numerous factors, and the low populations in recent years generally are believed to be the result of a gypsy moth disease caused by fungus *Entomophaga maimaiga*. Due to its wide range, gypsy moth populations periodically erupt to massive levels, causing extensive defoliation of broad leaf and coniferous forests. The population hike of the pest are spatially synchronized so that outbreaks occur concurrently over large geographic areas, greatly exacerbating the economic and ecological costs associated with high-density populations. In addition to Quercus spp. (oak) (most preferred host in USA), and the Larix (larch), Tilia (basswood), Diospyros (ebony), willow (preferred host in Ladakh, India) and Populus (aspen) spp. are capable of supporting massive outbreaks in Asia.

Like other things, the efficiency of the bio-agent also varies with the abiotic factors and soil inputs. The abiotic factors and inputs have direct influence on the overall agriculture activity, that intern supports the crop grown (Dar *et al*. 2014, 2017, 2018) [27].

Intensive efforts have been made in the early 20th century to introduce biological control agents against the gypsy moth, including parasitoids, predator, and pathogens (Fuester *et al*. 2014) [15]. Successful establishment of parasitoid introductions has limitations, as has the effects of parasitoids on the regulation of gypsy moth populations is a factor, besides harsh climate, adaptation and food availability for the parasitoid survival for sustainable control in the area. The parasitoids contribute to the overall mortality of gypsy moth populations; pathogens often play a more vital role too. This manuscript mainly focuses on the biopesticide management of gypsy moth, predation and natural mortality of the insect.

Methodology

A basic survey was made in Ladakh region from 2019 to 2020. All the Kargil and Zanaskar villages were visited and some results obtained about Gypsy moth are given. Samples obtained were send to division of entomology SUAST-K, and bio-control laboratory Kargil MARES station for the investigation and the results obtained are discussed in this article.

Pathogen *vs* Parasitoid

Entomopathogens are organisms used extensively to control insect pests in forests. These are natural organism which feed on insects, the successful use of both augmentation and classical biological control strategies to apply or introduce bacteria, baculoviruses, fungi, and nematodes are the common examples of these organisms. For example, the *Bacillus thuringiensis* var. *kurstaki* (Dar *et al*. 2017a) [3] has been used to effectively control numerous defoliators in forests especially gypsy moths and black hairy caterpillars. Baculoviruses are the best examples for the successful classical biological control, through augmentative approaches. The use of baculoviruses infecting gypsy moth has efficiently replaced introduction of fungus *Entomophaga maimaiga* in America.

Insect as parasitoid is an organism that lives in immediate association of host insect at its (host insect's) expenses. This association led to death of the host insect. This is one of the six major evolutionary strategies within parasitism differentiated by fatal prognosis for the host, a situation close to predation. Parasitoids can be end-parasitism (feeding and living inside), ecto-parasitism (living and feeding outside), paralyzing the host and living outside of it. Hyper-parasitism involves the parasitism of an insect that is itself a parasite (e.g. Oak gall 5 levels of parasitism are observed). Parasitoids are found in the variety of insect orders especially of endopterygotes. The split life style of the parasitoids is a feature favored it to be a parasitoid with complete metamorphosis, pre-adapted with parasitoid larvae and adult as free living. Insect orders to which most of the parasitoids belong are Hymenoptera, Diptera and Coleoptera.

Cause of death in gypsy moth can be narrowed down by considering the life stage at time of death, for example the infections by *Entomophaga maimaiga* and LdMNPV can occur in all larval stages but are usually most prevalent in late instars (Hajek 1994, Hajek and Snyder 1992) [16, 17]. Parasitoids are confined by their ability to only develop in specific life stages, and the physical characteristics of cadaver also provide useful clues that can aid in identifying the cause of death. When gypsy moth-parasitized larvae or pupae are held in the laboratory, eventually a life stage of the parasitoid may emerge. When field-collected larvae die during rearing and no other insect eventually appears in the container with the cadaver, the cause of death will likely be a pathogen.

Pathogens of Gypsy Moth

Fungal Pathogen

***Entomophaga maimaiga* (Zoopagomycota: Entomophthorales: Entomophthoraceae)**

Mechanism of Action

Native to Asia, *E. maimaiga* was deliberately released in the United States in 1910-11 and again in 1985-86 during the outbreak. However, attempts to establish this fungal pathogen were thought to have failed, epizootics were first seen during the very wet spring after which this fungus spread rapidly throughout the contiguous gypsy moth range. Like all fungi, *E. maimaiga* is greatly affected by moisture and temperature, thriving in cool and wet spring and early summer weather, since this fungus is benevolent source of larval mortality in both low and high-density gypsy moth populations. *E. maimaiga* produces two kinds of spores (conidia) and resting spores (azygospores), produced only after host death. The type of spore produced is dependent on host age.

Conidial Spores

Infective conidia (asexual short-lived spores) are usually produced from early instar cadavers, while resting spores and sometimes conidia also are produced from later instar cadavers and occasionally from pupae. Resting spores are produced near the end of the larval season, overwintering in soil and survived for at least 6-12 years; germinate and produce infective germ conidia. The conidia from either cadavers or resting spores are actively discharged and are dispersed by the wind, infecting gypsy moth larvae once they come into contact with its skin. Once they land on a host, the conidia grow through the cuticle and start consuming the living insect. After consumption of the internal materials by the fungus, the larva die, under humid conditions conidiophores can grow out through the cuticle; produce conidia at the ends of the conidiophores which are shot into the air disperse spores and then infect other larvae. If host is absent, a conidium can germinate and expel a secondary conidium, and infection cycle continues throughout the season. Resting spore production occurs in the 4th-6th instar larvae, which allows the spores to overwinter and start the cycle again during next year or in subsequent years.

Conidia are produced externally on infected gypsy moth larvae after they die. Whether an infected larva will produce conidia depends on a variety of factors, including larval age, fungal isolate, and environmental conditions. If conidia are produced from the cadaver, they will be formed within hours to a few days after larval death. Conidia are actively expelled from the cadaver, and *E. maimaiga* is spread within surrounding gypsy moth populations during the current season, although some spores may travel longer distances. Conidia produced by cadavers are clear, pear-shaped spores measuring approximately 20 µm x 25 µm. Conidia are usually produced from cadavers of early instars, which typically are found with the prolegs gripping a twig or branch and the anterior portion of the body at a 90 degree angle hanging downward compared with the posterior part of body. Once conidia have been discharged, some spores can be retained on the larval hairs and may appear similar to a sugar coating. The surface of a cadaver from which conidia are being ejected appears moist and white to light brown. After conidial discharge, these wet spores and conidiophores will decompose quickly, and soon there will be little to no indication that they were ever present. Therefore, in order to detect these fungal stages, daily monitoring of larval death and of cadavers is very important.

Resting spores

When gypsy moths are in the 4th to 6th instar stages, *E. maimaiga* will produce thick-walled resting spores inside of cadavers. The bodies of recently killed larvae containing resting spores are soft, and the contents appear to be liquid when pressed. By the time, the cadavers become dry and stiff with a firm, but not as fragile cuticle. Cadavers containing resting spores can often be found hanging vertically on tree trunks with pro-legs usually extended at 90 degrees from the body. After some time, the cadavers fall from the trees and disintegrate on the ground. Most of the resting spores overwinter in the top layers of the soil and germinate during the following year(s) infecting the gypsy moth larvae in successive generations. Resting spores develop from immature to mature spores in days following larval death. The first formed resting spores possess a single thin wall and have a granular interior, once spores mature, they develop a thickened wall and the granular interior coalesces into a small number of large lipid droplets. Normally, mature resting spores are observed in cadavers of larvae that have died at least several days before, but occasionally immature spores are also visible at that time. Resting spores are approximately 30 µm in diameter and sometimes can be mistaken for air bubbles.

Viral Pathogen and their mechanism of action

Viruses are diverse in nature infecting both beneficial (Ullah *et al.* 2020) [23] and harmful insects. The detailes account of few virsus species of gypsy moth are given below.

Lymantriadispar multiple nucleopolyhedrovirus (LdMNPV)

LdMNPV is a highly host-specific virus that infects gypsy moth larvae when they consume foliage contaminated with viral occlusion bodies. Virus cause epizootics resulting in the collapse of gypsy moth populations, but this usually only occurred after high density population, preferred for virus multiplication. Virus is found to infect insects in high density gypsy moth populations, but its prevalence is often low, and at times leading to the collapse of gypsy moth populations at a variety of densities. After ingestion by a gypsy moth larva, viral occlusion bodies (environmentally persistent protein packets containing the actual virus) dissolve in the alkalinity of the insect's gut, releasing the virions (infective virus particles) in heamolymph. The virions infect the midgut cells and infection subsequently spreads to the rest of the body. The virus replicates in the nuclei of infected cells, forming two types of progeny: budded virus and occluded virus. The budded virus leaves an infected cell and spreads the infection to additional cells within the insect. At the end of the infection cycle, new occlusion bodies are made that contain the occluded virus, subsequently cells burst, releasing the occlusion bodies. Destruction of infected cells eventually destroys the internal organs of the host, leaving the cadaver as slurry of occlusion bodies and cell fragments. The virus results in destruction of larval cuticle and produces cuticle-degrading enzymes, making the cuticle very thin and fragile (Miller 2013) [18]. After the host dies and the cadaver decomposes, the cuticle breaks down and viral occlusion bodies are released into the environment. Larvae which dies from viral infection can be seen often hang in an upside down V shape ("inverted V"); and have a very thin cuticle. The cadavers may break when collected or before being dissected, so if you have to pull to tear the cuticle apart, chances are less for the larva died from viral infection alone. A larva killed by virus will have a large number of occlusion bodies of 1-10 µm in diameter generally spherical with slightly uneven sides.

Pathogens

Fungal Pathogens

A broader account of role of Entomopathogenic fungi in insect pest management is given by Dar *et al*. (2017a) [3]. Long known as *Paecilomyces farinosus*, the entomopathogenic fungus has a relatively broad host range both in tropical and temperate zones. Its isolation can be done from isolated water, air, arthropods, plants, and other fungi, it infects and kills lepidopteran larvae and pupae and is most commonly found in forest soils with pine (Pinus *spp*.), oak (Quercus *spp*.), poplar (Populus *spp*.), acacia (Acacia *spp*.) and willow trees. It is a moderately fast-growing fungus, with white colonies that turn yellow and form woolly aerial mycelium.

Beauveria bassiana

This is a common fungal pathogen and causes larvae to harden after death, and white mycelia grows out of the dead insect through its cuticle. Contagious condition, termed "white muscardine," was found to be caused by the fungus *B. bassiana* after infection. *B. bassiana* has wide host range of over 200 insect species, mainly Lepidoptera and Coleoptera, and it is generally associated with shaded areas such as forests and uncultivated hedgerows. Like *E. maimaiga* and *I. farinosa*, infection is caused by conidia that attach to the host cuticle and germinate in humid environments, penetrate the cuticle by germ tubes growing from the conidia. Fungal growth increases upon entering the hemocoel, and the host dies due to depleted hemolymph, nutrients, or toxemia. When moisture levels are high, *B. bassiana* produces aerial conidia on the cuticle of the host, spores disperse in air and once come in contact with the cuticle of other larvae continues the cycle.

Insect Parasitoids

Hymenoptera (Wasps)

Most hymenopteran insect act either as pollinator of various fruit crop species (Dar *et al*. 2016; Dar *et al*. 2017b, 2017c, 2017d; Dar *et al*., 2018a; 2018b) [3, 4, 11, 20, 22, 5, 9], or as parasite on other species (Dar and Wani, 2018) [6]

Brachymeria intermedia

This chalcidid was introduced from Europe and repeatedly released for biological control, however it is very scarce in low density gypsy moth populations (Williams *et al*. 1993) [25]. It prefers open sunny areas and exhibits delayed density dependence, causing high gypsy moth mortality in outbreak populations where defoliation is severe. *B. intermedia* is a pupal endoparasitoid with a bias for male gypsy moth pupae, known to be polyphagous, few researchers reported that this species may also be a hyperparasite, attacking puparia of the tachinid parasitoids *Compsilura concinnata* and *Exorista larvarum* (Dowden 1935) [13].

Cotesia melanoscela

This braconid parasitoid completes two generations in a year and is specific for biological control of the gypsy moth, oligophagous in nature of feeding and thrives in xeric sites (Skinner *et al*. 1993) [22]. It is considered to be one of most valuable enemies of the gypsy moth larvae (Burgess and Crossman 1929) [1]. Its abundance is limited by host availability and a number of hyper-parasitoids, and its females lay 50-1,000 eggs, depositing a single egg in first or second instar larvae of *Lymentria* spp. During egg deposition, females also insert a virus (Polydnaviridae: Bracovirus), which prevents molting and suppresses the immune response of the host. Finally small parasitoid larva emerges from a parasitized (generally living) gypsy moth larva and spins a white cocoon nearby, keeps the gypsy moth larva alive for many days after parasite emergence.

Ichneumonid Wasps

During our work in Ladakh region we observed huge complex of parasitic and predatory wasps. In total we observed few species of the Ichneumon wasps parastic on the gypsy moth. This wasp species mostly attacks holometabolous insect species and spiders, eventually killing their hosts. In short this parasitoid species help in gypsy moth pest regulation under natural and semi-natural conditions-A promising agent in biological control. Further, the distribution of the ichneumonids is considered an exception to the latitudinal gradient in species diversity. This family is thought to be species-rich in temperate zones compared to tropics, however new species have been recovered from tropics, and we hope this too is a new species of this family from Ladakh (Fig-9).

Egg Parasitoids

Ooencyrtus kuvanae (Hymenoptera: Encyrtidae) and *Anastatus japonicus* (Hymenoptera: Eupelmidae) are two most common parsatoids of *Lymentria* spp. often causing 10-40 percent mortality of gypsy moth; with higher mortality rates occurring in dense host populations. *Ooencyrtus kuvanae* has also been reported as a hyperparasites of *Cotesia melanoscela*, but at very low level.

Other Parasitoids

Hymenoptera (Wasps) *Aleiodes indiscretus*

This braconid is native to India and is parasitoid of *L. obfuscata*, a relative of the gypsy moth (Shaw *et al*. 2013) [21]. It is an oligophagous endoparasitoid of 2nd and 3rd instar larvae of *Lymantria* and *Dasychira* species. Like other species of Aleiodes, dead host becomes dried and preserved whilst the parasitoid larva pupates and overwinters inside the mummified larval host, and adult (parasitoid) emerges from penultimate larval instar through a circular poster-dorsal hole. Adults are honey-yellow with a black ocellar triangle and a body length of 6-8 mm, with fulvous antennae and a slightly larger body in females than males.

Monodontomerus aereus Walker (Torymidae) Digger wasps

This group of wasp species are found abundant in Ladakh region. Torymid pupal parasitoid was imported from Europe (Clausen 1956) [2]. It is an oligophagous and univoltine, developing in the pupae of gypsy moth, brown tail moth, and several native Lepidoptera. This is also a secondary parasitoid of Hymenoptera and Diptera associated with gypsy moth and brown tail moth (Fuester *et al*. 2014) [15]. While development is internal in a lepidopteran pupa, development in a tachinid puparium or braconid cocoon is external. This hyperparasitic habit likely causes more harm, though it has not been found in sufficient numbers to impact either the primary or secondary host. The adults overwinter in old cocoons and webs of brown tail moths, with only females surviving winters (Muesebeck 1931) [19].

Apanteles melanoscelus

In Ladakh region, a braconid wasp, *Apanteles melanoscelus*, is laying an egg in a small gypsy motli caterpillar. This observation was made during August, 2019 to 2020 and a huge populations of the wasps were recorded under bark of the willow. Observation recorded showed that almost 100-150 wasps were recorded per 20cm$^{2.}$

Predators of gypsy moth and natural mortality

Gypsy moth in Ladakh

Dar S A (2019, 2020) conducted a survey at Ladakh region and observed that most of the willow species were heavenly infested with gypsy moth and almost 75-80 % of the foliage were damaged, and plants are left naked branches (a detailed account of web weaving and damaging beahviour of gypsy moth will be discussed in next article). The damage on the populous was found very less, and was 5-8% only. The larvae form webs on the branches and whole branches, bark and leaves were covered with webs (Fig-1). As much as 10-12 leaves were found bound together and silken webs were harboring hundreds of larvae, their eggs and in most cases natural parasitoids and parasite were also found. Generally, the leaves were found eaten from lower sides and broader portion of either side of veins were more preferred and were found damaged first (Fig-2). From May to ending August webs were denser and damage was found heavy. In recent years farmers claim for more damage, for that the possible reason could be climate changes that have altered the pest life cycle and availability of conducive factors for the population build up. In near past, the outbreak of pest occurred in Ladakh regain, that may be also contributed to climatic change.

Spiders

In Ladakh region we observed few species of spiders feeding on the gypsy moths inside their silken web, from July to September. It was observed that web contains few larvae, eggs and adults too, so from July to August ending, the spiders predicate on them and populations were reduced but non-significantly. In heavy infested areas, the spiders also weave their own silken nets near the pest webs that supported its predatory actions. Near forest areas in Ladakh with dense willow density, Gypsy moth make their webbing networks on the creaks, crevices, stony galleries, wood furniture, windows, and doors of the old resident buildings and on govt. buildings, as these places are not taken much care for outsides of walls. The human residential areas are generally used by spiders; therefore, sometimes moth webs and spiders catching webs are close enough that again gives an indications for predatory instinct of spiders on gypsy moths.

Beetles

Dar S A (2019, 2020) during the course of survey from July to September, the gypsy moth larvae and eggs were consumed by some beetles, which reside inside these webs till December. In every web of 10cm x5 cm area, minimum of 5-10 beetles was observed, and predation on moth larvae and eggs were also observed. The beetles *Calosoma beetle* (*Calosoma sycophanta*) is a “specialist,” in that it feeds almost entirely on gypsy moth. Adults and larval stages of this brightly colored beetle feed on gypsy moth caterpillars and pupae, and the moth pupal cases were left in silken webs, and this was found in abundance during June to September. Several native insects are also good predators and will attack gypsy moth, as well as other plant feeding insects. Further, during our study periods, we also observed some unknown battle species feeding on young larvae.

Ants

Few ant species especially black ant were also recorded to feed on larvae

Natural mortality of Gypsy moth larvae in Ladakh

Dar S A (2019-2020) observed that under cold arid conditions of Ladakh, the caterpillars may die even before they reach the surface of their egg mass, and these young caterpillars are occasionally found imbedded in the mass of egg shells, hairs, and non-viable eggs, silken webs, bark, branches, and on the ground too. In egg shells the caterpillars count were more and possibly it is because they were unable to get out of their egg mass. Generally, in Ladakh region, infestation is huge and once enormous numbers of tiny caterpillars are present, a few become so entangled in their own webbing that they are unable to escape out of the web network and this results in their starvation, and mechanical injury, ultimately leads to their mortality. During the whole infestation season (active larval season) almost 10-40% population die because of this undesirable complexity in and around silken webs, and this phenomenon has been observed most frequently on the underside of large, heavily infested branches of favored-food trees, heavy woven webs and on bark. During this occasion, the spiders take a small toll of the young caterpillars, but not so much because they actively prey on them; rather, the caterpillars simply become entangled in the spider webbing and die. Most ants show no interest in gypsy moth caterpillars, but occasionally see ants prey on newly hatched ones. In Ladakh the newly hatched gypsy moths were occasionally found in enormous numbers floating on the surface of water, and we counted an average of 45-50 dead caterpillars per square yard of open water in one site in July 2019. Ladakh is known for its harsh climate and it can be lethal to the gypsy moth, but it seems fortunate for the pest that it overwinters in egg stage under bark during this harsh periods, and in month of May hatching starts that synchronies with the profuse foliage on the willow and populous. It is also found that during low temperature regimes the young emerging larvae probably got killed, but this condition is very unusual to happen in Ladakh region, after May; however in Kashmir region there is some possibility to happen, that too depends on the life cycle of the pest, as it is normal for the insect pest to adapt with season and host availability at particular place. It is speculation that even when late snow covers the ground, and caterpillars will be immobilized by it, the insects are likely to revive as soon as the temperature rises. We observed that several species of birds prey on young caterpillars and both nuthatches and downy woodpeckers pick the insects off the tree bole, while scarlet tanagers tend to pick them from the leaves and twigs in the tree crown. Among parasitoids as discussed above, *Apúnteles melanoscelus*, is known to parasitize the young caterpillars, and the adult female wasp attacks the gypsy moth larva and inserting her ovipositer in it, forces an egg into abdomen through skin. The parasite spins a silken cocoon when it emerges, and, incidentally, tends to bind its erstwhile host to this cocoon; so we observed both the parasite cocoon and the dying host together. These parasitoids were commonly found on foliage of willow, populous, and other bushes, old wooden logs and in bark crevices. Analyzing the silky webs carefully at Taisuroo valley of Ladakh Kargil region, we observed that *Apúnteles melunoscelus* cocoons are often themselves heavily parasitized, especially the overwintering brood on willow creaks, and under bark by other species. The females of this parasites are found to be parasitized by a wingless insect, probably the species is *Gelis upuntelis*. This wingless species look like ant, at first glance, however if we collect cocoons and it may be collected. During the early larval stages of the gypsy moth we found much of the larval mortality especially at 1^{st},2^{nd} and 3^{rd} stages and it was clear that these stages were succumb to disease. From July to August our evidence indicated that caterpillars dispersal is huge and the larvae crewel in groups (almost at 4^{th} larval stage) and form webs too.

Fig 1: Silken web woven by Gypsy moth larvae, clubbing leaves together in groups and inside this silken mass are hundreds of larvae and their natural enemies, excreta and dead larvae, pupal cases, eggs and leaf bits.

Fig 2: Larva feeding on leaves, normally larvae feed on upper side of the leaves. The skeletozation of leaves has resulted into premature leaf fall and drying of plant.

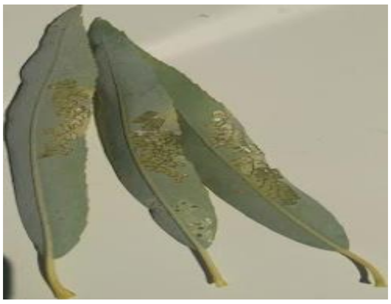

Fig 3: Larva feeding on lower side of the leaves, this is an unusual situation in infestations. One side feeding (left side in image) is a normal habit of this pest.

Fig 4: Larva feeding on the populous leaves, especially when the preferred host willow foliage have been already destroyed by it.

Fig 5: Larva has damaged populous leaves at the centre of the middle vein of leaf. This is a general observation of the attack on populous

Fig 6: Overwintering larvae and silken webs in creaks and crevices of the willow plant and egg overwintering sites

Fig 7: Digger wasp (Family: Torymidae)-parasitoid of Gypsy moth. (Ladakh)

Fig 8: Willow leaf drawn from silken web, covered by excretal pellets, and silken mass with few white creamy colored hard eggs, leaf bits, pupal cases, and tiny unknown insects, probably parasitoids, Ladakh

Fig 9: Ichneumon wasp -parasitoid of Gypsy moth in Ladakh. Recorded during month of August, 2019.

Note: Photographs were taken (Dar S A) from the Ladakh region during 2019-2020.

Conclusion

For the efficient management of gypsy moths in cold arid organic zones, the augmentation of natural enemies involves intensive biological control effort directed against this pest species are very useful. Using tree bands, blended with stickers and pesticides to capture or kill caterpillars may be of some value to an isolated willow tree with low pest populations. It is impractical to band every tree and only a very small percentage of the larvae would be caught, therefore this technique is useless. Fertilization of trees to enhance their vigor is a somewhat controversial issue which may be beneficial for individual shade tree vigor, and not for understory vegetation cover. Over the past decades there have been many unsuccessful attempts at biological weaponry control of gypsy moth in Ladakh region; however only possible option which may have shown some results includes commonly occurring pathogens and parasitoids found today within the range of the gypsy moth. Among various natural agents found to feed on Gypsy moth larvae includes, hymenopteran parasitoids, spiders, ants and some beetles. Under cold arid conditions, the caterpillars were observed to die even before they reach the surface of their egg mass, and these young caterpillars are occasionally found imbedded in the mass of egg shells, hairs, and non-viable eggs, silken webs, bark, branches, and on the ground too.

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