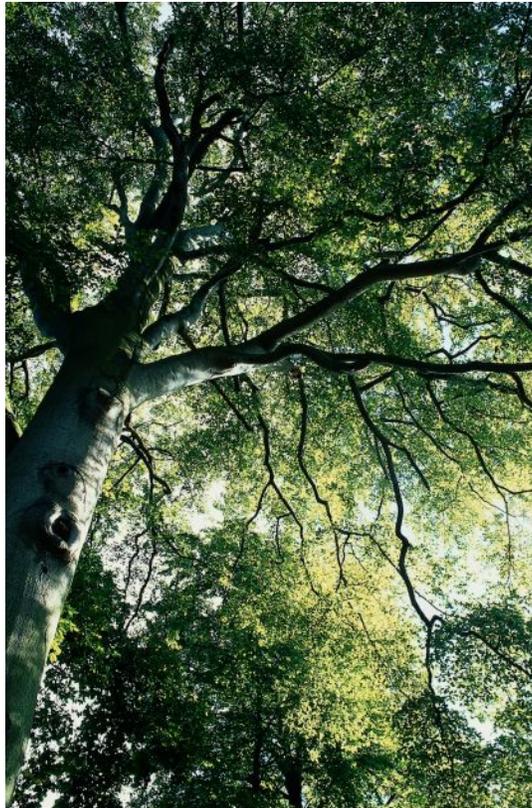


GYPSY MOTH (*LYMANTRIA DISPAR*):
IMPACTS AND OPTIONS FOR BIODIVERSITY-ORIENTED
LAND MANAGERS



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Foreword

In July 2001, Dale Schweitzer, representing NatureServe, contacted the U.S. Department of Agriculture Forest Service Forest Health Protection (FHP) in Region 8 concerning their interest in providing funding to update the Gypsy Moth Element Stewardship abstract prepared by this author in 1987-1988. FHP, R-8 and the Forest Health Technology Enterprise team provided financial assistance in completing this version to be posted on the NatureServe website.

The use of trade, firm or corporation names as well as remarks about insecticides or their impacts do not constitute an official endorsement or approval by the U.S. Department of Agriculture or U.S. Forest Service.

Introduction

The gypsy moth is native to a vast area of Eurasia. The established North American population originated from near Paris, France, and was introduced into Medford, Massachusetts, in 1869 (Ferguson 1978). The North American range expands annually; maps showing generally infested areas are readily available from the U.S. Department of Agriculture (USDA) Forest Service. A map in Appendix G of the 1995 FEIS (USDA Forest Service and Animal and Plant Health Inspection Service 1995, Gypsy moth management in the United States: A cooperative approach, referred to hereafter as the 1995 FEIS) shows the predicted range as of 2010 within the U.S. to extend from northeastern South Carolina across eastern Kentucky and much of Indiana into eastern Illinois and eastern Wisconsin. Spot introductions by human transport can occur almost anywhere in temperate North America. The eventual range of the gypsy moth in North America will almost certainly include most or all climatically suitable forested regions of southern Canada, virtually the entire eastern and central U.S., and probably much of the West.

Many identification resources are available in addition to standard moth books such as Covell (1984) and even many general insect guides. Given the extensive information available, identification should never be a problem. The details of the larval markings are very diagnostic: the combination of blue thoracic and red abdominal dots is distinctive to the gypsy moth in North America. It should be noted that the head of late instar gypsy moth larvae is contrastingly paler than the body, with very prominent hair tufts immediately behind it. Head markings on older larvae are unique. There is some variation in details, but gypsy moth larvae are easily recognizable, and no stage of the gypsy moth is similar to any other North American moth. There are, of course, other dark hairy caterpillars, but all differ greatly in details. Adult males are brown with a transverse, darker pattern and large feathered antennae. They fly actively during the daytime, less so at night, and often investigate vertical objects such as tree trunks or walls. Females of the established European strain cannot fly. They do have fully expanded wings, which are whitish with a dark pattern similar to the males'. Male wingspan is about 1 1/2 inches and female wingspan is about 2 1/2 inches. Adult gypsy moths do not feed. The appearance of both sexes of resting adults is unmistakable, but non-entomologists can mistake flying males for "brown butterflies." No other species produces large egg masses that have the same dense fuzzy covering, although the much smaller egg masses of native tussock moths (*Orgyia*) may have some hair; unlike those of the gypsy moth, however, they are laid on the female's cocoon (usually on an old leaf). Gypsy moth egg masses are roughly oval, 1 to 2 inches long, and densely covered with buff-colored hairs from the female's abdomen. They are most commonly placed on tree trunks or the undersides of limbs, but are also laid in a variety of other places. The transportation of egg masses on cars, recreational vehicles, and outdoor furniture, etc., is an important mechanism of dispersal to new areas.

The larvae are dark with sparse, stiff hairs and a pattern of red and blue dorsal spots. Please see any relevant pamphlet or Web site (e.g., Forest Service specific site) for an illustration. Gypsy moth caterpillars often rest in groups in crevices, etc., but they do not make a communal tent and are solitary feeders. Such tents in spring are made by eastern tent caterpillars on wild cherries and other species of *Prunus*, *Malus*, and *Crataegus*. The unrelated, dissimilar tent caterpillars are routinely mistaken for gypsy moth larvae by the uninformed public and sometimes by TV news crews. Unlike most Noctuoidea, gypsy moths pupate neither in the soil nor in a substantial cocoon. The dark, reddish-brown pupa is attached to

various objects in a minimal silk cocoon through which it is fully visible. The presence of obvious golden hairs on it will separate the pupae from almost all others. Usually a somewhat sheltered location is chosen for pupation.

The Asian gypsy moth is the same species but has females that fly and reportedly disperse more than 20 km, although undoubtedly few do so. In addition to the flying females, the Asian gypsy moth can be identified by DNA markers and possibly by differences in larval head maculation. For now, confirmation of Asian gypsy moth is best left to experts but *bona fide* observations of flying females should be reported to the USDA Forest Service, accompanied with the specimen if possible. Massive hybridization is expected if Asian and European strains eventually become established in the same places. Current policy in the U.S. and Canada is to attempt eradication when introductions of Asian gypsy moth occur--as in North Carolina and Oregon in the 1980s and 1990s. As of 2002, it is believed these efforts have been successful (see the 1995 FEIS). It is unclear if such hybrids might differ in population ecology from present strains.

Basic Life History

Gypsy moth eggs overwinter and hatch during warm weather in spring, usually soon after oaks begin to leaf out but a few days later than many native spring caterpillars. There is only a single annual generation in all parts of its range. First instar larvae can disperse via the wind on warm, sunny days and commence feeding once they find an acceptable plant. The great majority of hatching occurs in a 1-week period (Schweitzer, pers. obs.; Doane and McManus 1981, pp. 184-186), but it can spread out over a month with egg masses in the sunniest places hatching earlier. Larval development is slower than that of most other spring-feeding caterpillars (Schweitzer, pers. obs.) such as cankerworms (*Alsophila*, *Bistonini*), *Malacosoma*, *Xylenini* and most other spring Hadeninae, most *Catocala*, spring Lycaenidae, and Tortricidae. Most larvae hatch in early May and mature in late June or July in southern New England. Larval growth is substantially asynchronous due largely to the variety of plants eaten, and a few larvae may still be found in late July. The pre-pupal and pupal stages combined last about 2 weeks, so moths are generally seen at least throughout July and early August in southern New England. All stages occur earlier southward (depending on elevation) with both sexes often near peak by the end of June in Cumberland and Cape May Counties, New Jersey. Females usually lay their eggs in one mass on their first or second day as moths and soon die. Females usually mate only once, and because males can mate several times and live a few days, males are effectively in surplus supply. Depending largely on the nutritional quality of larval food, females lay from about 100 to 1,000 eggs. Fecundity is much lower in outbreak populations, especially in areas of heavy defoliation, than in low-density populations.

Females mate soon after their wings harden. Mating is nearly always in the daytime when males are most active. Egg masses are generally within a few meters of the female's cocoon. They are often placed on tree trunks or the underside of limbs. They may be placed in bark furrows or behind loose or shaggy bark if available. They are also often laid on boulders, outdoor furniture, in or on outbuildings, etc. While most egg masses are somewhat sheltered, many are not. Egg masses are generally fairly easy to find and egg mass counts are used to index outbreak potential. A count of 500 or more egg masses per acre, especially in an increasing population, generally indicates a high potential for heavy defoliation the

following spring, unless they are small due to previous defoliation stress on the larvae. Be careful to count only current year egg masses.

Gypsy Moth Habitat and Foodplant Comments

Almost any natural or artificial situation with woody vegetation and a temperate climate can support gypsy moths, but not all such habitats are likely to have outbreaks. Outbreaks rarely occur except in forests where oaks (or other favorite food plants) comprise at least 15 to 25% of the stand (Nichols 1980 and many other references), usually higher. Forests comprised of over 50% oaks are especially susceptible to defoliation. The 1995 FEIS regards oak-hickory and oak-pine forest types as the most vulnerable and the northern hardwoods forest type as much less susceptible in most of the U.S. However, forests composed mostly of inedible species, like tulip poplar or cedar, are unlikely to have outbreaks affecting associated species. Spruce-fir forests and others that are nearly pure conifers are also much less susceptible to the currently established European strain, but the Asian gypsy moth might reach outbreak levels in conifer forests. Most marginally susceptible types, such as northern hardwoods, support persistent populations but not outbreaks.

Oak forests in New England, Pennsylvania, and elsewhere were often nearly 100% defoliated for at least one season during the course of each gypsy moth population cycle in the mid to late 20th century and in some cases going back 100 years. In general, the degree of defoliation in peak years was directly correlated with the percentage of oaks and other highly favored species in a stand. Some good, early discussions include Gerardi and Grimm (1979), Mason (in Fosbroke and Hicks 1987), and Hicks and Fosbroke (in Fosbroke and Hicks 1987), but usually the information in the 1995 FEIS or below should suffice. The larvae can feed on over 500 species of plants but avoid most herbs. While one sees statements to the contrary, there are many plant species, including trees and shrubs, which gypsy moth larvae never or rarely eat. Private operators commonly spray trees for gypsy moth control that the larvae do not normally, or ever, eat (e.g., tulip poplar, cedar).

The following is a summary of the suitability of common trees and shrubs based mostly on the 1995 FEIS, Nichols (1980), and observations by this author (Dale Schweitzer). In general, oaks are the most important food plants, with white oaks slightly favored. Other highly favored species include mockernut hickory (Schweitzer), aspens, willows, some birches, basswood, *Malus* spp., most hawthorns, and witch hazel. These will probably be severely defoliated if oaks sustain defoliation. Other plants that are readily eaten, at least by older larvae, when they are growing with oaks include beech, sweetgum, most hickories, hemlocks, and blueberries. These and some other plants, like red and sugar maple, white pine, or rarely flowering dogwood (observed by Schweitzer, New Haven-Hamden, Connecticut, June 1981), may be defoliated in severe outbreaks when growing with oaks. First instars strongly avoid sweetgum but older larvae sometimes defoliate this species. Some forest species that will not be defoliated even in severe outbreaks include true ashes, tulip poplar (*Leriodendron*), sycamore, magnolias, persimmons, cedars, balsam firs, bald cypress, *Lonicera* spp., redbud, mountain laurel, and some clones of poison ivy. Most of these are completely avoided even by starving last instars, but the 1995 FEIS Appendix G (pages 2-4) suggests some of these may be eaten in extreme circumstances. Black

huckleberry, the dominant understory in many eastern oak forests, at least usually escapes heavy defoliation.

Appendix D of the 1995 FEIS ranks hundreds of species as susceptible, resistant, or immune. Coverage is weak for Ericaceae and some other understory groups but very thorough for trees. *Carya ovata* and *Pinus rigida* should be changed from immune to resistant like their congeners. Various sources, including the 1995 FEIS, Appendix G, note defoliation and sometimes mortality of hickories. *C. ovata* trees growing with oaks were severely and widely defoliated in New Haven County, Connecticut, in June 1981. Ridgetop *P. rigida* can be killed (Schweitzer, pers. obs.; Quimby 1985). In most other situations, though, pitch pine is at low risk, e.g., in sandy coastal pinelands. White pine is much more often defoliated than other pines.

So while virtually any kind of woodland, shaded park, backyard, or forest is potential gypsy moth habitat, not all such habitats are at risk for outbreaks. In general, the risk of heavy defoliation is high in wooded areas composed of 50% or more oaks or other highly favored trees. It is in these habitats where gypsy moth outbreaks and efforts to control them are most likely to be potential, periodic concerns to biodiversity oriented managers. Both long-term and short-term impacts need consideration.

Population Dynamics

Established gypsy moth populations remain low for varying periods of time, sometimes permanently. During this phase, predators exert some degree of control, especially native mice (*Peromyscus* spp.) and other vertebrates and invertebrates, as well as native and introduced parasitoids (Diptera, Hymenoptera) (e.g., Doane and McManus 1981, Nichols 1980, 1995 FEIS, Weseloh 1985b, Weseloh et al. 1983, and numerous other publications). Introduced predatory beetles (*Calosoma*) tend to have more impact at higher densities. Despite predators and parasitoids, gypsy moth populations in vulnerable forest types can increase to a point where natural enemies no longer exert effective control. Populations then build up within about 3 years to outbreak levels. In peak years of severe outbreaks in oak-dominated forests, 100% defoliation of all favored to moderately resistant trees often occurs. White oaks and other highly favored species may incur substantial defoliation the year before the general outbreak. Severe defoliation generally occurs for one or two seasons followed by a crash. Occasionally populations will fail to collapse for longer periods, and moderate to severe defoliation may continue to occur locally after generalized outbreaks in neighboring areas have collapsed. Such persistence is (or at least was) most likely in areas recently invaded by the gypsy moth, but since about the late 1990s has been much less frequent than previously due to the fungus *Entomophaga maimaiga* (Maier et al. 2003; R. Reardon, USDA Forest Service, pers. com., 2003). Collapse is especially likely in a season with near 100% defoliation of oaks.

An unusual and overlooked situation can persist for years in coastal plain southern New Jersey (especially in Cape May and Cumberland Counties from the 1980s to about 1996 when *Entomophaga* ended the situation) and may recur farther south if that fungus is slow to establish. Key ingredients appear to be low density (5 to 30%) of canopy oaks and a lot of sweetgum. Early instars concentrate on

the scattered oaks, which are defoliated in late May. Older larvae then disperse to sweetgums--which were unacceptable to early instars. The sweetgums may or may not incur moderate to heavy defoliation depending on their density and proximity to oaks. Larvae forced off oaks find abundant food, disperse sufficiently so that they are no longer at high density, and tend to produce normal egg masses. Red maple and blueberry are also readily available alternate food plants but are seldom significantly damaged. The percent stand defoliation remains low but individual oaks are defoliated repeatedly. Because of the greater number (often six or more) of heavy (60 to 100%) defoliations per decade, these oaks on mesic to hydric soils had higher mortality in the 1980s and 1990s than oaks in some xeric sites with more normal crashes. A few sweetgums and hickories were also killed. The Nature Conservancy's Eldora Preserve is an example of this damage pattern and probably most mature oaks were killed in the 1980s. New Jersey's only significant stand of *Quercus nigra* south of Dividing Creek lost almost all mature trees of that species, but hundreds (possibly >1,000) of saplings and pole-sized water oaks persist as of May 2004.

Heavy defoliation may occur in somewhat interrupted areas of several hundred thousand acres during the worst seasons and 1,000-acre outbreaks are not unusual. In June 1981, most oak and mixed forests from southern Maine to coastal Connecticut were heavily defoliated. Occasionally in sprayed areas (as reported in mainly older reports, e.g., Nichols 1980), populations can rebound to outbreak levels in 3 years, but generally they remain low for 5 or more years once they crash. Prior to the emergence of *Entomophaga* in 1989, the general rule was an outbreak every 6 to 12 years in New England. In the southern New Jersey Pinelands region, many oak-pine forests (especially in Burlington, Cape May, and Cumberland Counties) were defoliated several times when the gypsy moth first invaded in the late 1970s to 1980s, often with substantial mortality to subcanopy or even canopy oaks. Other similar oak-pine forests in Salem, Ocean, and Atlantic Counties have (as of 2002) never had an outbreak, in many cases without any control efforts. The 1995 FEIS and other sources report similar observations elsewhere. Failure of expected outbreaks to materialize was a problem in the Sample et al. (1996) field studies. Outbreaks often start in oak stands on stressed sites such as ridgetops.

Outbreaks are not fully synchronized, so that there are almost always some areas of heavy defoliation in any given season, at least along the leading edge of spread. Likewise, even in the worst years there are always areas with no noticeable defoliation. In New England, eastern New York, and northeastern Pennsylvania, outbreaks usually collapse after one to three seasons. Following collapse, it may be difficult to find any stage of the gypsy moth for a few years. This fact has hampered studies of low-level gypsy moth populations, so there are some gaps in knowledge of their population dynamics.

Short-term trend. When gypsy moth outbreaks occur, the short-term prognosis, whether or not any intervention occurs, is for decline to innocuous levels, usually within 1 to 3 years. Exceptions may still occasionally occur, but not as frequently as pre-1989 due to the recent impacts of *Entomophaga maimaiga*. Once gypsy moth becomes established in a new area, there is a high probability, but far from a certainty, that oak-dominated habitats will have one or more severe defoliations within a decade. Treatment with either chemical biocides or the microbial biocide *Bacillus thuringiensis* (=BTK) is commonly used to prevent defoliation. Neither has any documented long-term benefit in controlling gypsy moth, however. Some older works suggest that outbreaks recur more quickly after biocide use as opposed to natural collapse, but it is not likely that this would be the case with current suppression

strategies, and not all older works agreed on this point. Regardless of tactics used, if any, subsequent outbreaks may occur.

Long-term Trend. The gypsy moth continues to expand its range annually and will continue to do so for the foreseeable future. The USDA Forest Service maintains current information for the United States. In general, initial outbreaks in an area are the most protracted and most destructive. Before the emergence of *Entomophaga maimaiga* in 1989, the general pattern was that outbreaks would continue to recur every decade or so once gypsy moth becomes established in an area. However, these subsequent outbreaks tend to kill fewer trees and to collapse faster. *Entomophaga maimaiga*, however, may greatly reduce the frequency of future outbreaks. Indeed, there have been no large outbreaks in many parts of New England since several years before the 1989 explosion of *Entomophaga maimaiga*. Many Connecticut forests have had no defoliation (as of 2003) since 1981 or 1982. Chronic outbreaks in parts of Cumberland County, New Jersey, collapsed about 1996 and in most such places no gypsy moth stages were apparent for 5 years (Schweitzer), but a few adults were seen in 2002 and 2003. While *Entomophaga maimaiga* seems likely to have a major impact in reducing outbreaks, they are expected to continue to occur in some places, especially as the gypsy moth expands into new areas.

Native and introduced natural controls. Outbreak collapse usually involves death of an overwhelming majority of gypsy moth larvae due to some combination of gypsy moth nucleopolyhedrosis virus (NPV), starvation, or since 1989, the fungus *Entomophaga maimaiga*. NPV is introduced as probably is the fungus, although there is some uncertainty about the exact origin of the latter. Larvae killed by NPV generally remain attached to the substrate by some of the middle prolegs with both ends hanging limply in an inverted v-shape and are discolored. Larvae killed by the fungus usually die in a vertical head down position. The fungus can also provide excellent control in pre-outbreak conditions and can probably be credited with preventing outbreaks since 1989 in large areas of New England. It is now an important mortality agent in low-density populations. Mortality from parasitism can become very high or may remain low in outbreak populations. It seems to be the consensus that the important cumulative impact of parasitoids and predators is to slow the rate of increase in low-level populations and thus to lengthen the period between outbreaks, more than actually ending or preventing outbreaks. In addition, egg production is low in most females that fed as larvae during outbreak conditions.

Several, mostly non-native, parasitoids utilize gypsy moth larvae and pupae. Some useful references for identification include Sabrosky and Reardon (1976), Marsh (1979), Simons et al. (1979), and Gupta (1983); references for basic information include Hoy (1976), Reardon (1976), Coulson et al. (1986), and Williams et al. (1992). None of the parasitic wasps sting humans. Wallner (1989) and Elkinton and Liebhold (1990) provide reviews on the population dynamics of gypsy moth, while Weseloh (1972) and some of the references therein are among the important studies of parasitoid impacts, including those in low-level larval populations. At least two parasitoids are often noticeable in many States. A tiny introduced wasp, *Ooencyrtus kuvanae*, attacks egg masses and has five or six generations per year from about July to December. Due to its small size, it can only destroy eggs near the surface of the masses. Williams et al. (1990) reported an average of 26% parasitism of eggs. They kill the highest percentage of eggs in small egg masses laid in outbreak years. These wasps commonly find virtually 100% of egg masses in an area. Another small wasp, *Cotesia* (formerly *Apanteles*) *melanoscelus*, kills

gypsy moth larvae in about the third instar. The larva dies near or attached to the small, white cocoon made by the wasp larva. This tiny wasp is apparently a specialist on Lymantriidae (gypsy moth, satin moth, native *Orgyia*) (Wieber et al. 2003). Most gypsy moth larvae observed by the author in parts of Hamden, Connecticut, in 1982 (the year after a massive outbreak) and about half of the larvae observed at Eldora, Cape May County, New Jersey, in the early and mid 1990s (a suboutbreak period) were killed by this parasitoid. In general, though, its impact is limited by a complex of hyperparasitoids (Wieber et al. 2003). Parasites of eggs and early instars are generally not considered to have a major impact on gypsy moth populations (R. Reardon, USDA Forest Service, pers. com., 2003), especially at high densities, but probably do help slow increase of low-density populations.

Larvae of *Compsilura concinnata*, an introduced tachinid fly, parasitize gypsy moth caterpillars and hundreds of other species, including a few sawflies. Sometimes it reaches high levels in outbreak gypsy moth populations, but it usually does not greatly impact them, probably because it is a multiple-brooded generalist that quickly becomes limited by lack of alternate hosts which it may deplete or eradicate (see Boettner et al. 2000). Its long-term impact on native, summer-feeding Lepidoptera has apparently been drastic reductions and State-level extirpations of numerous medium- to larger-sized, once widespread (Farquhar 1934) species in New England. It does not appear to have greatly impacted any native spring feeders. As far as is known, other gypsy moth biocontrols are not seriously impacting native species.

Threats and Impacts of Gypsy Moth and Control Practices

Although such claims are made, it is not true that unchecked gypsy moth infestation will result in complete deforestation of large areas. Large-scale deforestation has failed to happen in the first 130 years although in some tracts half or more of trees have been killed. It is, however, quite likely that some trees will be killed during the first outbreak in an area and quite possible that others will die in subsequent outbreaks. Mortality might include high-quality canopy trees but is usually heavier among already stressed or weak individuals. It is also not true that every tree that refooliates a few weeks after an outbreak will recover. Many to most trees that die do so a year or more later often due to secondary agents, such as two-lined chestnut borer (a beetle) or *Armillaria* fungi (Dunbar and Stephens 1975). As gypsy moth invades new areas, the best case scenario is that no serious defoliation will occur; the worst case is probably roughly 50% mortality to oaks and other highly favored trees when two or more severe defoliations coincide with drought. Such severe damage is much less likely in subsequent outbreaks.

In North America, threats to gypsy moth populations are obviously not of concern, but threats to other organisms due to gypsy moth outbreaks and control efforts are major issues. At present, the main known cause of concern regarding biodiversity effects is the persistent (on foliage), highly lethal biocide diflubenzuron (trade name Dimilin®). This chitin inhibitor is lethal to immatures of at least most arthropods that ingest it, and it also functions to some extent as a contact insecticide. In the past at least, the most serious threats and impacts related to gypsy moth from a biodiversity perspective were generally related to control efforts (including use of biocontrols); however, except for very localized populations,

threats from current suppression programs are not comparable to those from practices used from the 1950s through the 1980s.

Current threats that could have consequences that persist for more than a few months ((see 1995 FEIS) include tree mortality, impacts on native fauna and flora from gypsy moth outbreaks, impacts on native Lepidoptera from increased generalist parasitoids, and, especially, eradication of localized Lepidoptera or other invertebrate populations by chemical biocides, or less likely by *Bacillus thuringiensis* var. *kurstaki* (= BTK). Defoliation itself has many temporary effects on both terrestrial and aquatic environments, but few or none of these would threaten long-term loss of native biota; however, short-term temperature changes could affect woodland stream fauna for a generation (often a year) or more.

Unlike, for example, balsam or hemlock woolly adelgids, out-of-control whitetail deer (*Odocoileus virginianus*), or several potentially emerging oak pathogens, gypsy moth outbreaks will not fundamentally alter the forest or eliminate strata but may alter its composition. If tree mortality does occur, some species will likely increase and some will likely decrease. On harsh sites, oaks that are killed by gypsy moth are usually replaced by release of understory oaks. On "better" sites, there is a greater chance of replacement by other genera such as maples, or on sandy sites by released understory pines. Despite defoliation and tree mortality, mixed forests will remain mixed forests and oak forest or woodland will usually remain oak dominated, as have millions of acres in New England. The forests at Medford and Melrose, Massachusetts, first experienced gypsy moth outbreaks around 1880 and in 1988 were still primarily oak or oak-hickory dominated on hotter slopes, with more mixed hardwoods, including some very large oaks, in more mesic places (Schweitzer, pers. obs.). Oaks were reproducing in part because there were almost no deer there in 1988. Witchhazel, pines, and hemlocks were common. Scrub oak and heaths dominated some outcrops and places that burned multiple times per decade.

As Muzika (1993) points out, tree mortality is not the only effect of gypsy moth outbreaks that can alter stand composition. Herb and shrub species commonly benefit from the increased light. Stand changes are possible if tree mortality occurs and it is possible, but undocumented, that such could occur even without direct overstory mortality. This topic is complex and impacts are likely to be very variable with location, climate, and site conditions. Pre-gypsy moth stand composition will also usually not be really "natural", having been influenced by centuries of logging, other disturbances, loss of American chestnut and more recently sometimes by extremely high deer densities and invasive alien plants. The impacts of stand composition change may not be great for arboreal herbivores (e.g., Lepidoptera, Orthoptera) overall because so many species are polyphagous among forest tree genera, although, of course, more specialized herbivores (e.g., *Catocala* moths) will be affected by changes in the abundance of food plant species or (usually) genera.

Apparent Impacts from Past (1950s-1980s) Control Programs

Chemical biocides have been very widely used to combat gypsy moth. Millions of acres were sprayed with DDT and/or carbaryl (see Doane and McManus 1981) with a peak of about 8,000,000 acres

sprayed with DDT in 1958. However, in the 1980s, concern for non-target impacts increased greatly and the USDA Forest Service funded or conducted substantial research and development on the topic. There was minimal concern expressed about the impacts of gypsy moth control efforts on non-target organisms before the 1980s (e.g., USDA Forest Service and Animal and Plant Health Inspection Service 1985, referred to hereafter as the 1985 FEIS), especially regarding biological control efforts, and large-scale spraying continued in several states through that decade. One exception was policy changes that greatly reduced aerial spraying in Connecticut after the early 1970s. Therefore, there was no systematic documentation of impacts through the 1980s. This has changed since then, at least in part due to many USDA Forest Service-sponsored or funded projects, not all of which are cited in this document. Appendix G of the 1995 FEIS has extensive coverage of non-target risks and several important USDA Forest Service-funded studies were published soon after that year.

As has been suggested by Peacock et al. (1998), Wagner et al. (1996), claimed by several USFWS candidate reviews, among other sources, and supported by the data in Severns (2002), localized populations of spring-feeding Lepidoptera might be completely eradicated by gypsy moth spraying, including BTK. There is now little doubt that the skipper *Pyrgus wyandot* is extirpated in most of its range due largely or entirely to gypsy moth spraying from about 1957 to 1989. Most of this was part of large-scale spraying. The species was extirpated in New Jersey by about 1960 (collection records compiled by David Iftner). All of the populations mentioned by Schweitzer (1989) from 1985 and 1986 field work in West Virginia were apparently eradicated by 1990 from gypsy moth spraying as was the classic occurrence in Green Ridge State Forest, Maryland. It is unknown if any sites have been recolonized, but a small colony reportedly persists in an unsprayed powerline just outside of Green Ridge State Forest. Several conversations with Lepidopterists in western Maryland and West Virginia in the late 1980s suggested eradication of *P. wyandot* and drastic reduction (at least short-term) of other spring butterflies in sprayed areas to be the norm. Dozens of other Lepidoptera declined or disappeared with *P. wyandot* in the late 1950s in northern New Jersey. Some, like *Papilio cresphontes* and *Chlosyne nycteis*, are probably no longer resident in the State, although much habitat remains for the former. Severns (2002) reports apparent elimination of three of 24 butterfly species from a small Oregon park following three applications of BTK the first spring of his study.

While search efforts have been inadequate and the species probably will be rediscovered, at least in Virginia and maybe more widely, the grasshopper *Appalachia hebaridi* is now ranked globally historic by NatureServe. There are no known collections since most of its known range in Pennsylvania was sprayed with DDT or carbaryl from the late 1950s to the 1970s or with diflubenzuron in the 1980s. It is also very unlikely that the regional collapse of *Erynnis persius persius* in and near New England during and after the 1950s could have been unrelated to massive, multi-million acre gypsy moth spraying that peaked in 1958. Based on specimens in older collections examined and verified by Dale Schweitzer, there is little doubt that this univoltine spring species was clearly of comparable abundance to the still common multivoltine *E. baptisiae* before the 1950s and is now absent at almost all "suitable" sites. Since separation of these species in the field is virtually impossible and many pre-date the description of *E. baptisiae*, collector bias can be ruled out. The uniquely (for their size) depauperate specialized moth fauna of the Rhode Island pine barrens is probably at least partly explained by gypsy moth spraying from the 1950s into the 1980s (Schweitzer, pers. obs.).

Some Lepidopterists have suggested that the decline of the regal fritillary, including the near extinction of the eastern subspecies *Speyeria idalia idalia*, was related to gypsy moth spraying. The multi-million acre DDT spray programs in the late 1950s probably did eradicate some populations in and near New England and in northern New Jersey. The last record in mainland Massachusetts was in 1958. However, in most regions, populations persisted for at least another 10 to 25 years and eventually died out even in unsprayed areas. Other factors were obviously involved. *Compsilura* (below) could have played a role but it must be noted that of the five eastern *Speyeria* species, *S. idalia* is the least associated with forests where that fly is most abundant. This fly also generally hunts for hosts in trees and shrubs, not in leaf litter or forest floor herbs. The other three northeastern *Speyeria* species have declined somewhat but are still widespread and common in most appropriate areas (Schweitzer, pers. obs., Allen 1997, Gochfeld and Burger 1997).

Impacts from biological control efforts, especially *Compsilura* and *Entomophaga*.

An even greater impact of past gypsy moth control programs was the drastic reduction or large-scale eradication of dozens of formerly common, large summer moths. See additional topics for more details. Almost all of the species were common or at least widespread (Farquhar 1934) and not localized rarities or habitat specialists. There is disagreement as to how much long-term impact resulted from the spraying of about 12,000,000 acres (Doane and McManus 1981) of forest with DDT or carbaryl in the late 1950s versus impacts from the introduced tachinid *Compsilura concinnata* (Hessel 1976, Schweitzer 1988, Boettner et al. 2000). It is reasonably clear that most of these species collapsed in or about the late 1950s, at least in western Massachusetts and from Connecticut southward to central New Jersey. Virtually all Lepidopterists active from northern New Jersey to Massachusetts at the time considered the crashes rapid, not gradual, and blamed aerial spraying at least in part (e.g., see Hessel 1976; Gochfeld and Burger 1997; Schweitzer 1988; also personal communications of this writer with Asher Treat, Charles Remington, Roger Tory Peterson, Joseph Muller, Sidney Hessel, and others). However, it is very difficult to explain the scarcity or lack of these moths decades later as residual impacts of past massive spraying.

Failure of these larger moths to recover in some areas is probably due mostly to the introduced parasitoid *Compsilura concinnata*. This fly could pose a serious threat of eradication of localized summer species in parts of western North America, particularly in isolated canyons. Boettner et al. (2000) experimentally documented extremely high mortality to *H. cecropia* and others from *Compsilura*. Early anecdotal reports of declines in saturniid abundance, but not eradications, date back to soon after the introduction of *Compsilura* (see Boettner et al. 2000). While Boettner et al. (2000) tend to discount the impact of spraying, *Compsilura* alone seems an unlikely sole cause for immediate (vs. gradual) crashes in the late 1950s since it had been present nearly half a century, but there is little doubt this parasitoid has drastically impeded or completely prevented recoveries. Many of the most widely eradicated species (e.g., *Citheronia regalis*, *Eacles imperialis*, *Sphinx drupiferarum*, most *Datana*, and undoubtedly others) occasionally to frequently remain as pupae for 2 or 3 years (Schweitzer, unpublished data) and therefore could not be eradicated by one year of 100% larval mortality over a large area.

Whatever combination of factors was involved, there is no doubt these crashes occurred within a few years of 1958, although it is a common myth that only Saturniidae and Sphingidae were affected.

Gregarious Notodontidae such as *Datana*, *Schizura*, and *Clostera* were also very scarce or absent in the affected areas in the 1960s, 1970s, and at least into the 1980s and in some areas are still. Overall, probably the most widely eradicated genera were *Datana*, *Citheronia*, *Eacles*, ash-feeding *Sphinx*, and *Lophocampa*. The obvious, common characteristics of all of these affected species are moderate to extreme large size and exposed (often gregarious) tree- or sometimes shrub-feeding caterpillars maturing from late July to October--precisely when large numbers of *Compsilura* females need native caterpillars. It is less clear why other Notodontidae, *Lapara*, and smerinthine Sphingidae were not also widely eliminated, although some of them apparently were reduced at least in the 1970s. It is noteworthy that *Anisota* are difficult, but possible, for *Compsilura* to parasitize (David Wagner, pers. com., 2001). Perhaps their granular cuticle makes Smerinthinae similarly difficult targets. While other Ceratocampinae (*Eacles imperialis* and both *Citheronia* species) have disappeared from 99 to 100% of their former ranges on the New England mainland, two of the three *Anisota* and the related *Dryocampa* have not been widely eradicated. *A. virginiensis* and *Dryocampa* are now at least moderately common in many places, although they were apparently absent in parts of southern Connecticut but not western Massachusetts in the mid and late 1970s (D. Schweitzer, T.D. Sargent, and Yale samples). Assuming old identifications are correct, *A. stigma* has been eradicated from much of its New England range, becoming confined to Cape Cod region barrens. There, however, it appears to be increasing in distribution since 1990 (Michael Nelson, pers. com., 2001). *A. stigma* is the only one of the moths discussed in this section for which habitat loss (pine barrens) is a plausible major factor in its decline. The other large moths discussed here routinely utilize a variety of common habitats, including dominant forest types, hedgerows, and thickets, although a few probably do best in shrublands. *Anisota senatoria* now has a somewhat reduced range in New England, being largely eradicated from the western half, but still regularly occurs eastward and around Albany, New York. *A. senatoria* is/was itself an outbreak-crash late summer defoliator of oaks. Boettner et al. (2000) found moderate *Compsilura* parasitism in *Hemileuca* larvae, although Jennifer Selfridge, also working in Massachusetts (email to Dale Schweitzer, September 2002), did not, despite simultaneous high levels in *A. polyphemus*. There is no evidence of major impact to either *Hemileuca* species though. Although *H. maia* has disappeared with its habitat in some places, it still persists in all of the substantial pitch pine-scrub oak barren areas in Massachusetts, eastern New York, Rhode Island, and probably Maine, but not in New Hampshire. *H. lucina*, an outbreak species of wet shrublands, bog edges, and powerlines, increased drastically in abundance in the late 1970s and early 1980s and expanded its limited range into Franklin County, Massachusetts; northeastern Connecticut; adjacent Rhode Island; and Vermont (Schweitzer, pers. obs.).

While the precise impacts of past massive aerial biocide applications and an out-of-control biocontrol agent cannot be deciphered with certainty now, between these two impacts, the genera *Citheronia*, *Eacles*, *Datana*, tree-feeding (but not shrub- or herb-feeding) *Sphinx* species, *Lophocampa caryae*, *Manduca jasminearum*, and others were eradicated or nearly so from substantial portions, or all, of their New England range and parts of adjacent New York and probably Pennsylvania. Attacine Saturniidae and *Automeris* are greatly reduced. In this author's opinion *Compsilura* is the most plausible explanation. If spraying were the sole cause, greater or complete recovery should have occurred by now, especially of the numerous species (e.g. most *Citheronia*, *Eacles*, *Datana*, all Schweitzer, pers. obs.) which sometime remain as pupae for two or more years and so could not be eradicated by any single biocide application. With the exception of *Citheronia*, most have partially recovered (starting mainly in

the 1990s) in northern New Jersey, and by the early 2000s *Datana* were scarce but no longer absent in parts of Connecticut. Species in these groups for which suitable habitats are present appeared unaffected in the 1970s and 1980s on Block Island, Nantucket, Martha's Vineyard, and extreme outer Cape Cod, areas long considered as poor habitat for *Compsilura* but also with reduced aerial spraying compared to the mainland, or as on Block Island, none at all.

It is far from certain whether major *Compsilura* impacts will continue to spread. Obviously, *Compsilura* will occupy suitable areas of North America where it was intentionally released and, at least eastward, it will probably become more widespread. However, established *Compsilura* does not necessarily mean obliteration of large, native summer-feeding moths. This fly has long been present in southern New Jersey, but at modest levels and with no obvious impacts at the population level to large moths. Saturniidae, including *Eacles*, and *Datana* are still among the most common moths at lights in Cumberland County, for example.

Observations of possible *Compsilura* impacts south and west of the Poconos region are equivocal. *Datana*, *Eacles*, *Citheronia*, and other Saturniidae do not seem to be abnormally scarce now in central and southern Pennsylvania based on collecting by Stephen Johnson and, to some extent, by this author through 2002. Indeed, *Callosamia promethea* seems abnormally abundant in central Pennsylvania with caged females sometimes assembling over 100 males (Johnson) and *Citheronia sepulcralis* is at least widespread. Nor were such big moths at all scarce in the 2000 Great Smoky Mountains National Park BioBlitz. Except for a lack of *Sphinx* species, Schweitzer noted reasonable to good numbers, especially of *Eacles* and *Datana*, in 1988 samples from Prince William Forest Park in Virginia. However, Saturniidae, Sphingidae, and some others were remarkably scarce in the 1999 USDA Forest Service samples around Highlands, North Carolina (Adams 2001). The extent to which *Compsilura concinnata* threatens North American Lepidoptera is unclear at present. Given its host breadth and the size of the U.S. Lepidoptera fauna, thousands of species are potential casualties and it has apparently drastically reduced or eradicated formerly widespread or even common, large summer moths from several States. This suggests it could have greater impacts in places like forested canyons in dry regions of the western U.S. where equivalent summer moths are much more localized than their eastern counterparts. There is probably nothing preserve managers can do to mitigate *Compsilura* impacts. Probably of even greater concern are the impacts of *Compsilura* on native parasitoids of Lepidoptera, especially native Tachinidae.

Besides its lasting impact on native summer Lepidoptera, *Compsilura* probably should be credited with the near eradication from most of New England of the introduced brown tailed moth, formerly a pest in and north of Massachusetts. Farquhar (1934) noted it was already declining by then and today its refugia are similar to those of severely impacted native species: extreme outer Cape Cod, various offshore islands and headlands, and far northern New England. So far, there have apparently been no published reports or credible observations of other gypsy moth biontrollers seriously impacting native Lepidoptera, although closer consideration of native Lymantriidae seems warranted. For example, Schweitzer encountered no species of *Dasychira* while a resident and very active collector in Delaware and Chester Counties, Pennsylvania, from 1965-1972.

Impacts from an established biocontrol are generally unavoidable and long term, whether such impacts are control of the target species or reduction or eradication of native non-targets. Not all impacts of introduced species on native species are significant at the population level. Hajek et al. (1995) documented that some native Lepidoptera in several families can become infected by *Entomophaga maimaiga* under extreme laboratory conditions not meant to mimic field exposure. However, Hajek et al. (1996) found only two cases of infection (*Malacosoma disstria* (Lasiocampidae), *Catocala ilia* (Noctuidae)) among 1,790 native caterpillars in one large, random study with high rates of infection among gypsy moth larvae. These authors also note that *Entomophaga maimaiga* is known only from gypsy moth in its native Japan. In other samples, though, they did find low to moderate infectivity in native Lymantriidae (Hajek et al. 1996, Hajek et al. 2000, Hajek et al. in press;), especially if the larvae spend time on the ground or in the leaf litter. The highest field incidence for any native species was 36% for *Dasychira obliquata* during a peak gypsy moth year. In most years, no infected native Lymantriidae were recovered (Hajek et al. 1996, Hajek et al. 2003). They also found single cases of infection in a gelechiid (n=84) and in the noctuid *Sunira bicolorago* (n=20) among 358 caterpillars from samples in and near forest leaf litter (Hajek et al. 2000). Low to moderate levels of mortality in extreme years should be easily absorbed by populations of common forest moths and probably have less impact than gypsy moth outbreaks. An ability to infect native species at levels too low to threaten their populations could be an extremely useful feature, allowing the fungus to better maintain itself when gypsy moth larvae become scarce for long periods. Non-target impacts from *Entomophaga maimaiga* do not appear to pose any conservation concerns in terms of native Lepidoptera, including Lymantriidae. This increasingly successful biocontrol will probably eventually occupy essentially the same range as the gypsy moth, at least in humid eastern North America.

Entomophaga maimaiga was introduced to New England from Japan in 1909 and considered a failure. Whether from this introduction or some other undocumented event, *Entomophaga maimaiga* collapsed a huge incipient outbreak in Connecticut in 1989 and most of that State has not had severe defoliation since 1981 or 1982. This event got a lot of press coverage, including articles in the New York Times, Science News, and Discover magazine. It is reviewed above and appears to be very safe in terms of non-target impacts. The USDA Forest Service Gypsy Moth News (April 1993) was appropriately titled "*Maimaiga* Mania" and is a useful practical reference, for example, if one wants to determine if virus or fungus is killing gypsy moth larvae on a site (see also Reardon et al. 1996, Reardon and Hajek 1998). Spectacular collapses of gypsy moth populations continued south through New Jersey and into at least West Virginia. This fungus is now clearly established and likely to be a permanent major factor in regional forest ecology, although it is unlikely it will completely prevent all outbreaks.

Potential Impacts from More Current Gypsy Moth Control Practices

Since about 1990, gypsy moth control has taken a more focused Integrated Pest Management (IPM) approach. Potential biocontrols are getting more intensive screening for non-target effects; for example, this author provided potential host suggestions for at least two such parasitoids for testing at the Beneficial Insects Laboratory in Newark, Delaware. It is still possible another damaging species could be released and established. Under Cooperative Suppression Programs, spraying does not occur unless gypsy

moth densities exceed certain thresholds. Completely unwarranted private spraying still occurs though, and unscrupulous or ignorant operators still deceive gullible neighborhood associations into annual spraying. Massive, indiscriminant aerial spraying, such as in the 1950s to early 1970s, no longer occurs (1995 FEIS). Even by the mid 1970s or early 1980s, such massive biocide use had ceased in Connecticut and became spottier elsewhere in the Northeast where gypsy moth was well established. However tens to hundreds of thousands of acres were sprayed nationwide in some years at least into the 1990s, mostly with BTK or diflubenzuron. For example >151,000 hectares (373,121 acres) were sprayed with BTK in 1994, including 57,000 hectares in Michigan (e.g., Peacock *et al.*, 1998, Wagner *et al.*, 1996), and additional acreage was sprayed with diflubenzuron in some states. At current local scales of biocide applications, eradication of common or widespread species, at least among dispersive insect groups in areas with substantial forest, would not be expected and has not been reported. The potential for local eradications of native fauna is probably much higher for parts of the Midwest where forests are reduced to 10- to 100-acre islands in a sea of agriculture. Mortality levels even from BTK could be sufficient to cause eradications in such small habitat islands and recolonization could be difficult even for some common species on such landscapes.

Long-term to permanent impacts of current suppression programs in extensively forested regions should be limited to species occurring in localized colonies in special habitats, such as *Pyrgus wyandot*. For this reason, care needs to be taken not to spray large portions of shale barrens, pitch pine-scrub oak barrens, and other habitats likely to harbor specialized spring-feeding Lepidoptera, even with BTK. Another species of concern in Appalachian gypsy moth eradication and suppression projects recently has been *Phyciodes batesii maconensis*. A major global concern for *Speyeria diana* in the 1980s was the potential for massive impacts from large-scale gypsy moth spraying to this known BTK-sensitive species, such as occurred (largely using diflubenzuron) just north of its range in West Virginia in the late 1980s when the species was placed on the U.S. Fish and Wildlife Service Candidate (C2) list. Such threats did not materialize since indiscriminant, large-scale spraying of National Forest and National Park Service lands did not occur and does not now seem likely under current IPM-based policies.

A shift from chemical biocides to BTK and possible future phase-in of Mimic® rather than Dimilin® should confine direct, non-target impacts much more narrowly to hundreds of Lepidoptera. BTK should benefit summer-feeding species and insensitive to moderately BTK-sensitive spring species by preventing heavy defoliation and parasitoid buildup. It is distinctly possible that BTK-based suppression efforts have been a factor in the partial recovery of Saturniidae, *Datana*, and *Lophocampa*, etc., in places like northern New Jersey during the late 1980s and 1990s. Actual data on this topic would be interesting.

Potential Impacts From Gypsy Moth

Public nuisance factors during gypsy moth outbreaks can be severe (see Goebel in Fosbroke and Hicks 1987, 1995 FEIS) but are not dealt with here. Defoliation is obviously aesthetically displeasing and can have direct economic impacts. The extreme number of larvae is sometimes also a legitimate nuisance, even ignoring irrational entomophobia. A few people are allergic to the larval hairs, but neither current

control practices nor gypsy moth pose serious human health risks (see 1995 FEIS). Generally, biodiversity managers need to consider three possible impacts: tree mortality, impacts of control measures, and sometimes impacts of outbreaks themselves, including defoliation *per se* on native species. It should be remembered that spring defoliation by native species, mainly by various cankerworms (*Alsophila pometaria* and certain Bistonini), is a natural process in eastern North American forests. However, gypsy moth outbreaks are potentially much more frequent, more persistent, more widespread, and sometimes more severe than native defoliator outbreaks--or at least they were in the recent past.

The most obvious, long-term ecological impact of defoliator outbreaks is tree mortality, which is very variable and is unlikely to be substantial unless there are two or more consecutive heavy defoliations. Rarely are the affected trees rare species themselves, so low or moderate tree mortality *per se* might not necessarily concern biodiversity managers. Oaks are most likely to be killed (Nichols 1980 and many others) followed by conifers, but hickories and others also may be killed. For initial outbreaks, 10 to 30% mortality of oaks and other highly susceptible hardwoods is likely if two or more severe defoliations occur, with generally lower mortality in subsequent outbreaks. Mortality is often 0 to 10% (Gansner and Herrick 1979), but in worst case scenarios (e.g., sites selected for the Quimby 1985 study) can run about 50% of the stand. A useful review is Hicks and Fosbroke (in Fosbroke and Hicks 1987), but USDA Forest Service staff can probably suggest more current works. Trees on poor sites, such as ridgetops, or in poor condition or stressed by low soil moisture are most likely to die. Defoliation insufficient to force oaks to re-leaf causes virtually no mortality to hardwoods. Heavy tree mortality may alter future stand composition, especially if edaphic conditions are good for less favored species. Healthy hardwoods normally recover from one complete defoliation, but hemlocks and some other conifers generally die, although white pines often recover (Stephens 1984). Pines in extensive pine barrens and pine forests are not at risk of defoliation from the established European strain of the gypsy moth.

Besides tree mortality, other changes, such as altered competitive interactions, reduced seed production, and changes in herbaceous flora which might affect germination of tree and shrub seeds can alter future forest composition in some situations, as can deliberate silvicultural manipulations. See Muzika (1993) for a useful introduction to the many possible ecological factors besides tree mortality. As she points out, composition changes are possible, but also vary greatly with site conditions and location. Probably an even more over-riding impact now in many areas, such as many national parks and places like Connecticut and northern New Jersey where hunting is minimal, is extreme herbivory by out-of-control deer, often leading to drastic reduction or total elimination of tree reproduction. Deer and invasive exotic plants are likely to interact with direct gypsy moth impacts in affecting future forest composition; the relative importance of gypsy moth will vary, but this author suspects it will usually be the least important of these three factors in many areas. Stand composition is a complex issue that is not addressed in detail in this document and review of post-FEIS literature on the topic was minimal. In some places, poor acid soils prevent replacement of oaks with other species.

Other impacts of defoliation are numerous, but mostly short term (1995 FEIS , Appendix G), but in certain circumstances, localized populations of Lepidoptera and other herbivores could be eradicated if defoliation is severe (see threats section above), especially on west facing xeric ridges where defoliation

may occur earlier. In general, the conclusion of the 1995 FEIS (Appendix G) that impacts of gypsy moth outbreaks to native Lepidoptera are mostly short term is certainly correct (see also Sample et al. 1996) but the possibility exists for long-term impacts.

Soil and litter fauna, including salamanders, are affected by increased insolation and temperature for several weeks while the canopy refoiliates. However, mortality is apparently not generally high since most can move deeper into the humus or find shelter. It is worth remembering that some forests defoliated by gypsy moth are also subject to occasional defoliation by native caterpillars. A temporary rise in water temperature of streams and ponds may be a concern but long-term biotic changes are not the norm. Nesting success of birds may or may not be affected positively or negatively by outbreaks. See the 1995 FEIS and references in it for more details regarding birds. Gray squirrels are among the most heavily impacted vertebrates due to the loss for several years of hard mast production, especially acorns, and reductions may be long term if large numbers of mast-producing trees are killed. Many native and exotic understory plant species are temporarily favored by the increased light during outbreaks (e.g., Muzika 1993), for example, the globally rare orchid *Isotria medeoloides* (Brackley 1985) and *Asclepias tuberosa* (Schweitzer). Probably the greatest concern for rare and even common native understory plants and their native herbivores if tree mortality occurs is increased invasion of exotic plants or aggressive natives like *Smilax rotundifolia* with increased light.

Impacts of gypsy moth outbreaks on native Lepidoptera and other leaf eaters. Threats from gypsy moth outbreaks to native species are generally moderate at most and short term (1995 FEIS, Appendix G). But on closer consideration, severe short-term to long-term impacts are likely on a few Lepidoptera and other herbivores in some situations. Tree mortality and large-scale starvation of native herbivores in outbreak years are probably the direct effects most likely to have long-term impacts, if either occurs. If tree mortality occurs, there could be potential for increased invasion by understory exotic plants. Large-scale starvation of spring-feeding caterpillars such as most *Xylenini*, *Orthosia*, the earlier *Catocala* species, and *Bistonini* is unlikely because most spring caterpillars mature before defoliation typically occurs. A few spring feeders can overwinter more than once as underground pupae, e.g., *Feralia major* (commonly at least 2 years) and *Psaphida rolandi* (apparently usually at least 2, sometimes up to 7 years) (both Schweitzer, unpublished data), but most spring feeders overwinter as eggs, larvae, or adults, which can only do so once.

Summer-feeding caterpillars may face starvation in early summer following severe defoliation and will encounter altered foliage quality (Schultz and Baldwin 1982, Heichel and Turner 1976) if they are feeding on replacement leaves of oaks and other trees. Most summer tree feeders (Notodontidae, Ceratocampinae, some Limacodidae) reared by Schweitzer (unpublished data) have one, or often both, of two life history traits that would prevent outright loss of a population to starvation from a single defoliation. For about 40% of summer-feeding Macrolepidoptera, 5 to 70% of pupae overwinter more than once, so there is always a reserve. For about half of summer species, eclosion is staggered over 30 to 70 days starting near the time of peak defoliation, so later larvae would have at least low-quality refoiliated leaves, even after severe outbreaks.

While some summer feeders are staggered, many are not and normally begin larval feeding in June. Synchronized early summer species beginning their larval stage at the time of maximum defoliation or during the next 3 to 4 weeks (longer if hatchlings cannot use young foliage) are obviously at high risk of starvation when defoliation is severe. A few examples could include hatchlings of *Hypomecis*, *Lytrosis*, *Euchlaena*, *Hyperaeschra georgica*, and *Hyperstrotia* in June. The potential for starvation is also high for *Nadata gibbosa*, *Actias luna*, and *Antheraea polyphemus*, both to early larvae present with gypsy moth larvae and to more numerous, later larvae hatching during the period trees are leafless.

There are also a few spring-feeding species whose late instars develop slowly that would seem to be at risk during the defoliation period. Extreme examples are *Morrisonia confusa* (often on oaks; see also Wood and Butler 1991), an oak-feeding *Hydriomena* (probably *H. pluviata*), and *Lambdina "turbataria."* All of these start feeding in April or May but remain as larvae until late August to October in Cumberland County, New Jersey (Schweitzer, pers. obs.). It is unclear how, or if, these species survive severe outbreaks. The four species of the *Catocala amica* group mature later than most other spring oak specialists, about when or just after defoliation typically occurs in New Jersey and Connecticut, and so are at risk. A few hickory-specialized *Catocala* also linger as larvae (Sargent 1976, Schweitzer, pers. obs.) and are at high to extreme risk of starvation in severe outbreaks. Such species include *C. habilis*, *C. robinsoni*, *C. vidua*, and *C. obscura*. Even at very high lab exposure, the BTK assay data in Peacock et al. (1998) imply that at least two of these should fare better with a BTK application than in severe defoliation. Buckmoth larvae (*Hemileuca maia*) cannot complete development before defoliation, but if they can reach the penultimate instar (which most usually can in southern New Jersey), mortality appears low. Somehow many survive and mature quickly when reforescence occurs. They may find some alternate food, perhaps *Gaylussacia* leaves, or they may simply survive 3 weeks or so without food. By direct observation of captive larvae, 8 days of starvation has little, if any, lasting effect on last instar buckmoth larvae.

Since defoliation often occurs earliest in such places, scrub oak-feeding Lepidoptera and other insects on xeric ridgetops and west slopes are at high to extreme risk of starvation, which could eradicate them if they do not occur in other microhabitats. For example, Schweitzer observed on West Rock Ridge, New Haven, Connecticut, that oak defoliation was virtually 100% on May 25, 1981, on the crest and west face, but on the lower east slope did not reach that level until June 11. This difference should have a huge impact on survival of many spring feeders, since most (sleeved and wild larvae of Xylenini and some *Catocala*) were observed to mature during that interval. As Gall (1984) observed, survival on the west face would have been virtually impossible for many *Catocala* and not all could have matured even by June 11. Indeed, both of us observed many small *Catocala* adults there in July 1981.

While such events would not have been documented at the time, two likely examples of gypsy moth-caused extirpations are noted here. Specimens at Yale Peabody Museum and elsewhere indicate that two species found in scrub oak habitats, *Erynnis brizo* and *Chaetagnela tremula*, occurred on West Rock Ridge in the 1960s. Neither species occurred from 1975-1982 (Schweitzer, pers. obs.) after the major outbreak in 1971. Both feed largely on scrub oaks; *C. tremula* also feeds on heaths and other shrubs. Both species are larvae in spring. In an even more extreme incident at Hopkinton, Rhode Island, on 16 May, 1986, Dale Schweitzer observed nearly 100% defoliation of barely opened scrub oak buds in

a small (<100 acre) sand plain pine barren by first and second instar gypsy moth larvae obviously blown in from an adjacent, phenologically more advanced oak forest. It is very unlikely any obligate scrub oak feeders survived that spring.

Native Lepidoptera are affected by other aspects of outbreaks besides starvation (useful discussion in Sample et al. 1996), but it is very unlikely these impacts would be long term, and as those authors suggest, such impacts may be within the range of normal fluctuations. As they document and one can easily observe, even in suboutbreak conditions, gypsy moth larvae can far outnumber all native caterpillars combined and this might directly affect the latter. Native Lepidoptera may be impacted by induced increases in tannins or other defensive chemicals (Schultz and Baldwin 1982) in replacement leaves and the next season. Earlier than normal foliation the next spring (Heichel and Turner 1976) would affect synchrony of egg hatch and weight at maturity of spring feeders such as Xylenini and *Alsophila* (Schweitzer 1979, Schneider 1980). The main effect of foodplant changes will generally be small size and/or reduced fecundity (at least for Xylenini and *Catocala*, Schweitzer pers. obs.), which is well known for gypsy moth itself. Undersized, but functional, adults are commonly observed after defoliation for summer-feeding Notodontidae as well. Fecundity reductions are undoubtedly common in natives as well as gypsy moths, and Sample et al. (1996) suggest they might occur even without severe defoliation. However, there are no such data supporting or refuting this suggestion for natives.

Indeed, general moth collecting, *Catocala* and Xylenini collecting in particular, is very often excellent immediately after outbreaks; the 1981 New Haven butterfly count (Gall and Schweitzer 1982) established a record number of 55 species for an eastern U.S. count that held for over a decade, despite severe defoliation and limited effort by the observers. Sargent (1976) documents 1971 as a very good *Catocala* year in southwestern New England as it was in the Poconos of Pennsylvania (Schweitzer, pers. obs.). This was also a year of high gypsy moth defoliation. Factors that favor gypsy moth increases (like warm, dry springs) probably also favor natives. Native species sometimes crash the year following gypsy moth outbreaks, but in some cases (such as the 1982 and 1983 New Haven butterfly counts), crashes could be explained by extreme weather events, such as torrential spring rains and floods, or may have been due to some effect of the widespread defoliation. Data on impacts of gypsy moth outbreaks on native species remain few at this time. Those of Sample et al. (1996) are given mainly at the family level—not an ecologically useful operational taxonomic unit (OUT) for most macromoths other than Notodontidae and Limacodidae.

Undoubtedly, starvation can seriously impact some native Lepidoptera, at least when defoliation comes early. However, data are minimal. Lepidoptera that often seem to be reduced for a few years (observations by Dale Schweitzer and Tim McCabe) following gypsy moth outbreaks include *Satyrium* species (starting the year after), *Nemoria bistrisaria*, and some *Acrionicta* species. The mechanism in the last case may not be nutritional. With 20-20 hindsight, though, it does seem clear that gypsy moth outbreaks do not generally cause extirpations of widespread forest species in the affected areas. To what extent they threaten localized ridgetop species remains undocumented, but past outbreaks probably do explain some current absences of these natives as noted above. It now seems very likely that some of the differences between ridgetop and sand plain pine barrens moth faunas reported by Schweitzer and Rawinski (1988) reflect species losses related to past gypsy moth outbreaks. Since then, as more sites are

collected for moths, most of the so-called sand plain species have turned up on one or more large ridgetop barrens.

Summary of Potential Impacts Related to Gypsy Moth

Both gypsy moth outbreaks and most control strategies have impacts on native biota. It is possible even sub-outbreak populations of gypsy moth larvae may also impact at least native Lepidoptera (Sample *et al.* 1996) In terms of non-target impacts, chemical biocides have the greatest short-term effect on most native biota of the current management strategies. BTK probably reduces native Lepidoptera more than outbreaks themselves overall, but this could not possibly hold consistently at the species level given the great variation in BTK sensitivity (including lack of any), variable risks for starvation, and other factors. BTK, unlike chemical biocides other than perhaps Mimic®, has little or no impact beyond Lepidoptera. If benign options like Disrupt II® (a synthetic pheromone product, see below) or Gypchek are available, any of these will probably reduce negative impacts associated with gypsy moth with little or no non-target impacts. See the 1995 FEIS for more discussion on the many short-term impacts of gypsy moth outbreaks on other fauna, especially birds and other vertebrates.

Protection Needs

Protecting gypsy moth would, of course, never be desired in North America. Other continents where it is native are beyond the scope of this document. However, while the gypsy moth was native and is now considered extirpated in Great Britain, no other reports of conservation concern were found. See Management Sections below regarding protecting native species and natural communities from impacts associated with gypsy moth or, more commonly, suppression efforts.

Based on inquiries to this writer, the major gypsy moth-related protection concern for Nature Conservancy preserves, state natural areas, and other lands similarly managed for biodiversity during the 1980s and 1990s was responding to proposed spray blocks including such lands. Preventing impacts from either BTK or diflubenzuron to state-rare, non-target Lepidoptera was the most common concern from natural heritage programs. Inquiries about such impacts by state parks were occasionally received. On the other hand, in some states (e.g., Delaware and Pennsylvania), natural areas and/or state parks are or were sprayed with diflubenzuron (at least in the late 1980s and early 1990s) and designation of lands as either could be (or have been) a level of threat and not protection for native Lepidoptera and some other arthropods. Protection from spraying is usually simply a matter of saying no; when a proposal includes use of chemical biocides. That is this author's recommended response if biodiversity of the site matters. Biodiversity oriented managers should insist on appropriate buffers with chemical biocides, and also with BTK if sensitive, rare Lepidoptera would or might be present as larvae. In some cases, though, buffers could be waived with BTK and managers should not necessarily decline BTK treatment on preserves (see below). Even in some "sensitive areas," BTK may be a very reasonable option to consider. In others, its use could eradicate localized butterflies or other Lepidoptera.

Protecting special habitats. Because of the very high probability that regionally or globally rare, spring-feeding Lepidoptera would be severely impacted or eradicated (see Peacock et al., 1998, Wagner et al., 1996, several USFWS candidate reviews, Severns, 2002), certain habitats generally need to be protected from gypsy moth spraying with either chemical biocides or the microbial larvacide BTK. However, use of Gypchek should be considered appropriate in such places, unless perhaps if rare Lymantriidae are documented or expected, which is probably possible only in the coastal plain. Some obvious examples of habitats that should be protected from gypsy moth spraying include:

- shale barrens and powerline right-of-ways on south or west shale slopes;
- cedar glades;
- limestone glades;
- bogs, fens, and cedar swamps;
- pitch pine-scrub oak barrens;
- Appalachian balds and heaths; and
- known habitats for rare, spring-feeding Lepidoptera (unless they are not BTK-sensitive).

For now, Appalachian oak-pitch pine ridgetops with little or no scrub oak do not appear to be of special concern, although they might be if *Brachionycha borealis* is present. Generally, the spring (and especially fall) moth fauna of Appalachian ridges is not well documented and the larvae of these species are among those most likely to be exposed to BTK. In some States, natural heritage programs review spray proposals and/or can provide information about the potential for rare Lepidoptera in significant habitats. However, heritage data are almost always incomplete and lack of records of rare species *per se* should not be taken as evidence of their absence if potential habitats occur. An area may simply never have been sampled by a Lepidopterist. With larger (1,000 acres), fairly homogenous ridgetop scrub oak barrens, a good argument can be made for spraying part with BTK (or better all with Gypchek) if severe (but not moderate) defoliation is expected. Early defoliation may threaten barrens specialists with starvation. Some of these same spring species are also highly sensitive to BTK but others are not (Peacock et al. 1998). Conversely, a BTK application should not affect summer caterpillars and other herbivores, but defoliation will.

All significant biodiversity areas, whether harboring rare Lepidoptera or not, should be protected from diflubenzuron (Dimilin®) and other chemical biocides. Mimic® might be a reasonable option for limited use where there is very little or no chance of rare Lepidoptera, but its use has not been reviewed for this document. At present, it is uncertain if this chemical biocide is likely to persist long enough to kill many summer caterpillars but Butler et al. (1997) indicate impact on some species of summer caterpillars. If specialized, spring-feeding Lepidoptera are not an issue, and sometimes even if they are, BTK should be considered. Gypchek is probably always appropriate if it is an available option north of the Delmarva region, but in some southern coastal plain areas, impacts on rare *Dasychira* or *Orgyia detrita* might be a concern. A history of large-scale, past chemical biocide applications, including diflubenzuron, carbaryl, and DDT, may be an appropriate basis for down-ranking "natural communities," etc., by natural heritage programs and The Nature Conservancy in determining site protection priorities. If there is a history of past BTK use, a quick survey of butterflies or selected moths would give an indication if long-term

impacts occurred based on what can be found versus what should be present, or better yet what was present if there is pre-spray documentation. Useful data can often be obtained for butterflies in two half-day visits in spring and early summer. Healthy populations of known sensitive species or localized spring butterflies would be strong evidence that the fauna has recovered from any BTK impacts. Based on current data, protection from impacts of gypsy moth populations below severe defoliation thresholds does not seem warranted based on biodiversity concerns.

Management Summary, Current Management Programs

The USDA Forest Service and USDA Animal and Plant Health Inspection Service (APHIS) coordinate gypsy moth eradication projects; the number of acres involved largely determines the leadership role. Eradication projects are typically activated for Asian gypsy moth detections in the U.S. and for detections of European gypsy moth substantially (usually >200 miles) ahead of the advancing front of general infestation. These projects often are small but may involve thousands of acres. Gypchek may be used in sensitive areas and pheromone flakes (DisruptII®) are sometimes used in very low-density areas, but the primary treatment is usually two or three applications of BTK, sometimes for more than one season. Dimilin® has also been used. The USDA Forest Service also coordinates a "Slow the Spread" program, within 200 miles in front of the generally infested areas. Tactics include DisruptII® where gypsy moth densities are low and BTK where numbers are higher. Its goal is self-explanatory. The USDA Forest Service coordinates a "suppression" program, the goal of which is to reduce potentially defoliating populations of gypsy moth in areas where it is already permanently established. BTK and Dimilin® are the usual tools. The USDA Forest Service generally prefers BTK on its own lands when suppression is desired.

Most gypsy moth spraying is part of suppression projects, which usually involve Federal, State, and county agencies. Generally, the goal is to reduce defoliation and nuisance. Concern for non-target impacts varies greatly depending on actual local decision makers and local agencies. Usually an integrated approach is taken and treatment is considered only if monitoring, such as egg mass counts, shows a high potential for defoliation. Suppression programs are responsible for most use of chemical biocides and probably pose more threat to non-target biota than typical USDA eradication efforts. While suppression efforts in most States now rely on BTK, some states still use use of Dimilin® in State Cooperative Suppression Programs, presumably because it is less expensive and more effective at killing gypsy moth larvae. The difference in effectiveness is sometimes overstated by applicators and it should be noted that despite any difference, BTK usually does adequately suppress defoliation. Dimilin® cannot be used near the Delaware and Chesapeake Bays and near estuaries due to impacts on juvenile crabs and other Crustacea. Some States, such as Vermont, Connecticut, New Jersey, and recently Pennsylvania almost never use chemical biocides; others, such Maryland and West Virginia, commonly use Dimilin®. While State regulations vary, landowners are generally notified of potentially defoliating populations and intent to spray and have the option to refuse treatment, although few do so. Biodiversity managers should virtually always refuse diflubenzuron (Dimilin®) or other chemical biocides (for now, at least, including Mimic®) and insist on at least the minimum buffer currently recommended for preserves, other sensitive areas, vernal ponds, or streams. This author recommends that an attorney should be consulted

immediately if there is resistance to excluding a preserve. As discussed below, whether or not to use BTK is a much more complicated decision and it might be a mistake to simply refuse to allow it without careful site-specific evaluation of risks. Also consider whether Gypchek would be an option, although the supply is limited.

Overview of Gypsy Moth Management Practices

Despite recently increased control from *Entomophaga*, gypsy moth will probably be a factor in North American forest ecology for the foreseeable future and it can certainly be expected to continue to expand its range by natural dispersal and to be moved to more distant areas by human transport. If gypsy moth populations reach the release phase, an outbreak usually develops (but not as certainly as pre-1989 due to *Entomophaga*) and managers must decide whether to control them or let outbreaks run their course. On preserves such as those of The Nature Conservancy, or State "natural areas" which are actually managed as such, only biodiversity related issues (including possible tree mortality) may need consideration. In some other contexts, such as State parks, scenic and recreational areas, and residential areas, nuisance factors may also be important. Non-target impacts associated with standard management tactics are discussed below.

BTK, Gypchek, and the several chemical biocides currently used are generally effective at suppressing defoliation. Private operators sometimes use several chemicals not used in Federal-state Cooperative Suppression Programs. Note that non-target impacts of carbaryl are so severe that it is not used in government-sponsored Cooperative Suppression Programs. Dimilin® often provides greater reduction of gypsy moth larvae (and has much greater impact on non-target caterpillars, etc.) than BTK or Gypchek, but the results are not immediate because it does not kill until the next naturally occurring molt and larvae continue to feed until then. The newer Mimic® would likely kill faster since it induces a premature molt. BTK typically begins to affect larvae at their next feeding, and thus feeding is greatly reduced within a day or two. Gypchek causes a viral disease that takes about 7 to 10 days to kill, but when applications are timed properly against young larvae, it is quite effective at suppressing noticeable defoliation with little or no impact on non-targets. Data in Reardon et al. (1996) suggest about a 60- 85% reduction of larvae and about a 50% reduction in defoliation--which is normally enough to prevent significant damage to trees. BTK, at least as a single application, may not adequately prevent significant defoliation in truly extreme situations with thousands of egg masses per acre and the same is probably true of Gypchek. However in such cases naturally occurring NPV associated with such high populations will usually cause a major decline or crash.

Broad non-target impacts, which persist beyond the first season in the case of Dimilin®, nearly always make use of most chemical biocides inappropriate in preserves, natural areas, or any more or less natural lands where biodiversity is a management goal. In some cases, it is virtually impossible to assess whether BTK or no action is the preferred alternative in terms of impacts on native biota. Any review of options should always strongly consider, but not assume, no action as a possible alternative. It should be stressed that both BTK, which impacts some non-target Lepidoptera, and Gypchek, which apparently has

minimal or no non-target impacts, are normally adequate for foliage protection when applied at the proper time. In cases where these alternatives would not be adequate due to extreme larval density, consider the high probability that the outbreak may collapse after the upcoming defoliation without treatment. Aside from small-scale, occasional applications around buildings or in high human use areas, extremely high-density outbreaks in old growth forest would be virtually the only situation where a biodiversity oriented manager might want to consider chemical biocides.

Impacts Related to Gypsy Moth and Its Management for Biodiversity Managers to Consider

Concern about **defoliation** itself is not usually a major issue for managers of biodiversity oriented preserves, but **tree mortality** sometimes is. Consideration should be given to protecting unusual forest types from further defoliation if severe defoliation occurred the previous year. Similarly, overstory composition changes may be a concern in high-quality, second growth forests such as some preserves and natural areas. Managers of such areas should not be overly concerned about gypsy moth if they are unable or unwilling to address other severe threats, such as out-of-control deer and exotic weeds which can greatly affect or eliminate tree reproduction and lower strata. However, where an effort is being made to maintain a near-natural forest community, gypsy moth impacts should be realistically evaluated.

Old growth forests should be protected from at least repeated severe defoliation. Gypchek is acceptable and in most cases BTK should be considered preferable to repeated defoliation. Old growth forests are not likely to contain Lepidoptera not found in similar, adjacent second growth forest, and risks to other terrestrial organisms is minimal at worst. For example, once surviving specimens at Rutgers University were examined and misidentifications, such as *Heterocampa "varia"* and a large majority of the *Papaipema*, were corrected by Dale Schweitzer, the moth list for the old growth Hutcheson Memorial Forest, New Jersey, compiled by Moulding and Madenjian (1979), contained no globally rare species among the 410 species encountered in a 5-year light trapping study. *Oligia crytora* (2), *Cygnia inopinatus* (1), and *Tornos scolopacinarius* (1), if correctly identified, are the only possibly State-rare species; however, the last two are not forest species and *Oligia* larvae are internal feeders in gaminoids at spray time. *C. inopinatus* was probably a misidentification of the common *C. tenera*. One might expect litter-feeding Herminiinae to contain unusual species in old growth areas, but there are only common ones in the Moulding and Madenjian list, and among the specimens examined. There is no actual evidence that any rare Herminiinae are particularly associated with old growth. Some oak mortality has occurred since then at Hutcheson Memorial Forest due to unchecked gypsy moth outbreaks in the 1980s (Thomas Breden, pers. com., 2003), and there is little doubt that one or more BTK applications would have had much less impact in this case. There is no reason to believe these findings are atypical, so there should be no long-term, negative impact from BTK in most old growth areas, especially if there are unsprayed, similar second growth stands nearby. The Lepidoptera species most likely to be of concern in the context of old growth forests is Diana fritillary, but its optimal Appalachian habitats usually are not susceptible to heavy defoliation. It is highly sensitive to BTK (Peacock et al. 1998).

Globally **rare plants** are almost never a direct management issue in dealing with gypsy moth. Few globally rare plants are vulnerable to defoliation, in large part because gypsy moth larvae seldom eat herbaceous species. A more important concern with globally rare plants might be protecting their habitat if they are especially sensitive to decreased canopy cover caused by tree mortality or might be impacted by an increase of exotics with increased light. Information on susceptibility of new growth of box huckleberry would be useful but other species in that genus are disfavored as foods. *Betula uber* would seem to be at minimal risk based on its habitat. State-rare species of trees and shrubs could be an issue. For example, two State-uncommon peripheral oaks, *Quercus nigra* and *Q. michauxii*, were substantially reduced by persistent initial outbreaks in Cumberland County, New Jersey. The latter may have been eliminated from Bear Swamp West preserve (Steven Heckscher, pers. com., 1990) but seems to have been impacted little in adjacent Bear Swamp East where overall tree mortality was lower. Most of the few mature *Q. nigra* were killed by the multiple defoliations (see above).

Some globally significant natural communities might be at risk of unacceptable levels of alteration from repeated defoliations, especially with initial invasions. Substantial stand changes are most likely in mixed-hardwood stands with substantial oaks but not oak dominance. Such stands are usually on moderately acid or near neutral mesic soils. See the 1995 FEIS, Appendix G, for more information and references. Mortality of scrub oak (*Quercus ilicifolia*) from gypsy moth defoliation appears to be unreported and seems very unlikely since it persists with nearly annual mowing for more than 60 years (Schweitzer, pers. obs) and probably much longer. This shrub is an important component of several rare natural communities and a foodplant for many rare Lepidoptera. Foodplant mortality is not likely to be a significant impact to barrens Lepidoptera.

Generally, protection of **native fauna** from outbreaks will not be a concern since impacts are usually only short term (see 1995 FEIS, Appendix G). Special cases could occur, most likely involving localized occurrences of rare Lepidoptera that are especially vulnerable to competition or starvation during severe outbreaks, and perhaps rare salamanders which may be forced to seek shelter to escape increased insolation while trees are leafless. A tentative decision was made on the recommendation of this author to use partial treatment with BTK to protect disjunct occurrences of *Heterocampa varia* and *Acronicta albarufa* on Nature Conservancy lands at Manumuskin, New Jersey, in the 1990s. Both are summer oak feeders. However, while surrounding xeric and mesic forests were mostly 80 to 100% defoliated once or twice, the ultraxeric oak woodlands these species prefer locally had neither detectable defoliation nor high numbers of gypsy moth larvae so no treatment was needed. Delayed phenology of the oaks probably minimized gypsy moth hatchling establishment.

In some cases, a BTK treatment could even be considered to protect occurrences of spring-feeding moths if severe defoliation is anticipated and Gypchek is not an option. A manager may also wish to consider the relative impacts of BTK versus expected defoliation. For spring-feeding butterflies, BTK impacts will probably exceed defoliation impacts, except if defoliation would lead to virtually 100% starvation. If severe defoliation is likely to occur unusually early, posing a risk (or certainty) of mass starvation, moderately BTK-sensitive or insensitive (Peacock et al. 1998) spring-feeding and nearly all summer-feeding native caterpillars should benefit from BTK treatment as opposed to no action. Beneficiaries probably include a majority of forest moths, but some of the others and most breeding

butterflies could be severely reduced or even eradicated. If defoliation occurs at a more normal time (e.g., mid or late June for Connecticut), spring species are likely to be less impacted by severe defoliation than by BTK. The benefits from BTK would probably outweigh the risk to a species with lab assay BTK mortality up to about 80% and good recovery of survivors. Field mortality will probably be lower. The practical problem, though, is that it is generally impossible to know the sensitivity of the species of concern unless the actual species (not its family or even genus) is included in published (usually Peacock et al. 1998) or otherwise available data.

Determining whether or not a particular Lepidoptera species is at risk from BTK is difficult and comparing that risk to that from a gypsy moth outbreak is even more so, although Linda Butler's work may provide better information in a few years. To be sure, a manager needs to know the phenology of the species and its sensitivity to BTK, but the latter is unknown and unpredictable for many moths. See discussion elsewhere in this document. For now, at least, it appears butterfly larvae generally are highly sensitive. For other Macrolepidoptera, the Peacock et al. (1998) assay data indicate that nearly all species probably incur significant mortality from BTK applications if they are first or second instars, and for half of these species, nearly all larvae were killed in these lab assays. However, it is very likely mortality would be lower in field situations. Peacock et al. (1998), Tables 2, 3, and 4 can sometimes be useful to roughly estimate exposure risk based on instars present for species of concern.

Appendix B in Hall et al. (1999) is a compilation (mostly by Dale Schweitzer) of the risk from BTK for each of 668 species of macromoths encountered in the Cape Fear region of North Carolina, based on stated assumptions about BTK persistence, what is known of the phenology of each species, and local collection dates. Selected rare species are considered separately. BTK was assumed lethal to first and second instars and borers were considered not at risk. Species exposed as third or later instars were considered possibly at risk since there is no way to predict whether BTK ingestion would kill a large percentage of them or not (Peacock et al. (1998). Assessment is based on a two or three application scenario and so some later appearing species considered at partial (moderate to high) risk might be at much lower risk from single applications. Most species considered at full risk of exposure would remain at high to full risk from single applications. Seventy-five species could not be assessed at all. Of 593 species actually assessed, 187 (31.5%) were considered definitely or probably (29 species) not at risk of exposure and 160 (27.0%) were considered definitely or probably (9 species) at high risk. The non-risk group is slightly inflated by migrants. In most cases exposure potential is similar within a genus. An important point for applying the information from this Appendix in more northern climates is that the assessment would almost always be similar for a given species in different regions except for most Notodontidae assessed at moderate to high risk. Some Notodontidae start flying quite early in southeastern North Carolina and were thus assessed as at some risk as hatchlings. Most of these same species would have little or no risk of exposure northward, especially from single applications. For example among southern New Jersey Notodontidae only *Nadata gibbosa* and *Clostera inclusa* might be at more than minimal risk since adults of other Notodontidae do not appear in substantial numbers until late May or June (spring flying *Gluphisia* and *Ellidia* do not occur) and a typical BTK application there would be in early May. In general for species for which "Estimated Larval Exposure" is given as "part" and the "Overall Potential Risk from BTK" is given as "moderate than high" the risk will probably usually be more moderate than high, and could even be low or none from single applications. Species that

overwinter as pupae and were scored as at partial risk, e.g. several *Acronicta*, would mostly be at much lower risk in single applications since fewer eggs would be laid before the application date.

Overwintering stages are given for about 600 species. Species of *Euchlaena* are exposed as late instars to typical first (or only) applications and *Protoboarmia*, pupate before typical first applications, but could be fully exposed as hatchlings following third applications. The assessment is incorrect for both *Eulithis* which overwinter as eggs (Wagner et al., 2001), not pupae, and would probably be fully exposed but it is uncertain in what instars. Likewise, *Meganola phylla* must actually overwinter as either eggs or early instars because they mature in spring (mid May in New Jersey) before the first adult flight and would be fully exposed as mostly last instars.

Local Lepidopterists might be able to help land stewards determine the precise phenology and risk of exposure of species of concern. Dale Schweitzer can be contacted for rare species. The NatureServe Website may also be helpful. In some cases published literature would suffice. However, consider the ecology of the species: even 100% mortality of larvae present on application day may not be cause for concern if large numbers of eggs will be hatching a week or more later. At this time of year, no macromoth eggs can normally develop to hatching in less than 10 days and many need twice that, so sensitive species such as *Actias luna*, *Antheraea polyphemus*, spring *Zale*, *Eutrapela clemataria*, and *Lambdina "fervidara"* still flying as adults should not be at risk unless they are unusually sensitive to BTK residue for several weeks. Likewise, hatchling mortality may not be of much concern if mid instars are less sensitive (which is by no means a safe assumption except with most Xylenini) and are already present. On the other hand, species such as *Hemileuca maia*, *Ennomos magnarius*, and many *Catocala* would be 100% at risk as first or second instars from eggs laid the previous fall, and *H. maia*, *E. magnarius*, and some *Catocala* were highly sensitive in the lab assays. Early spring species that finished oviposition within 2 weeks before application would also have very high exposure as first or second instars; likely examples include *Pyrgus wyandot*, *Euchloe olympia*, and *Callophrys henrici*.

If the species of concern is a xylenine noctuid (=Lithophanini and Antitypini in Forbes 1954) of a genus other than *Lithophane* and present in third or later instar, the impacts of BTK will very likely be trivial or at least not worse than from severe defoliation. This is based on Peacock et al. (1998) results consistently showing low or no BTK sensitivity for species of *Chaetagnalea*, *Sericagnalea*, *Metaxagnalea*, *Sunira*, *Eupsilia*, and *Xylotype*, and moderate BTK sensitivity for *Xystoepplus*. The four species of *Lithophane* were more variable, with *L. grotei* extremely sensitive in a mid instar. On the other hand, more than half of treated second instars of the globally rare *L. lemmeri* produced normal adults, making it probably the least sensitive species assayed as first or second instars. *Catocala* is another group with multiple, State-rare species in the eastern U.S. that occasionally are at risk of severe mortality in gypsy moth outbreaks (Gall 1984). The species assayed varied greatly in sensitivity to BTK. However, impact to this genus appeared unexpectedly minimal from the Highlands, North Carolina, gypsy moth eradication project (Schweitzer 2000), although the data were not extensive.

Protection of native Lepidoptera or other organisms from impacts of established biocontrols is essentially impossible, at least at present. A land steward might decide to decline releases of future biological control species on a preserve. However, if the organism establishes elsewhere in the area, it will soon be present anyway. Serious impacts on native species are known or strongly suspected only

from *Compsilura concinnata* among the parasitoids and pathogens now established, but impacts from the pupal parasitoid *Coccygomimus pedalis* (Hymenoptera: Ichneumonidae) may also be a concern. No effective action to maintain or restore populations of species affected by exotic parasitoids is now possible since the problem extends far beyond any preserve boundaries. Misguided efforts to release Saturniidae into such areas could even negatively impact any remnant native stock if the stock is not of local origin. For example, some Saturniidae have very different regional voltinism patterns or foodplants.

Compsilura sometimes reaches high levels in gypsy moth outbreaks. In this case, impacts from both gypsy moth and *Compsilura* might be reduced with BTK or even with a quickly lethal, non-persistent chemical biocide, which should benefit vulnerable summer caterpillars, although to the detriment of spring species. Gypchek or BTK probably would not kill caterpillars quickly enough to prevent maturation of most *Compsilura* already inside them. Such use of BTK could backfire and lead to unusually high parasitism of native spring caterpillars since *Compsilura* females would not be killed by BTK but would be deprived of gypsy moth larvae. Data are not available on this issue. Furthermore, sub-lethal effects on native spring caterpillars could leave them more vulnerable than usual to parasitism (1995 FEIS, Appendix G). In reality, though, a manager will probably not know that *Compsilura* numbers are excessive in time to consider acting.

Overview of Management Methods and Options

As of 2003, the widely available options for short-term suppression of gypsy moth outbreaks include:

- No action, allowing the outbreak to run its course;
- Use of a chemical biocide, usually Dimilin®, a chitin inhibitor that is lethal to immatures of most arthropods and impacts some other organisms that contain chitin;
- Use of one or more aerial applications of *Bacillus thuringiensis* var. *kurstaki* (BTK), a soil bacterium that kills many, but not all, species of actively feeding caterpillars; and
- Gypchek, the commercial Forest Service product based on a virus highly lethal to gypsy moth caterpillars, if the area is part of government-sponsored suppression, eradication, or slow-the-spread programs.

All of these, except generally not Gypchek, have non-target impacts, although non-target impacts of taking no action are minimal if severe defoliation does not occur as a result. None of them provide long-term control in the generally infested area. The no action alternative will impact some native flora and fauna if heavy defoliation occurs, but few or no lasting impacts are likely (1995 FEIS) unless tree mortality is high. Dimilin® has broad non-target impacts (sometimes understated in published studies (see below) and has especially severe impacts on Lepidoptera and other leaf chewers and on aquatic leaf shredders (1995 FEIS). Lethal doses generally remain on leaves until after leaf fall and on some evergreens and in the upper litter such impacts persist into the second season. Extirpation of localized Lepidoptera populations or other specialized leaf chewers is a distinct possibility in certain habitats. Use of Dimilin® is generally not appropriate on lands managed for biodiversity. BTK impacts are virtually

limited to some of the hundreds of species of caterpillars feeding around the time of application but a few species may be affected for longer periods.

Gypchek, the commercial Forest Service product of the NPV virus, is available through the USDA Forest Service (contact Richard Reardon, Morgantown, WV, rreardon@fs.fed.us), but its use is restricted to government-sponsored (Federal, State, county, etc.) suppression or eradication programs. It can be used on private lands as part of cooperative suppression programs. However, quantities of Gypchek are limited. Gypchek is known to affect other native Lymantriidae under laboratory conditions with massive doses (R. Reardon, USDA Forest Service, pers. com., March 2003). Whether native lymantriids are significantly affected in the field is being evaluated as part of a long-term project to evaluate non-target impacts of consecutive yearly application of BTK and Gypchek (Butler et al. 2003). Otherwise, there are no suspected negative impacts on non-target species and in most places the few native Lymantriidae are common widespread species. See Barber et al. (1993) and Reardon et al. (1996) for more about this product. It is presumed and generally stated to have little or no impact on other caterpillars. There are no known observations to contradict such assumptions and Gypchek appears to be a good option for biodiversity managers if it is available.

There are other methods discussed below that do not have non-target impacts but they may not be options. USDA Forest Service staff, and sometimes other professionals, may be able to offer good, up-to-date information regarding these options. Pheromone-based mating disruption (DisruptII®) has no documented non-target impacts but may not be available or appropriate. For example, if gypsy moth density is already high, pheromone-based mating disruption is ineffective. Synthetic gypsy moth pheromones can disrupt mating and can give good control or even local eradication when used against low-density populations. When used for control, pheromone is broadcast in tiny, plastic laminate flakes over substantial areas and traps are used for monitoring. This technology has no known harmful impacts. For now, pheromone-based suppression will not be technically feasible for most managers (due to cost and application equipment) unless as part of a larger USDA Forest Service-sponsored program in the area. Since the gypsy moth has no native close relatives, disruption of other species' mating seems unlikely in North America and notably there have been no reports of males of other species being lured to traps baited with gypsy moth pheromone. Sterile male release (see Reardon and Mastro 1993) is also without negative impacts but is usually not an option.

Various Microsporidia have been investigated as biological controls of gypsy moth larvae. Some are reported to be significant in gypsy moth populations in Europe (McManus et al. 1989) and some have the advantage that they are passed on to offspring via eggs. According to Richard Reardon (USDA Forest Service, pers. com., 2003), they are more likely to cause chronic, sub-lethal infection than direct mortality. At least two have been "experimentally" introduced in Maryland and one is probably established. The literature reviewed contained little on non-target impacts, if there would be any. Impacts on native caterpillars have been investigated in the 1990s and some species can host these pathogens, at least in the lab. Results have not been reviewed for this document, and it is unknown if these biocontrols would have significant negative impacts on native species. Nothing on these organisms appears in Appendix G of the 1995 FEIS and they are not now a management option.

Biodiversity oriented managers must first determine which options are available and decide if any such treatment option will be considered or allowed. This should be done in advance, and at the latest over the winter. Decisions and treatments should be made before defoliation is obvious. Once significant defoliation is noticeable, gypsy moth larvae are usually too large for BTK to be effective. Even Dimilin® will not be effective with last instar larvae because it cannot kill them until their next molt, which would be at pupation, so feeding would be unaffected. Mimic® might reduce further defoliation in such circumstances, but a manager concerned with biodiversity conservation might regard the non-target impacts as unacceptable. If defoliation is already occurring, a biodiversity oriented manager will usually have no choice but to allow it to run its course and plan monitoring and possible treatment options for next year. However, in rare situations where serious defoliation is suddenly noticed (usually on west facing ridges) due to an extreme number of third or earlier instars, BTK will reduce feeding in a couple of days and, in combination with other factors, will kill most of them. This might adequately reduce defoliation depending on larval density. In such cases, risks of starvation to non-target Lepidoptera and some other fauna in heavily defoliated sites are probably very high, which should be weighed against BTK impacts on them. BTK should be considered and is appropriate in environmentally sensitive areas that can be reasonably assumed to not have specialized, spring-feeding Lepidoptera or rare swallowtails. It may be appropriate even where such species do occur depending on their relative sensitivity to BTK, vulnerability to defoliation impacts, and recolonization potential.

Diflubenzuron (trade name Dimilin®), promoted as an "insect growth regulator" is the only chemical treatment currently widely used in Cooperative Suppression Programs. There has been a marked shift toward using BTK in some States and by the USDA Forest Service. Mimic® has recently been evaluated against gypsy moth (Reardon et al. 2000) and is registered for that use, but cannot be used in Cooperative Suppression Programs until completion of the new FEIS in 2005. It is also promoted as a "growth regulator." Mimic® has not been thoroughly reviewed for this document but would likely have broad impacts within Lepidoptera for an uncertain period of time. Its persistence on foliage is not well documented (R. Reardon, USDA Forest Service, pers. com., 2003). It is said to be specific to caterpillars and kills by inducing a premature lethal molt. Carbaryl (Sevin®) is still used in some private operations. It is acutely toxic, especially by ingestion, to most arthropods; very destructive in aquatic systems; and severely impacts pollinators, including native species and honeybees. However, it does not persist for months or longer on foliage, leaf litter, bark, etc., like diflubenzuron can, so carbaryl probably does not impact canopy herbivores as severely. Unlike diflubenzuron, carbaryl kills adult as well as immature arthropods quickly. Carbaryl is not discussed further in this document. Probably even more lethal to a vast array of non-target species are synthetic pyrethroids that are used by some private operators. They are related to chemicals found naturally in certain plants, which is sometimes used to falsely imply they are harmless to the environment. Due to non-target impacts and the availability of more benign, but effective, control options, for biodiversity oriented managers the use of Dimilin®, carbaryl (Sevin®), and synthetic pyrethroids is almost always inappropriate, except for small-scale, high human-use areas.

Non-target issues with diflubenzuron (Dimilin®)

The literature on diflubenzuron (Dimilin®) is too extensive to cover fully here (see 1995 FEIS). Diflubenzuron disrupts chitin formation in insects and other arthropods (broad sense) that produce it by similar processes, such as Crustacea. Death is at the next molt. Therefore, it cannot kill adult insects. It is lethal to immature arthropods that ingest it, often at doses of a few parts per million and for some aquatics at doses of a few parts per billion. It also has the potential to impact fungi that produce chitin (Dubey, 1995). It is also considered a contact insecticide, but most research suggests that this is not a major source of non-target mortality in applications aimed at gypsy moth and that ingestion is clearly the major source of mortality to most terrestrial organisms and aquatic leaf shredders. It can kill eggs upon contact or affect fecundity of exposed adult females of some insects and even at least one nematode. It is apparently not clear how widespread impacts on eggs are., especially in field situations See the 1995 FEIS, Appendix G, for an extensive list of affected organisms.

Some published studies of diflubenzuron impacts, in some cases aimed mainly at assessing immediate impacts on vertebrate food supplies, show only modest impact to moths overall, especially the same summer. Most moths in same-summer samples come from unexposed overwintered pupae and/or from habitats other than local forests. Larval sampling in areas treated with diflubenzuron underestimates mortality (1995 FEIS), probably greatly, because generally no attempt is made to rear "survivors" to adults. Undoubtedly, most would die at subsequent molts, especially considering that they would continue to ingest diflubenzuron at subsequent feedings. Nevertheless, field studies show significant, sometimes major, reductions of Lepidoptera in treated areas, which remain significant at least through the second summer. In general, mortality to non-target, spring-feeding Lepidoptera (and probably other immature, leaf-chewing arthropods) should be similar to that of gypsy moth larvae. Mortality might be lower but is substantial among summer-feeding caterpillars (1995 FEIS), and few mobile larvae probably escape lethal exposure even in mid or late summer. Sedentary species occasionally might. Good data on actual mortality levels for summer leaf eaters were not found and the FEIS estimates are probably too low since caterpillars typically move around and will likely eventually eat a lethal dose.

See Appendix G of the 1995 FEIS for discussion of the fate of diflubenzuron in the environment. Most of the diflubenzuron that washes off foliage does so with the first major rainfall, but a substantial amount adheres to leaf surfaces for weeks to months. Typically 20 to 80% of the original amount applied remains 2 to 3 weeks after treatment, but thereafter its decline in the canopy is slow for the rest of the season and 5 to 50% will remain until leaf fall (Wimmer et al. 1993). There is some effective dilution via leaf expansion but not likely enough to reduce mortality to leaf chewers. Potentially lethal doses usually remain on foliage for the rest of the growing season. Diflubenzuron probably can remain lethal on broadleaf evergreens for more than a year. However, on pine needles, the 1995 FEIS (citing Mutanen et al. 1988) states that by 61 days, levels were undetectable on two samples and 10 and 25% of the original concentration on two others. Other studies show that traces of diflubenzuron or its metabolites were still present on foliage or leaf litter at 319 days. Longer persistence has been presented at conferences but is not reported in the FEIS. Citing data from Mary Wimmer, the FEIS states that residues in leaf litter were over 1,000 ppb soon after application, dropping due to microbial activity to 15 to 200 ppb just before leaf fall and then rising again with leaf fall. Residues remained stable over winter and declined to 100 to 400

ppb by the end of the second summer. Obviously, leaf litter will remain highly toxic to litter-feeding Lepidoptera and many other detritivores through at least two seasons (noted in 1995 FEIS, Appendix G) and probably to some extent into the third season or beyond. It is also well known that residues adhered to falling leaves kill leaf shredders in streams for at least several months.

Diflubenzuron breaks down within a few days from microbial action in some soils and eutrophic pond mud but this can vary with microbial action and other factors. Its half-life is usually a few days in eutrophic ponds. However, significant amounts commonly do remain in the water column for several days to two weeks (1995 FEIS, Appendix G, page 7-6). One study showed 98% degradation within 4 weeks and another showed 50% degradation within 2 days in soil in field situations. A half-life of 3.5 to 7 days may be typical in soil but persistence is longer in soils with low microbial activity or at low temperature. Without microbial action in sterile soils, degradation is reported at 6% in 4 weeks in one study and negligible in one year in another. Despite its persistence in some situations, Diflubenzuron does not biomagnify up the food chain like DDT.

Impact to narrowly endemic cave fauna in Appalachia is a serious conservation concern. Diflubenzuron is not expected to reach ground water because it rarely penetrates far into soil. Therefore, there should not be an impact if a cave is fed solely by ground water. However, if there is a surface stream involved, lethal levels could easily occur since diflubenzuron is somewhat soluble in water, is often suspended in the water column, and can readily enter caves adhered to leaf litter and other particulate matter. Short-term exposure to diflubenzuron causes very high mortality to immatures of crustaceans (including true crabs and horseshoe crabs as well as small freshwater types) and diverse insect orders. The expected impact of a lethal dose (which could be as low as 10 ppb or slightly less) in a cave system would be death at next molt for most to all immatures of aquatic cave arthropods (broad sense) and possibly impairment of egg development in adult females. Extinction of endemic species would be a very real possibility. Exactly what species are at risk would depend in part whether exposure was from dissolved or suspended diflubenzuron or via contaminated leaf remains and depends in part on the feeding habitats of the organisms. Potential impacts on endemic carabid beetles are particularly hard to assess. High mortality to terrestrial cave arthropods from diflubenzuron seems unlikely unless they would actually ingest it, but this is uncertain. They might be exposed via predation or scavenging.

In general, Lepidoptera larvae, other chewing herbivores, and leaf shredders in streams are the most severely impacted non-target groups from diflubenzuron. Insects that do not ingest diflubenzuron, including sucking insects in the canopy, bees, wasps, ants, and many others are usually not reported to be greatly reduced in field studies, although species-level data are few. Some studies indicate reductions of spiders. Sucking insects might in fact be impacted since Kim et al. (1992) documented major fecundity reductions in the lab. Reductions in canopy and subcanopy arthropods were substantial enough overall that Whitmore et al. (1993) were able to demonstrate significant reductions in fat accumulation in seven species of Neotropical migrant bird species. Bird species that depend heavily on caterpillars would be most likely to be affected. See the 1995 FEIS and references therein for details.

Studies, such as Martinat et al. (1988), that use very broad operational taxonomic units (OTUs) and do not follow immature insects to the adult stage underestimate diflubenzuron (Dimilin®) effects,

probably severely so for Lepidoptera, as is noted in the 1995 FEIS. Such field studies may, however, provide good data relevant to birds and other predators for whom viability of prey is not directly important. *Abagrotis alternata* was noted as apparently unaffected by a diflubenzuron treatment by Butler et al. (1997), but that species would be present overwhelmingly as last instars at spray time (e.g., Peacock et al. 1998) and only late (mostly last) instars are sampled under burlap bands. There is no known mechanism by which last instars could be affected by diflubenzuron prior to pupation when most or all treated larvae probably died unobserved underground. No caterpillars of gypsy moth, *Lithophane hemina*, *Orthosia rubescens*, or *Morrisonia* (as "*Polia*") *latex*, the four most common species collected under burlap bands, were found post-spray in the treated plots in the treatment year (Butler et al. 1997, Table 3). These three native noctuids are collected by this method as late instars--solely as last instars for *L. hemina* but sometimes as penultimates for *O. rubescens*. Younger larvae are green and stay among foliage. *L. hemina* would be mostly mid instars at spray time (e.g., see data on congeners, especially *L. petulca*, in Peacock et al. 1998), *O. rubescens* would probably be mostly antepenultimates and penultimates (this species runs slightly later than the two congeners reported by Peacock et al. 1998), and few or no eggs of *M. latex* would have been laid yet (Wood and Butler 1989, Schweitzer, pers. obs.). The data for these three plus gypsy moth indicate virtual eradication of spring Macrolepidoptera larvae by the last instar, including *M. latex*, which were not yet even present as larvae at spray time. Caterpillars collected off foliage would include various instars and their viability was not assessed. In addition, caterpillars alive on sample dates would likely ingest additional diflubenzuron. It has not been demonstrated, and is not expected, that substantial numbers of immature leaf chewers, such as caterpillars, katydids, or tree crickets, survive to the adult stage after eating diflubenzuron. A reasonable assumption is that mortality to native spring- and early summer-feeding caterpillars and probably other leaf chewers from this biocide will be comparable to that for gypsy moth. An interesting area for investigation would be the impacts of Dimilin® ingestion by adult female scarabaeid beetles, which are commonly seen eating tree leaves in late spring, on their fecundity and egg viability.

This author (Dale Schweitzer) examined a number of moth samples from the summer of 1989 for the Delaware Natural Heritage Program. The samples noted here were from more or less wooded habitat sprayed with diflubenzuron in May. Nearby fields, thickets, and tidal marsh were not sprayed. These were not paired controlled studies, but the samples clearly indicate a severely impacted forest moth fauna. Marsh, thicket, old-field, and lawn species were well represented, but there were almost no forest species except for some that came from previous years' pupae. There were no litter-feeding Herminiinae (normally an abundant and diverse group) in most of these samples. The total number of tree feeders that could have been larvae in May to July that year was five moths of four species in a blacklight sample on 6 August at Pike Creek "Natural Area." Two of these were *Hypsoropha hormos*, a persimmon feeder and therefore probably from an unsprayed old field or thicket. There were six individuals of three forest species in a 2 September trap sample out of about 33 moths, mainly weedy Pyralidae. Four of the six were *Semiothisa granitata*, which suggests that residues on pines were no longer lethal by about late July, which is consistent with the 1995 FEIS (Appendix G) (see above). The other two could easily have come off wild cherries in old fields or thickets but were larvae since June. A July 12 sample contained a mere 47 macromoths at Ted Harvey Wildlife Refuge. Two oak feeding *Catocala* and one *Abagrotis alternata* were probably the only individuals that would have been larvae in forest trees that year. One *Anavitrinella* could have come from the forest but probably came from another habitat. Old-field and thicket species,

such as the *Prunus*-feeding *Catocala ultronia* (3) and dogbane feeders (3 of two species), seemed normal, and there were three of the persimmon-feeding *H. hormos*. Forest tree feeders from previous years' pupae were better represented with 12 individuals of at least four species of Notodontidae in that sample which probably came mostly from oaks or maples. Overall, one would conclude a modest reduction (perhaps 70 to 80%) of moths comparable to some published studies, but these samples strongly suggest that forest species were virtually eradicated as larvae, at least into July. Identical traps in comparable, except more light-polluted, New Jersey forests a few dozen kilometers to the east generally collect 100-600 forest moths per night at those seasons (Schweitzer 1999-2001 data), suggesting about a 95 to 100% reduction of forest species in the Delaware samples.

Non-target issues with *Bacillus thuringiensis* var. *kurstaki* (= BTK)

For biodiversity oriented managers, if Gypchek for moderate to high density gypsy moth populations and DisruptII® for low density population are not available, the only current options are no action or aerial application of *Bacillus thuringiensis* var. *kurstaki* (= BTK) formulations. While a great deal is known about BTK impacts, these proved to be extremely variable among species of Lepidoptera. Hall et al. (1999) estimated over a quarter of the macromoth fauna in their study area to be at high risk mortality in a three application scenario and slightly more species (mostly summer species and borers) to be probably at no risk. BTK occurs naturally in some soils, but rarely on foliage. Like chemical biocides, BTK is used for short-term control, but unlike diflubenzuron, the lethal crystal protein exotoxins are non-persistent and are nearly specific to some caterpillars. However, the spores are much more persistent. Generally, lethal effects from BTK persist a week or less after application (e.g., 1985 and 1995 FEIS, Sample et al. 1996, many others), but Johnson et al. (1995) showed that lethal effects persist for at least a month with swallowtails. High susceptibility to spores alone probably explains such lethal residual effects (R. Reardon, USDA Forest Service, pers. com., August 2002). Most studies do not find persistent effects, implying that most native Lepidoptera are not highly susceptible to the spores alone. Miller (1990a,b) demonstrated that even from two or three applications, impacts disappeared before August. Wagner et al. (1996) found that differences between plots treated once in May and untreated plots disappeared in June. Wagner's results strongly imply impacts for only about a week or less since the sampled caterpillars required several weeks of growth. The data in Butler et al. (1995) suggest BTK applied in May had little or no impact on a wide array of summer caterpillars. Schweitzer noted large nests of *Hyphantria cunea* and defoliation by the catalpa sphinx (*Ceratomia catalpae*) about 6 weeks after BTK spraying in Port Norris, New Jersey, in the 1990s, implying little impact to hatchlings of either species by late May or early June. Still, while most Lepidoptera are not greatly impacted by spores months after applications, the possibility of persistent lethal effects, such as reported for swallowtails, exists for other species. More information on impacts on caterpillars, such as Saturniidae, from the persistent spores is needed.

BTK will generally reduce defoliation and high numbers of gypsy moth caterpillars when properly applied. A single application should result in about 60 to 90% reduction of gypsy moth larvae (R. Reardon, USDA Forest Service, pers. com., 2003), which is usually sufficient to provide foliage protection. A second application is often used in suppression against unusually dense larval populations and in eradication projects. Mortality from two or three applications is generally at least 80 to 90% and

this strategy is commonly used in USDA Forest Service eradication projects, sometimes for two seasons. Biodiversity managers should carefully consider BTK and balance its impacts against those of defoliation. Since gypsy moth outbreaks and BTK have different negative impacts, from a biodiversity perspective, a case can often be made for partial treatment of outbreak areas, especially in large forested tracts.

The specific mode of action of BTK is poorly understood (R. Reardon, USDA Forest Service, pers. com., 2003). Toxic protein crystals and spores formed by the bacteria are ingested, damage the gut, and enter the haemocoel; the caterpillar may succumb to a massive septicemia. For some species, both the spores and the crystal must be ingested for high mortality to occur while for others, only one or the other is needed (R. Reardon, USDA Forest Service, pers. com., 2003). Sub-lethal effects also commonly occur (Peacock et al. 1998 and numerous other studies). All strains of *Bacillus thuringiensis* (BT) must be ingested to kill. In terrestrial systems, non-target impacts from BTK will be limited, or very nearly so, to Lepidoptera larvae. Appendix G of the 1995 FEIS reviews investigations of BTK impacts on other organisms. It can kill some aquatic insects, primarily midges and black flies, which is not surprising since another BT strain is often used to kill these. Less expected was mortality to some species of stoneflies (1995 FEIS, Table 5-1). Biodiversity managers should consider buffers to minimize BTK in ponds and streams. Some other strains of BT kill leaf-chewing larval or adult beetles, but apparently this impact has not been reported with BTK. It apparently does not affect Orthoptera and definitely does not kill at least most sawfly larvae. Concern for adult butterflies, such as monarchs, appears groundless. Data (see 1995 FEIS) are clearly adequate to conclude that most terrestrial, aquatic, estuarine, and marine arthropoda (broad sense) are unaffected by BTK; however, with so many species and so much variation within Lepidoptera (even within families and genera) and variable effects among stoneflies (1995 FEIS), there is some chance a few additional arthropods will prove sensitive to BTK. Note, however, that mortality in sensitive species is not always high enough to be of conservation concern, even among Lepidoptera (Peacock et al. 1998, Wagner et al. 1996). For example (1995 FEIS, Table 5-1), mortality to one of the stoneflies was only 30%. There are (same reference) some other studies that show low field mortality or mortality at high concentrations in artificial diets for other non-lepidopterous insects. Some field reductions may be from indirect effects. While some of the references cited in the FEIS were not reviewed in preparation of the present document, it appears that significant direct impacts from BTK on terrestrial non-targets other than caterpillars are, at worst, quite rare.

Within the Lepidoptera, impacts of various BT strains, including BTK, are widespread (Krieg and Langenbruch 1981, Peacock et al. 1998). Field studies, including Miller (1990a,b), Sample et al. (1996), Wagner et al. (1996), and others showed reductions (often about 30 to 70%) in Lepidoptera abundance, and sometimes species richness, following BTK applications. However, most field studies do not examine species-level effects, so findings are invariably cumulative impacts on species that were unaffected, moderately affected, severely affected, or even eradicated. While the study was not optimally designed, the results of the sampling associated with the Highlands North Carolina Eradication Project (Schweitzer 2000, Adams 2001) indicated remarkably little impact to a very diverse macromoth fauna containing more than 758 species. See the discussion in Wagner et al. (1996) for a realistic assessment of the technical difficulty of sampling caterpillars, which would be the ideal way to assess BTK impacts. That study contains some useful species-level data and Butler et al. (1995) also present useful species-level data, as do the Schweitzer and Adams Highlands reports.

The Peacock et al. (1998) lab assays are the most useful source of species-level information concerning species-level BTK impacts in the lab. Native non-target species were assayed using a spray tower (illustrated in Wagner and Miller 1995) in instars actually present at the time of gypsy moth suppression applications. Effects under ideal laboratory conditions ranged from none through slight developmental delay to 100% mortality in under 5 days. While the authors note that field mortality would likely be lower than in these assays, Richard Reardon (USDA Forest Service, pers. com., 2003) also suggests that the droplet distribution and density used probably means these assays go well beyond the worst-case field situation intended. Therefore, high mortality levels in the laboratory need to be interpreted with some caution. In contrast to diflubenzuron studies, some BTK field studies did include rearing out larvae to determine viability (or verify identity); the data and discussion in Peacock et al. (1998) and Wagner et al. (1996) address this issue. Most, but definitely not all, larvae alive a week after BTK applications are viable (see below).

Mortality was significant for 27 of the 42 species (64%) assayed with Foray 48B at 36 BIU equivalent, but 14 of these 27 produced viable adults and for some, more than a third survived. Thirteen of the 42 species (31%) were considered highly sensitive and at some risk of eradication from sprayed areas. Results were similar for Foray 48B and Dipel 8AF, two then widely used BTK formulations. Sensitivity was highly variable within Geometridae, Noctuidae, and Lymantriidae (see also Wagner et al. 1996) and varied greatly within the genera *Catocala* and *Lithophane* in these data as well as within *Orthosia* and *Dasychira* if compared with Wagner et al. (1996). The fact that a few to many individuals recover from BTK effects, even for sensitive species, is an important difference from diflubenzuron. Furthermore, larvae will usually have little or no further exposure, at least to the protein crystals. Note, however, that Peacock et al. (1998) reported delayed mortality in a few species, including some that did not have significant mortality at 5 to 7 days. One butterfly (*Limenitis arthemis*) had significant (100%) mortality, but only at or after pupation. So, reliable claims of insensitivity to BTK really should ideally be based on survival to the adult stage and such claims should be rejected if not based at least on survival to pupation (see Peacock et al. 1998).

No Microlepidoptera were included in these lab assays. Most micros gain some protection by feeding within shelters. Wagner et al. (1996) reported that 16 of the 17 most abundant micros were more frequent in untreated plots, but species-level results were not significant. Sample et al. (1996) reported modest reductions of micros in their adult, but not larval, samples. However, Miller (1990b) and many other references reported successful control of spruce budworm (a tortricid) with BTK. Krieg and Langenbruch (1981) reported numerous micros as affected by BT varieties.

An unexpected finding from these lab assays was that BTK sensitivity is a species- and/or instar-level trait, and based on the Peacock et al. (1998) data, there appears to be little basis for predicting sensitivity of third and later instars of macromoths, even on the basis of data for congenics. Still, some generalizations are justified regarding BTK impacts on caterpillars. In the absence of data to the contrary, first and second instar larvae can be presumed sensitive. All of the 18 species assayed by Peacock et al. (1998) as first to third instars had significant mortality, which was 95 to 100% for eight (42%) of them. For some species, sensitivity was clearly reduced in the third instar. For 25 species evaluated as fourth to

last instar, 10 had significant mortality, which exceeded 95% in five species (20%). While some species are highly sensitive in all instars, consecutive instars of other species differed substantially. By the third instar, the only generalization apparently justified by the lab assay data is that Xylenini other than some *Lithophane* species are insensitive or only moderately sensitive.

The claim by Wagner and Miller (1995) that Saturniidae are highly sensitive to BTK is neither justified nor refutable based on the data in Peacock et al. (1998) because of high control mortality for two of the three species, in contrast to other assays in which the median control mortality at day seven was zero. Kaya et al. (1974) found that 13% of fourth and fifth instars, but virtually no early instars, of another saturniid, *Anisota senatoria*, survived BT var. *alesti* applications. Except for *Hemileuca maia* (which is highly sensitive to BTK), no other eastern U.S. forest Saturniidae would have high exposure within a week (or often even a month) of typical single gypsy moth suppression applications. Assuming they are not at risk from lingering residual spores a month or more later, most Saturniidae and other summer-feeding moths, such as most *Acronicta* (Noctuidae), Notodontidae, and Limacodidae, actually should benefit from gypsy moth suppression applications of BTK. Treated areas will probably not be defoliated and thus their larvae will have normal food resources and lower generalist parasitoid levels in summer. Reduction of gypsy moth larval numbers might reduce impacts later in the season on native summer species from *Compsilura*.

Herminiine Noctuidae whose larvae feed in leaf litter (Hohn and Wagner 2000) have been suggested as a potentially severely impacted group--especially if BTK spores were to persist and germinate in the litter, possibly contaminating their food supply for several years. Unpublished laboratory data (D. Wagner and L. Butler, pers. com. to Schweitzer in 2002) show several Herminiinae to be BTK sensitive and it is even possible that species in some genera are consistently very sensitive in contrast to the intrageneric variations in sensitivity reported by Peacock et al. (1998) for other genera. Field samples of adults in the Highlands North Carolina Eradication project reports (Schweitzer 2000, Adams 2001, and some additional interpretation herein) are highly consistent with sensitivity for many of the genera and species despite some sampling design issues. *Idia* species appeared unaffected but *Renia* species were rather uniformly represented at all sites early in the first season, but for adults from larvae present at treatment time, frequencies per sample averaged 5.0 for the untreated samples and 0.5 at both treated sites. *Polypogon* (aka *Zanclognatha*) also appeared affected. Numbers of *Renia* and *Polypogon* were lowest the year of treatment, suggesting that there probably is not a large lingering impact from BTK spores in the litter or active bacteria in the soil. Actually, the data in the final report (Adams 2001) seem definitive on that important issue. Herminiinae numbers clearly did not continue to decline further in 2000 and 2001 from the 1999 spraying, which is inconsistent with a severe lingering impact due to BTK persistence or reproduction seriously affecting the larval food supply of Herminiinae for several years. More data are desirable for Herminiinae, but current results suggest variable sensitivity the first season with recovery starting the next season--in other words, impacts comparable to other Noctuidae. There does not appear to be a basis for concern over severe long-term impacts on Herminiinae other than rare or highly localized species. However, it should be stressed that Herminiinae were almost unique among macromoths in showing any apparent impacts in these Highlands samples. Since potentially lethal Dimilin® residues do remain on leaf litter, at least into the second summer and possibly longer,

Herminiinae are likely to be much less impacted by BTK than by Dimilin®, and were absent in the Delaware samples previously discussed.

Many species of butterflies, possibly all species, are sensitive to BTK. The published literature documents very high (often 100%) mortality to species in the Pieridae, Papilionidae, Lycaenidae, and Nymphalidae (Peacock et al. 1998, Wagner et al. 1996, Krieg and Langenbruch 1981, Herms et al. 1997, Johnson et al. 1995, Wagner and Miller 1995). Drift from a single application of BTK apparently eradicated the population of *Speyeria idalia* at Gettysburg National Battlefield in the early 1980s. According to the USFWS Candidate Evaluation forms, several populations of the imperiled *Euphydryas editha taylora* were eradicated by BTK applications aimed at Asian Gypsy Moth. No treated larvae of *Papilio glaucus*, *Speyeria diana*, *Asterocampa clyton*, or *Limenitis arthemis astyanax* produced adults in the Peacock et al. (1998) assays. Wagner's field data suggest major reduction or eradication of *Satyrus calanus falacer*. Substantial reductions of several butterfly taxa, especially *Callophrys fotis* and *Neominois ridingsii*, occurred even from down canyon drift in a Utah gypsy moth eradication effort (Whaley et al. 1998). Concern is clearly justified concerning eradication of localized populations of butterflies with spring-feeding larvae such as *Asterocampa*, regionally localized *Polygonia* and relatives, azures, elfins, many hairstreaks, and the spring forest Pieridae.

Severns (2002) documented reductions in adult butterflies mostly exposed as larvae in a small Oregon park from three applications of BTK, including apparent eradication of three relatively sedentary species: *Callophrys grynea*, *Parnassius clodius*, and *Phyciodes pratensis* based on a four year study. However no more than five of any of these three were seen in the pre-spray survey. If these three were eradicated this would be a 12.5% loss of species richness to this depauperate fauna, or 16.7% if the four he notes as migrants plus the also migratory *Pyrgus communis* and *Nymphalis antiopa* are excluded, or still higher if several other species are also migrants. Species diversity indices were also reduced significantly. The three most common species the first year dropped in years two and three as follows: *Celastrina echo* from 13 to 4 and 4; *Glaucopsyche lygdamus* from 97 to 16 and 55; *Phyciodes mylitta* from 15 to 6 and 8. All three had recovered by year 4. These and the apparent *Coenonympha* impact reported are really rather modest reductions for three applications and suggest reasonably common butterflies are usually not at great risk of local extinction from BTK applied in one season, especially in more typical single applications.

No reports of insensitivity or moderate laboratory sensitivity to BTK were found for any butterfly, but Krieg and Langenbruch's tabulation suggests only moderate sensitivity for "*Vanessa*" *io* exposed to another BT strain. This could be misleading, though, since most or all BT mortality is delayed until pupation for two other Nymphalidae: *Vanessa cardui* (Morris 1969) and *Limenitis arthemis* (Peacock et al. 1998). Wagner and Miller (1995), referring to the Peacock et al. data, reported that the "spring azure" is highly sensitive. The species was not stated because only NABA sanctioned common names were allowed by the editor, and these do not correspond well to actual taxa in *Celastrina*. The species was *Celastrina lucia*. Significant differences in larval survival between treatment replicates precluded formal analysis or inclusion in the published results (Schweitzer, pers. obs.). In addition, few control pupae and no treated pupae eclosed, probably due to inappropriate pupal storage. The sensitivity of this species is unclear, other than that some treated larvae did pupate.

Taken together, field studies show that BTK significantly reduces, but does not come close to eliminating, native Lepidoptera as a whole (e.g., Wagner et al. 1996, Sample et al. 1996, Butler et al. 1995, Miller 1990a,b). In general, effects do not persist on summer foliage, so summer-feeding species undoubtedly often benefit from BTK applications if these prevent severe defoliation or even high numbers of gypsy moth caterpillars. A few widely cited studies document that reductions of caterpillars cause emigration or decreased reproduction by vertebrates, including birds (Rodenhouse and Holmes 1992) and shrews (Bellocq et al. 1992) in BTK-treated areas. Some studies, such as Holmes (1998), do not show such effects. See the 1995 FEIS for more studies. Such effects are also well known from chemical biocides applied against gypsy moth. Generally, though, BTK impacts on vertebrate food supplies are much less than those from diflubenzuron and it is possible that in some cases they are less than those from gypsy moth defoliation, although data are not adequate regarding the last point.

The field studies cited could not adequately address the issue of impacts on highly localized species (e.g., almost all species tracked by natural heritage programs or ranked as globally rare by NatureServe), although there is discussion in Peacock et al. (1998) and Wagner et al. (1996) and apparent eradication is reported by Severns (2002). A few of these rare species (with varying sensitivities) are covered by the lab assays. Risks to such rare species must be assessed species by species, at least for macro-moths. In the absence of actual data, the most prudent suggestion seems to be that managers should assume BTK is lethal to caterpillars of rare species (other than most Xylenini) feeding within a week of application and highly lethal if they are first or second instar. A reasonable working assumption when faced with lack of data for a given species that would be present as larvae would be to assume that the impacts on it will be comparable to those of the targeted gypsy moth. First to third instar gypsy moth larvae do appear to be more sensitive to BTK than most native species assayed by Peacock et al. (1998), but some caterpillars are more sensitive than gypsy moth larvae.

The data in Butler et al. (1995) suggest that various families of sucking insects (Homoptera) benefit from BTK as compared to moderate defoliation. They probably benefit much more from BTK compared to near 100% defoliation. While there are no data, it would seem very likely that total defoliation obliterates these insects. Schweitzer strongly suspects that drastic declines of sucking insects like aphids, membracids, etc., might explain why sometimes (e.g., very late June and July 1981 around New Haven, Connecticut) sugar baiting for moths can be spectacularly good after near total defoliation. Honeydew from these sucking insects is an adult noctuid food source, and it is well known that a shortage of natural food can increase the effectiveness of sugar baits. One would expect some other insect herbivores, such as katydids, tree crickets, Cynipidae, and sawflies, to benefit from BTK applications when the alternative would be severe defoliation.

In eradication projects, the USDA Forest Service often uses two or three BTK applications over a large portion of the treatment area for one or two seasons. Impacts on non-targets from these projects undoubtedly vary. Miller (1990a) is an often-cited study from Oregon that showed substantial impacts, but without species-level data, little can really be concluded. Schweitzer (2000) and Adams (2001) concluded that the 1999 Highlands, North Carolina, eradication project had very little impact on most native moths even in thrice sprayed areas. Impacts based on adult sampling were clearly minor or less for

most species, including several that were sensitive in the lab assays. One has to wonder if larval mortality to BTK might have been offset by relaxation of some other density dependent mortality agent in this instance. Exceptions included major reductions of certain Herminiinae and probably *Feralia jocosus*. In particular, there was no hint of any impacts on summer-feeding species, which is consistent with published studies. The Highlands studies did not look at butterflies.

Dale Schweitzer and Jane Carter assayed six species using two applications of 36 BIU equivalent 10 days apart at the USDA Forest Service facility used by them previously (Peacock et al. 1998) and illustrated by Wagner and Miller (1995). These results are unpublished. For the geometrid *Prochoerodes transversata*, the second treatment killed all survivors of the first. For five noctuids, the second treatment produced zero or insignificant additional mortality; these species included *Eupsilia vinulenta*, *Chaetagnalea sericea*, and *Sericagnalea signata*, which are essentially insensitive to BTK, and *Egira alternans* and *Lithophane grotei*, which had significant first treatment mortality and were sensitive in the published assays.

Non-target issues with *Entomophaga maimaiga*.

The fungus *Entomophaga maimaiga* is now well established, spreading naturally and likely to be a permanent major factor in regional forest ecology, although it is unlikely it will completely prevent all gypsy moth outbreaks. As discussed in the **Impacts From Biological Control Efforts** section above, negative impacts from this fungus range from none or trivial to minor (some native Lymantriidae only) and this fungus is safe for application on virtually any preserve should its intentional use become an option. Reported impacts in the lymantriid genus *Dasychira* suggest little cause for concern. *Orgyia detrita* might be of concern but there is no information for that genus. The species is still present as of July 2003, but remains rare as it always has been, in southern New Jersey suggesting it is not greatly impacted.

Evaluation of Natural Communities or Rare Species Occurrences With a History of Gypsy Moth Spraying

Because of diflubenzuron's severe impact on several major non-target groups in forest canopy and aquatic systems as well as its persistence on foliage, leaf litter, and other surfaces, natural heritage programs should re-rank tracked Lepidoptera, Orthoptera, and certain aquatic insect occurrences to historic if most habitat is treated with diflubenzuron (Dimilin®), except for Lepidoptera known to have multiple overwintering as pupae if the areas were only treated once. Diflubenzuron, carbaryl, or DDT applications, even if they occurred decades previously, should also be considered a negative factor in evaluating "natural community" occurrences if community is assumed to include more than flora, since eradication of specialized arthropods may have occurred. Data on persistence and non-target impacts from the apparently caterpillar-specific Mimic® have not been evaluated for this document. BTK applications are appropriate for consideration in evaluation of natural communities only if there is a reasonable expectation that specialized spring-feeding Lepidoptera were unlikely to be widely present in nearby unsprayed areas. If the species is/are Xylenii other than *Lithophane*, there appears to be no basis for

concern. Concern might be greatest with less common or localized spring butterflies. In the absence of better current information, occurrences specialized spring-feeding Lepidoptera may be considered "historic" (but not as extirpated) if their last observation was prior to large-scale BTK use in their habitat. Ideally, though, the site should be rechecked, especially for butterflies. In most places five or fewer visits would be needed for a reasonable assessment of butterfly recovery at the present/absence level: one or two in spring for *Eyrnnis* and other spring skippers as well as elfins, azures, forest pierids, and other spring species, two or three in June-July for *Satyrrium*, *Speyeria*, *Asterocampa*, *Enodia*, *Satyrodes* and other summer butterflies and skippers.

Monitoring Methods

The need to monitor varies with location, year, and management concerns. Preserve managers often can simply rely on government monitoring programs in the area. However, it is far better to have actual egg mass counts or other monitoring from the exact place of concern itself. Thresholds for treatment are based on the predicted likelihood of defoliation above a specified level, which may vary by State or other entity, but is generally in the 250 to 1,000 egg mass per acre range (e.g., Reardon 1996 and pers. com., 2003). Besides egg mass counts, pheromone-based male trapping is used for monitoring and indices for action have been developed (e.g., Reardon 1996 and pers. com., 2003). Pheromone-based trapping is especially useful for detecting low-density populations and is the usual method of choice for evaluating the effectiveness of management actions and for detecting gypsy moth in new areas.

Dichlorovos, the organophosphate neurotoxin in no-pest strips (see 1995 FEIS, Appendix G) is sometimes placed in pheromone-baited male moth survey traps. Disparlure is the synthetic gypsy moth pheromone most often used. Grids of such traps are used for detection or quantitative survey work and are not now used for control purposes. Males are attracted and killed inside the trap. Dichlorovos will likely kill other invertebrates that wander inside the traps or outside them if the traps are destroyed and knocked to the ground. It is very unlikely the dosage would be harmful to any organism any meaningful distance from the traps in normal use. Significant non-target effects are not expected and not reported in the FEIS or elsewhere. The only likely objection to this methodology by preserve managers would be on philosophical grounds. An alternative may be traps with a sticky coating (such as Tangelfoot®) inside but these might kill a few small mammals should the traps fall to the ground.

While most outbreaks can be forecast with appropriate monitoring, no method is completely accurate. As noted above, outbreaks may fail to materialize or can occur unexpectedly. Unusual woodland types may be more (e.g., ridge top barrens) or much less (e.g., Manumuskin, New Jersey, ultraxeric oak woodlands) prone to outbreaks than surrounding forests. If a decision has been made that no action will be taken to suppress gypsy moth outbreaks, then there is probably no reason to monitor populations. If some forms of treatment are deemed potentially appropriate, monitoring is important for their judicious implementation and may or may not be important for evaluating effectiveness. Monitoring is important on preserves or other natural areas where a decision has been made that BTK or more benign treatments will be used to suppress outbreaks--for example, in old growth forests. Monitoring of egg masses may also be needed the next winter to allow an informed decision as to whether or not action

should be taken to prevent a recurrence in areas defoliated sufficiently to cause summer refoliation of oaks. If a severe defoliation has already occurred, never assume a second defoliation will or will not follow without egg mass counts or other appropriate monitoring.

Get objective, professional help if staff members cannot do necessary monitoring and egg masses are numerous. Do not rely on information from commercial pest control applicators regarding the likelihood of defoliation or its impacts. Often advice from state departments of agriculture or forestry is useful, but this writer recommends consulting with USDA Forest Service experts if possible. In any case, treatment decisions should be based on male trapping for eradication or, egg mass data for suppression. Beware, though, of claims that BTK will be ineffective at preventing defoliation unless this is based on extremely high egg mass counts, in which case such a claim is probably accurate. However, consider whether two applications of BTK might be a useful approach. Normally, BTK is effective enough to prevent significant damage to trees from defoliation.

Monitoring Programs and Contacts

USDA Forest Service, State, and sometimes local agencies generally have monitoring programs in infested areas along the leading edge of advance and often beyond it, at least where Cooperative Suppression or Slow the Spread Programs are in place. Monitoring within the established range is usually by egg mass counts. With extremely low or high densities, estimation of egg mass density may be relatively inaccurate but assessing defoliation potential or lack of it may still be easy under extreme conditions. In more typical situations for conducting such counts, assessing defoliation potential is often not as easy as one might expect. The size of current-year egg masses and the presence of old ones are confounding factors. Defoliation can even occur where there were few egg masses if large numbers of hatchlings are blown in from elsewhere, or may not occur when counts are high. See Fleischer et al. (1992) for discussion of some specific protocols for estimating egg masses. If monitoring is needed, for example, on a Nature Conservancy preserve, contact local professionals for advice or direct help. Often a gypsy moth control agency can be found in local phone book government listings. Biodiversity managers should always cooperate with local monitoring agencies unless a high egg mass count would lead to pressure to apply diflubenzuron or other unacceptable biocides in sensitive areas. No-spray requests are generally honored.

Management Research Programs

Research aimed at developing BT strains more lethal to gypsy moth and less lethal to other Lepidoptera, such as butterflies, would obviously be useful to biodiversity managers. Such research has been considered and may be ongoing, but the topic was not reviewed in preparing this document. Research on new biocides and other control measures will probably continue, at least by pesticide manufacturers. The USDA Forest Service is continuing to sponsor Linda Butler's long-term research (as of 2003 in its eighth year) on the impacts of Gypchek, and *Entomophaga maimaiga* on gypsy moth and non-target species.

Management Research Needs

More research on the impacts, or lack thereof, of gypsy moth outbreaks on native spring- and summer-feeding Lepidoptera and comparison with BTK treatment effects seems like a high priority. However, field studies present some extreme difficulties (Wagner et al. 1996, Sample et al. 1996). Observations of sleeved larvae of native spring species to quantify maturation dates relative to defoliation would give a better idea of which species are vulnerable to the most severe impact--outright starvation. Native summer species could be sleeved at low density to assay relative suitability of regrowth foliage after defoliation versus normal foliage. One could sample adult Xylenini and some other moths in defoliated and BTK-treated areas and compare fecundity directly or indirectly using moth weights. However, treatment areas would have to be at least thousands of acres in size since these moths are dispersive.

Research seems warranted to determine if there is any possibility of effective control of the parasitoid *Compsilura concinnata*. This could potentially benefit dozens of summer species that have been greatly reduced in New England and elsewhere and lead to re-establishment of now absent, large native moths. Native parasitoids might also benefit.

A more general topic for which data seem inconsistent is persistence of lethal BTK residue on foliage. For most species, the lethal period is clearly only a few days but for a few, such as *Papilio glaucus*, it is reportedly much longer. Species that are unusually sensitive to the spores alone could probably be killed to some extent for the rest of the summer. Direct assays using larvae of known sensitive species sleeved in field treatment areas, perhaps at 10-day intervals, would answer questions about lethal residual impacts on groups like Saturniidae about which concerns have been raised. The USDA Forest Service also maintains an excellent facility for bioassays with caterpillars at Ansonia, Connecticut. It is critical that any such experiments be designed such that control mortality approaches zero (the median in Peacock et al. 1998). High control mortality (except when hatchlings fail to establish in the rearing sleeve) generally raises the possibility of other major stresses to larvae besides BTK. The best way to achieve such low mortality is to sleeve larvae on growing plants as soon as practical.

Some miscellaneous research topics follow:

- Better understanding of mortality as a function of dosage would be useful in protecting very sensitive non-targets, such as some butterflies, from BTK drift.
- A definitive answer to questions regarding field sensitivity of native Lymantriidae (*Orgyia*, *Dasychira*) to NPV.
- Research aimed at predicting sensitivity of native Lepidoptera to BTK and developing a basis for predicting species-level effects without actually doing assays.
- Research into the possibility of using BTK as part of a strategy to reduce *Compsilura* impacts on larger summer moths.
- Documentation on the current status of native parasitoids, especially Tachinidae, in areas heavily infested by *Compsilura*.

- Some effort to establish baseline data and monitor Saturniidae, Sphingidae, *Datana*, and perhaps others, as *Compsilura* continues to expand and increase, including where this fly was introduced in the western U.S.

Restoration Potential

Restoration of gypsy moth is obviously not an issue, except perhaps in Great Britain where it is extirpated. Restoration of damaged flora and fauna might be. Native fauna that are impacted, but not eradicated, by either control efforts or by gypsy moth itself will usually recover within a few years without intervention unless limiting factors (e.g., *Compsilura*, loss of foodplant) persist. Native fauna eradicated by control programs may or may not eventually recolonize. For example, *Pyrgus wyandot* has not done so in northern New Jersey after more than 40 years; even if this species does not become extinct (as now seems fairly likely), recovery in much of its former range would surely require reintroduction. Isolated populations may have no recovery potential if eradicated. It is recommended that the U.S. Fish and Wildlife Service consider prompt listing and recovery efforts for *P. wyandot* while a few extant colonies are still known. Similarly, a truly isolated, relict bog copper (*Lycaena epixanthe*) occurrence southward could not be expected to recolonize until the next post-glacial period. More generalized forest species should recover or recolonize within 1 to 3 years in most cases. Restoration of Saturniidae, Sphingidae, *Datana* and others, and native parasitoids in New England for now seems impossible and will remain so unless *Compsilura* permanently declines. The recent partial recoveries of many affected species in northern New Jersey (based on 1990s to 2002 records in the collections of Allen Barlow, Tony McBride, and Rutgers University and very recent observations by Elizabeth Johnson of *Eacles* near Pottersville) do offer some hope that the same might someday happen in New England. No effective control other than lack of host caterpillars is known for *Compsilura*, although some native hyperparasites might possibly be helpful. Release of exotic hyperparasites is not recommended out of concern for already depleted native Tachinidae.

Planting or encouraging affected tree species once the initial invasion has passed could mitigate stand changes in second growth forests. This should be especially feasible where *Entomophaga* is providing good gypsy moth control and could be considered for restoring populations of State-rare species of oaks in New Jersey, for example. However, biodiversity managers should consider that pre-gypsy moth forest composition in many parts of eastern North America was already quite unnatural following centuries of logging, altered fire regimes, and loss of the American chestnut, a former dominant in many stands. The argument is often made that a reduction in oaks is beneficial in reducing the frequency of severe defoliation, and it is also by no means certain that such a reduction makes a forest any less "natural."

Additional Topics: Decline of Larger Summer Moths In and Near New England

The demise of Saturniidae and other large summer moths in the Northeast starting around 1958 was, of course, not well documented at the time. The best attempts at documentation include Morrell (1979) and Hessel (1976). Despite the lack of ideal documentation, many anecdotal observations were made and opinions expressed by Lepidopterists at the time. These may be of some use and so are summarized here despite the lack of what would be considered ideal scientific documentation. Some more or less random, but illustrative, observations are given below mostly from Dale Schweitzer, who was a resident collector in Connecticut and Massachusetts from September 1972 through July of 1988.

Schweitzer ran a 20-W blacklight nightly in warm weather from late March through July in then rural forested Southford, Connecticut in 1975 and occasionally also a Mercury Vapor light. *Dryocampa rubicunda* was occasional but the grand total for all other Saturniidae, *Sphinx*, *Lophocampa*, *Datana* was zero. Less than 20 Sphingidae were encountered, but general noctuid and geometrid collecting was fairly good and Lycaenidae and Hesperidae seemed normal or better. Aside from off-shore islands and the barrens of Plymouth, Massachusetts (where *Datana drexelii*, *Sphinx gordius*, and *S. poecila* existed), his 1972-1988 southern New England observed total for *Datana*, *Citheronia*, *Eacles*, and *Lophocampa* was zero; for *Sphinx* species, several *Sphinx gordius* and *S. poecila* were collected or observed, mainly in Norfolk County, and one *S. kalmiae* was collected in Franklin County, Massachusetts in 1974. Most Attacine Saturniidae species were rare to absent. *Hyalophora* was found in cities and *Actias luna* was common in 1978-1979 in northeastern Connecticut and Worcester County, Massachusetts. Otherwise, combined trap-night totals for these groups with Mercury Vapor or black lights in the late 1970s and 1980s were nearly always zero. Tethered luna moth females on several occasions could not attract males around New Haven but this species was fairly common a few dozen miles to the north. A possible explanation is that the luna moth, which is the earliest Saturniid in New England, is univoltine in those more northern areas, making it easier for larvae to escape *Compsilura*. Schweitzer's 17-year total for *A. polyphemus* was one road-kill male at Woodbridge, Connecticut, in 1975. *Automeris io* was regularly observed at the Montague, Massachusetts pine barrens (but not in forests of adjacent Sunderland and Leverett), in 1973 and 1974 and on parts of Cape Cod in various years, but otherwise only one was seen in these 17 years--Wethersfield, Connecticut, in 1983. That species is known to be much less rare in Connecticut now but is still not a nearly nightly catch as it often is in southern New Jersey. Both *Callosamia* species, however, were present in reasonable numbers in New Haven County, Connecticut, in the early 1980s where other affected species were not. *C. promethea* was finding refugia in roadside thickets away from forests; it is quite unclear how *C. angulifera* persisted.

Per-hour observations in southern New Jersey (1975-2002) routinely exceeded per-decade observations from New England (1972-1988) whether observations of cocoons, larvae or adults are considered. Other active collectors in the region (e.g., W. D. Winter, collection now at Harvard; T. D. Sargent, collection at Yale; Asher Treat) very rarely (usually < 1 per trap year) or never collected these same species in Massachusetts in the 1970s and 1980s with Mercury Vapor lights, although *A. luna* was not consistently absent and was locally common northward.

Dorothy Lane DuPont frequently sampled moths at her forested home in Guilford, Connecticut, and samples from 1974 to about 1980 (now at Yale Peabody Museum) contained a few *Dryocampa* but no other Saturniidae or *Sphinx* and few or none of the others previously noted as declined (D. Schweitzer, pers obs.). These moths were also absent from samples taken around Greenwich, Connecticut, ca. 1975-1982 by Yale Peabody Museum staff. Information on *Datana* for this sites is not available, but Schweitzer concurrently never encountered the genus and does not recall seeing them in those samples.

Likewise, Robert Godefroi, from 1992 to 2003 has encountered no Ceratocampine Saturniidae except *Dryocampa rubicunda* (frequently), no *Automeris* or *Lophocampa*, and has taken only one *Sphinx* (a *poecila* in 2003) using Mercury Vapor light about 20 nights per summer in and near Andover, Essex Co., Massachusetts. He concurs with Schweitzer's observations in adjacent Middlesex County (both about or two cocoons per decade) that *Callosamia promethea* is very rare nearly 100 years after the first reports of Boston area declines. He does get *A. luna* and *A. polyphemus* occasionally and has taken at least one *Hyalophora cecropia* within the last ten years. This is the Type Locality for *Citheronia sepulcralis* for which there is suitable habitat within a kilometer of his house, and suitable habitat is much closer for the other species discussed. Godefroi does collect a few *Datana*, apparently all *D. drexelii*, most years in the Andover area suggesting limited recent recovery of this genus there as in Connecticut (but see end of this section).

From June 20 to August 28, 1971, Dale Schweitzer operated 40-w BLB and 20-w BL traps all night at Resica Falls in the Pennsylvania Poconos. Day and night collecting was superb overall (especially for *Satyrium*, *Catocala*, and *Acronicta*) despite moderately heavy gypsy moth defoliation. However, he trapped fewer than five *Sphinx* (all *S. poecila*), no *M. jasminearum*, one *Datana (drexelii)*, no *Lophocampa*, one *A. luna*, one *Callosamia angulifera*, one *C. promethea*, perhaps a dozen *Dryocampa*, and no other Saturniidae in about 130 trap-nights.

Datana, *Citheronia*, and *Eacles* no longer occur in the Albany, New York, area based on nightly collecting by Tim McCabe for about 20 years. *Anisota* are present. *Sphinx franckii*, which was uncommon to rare to begin with, has not been seen from New Jersey since the 1950s. Several *Sphinx* and *Citheronia* may be the only affected large moths still absent from all of northern and central New Jersey, although the other usually affected species were rare or absent in the 1960s, 1970s, and 1980s (Joseph Muller, D. Schweitzer).

On the northern edge of the *Compsilura* impact zone, Schweitzer found common to abundant occurrences of *Sphinx poecila*, *Actias luna*, *Callosamia promethea*, *Hyalophora cecropia*, *Dryocampa rubicunda*, *Anisota virginienensis*, and *Hemileuca lucina*, but *Citheronia sepulcralis*, *A. polyphemus*, all other *Sphinx*, *Automeris*, *Lophocampa*, and *Datana* were apparently absent in York County, Maine, from 1980 to 1982. Habitat was mostly sandy oak-pine forest and pine barrens. Samples in 2002 from Ossipee pine barrens in New Hampshire (Schweitzer 2002) contained no Saturniidae except *Dryocampa rubicunda* but did contain several *Datana drexelii*, *D. ministra*, and *Sphinx poecila*, as well as six other species of Sphingidae, including *Dolba hyloeus* and *Ceratomia amyntor*, two species which Schweitzer did not encounter in southern New England from 1972-1988.

It is worth noting that the heath feeding *Datana drexelii*, *Sphinx gordius*, and *S. poecila* turned up at several of the above sites where their tree feeding congeners did not in the 1970s, 1980s and 1990s. This is consistent with *Compsilura* hunting mainly in forest trees and not in open brushland. Even so, while these heath feeders are still present they are apparently generally scarce. Schweitzer also notes that *Dryocampa rubicunda* seems to peak earlier in New England, or at least to be much less staggered than in southern new Jersey, suggesting a possible recent shift of its flight season which, if true, would be an apparent adaptation to *Compsilura*.

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