WHITE GRUBS: A DESCRIPTION FOR FORESTERS, AND AN EVALUATION OF THEIR SILVICULTURAL SIGNIFICANCE

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ABSTRACT

The damage caused in wildland areas by white grubs, the larvae of Scarabaeid beetles, especially *Phyllophaga* spp. and related genera, is a highly variable element in the success of young forest plantations and the course of natural succession in old fields. Grub population densities may reach 130/m^2 with a live weight of 1,300 kg/ha. Even when no damage is perceived, a population density of 5 or 6/m^2 is common in many soils. Roots of herbaceous plants and of both conifers and hardwoods are eaten. Pine (*Pinus* spp.) generally and Japanese larch (*Larix leptolepis* Sieb. & Zucc.) are much more susceptible to lethal damage than is white spruce (*Picea glauca* [Moench] Voss). Mortality is not an adequate measure of damage in young plantations of white spruce because root pruning by grubs may aggravate growth "check", especially on soils of low fertility or in years of subnormal rainfall. The course of natural succession in old fields and pastures is undoubtedly influenced in areas subject to white grub damage.

RÉSUMÉ

Les dommages causés en lieux sauvages par les vers blancs, ces larves de Scarabées appartenant surtout au genre *Phyllophaga* et genres affins, constituent un élément très variable du succès des jeunes plantations forestières et du développement naturel de la forêt dans les champs abandonnés. La densité de population de ces vers peut atteindre 130/m^2, équivalant à un poids de 1300 kg/ha. Une densité de 5 ou 6/m^2 se révèle commune dans plusieurs types de sols où aucun dommage n'est perçu. Les racines de plantes herbacées, outre celles des arbres résineux et feuillus, sont mangées. Les Pins (*Pinus*) en général et le Mélèze du Japon (*Larix leptolepis* Sieb. & Zucc.) sont plus souvent tués que l'Épinette blanche (*Picea glauca* [Moench] Voss). Le taux de mortalité n'est pas un indice adéquat de dommages dans les plantations de jeunes Épinettes blanches parce que l'élagage des racines par les vers blancs peut aggraver le "ralentissement" de la croissance, surtout en sol peu fertile où lors d'années à plusiosité plus basse que la normale. Le cours de la succession naturelle de la végétation dans les champs et pâturages abandonnés est sans doute ralenti par l'action des vers blancs là où ils pullulent.

TABLE OF CONTENTS

INTRODUCTION

White grubs are the larvae of *Phyllophaga* Harris spp. and related genera of Coleoptera, Scarabaeidae. The grubs, commonly referred to as "May beetles" and "June bugs", are well-known pests of lawns, pastures, and untilled crops, and on occasion they have caused serious damage in forest nurseries. The effects of damage done by white grubs in wildland areas are not easily detected and often go unnoticed unless wholesale mortality among newly planted seedlings of particularly susceptible species leads to investigation. The purpose of this paper is to present the practising forester with a generalized account of the ecology of these insects together with morphological descriptions of the various life-cycle stages. Identification keys are not provided for two reasons: identification of species or even genus is probably inconsequential for most silvicultural purposes, although food preferences among grub species probably vary to some extent; and definitive identification requires the services of a specialist entomologist. A particular purpose of this paper is to direct the forester's attention to damage by white grubs as a widespread, highly variable element in both the success of young forest plantations and the course of natural succession in old fields and pastures.

THE INSECTS

Species

Phyllophaga and *Serica* MacLeay are silviculturally the most important grub genera in North America. The European chafer (*Amphimallon majalis* Razoum.) has spread into Ontario's Niagara Peninsula since its discovery near Rochester, New York in 1940 (Tashiro 1972), but although this grub has caused severe damage to pastures, lawns, grain crops, and legumes (Ritcher 1966) it has not yet, apparently, been found damaging tree roots. This may reflect the relative difficulty of correctly attributing damage caused by this species, which has a 1-year life cycle, when other species with longer life cycles are also present. The species most commonly encountered during the course of our studies in eastern Ontario were *Phyllophaga fusca* Froel., *P. futilis* Lec. and, less commonly, *P. anxia* Lec.; species of *Serica* were uncommon but not rare.

Other Scarabaeid genera that have been reported from the eastern United States include *Geotrupes* Latreille, *Dichelonyx* Harris, *Polyphylla* Harris, *Diplotaxis* Kirby, and *Anomala* Samduelle. Heit and Henry (1940) found that *Polyphylla variolosa* Hentz caused serious injury to seedlings and transplants in Saratoga Forest Tree Nursery, New York. They also reported that *Diplotaxis sordida* Say had killed several thousand Norway spruce (*Picea abies* [L.] Karst.) transplants in the same nursery in 1936, and that although larvae of *Anomala lucicola* Fab. had not been known to damage transplants, they had caused heavy mortality in larch (*Larix decidua* Mill.) seedbeds in one year. The literature search has not yet yielded any account of damage by larvae of these genera in eastern Canada, but species may spread, particularly in consequence of the decline in the amount of cultivated land in eastern Canada.

White grubs causing silvicultural problems in Britain and Scandinavia are mainly species of *Melolontha* L.

The larvae of these insects are recognizable by their strongly curved, milky white, shiny bodies with three pairs of prominent legs and darker chitinized head and mouth parts (Fig. 1). Speers and Schmiege (1961) have given a good general account, and Luginbill and Painter (1953) and Ritcher (1966) have provided detailed descriptions. Nairn and Wong (1965) devised a useful field key to the adult beetles occurring in Manitoba.

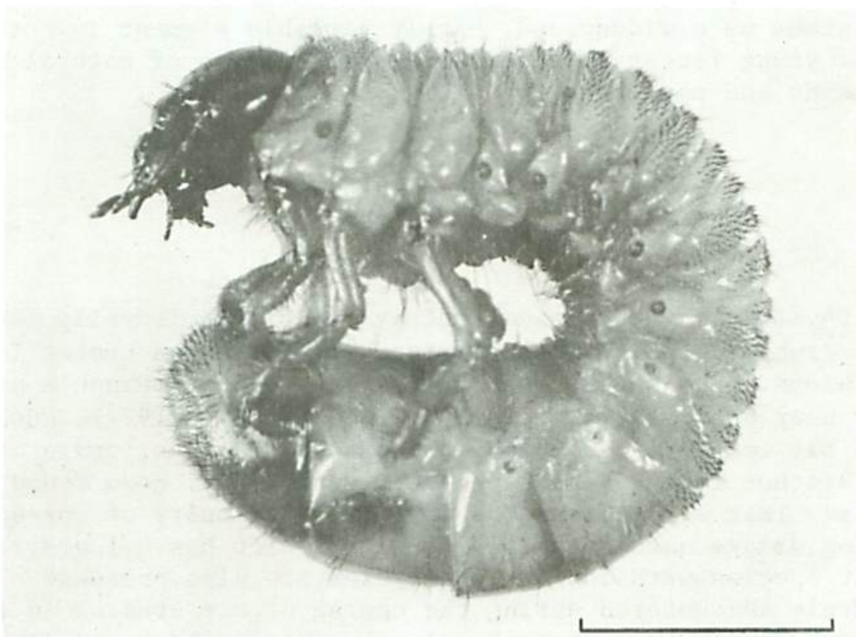

Figure 1. White grub, larva of *Phyllophaga* sp. (Ref. 9581, Can. Dep. Agric., Res. Branch, Bio-Graphic Unit.) Scale given by 1-cm bar.

Life cycle

The following is a generalized account of the life cycle, which is similar in the several species. Adult beetles (Fig. 2) emerge from

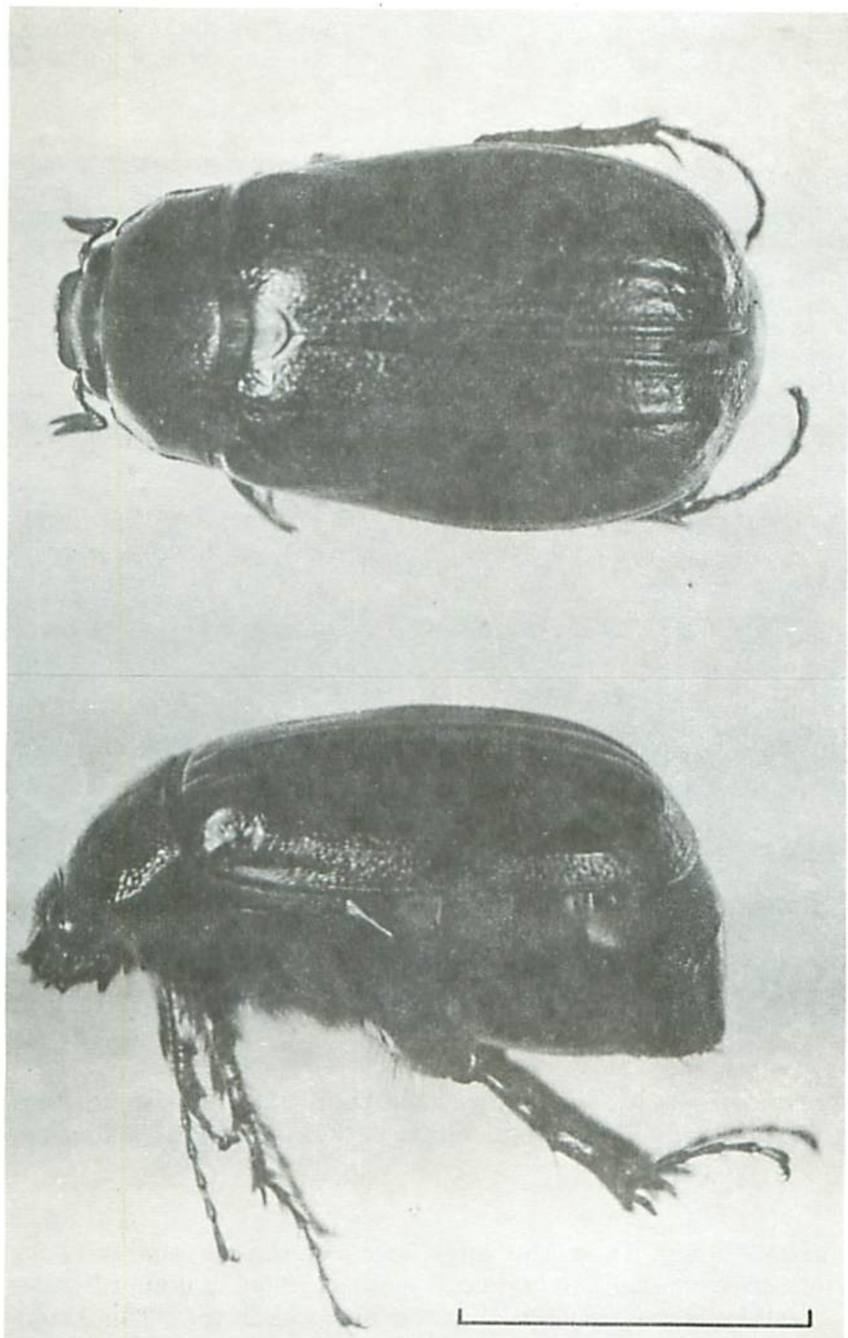

Figure 2. Adult *Phyllophaga* sp. (Ref. 16266, Can. Dep. Agric., Res. Branch, Bio-Graphic Unit.) Scale given by 1-cm bar.

the soil in spring or early summer. They fly at dusk to hardwood trees and feed on the foliage, where mating takes place. At or soon after dawn the beetles return to the soil. Flight is repeated daily for 2-3 weeks, and finally the females burrow into the soil to lay their eggs (Fig. 3).

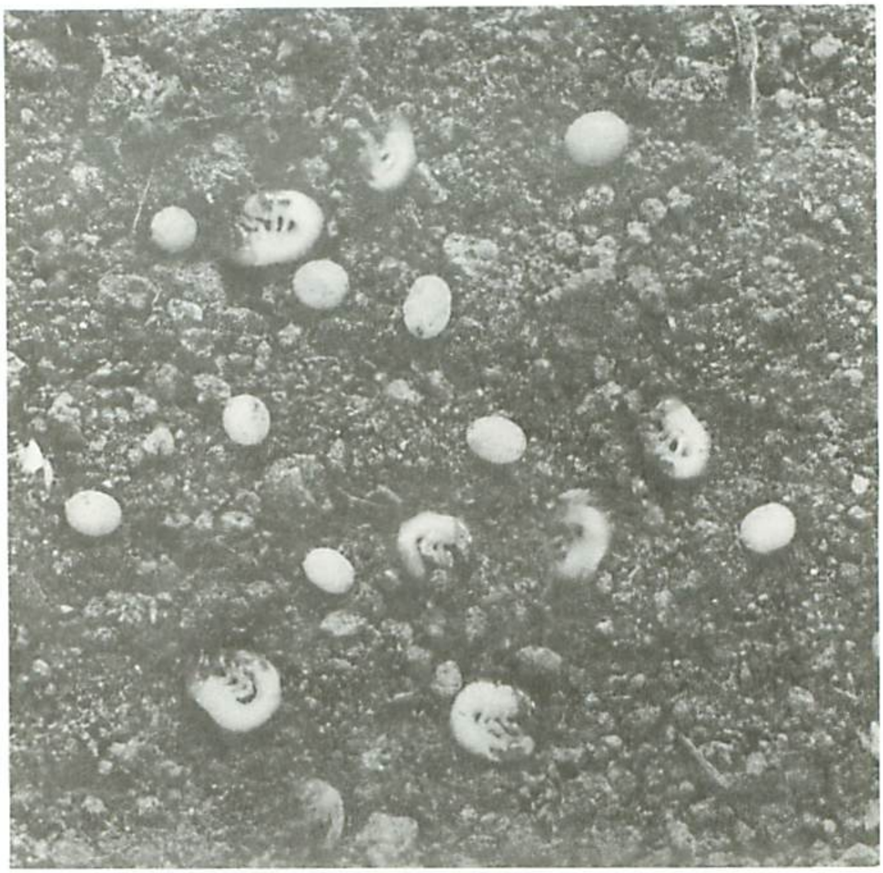

Figure 3. Eggs of *Phyllophaga* sp. together with newly hatched larvae. (Ref. 2373, Can. Dep. Agric., Res. Branch, Bio-Graphic Unit.) x3, linear

White grubs hatch from the eggs and remain in the soil, growing larger at each instar stage for up to 5 years, the length of time depending on species and to some extent climate and weather. The grubs move through the soil in response to gradients of moisture and temperature and, according to Klingler (1958), also move along positive carbon dioxide gradients towards respiring roots. Fully developed grubs pupate (Fig. 4) in the soil in midsummer and are transformed into teneral adults about a month later. The adults overwinter in the soil and emerge in spring or early summer to repeat the cycle. In Ontario, flights of adult beetles begin as the new leaves of aspen (*Populus tremuloides* Michx.) are flushing.

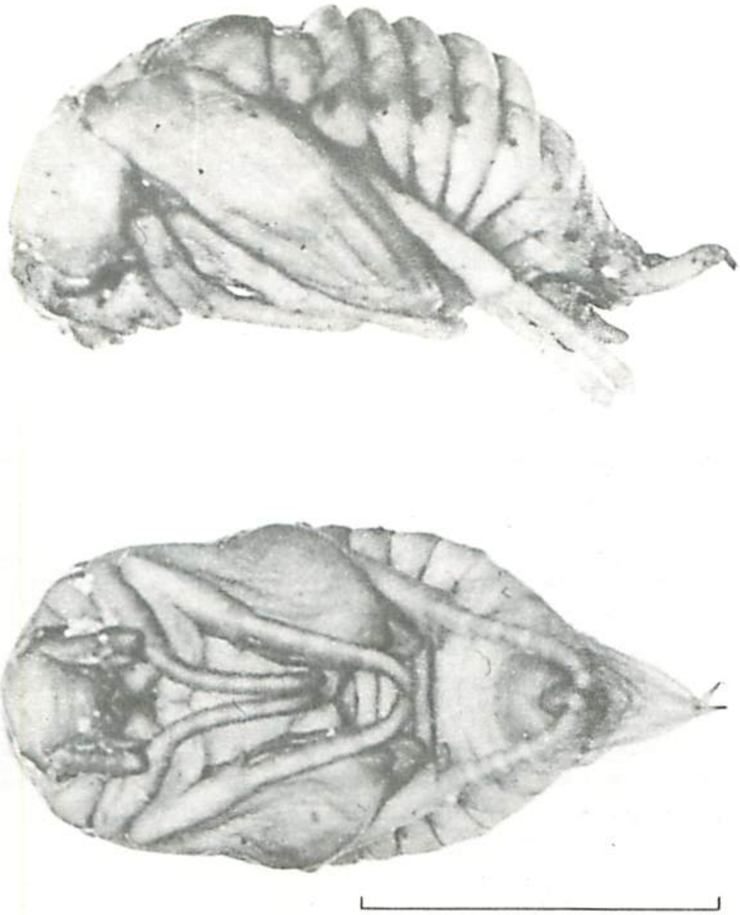

Figure 4. Pupa of *Phyllophaga* sp. (Ref. 2596, Can. Dep. Agric., Res. Branch, Bio-Graphic Unit.) Scale given by 1-cm bar.

The general opinion, as expressed by Allan (1963?), is that upon leaving the trees on which they have been feeding and mating the adult females soon after dawn "seek out" grassy or weedy places on the ground for their egg laying. But Sweetman (1927) maintained that "May beetles do not select places for oviposition according to the vegetational covering but fly at random from the food plants". Guppy[2] also affirmed that the beetles descend from trees to soil at dawn by a short, direct flight that bears no characteristics of a search, although evening flights of older beetles are commonly directed towards open fields.

The female lays a few pearly white eggs after burrowing into the soil to depths of 5-15 cm. (NOTE: Basic conversion factors for all measurements used in this report are given in the Appendix.) The egg-laying activity of a beetle may occur over a period of weeks, but repeated fertilizations may be necessary (Forbes 1907). The egg, at first ovoid and about 2.5 mm long, later becomes spherical and cream-coloured (Speers and Schmiege 1961).

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[2] J.C. Guppy, Research Scientist, Canada Department of Agriculture, Entomology Research Institute, Ottawa, personal communication.

Phyllophaga larvae are approximately 3 mm long when they hatch, about a month after the eggs are laid. The mature larvae are usually 3-4 cm long and strongly curved.

The pupa somewhat resembles the adult beetle in appearance and size, but of course it does not feed. It darkens from yellowish to light brown during its month-long development into the adult.

Except for the few species (e.g., *Amphimallon majalis*, but no *Phyllophaga*) with a 1-year life cycle, different stages of the insect may be present in the soil at any given time. If only one brood (let us call it brood "A") is present and the common 3-year cycle proceeds normally, eggs are laid every 3 years to initiate the next cycle of the brood. However, the same species may also be present as brood "B", with its egg laying taking place every third year, 1 year behind brood "A". Similarly, brood "C" may be present. If two or more broods are present, the population will consist of broods at different stages of development. Successive cycles of a brood sometimes build up to epidemic proportions causing severe damage every third year when the second-year grubs feed voraciously. Such damage may recur regularly over a long period; but sometimes a grub population "crashes", i.e., suffers unusually high mortality, and the expected damage fails to materialize.

Distribution

White grubs are found in every Canadian province and in much of the nonarid United States. Although they are of economic importance chiefly in Ontario and Quebec, they have caused considerable damage in pine plantations in Manitoba (Warren and Hildahl 1963, Ives and Warren 1965). The literature emphasizes the association of grubs with sandy and sandy loam soils, but severe damage can occur on loams and silt loams. White grubs are seldom, if ever, considered a problem in heavy clay soils, wet bottomlands, and muck. Nevertheless, they do occur in soils as heavy as the Rideau clays of the Ottawa area, often at about the same density as on neighbouring sands and loams. Different species of white grubs probably prefer or require different soil conditions, but much more needs to be learned in this regard. Damage is probably influenced less by soil texture itself than by factors (such as soil fertility, soil moisture supply, and rooting depth) that regulate both the food supply available to the grubs and the capacity of the damaged plants to survive and outgrow damage.

Injury by grubs is chiefly a problem of land that has been under sod for 2 years or more (Hammond 1960). Grub populations tend to build up on open land that has not been managed for a year or more (Stoeckeler and Jones 1957, Speers and Schmiege 1961). Fields covered almost entirely with goldenrod (*Solidago* L. spp.) or dicotyledonous weeds usually carry much lower populations of white grubs than does grassland (Stone and Schwardt 1943). Following heavy damage, sod is relatively free from attack for a few years, presumably because sparse sod cover does not invite oviposition (Stone and Schwardt 1943), or because grub mortality is high. Sweetman (1927) and Fluke et al. (1932) have claimed that some rich pastures have such a thick root mat that burrowing by adult beetles, and therefore oviposition, are reduced or prevented. Brushy areas are probably the least susceptible to injury, but grassy glades in stands of aspen may carry high populations.

Population density

The population density of grubs in soil varies greatly. Even when no damage is perceived, it is common to find 5 or 6 grubs/m^2. Haig[3], in the course of ploughing for forest planting in Manitoba, estimated that at least one grub per lineal foot was exposed, indicating far greater numbers within the furrow slice. At peak populations, densities have been found (cf. Davis 1918) to exceed 132 grubs/m^2, i.e., more than 1.3 million grubs/ha. If it is assumed that the weight of a grub is 0.78 g, the latter density would give 1,032 kg/ha. The mean live and oven-dry weights of one sample of 10 third-instar larvae of *Phyllophaga fusca* were 0.78 g and 0.12 g, respectively. Chemical determinations of these larvae gave the following estimates of the concentrations of major nutrients: N = 8.5%; P = 0.2%; K = 2.8%; Ca = 0.4%; and Mg = 0.4%. The amount of root tissue consumed by populations of this magnitude is obviously large, and even if the nutrients are sidetracked only temporarily, the indirect effect on the nutrition of trees newly planted on infertile sites must be considerable, quite apart from the more obvious direct effects. In theory, at least, any trees that survive when surrounding sod is destroyed by white grub attack are likely thereafter to benefit from reduced competition, but no such instances have been found in the field.

Damage by white grubs is generally much more readily observable in pastures and agricultural crops than in forest land, and this provides the forester with a guide to population density fluctuations. This guide is especially useful in determining population peaks, the years in which they occur, and the extent of damage, all of which often go unperceived in adjacent reforested or naturally reverting lands.

The forester in charge of large-scale planting in areas likely to experience white grub problems will probably want to monitor population levels directly, in spite of the limitations of preplanting surveys outlined in the section entitled "Control".

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[3] R.A. Haig, Research Manager, Great Lakes Forest Research Centre, Sault Ste. Marie, Ontario, personal communication.

Feeding habits

(i) Adults

Adult beetles of the different species may differ in their food preferences, but aspen seems to be a preferred species, at least in Ontario. Butternut (*Juglans cinerea* L.), walnut (*J. nigra* L.), basswood (*Tilia americana* L.), ashes (*Fraxinus* L. spp.), and white oak (*Quercus alba* L.), are also highly palatable (Hammond 1948). Guppy[4] observed that, although beetles will feed on Manitoba maple (*Acer negundo* L.), they avoid sugar maple (*A. saccharum* Marsh.) and red maple (*A. rubrum* L.). He also observed that young leaves of white birch (*Betula papyrifera* Marsh.) may be unpalatable but older leaves are used for food. Adults of *Amphimallon majalis*, which have a 1-year life cycle, are believed not to feed at all.

(ii) Larvae

According to Speers and Schmiege (1961), a larva feeds initially on organic matter contained in a ball of soil with which, they say, the female envelops the egg. Guppy[5], however, has found no evidence in Ontario to support this view, and suggests that a larva simply feeds on organic matter fortuitously present. Thereafter the larvae eat roots or other underground parts of plants. In sod they feed at depths of 2-5 cm cutting off roots along a plane parallel to the soil surface (Fig. 5). Among trees, virtually all species planted in Canada are attacked, although not all are equally vulnerable (see page 12).

With the common eastern Canadian species, first-year grubs feed mainly on fine roots from July to September; second-year and third-year grubs cause most of the damage because of their larger appetites. It is generally assumed that the second-year larva is the more damaging because, early in the third year, generally, the larva is transformed into the pupa which does not feed.

Factors affecting damage

As mentioned earlier, white grub damage in Ontario often reaches a peak at 3-year intervals. The amount of damage at peak times may vary quite widely. In many parts of Ontario and Quebec, including the Ottawa and Gatineau valleys, the second-year grubs of brood "A" have for many years caused severe damage every third year (e.g., in 1954 and 1957) (Hammond 1960). However, such clearly cyclic damage is by no means universal. The 3-year cycle, observed by Stone and Schwardt (1943) in New York State, was broken when the heavy damage expected in 1944 and 1947 did not materialize. The population had "crashed". The

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[4] J.C. Guppy, Research Scientist, Canada Department of Agriculture, Entomology Research Institute, Ottawa, personal communication.

[5] ibid.

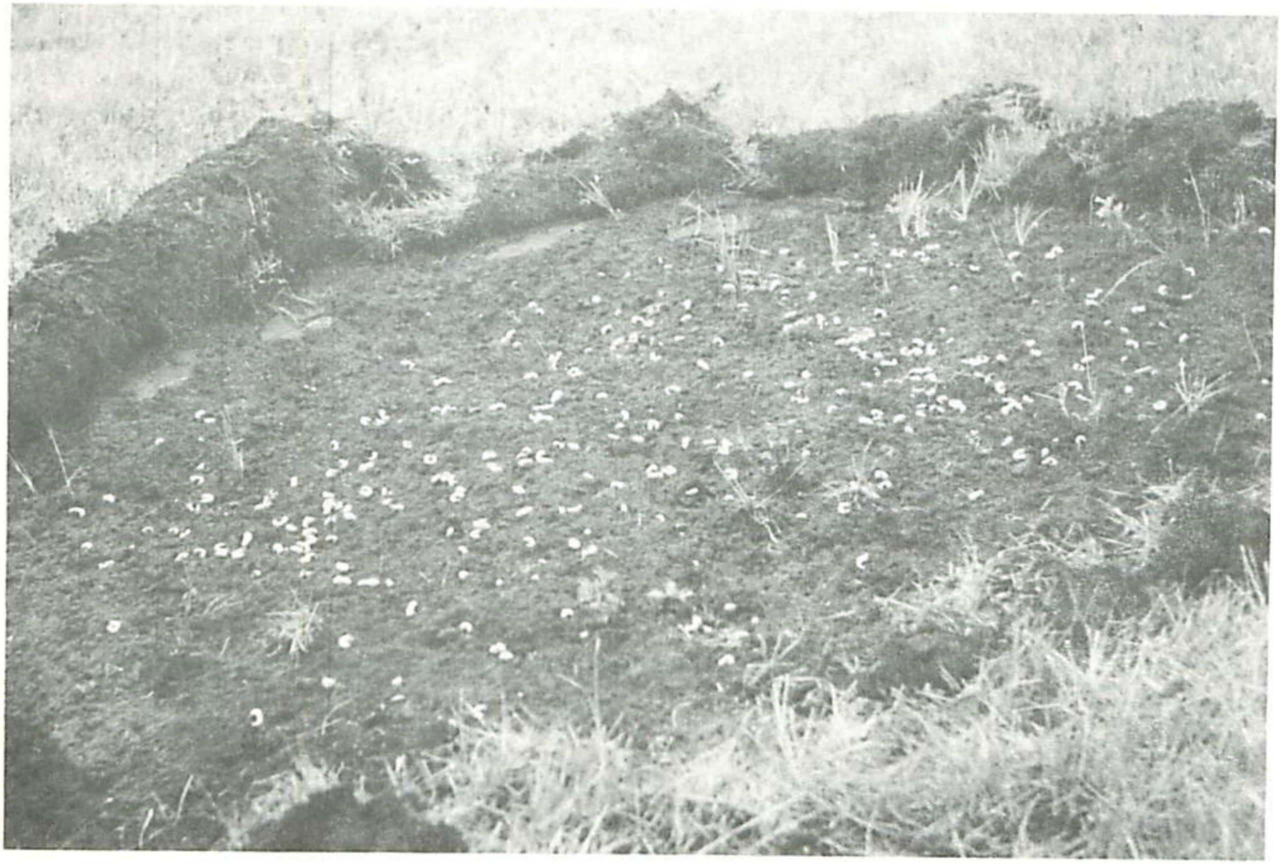

Figure 5. Grass sod rolled back after destruction of roots by white grubs. The population density here was about $85/m^2$. (Ref. 20213, Can. Dep. Agric., Res. Branch, Bio-Graphic Unit.)

other main interference with clear perception of cyclic damage is the presence of more than one brood. For example, severe damage occurred in 1954, 1956, 1957, and 1959 in a narrow strip along Lake Ontario from Oshawa to Burlington and in the Niagara Peninsula (Hammond 1960), and this suggests that two broods were present at high densities.

Damage increases, or at least becomes more apparent, in dry years (Argetsinger et al., 1955). Experiments by Graber et al. (1931) in Wisconsin demonstrated that a moisture deficiency greatly intensified injury to bluegrass (*Poa pratensis* L.) sod especially where soil fertility was low and alternative organic food was limited.

Reduction of food supply, e.g., by scalping, can also concentrate damage on any trees planted in the bare areas. Shirley (1945) reported greater losses from white grub attack among trees planted in scalped spots than among control trees, in spite of the reduced competition from vegetation in the scalped areas.

Fowler (1969) found that curvilinear regressions explained more variation than did linear regressions when "damage index" (R^2= .66 *vs.* r^2 = .51) and "percentage of trees damaged" (R^2 = .65 *vs.* r^2 = .45) were plotted against "*Phyllophaga* larvae per cubic foot of soil" in young red pine plantations (n = 16) in Upper Michigan and northern Wisconsin. The curvilinear relationships showed that damage increased rapidly with increasing population level at the outset but reached a maximum at about 1.3 larvae per cubic foot of soil, when about 63 per cent of the trees were damaged. There seems to be no reason that damage would not continue to increase with increasing population densities; however, more samples at the higher densities would be needed to settle the question. Also, it may be less revealing to express density in "larvae per cubic foot" than in "larvae per unit area".

Soil depth and the overwintering of white grubs

The literature affirms repeatedly that white grubs descend in the soil to pass the winter below the frost level: "It is a well-known fact that [white grubs] go deep in the soil in the fall, returning to the upper layer...in the spring" (McColloch and Hayes 1923); grubs hibernate in the soil during the winter "at depths determined by temperatures and frost levels" (Speers and Schmiege 1961); grubs "move down to the subsoil" to hibernate (Hammond 1960); grubs go "deep into the soil" in the fall (Allan 1963?); grubs "go down as a protection against the approaching winter's cold, and [in Illinois] may reach a depth of two to two and a half feet" (Forbes 1907); grubs [in Iowa] pass the winter "below the frost line, from four to six feet below the surface" (Ball and Walter 1919). According to Criddle (1918), in Manitoba white grubs winter in soil at depths that vary with species and soil moisture: "...thus the average depth at which the larva of [*Phyllophaga*] *anxia* hibernates is forty-four inches in dryish woods and from fourteen to twenty-five inches in wet situations. The average depth of [*P.*] *nitida* is thirty-four inches, [*P.*] *rugosa* seventy-four inches, and [*P.*] *drakii* about forty inches." In one study in western Quebec, Guppy[6] found that most of the white grubs present, all of which were either *Phyllophaga fusca* or *P. anxia*, moved down in winter to the 25- to 45-cm depth in deep sandy loam soil.

How, then, do the young grubs escape frost on shallow-to-bedrock soils? It is often supposed that the grubs migrate down cracks and fissures in the bedrock. Some strata are well jointed, but the rather extensive, smooth and unbroken surface of the bedrock in exposures of

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6 op. cit.

some flat-lying limestones and sandstones (e.g., in eastern Ontario) suggests that the grubs would often have to travel many metres before reaching any sort of fissure. Nevertheless, high populations of grubs do occur in these soils, as indeed would be expected from the nature of the ground vegetation and general occurrence of small stands of aspen and other hardwoods. Inasmuch as many areas of such soils are being reforested, it is of some importance to know the limitation that overwintering may impose on grub populations.

In studies reported more fully elsewhere (Sutton and Stone, unpublished), white grubs of *Phyllophaga fusca* (the only species tested) successfully overwintered in cages within 10 cm of the surface of an Uplands sand in Ottawa's Green Belt. The depth of soil freezing was not ascertained here, but at the nearby Central Experimental Farm soil temperatures at a depth of 10 cm, under snow cover, reached a minimum of 23°F during the winter. White grubs of several species had earlier overwintered within 30 cm of the soil surface, again at undetermined soil temperatures.

Numerous other observations indicate that dense fragipans and temporary water tables above them, or even true groundwater tables, like impermeable bedrock at shallow depths, do *not* prevent successful overwintering of high grub populations in many years.

The depth to which soil freezes in eastern Canada in winter varies greatly. In the Ottawa area, soil under snow cover quite commonly remains unfrozen throughout the winter[7]. However, deep penetration may occur as in the winter of 1971-1972 when soil under snow froze to a depth of more than 50 cm. The role of soil freezing may well be important in determining the level of overwinter mortality among white grubs. Although it cannot be substantiated from the evidence reported here, the "crash" of a large population of white grubs may be associated with particularly low soil temperatures and the depression of grub body temperature to the supercooling point. But perhaps, in addition to the degree of temperature depression, the rate of cooling, duration of low temperatures, and rate of warming all influence what happens to the white grub population.

SILVICULTURAL IMPORTANCE

Adult beetles

The damage done by adult beetles in feeding on the foliage of hardwood trees is of little or no silvicultural importance; it is transitory and is often concentrated in unmerchantable trees.

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[7] S. Edey, Head, Climatology Section, Research Branch, Plant Research Institute, Canada Department of Agriculture, Ottawa, personal communication.

White grubs

Damage to root systems by white grubs has consequences that are important ecologically and silviculturally. One kind of effect, the death of crop trees, is well known to foresters both in nurseries and in young plantations. Other effects, such as changes in the course of ecological succession, and growth retardation of crop trees, have largely escaped notice. These effects will now be discussed.

(i) Death of crop trees

In the past, mortality among trees in forest nurseries has on occasion been very high. For more than 60 years the white grub has been recognized as a problem in forest nurseries. Toumey and Korstian (1942), writing before the rise of synthetic insecticides, regarded white grubs as the most destructive of all soil-inhabiting insects in nurseries. No tree species grown in eastern Canada or in the northeastern or north-central United States is immune. However, the damage is localized and is now controllable.

It was not until the early 1940s that the danger to forest plantations was recognized (Speers and Schmiege 1961). Since then, reports of damage have largely concerned pines (e.g., Stone and Schwardt 1943, Watts and Hatcher 1954, Shenefelt et al. 1961, Cayford and Haig 1964, Ives and Warren 1965, Fowler 1969). Heavy mortality among trees of other genera, e.g., Japanese larch (*Larix leptolepis* [Sieb. & Zucc.] Gord.) (Stone and Schwardt 1943) and white spruce (*Picea glauca* [Moench] Voss)[8], is not unknown but it is relatively rare.

No doubt some of this differential derives from the vulnerability of taproot systems to heavy damage (Fig. 6) once they have been located by a grub. Some derives, as well, from the common choice of pines for planting on abandoned farmland with light-textured soils that are likely to be grub infested. But differential in the susceptibility of species also plays an important part in determining levels of mortality. Sutton and Stone (unpublished) have described how mortality among young white pines (*Pinus strobus* L.) exceeded 50 per cent after heavy attack by white grubs in eastern Ontario while virtually all of the interplanted white spruce survived.

Sutton and Stone (unpublished) also reported another instance in which many white pine were dead in areas where interplanted white spruce showed little or no mortality. Here there was clear evidence of root damage to both the white pine and the white spruce. However, whereas the root systems of the pine had received massive damage, those of the

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8 R.A. Haig, Research Manager, Great Lakes Forest Research Centre, Sault Ste. Marie, Ontario, personal communication.

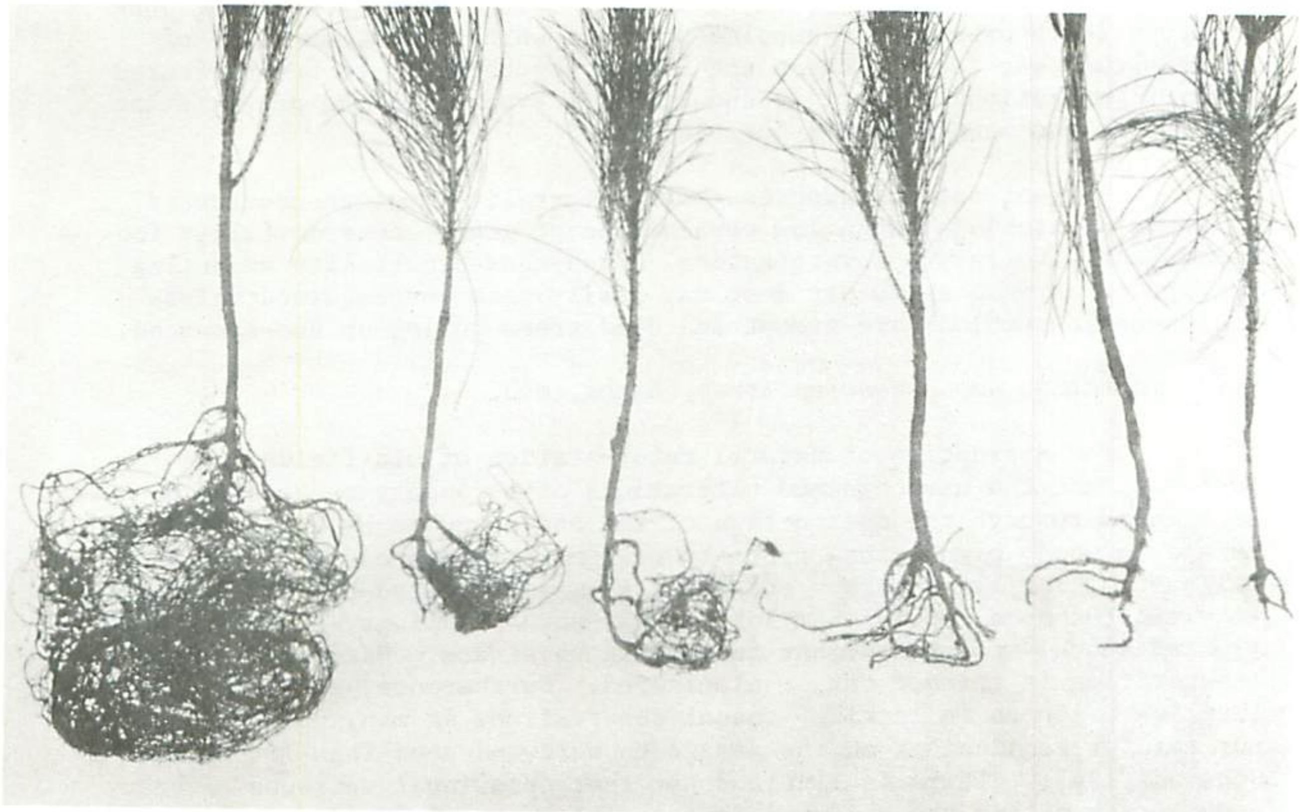

Figure 6. Degrees of root system damage in red pine. (Ref. 662547, Can. Dep. Agric., Res. Branch, Bio-Graphic Unit.)

spruce displayed no such marked damage; instead they showed regeneration of lateral roots of small diameter at many points where they had been severed, presumably by grubs. The main roots of the spruce bore no sign of girdling, complete or partial. We concluded that although trees of both species were subject to damage, only in the pine was damage massive and attended by high mortality.

This superior survival of white spruce in the field almost certainly relates to palatability factors. The grubs often strip the pine roots almost to the soil surface, completely consuming the softer tissues. In contrast, medium- and small-sized roots of white spruce seem merely to be clipped, leaving the stubs to regenerate. Differential resistance of white spruce has not been noted in nursery beds, but the effect here may be obscured by such factors as small size of seedlings attacked, and absence of other food over relatively large areas.

In eastern Ontario, in field soils with rather low larval populations (both natural and supplemented) of white grubs, survival of white spruce was found (Sutton and Stone, unpublished) to be unaffected by grub populations of 3, 6.6, and $10.3/m^2$, even where the pre-existing vegetation had been killed by herbicides.

A great deal of noncatastrophic mortality must go undetected in young plantations, when low populations of grubs cause mortality too sporadically to invite investigation. Grub-caused mortality amounting perhaps to as much as 30 per cent may easily pass unrecognized unless follow-up inspections are prompt and dead trees pulled up and examined.

(ii) Mortality among noncrop trees, herbs, etc.

The disruption of natural reforestation of old fields and pastures, and the unrecognized alterations of secondary succession on such lands through the destruction of the sod cover or by species-specific damage to woody plants, are probably much more widespread than hitherto believed. Even large shrubs and saplings may be killed by massive root girdling (Hammond 1960). Similarly, self-sown seedlings, no less than planted stock, are susceptible to white grub attack. Natural coniferous regeneration is thinned out or eliminated. Furthermore, although quantitative evidence is lacking, casual observations at many points reinforce our earlier conclusions on the damage to hardwood seedlings (Stone and Schwardt 1943). There is little doubt that occasional episodes of heavy grub attack retard the hardwood invasion of many old fields. Differences in palatability presumably occur (cf. Davis 1918) but have not been determined. Woody species able to resprout from the root, such as aspen, choke cherry (*Prunus virginiana* L.), pin cherry (*P. pensylvanica* L.f.), and the shrub dogwoods (*Cornus* L. spp.) may survive in spite of severe injury and then find themselves with little competition. Again, heavy populations of grubs drastically reduce the dominance of perennial grasses such as some *Poa, Festuca, Phleum* and *Dactylis* species, and almost certainly favour the establishment or spread of other species.

Thus it seems evident that the rate of successional change, if not its direction, and the strength, if not the nature, of competition can be influenced drastically by white grubs.

(iii) Growth retardation

The impact of grub damage is commonly considered solely in terms of survival. This may be an adequate measure for some species but certainly not for white spruce. Even after severe injury to roots, mortality may be so slight that grub activity is unsuspected, yet reduced uptake of water and nutrients retards height growth and impairs the efficiency of foliage. Deterioration among newly planted stock may depress growth for many years. The effects of white grub activity may intensify, prolong, or simulate the condition of "check", notably so on soils of low fertility or in years of subnormal rainfall. As well, some degree of such injury to larger trees probably goes undetected although it appreciably affects the rate of canopy closure.

Evidence for growth retardation of white spruce comes from our observations in eastern Ontario of white pine and white spruce intermixed in a young plantation (Sutton and Stone, unpublished). Here on a level and rather uniform sandy site we found the height increment of the spruce to be significantly correlated with white pine survival. Over all, spruce height increment decreased to about 87% in the year following white grub attack, but in local areas little affected by grubs there was an increase in spruce height increment of 62% over the previous year. The results were expressed by the linear regression:

$$Y = 159.3 - 4.5\ X \qquad (r^2 = .92^*)$$

where Y is the height increment of 4-year-old white spruce as a percentage of height increment in the previous grub-attack year, and X is the percentage mortality of the interplanted 2-year-old white pine. The evidence is circumstantial but strong. It warrants the inference that white grubs may have a large impact on the height increment of young white spruce and hence also on the length of time taken to overtop competing vegetation.

CONTROL

Protracted drought causes heavy mortality of white grubs, especially among newly hatched larvae (Speers and Schmiege 1961). Natural, living enemies do not effectively control populations of white grubs, except for certain parasites (cf. Criddle 1918) and skunks which may root out large numbers locally. Pigs have given excellent control in agricultural situations (cf. Davis 1918), but their use in the forest is seldom practical. On ploughed land, poultry has given good control (cf. Davis 1918), but again the method is unsuited to forest situations. Mechanical and chemical measures used effectively in nurseries (cf. Toumey and Korstian 1942) are not appropriate for forest plantations.

Injury to new plantations can be reduced by two means, avoidance and direct control. When preplanting surveys reveal population densities of 10-20/m^2 or more, planting should be postponed unless chemical treatments are planned. Rudolf (1950) noted that high mortality among young pine in the Lake States occurs when population densities exceed 20/m^2. Shenefelt et al. (1954) set the lower limit for successful planting of red pine (*Pinus resinosa* Ait.) in sandy soils in Wisconsin at 5 grubs/m^2, unless chemical protection is given. With white spruce in our study, however, a population density of $10/m^2$ resulted in no apparent damage even when other vegetation was eliminated.

Prediction from preplanting surveys is useful for only the following year or two, and this is by no means sufficient for seedlings to escape damage if heavy populations subsequently develop. Although white spruce is more resistant to outright mortality than are red pine and white pine, the suitability to the permanent site features rather than the immediate hazard from white grubs should determine the choice of species. Accordingly, routine treatment with an insecticide appears to be worthwhile for all species planted in areas of high risk. White grubs are readily controlled by any one of several chlorinated hydrocarbons such as aldrin and chlordane.

Until aldrin was banned a few years ago in Ontario and elsewhere, its use in the treatment of new plantings had become almost standard practice: 0.5 - 1.0 per cent aldrin solution applied to the root systems of stock at planting gave good results (Speers and Schmiege 1961, Shenefelt et al. 1961). A treatment that gave satisfactory results in the Ottawa area was that of spraying the area to be protected around each tree with 2.5-3.0 oz of a solution made by diluting 1 oz of liquid aldrin concentrate with 1 gal of water, giving about 80 lb of aldrin per acre of plantation. Granular or dust forms of aldrin broadcast, and wettable powders or emulsible concentrates mixed with water, seemed to be equally effective.

In passing, it might be noted that 2 per cent aldrin emulsion produced no phytotoxic effects in red pine and jack pine (*Pinus banksiana* Lamb.) when applied (at 0.2 kg per 1000 trees) beneath seedlings at the time of planting with the Lowther tree planter (Ives and Warren 1964). Nevertheless, Nairn and Ives (1968) later showed that both aldrin at the same rate per tree and the solvent (heavy aromatic naphtha) caused significantly greater mortality of red pine and jack pine seedlings when the roots were treated directly.

The ban in recent years in many places on the silvicultural use of aldrin derived from the pesticide's high mammalian toxicity and its ready conversion in soil to the persistent dieldrin.

The current status of aldrin in Canada is given by memoranda T62 (31/VIII/70) and R35 (10/VIII/73) issued by the Plant Products Division, Production and Marketing Branch, Canada Department of Agriculture. Use of aldrin in soil treatments and seed treatments is approved in several agricultural crops raised for human consumption, but there is no mention of silvicultural use. Aldrin is currently being re-evaluated.[9]

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9 J.R. Forget, Control Products Section, Plant Products Division, Production and Marketing Branch, Canada Department of Agriculture, Ottawa, Ontario, personal communication.

In the United States, an advisory committee recommended to the Environmental Protection Agency in 1972 that aldrin and dieldrin be allowed in certain cases "until they can safely and economically be replaced by nonpersistent pesticides" (Anon. 1972). Uses that were determined to be "valuable and not harmful" included direct application to the soil, seed treatments when the seed is labelled "not for food use," and dipping of plant roots or tops during transplantation.

Since 1968, the less effective but much safer (i.e., to man) chlordane, applied as a dust directly around the roots in the planting hole at 10-15 g of 25 per cent formulation per tree has been used in Ontario with seeming success. Chlordane is also available as wettable powder and emulsifiable concentrate.

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APPENDIX

Basic conversion factors are listed below for all measurements used in the text of this report.

1 millimetre	= .04 inches
1 centimetre	= .39 inches
1 metre	= 3.28 feet
1 hectare	= 2.47 acres
1 gram	= .04 ounces
1 kilogram	= 2.2 pounds
1 litre	= .22 gallons

^{o} Celsius = $9t/5 + 32^{o}$ Fahrenheit