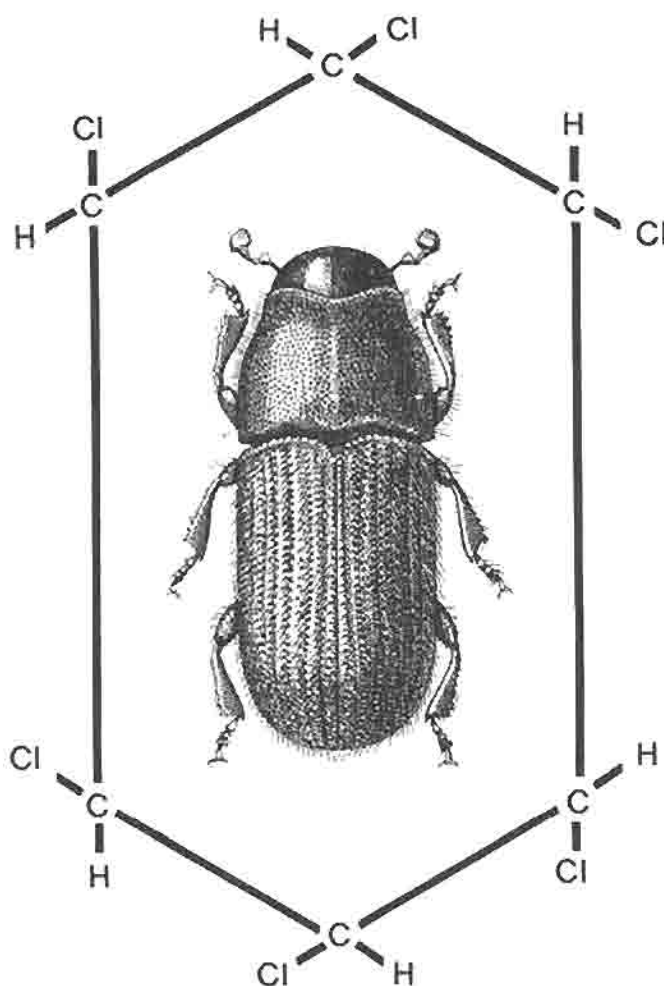


LINDANE IN FORESTRY... a continuing controversy

PACIFIC SOUTHWEST Forest and Range Experiment Station

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U.S. DEPARTMENT OF AGRICULTURE
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USDA FOREST SERVICE
GENERAL TECHNICAL
REPORT PSW-14 /1976



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Thomas W. Koerber, compiler

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Koerber, Thomas W., compiler.

1976. Lindane in forestry...a continuing controversy. USDA Forest Serv. Gen. Tech. Rep. PSW-14, 30 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Use of the chlorinated hydrocarbon insecticide lindane to control bark beetles is controversial. Differences of opinion persist, even among knowledgeable entomologists, on whether use is justified in view of potentially harmful side effects. Effectiveness of lindane treatments, as employed in preventing tree mortality from bark beetles, is also in question. In seven papers, relevant information from many sources is reviewed by investigators who hold divergent views. The papers present data on the biological characteristics of lindane, its persistence in the environment and effects on both target and nontarget organisms. The place of lindane in a spectrum of forest management alternatives is presented together with arguments both for and against its continued use.

Oxford: 453--145.7x19.92 Scolytidae--414.12 Lindane.

Retrieval Terms: Bark beetle control; lindane; cyclohexane, 1,2,3,4, 5,6-hexachloro-(benzene hexachloride)gamma isomer.

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PREFACE

The use of pesticides in resource management is a highly controversial issue. Arguments on the subject appear almost daily in technical journals, in the press, and in the proceedings of legislative bodies. Even well-informed persons do not agree on the best policy to follow. Meanwhile, pest management decisions are required on a day-to-day basis.

The use of chlorinated hydrocarbon pesticides, because of their persistence in the environment, has been particularly controversial. In November 1969, the Marak Commission on Pesticides and Their Relationship to Environmental Health recommended that the use of chlorinated hydrocarbon insecticides, including lindane,^{1/} be restricted to essential purposes and be replaced by safer alternatives whenever possible. The U. S. Department of Agriculture invited submission of views on the proposed restrictions (Federal Register, vol. 35, no. 148). Dr. Ralph C. Hall, then Chairman of the California Forest Pest Control Action Council^{2/} drafted a brief in support of continued use of lindane to control bark beetles in California forests. This statement was approved by the Executive Committee of the Council on October 22, 1970, and forwarded to the Director of the Pesticide Regulation Division of the Agricultural Research Service.

^{1/} The name "lindane" strictly denotes the gamma isomer of benzene hexachloride (BHC). As broadly used in this publication, "lindane" may refer either to the pure gamma isomer or to the gamma isomer content of a mixture of BHC isomers.

^{2/} The California Forest Pest Control Action Council was formed in 1951 in recognition of the need for close cooperation among land managers concerned with forest pest problems. Primarily an advisory and coordinating group, the Council sponsors a Statewide cooperative forest pest detection survey; publishes an annual report of forest pest conditions; studies, endorses, and supports desirable pest control actions; reviews control needs and programs; and provides a forum for the exchange of pest control information. The California State Board of Forestry has designated the Council as its official advisory group for forest insect, disease, and animal problems.

When the Insect Committee of the Council next met on November 18, some members objected to the content of the brief, and to the lack of consultation with the Insect Committee in its preparation. A resolution stating that the Insect Committee was not in support of the Executive Committee was passed and presented at the meeting of the full Council the following day. The resolution was tabled by the full Council on the grounds that too little time was available to discuss the issue properly.

A special meeting of the Insect Committee was held on February 3, 1971, to discuss the issue. Reports presenting both sides of the controversy and bringing together relevant information from scattered sources had been prepared by members of the Insect Committee. These reports were distributed to the members before the meeting so that those participating in the discussion were well informed on both sides of the issue and prepared to question or defend specific points of fact or opinion.

After a full day of discussion, the proposed resolution denying support to the recommendation of continued use of lindane was defeated by a vote of 21-20. An alternative resolution recommending the continued registration of lindane for control of bark beetles, wood borers, powder post beetles, ambrosia beetles, and termites, when noninsecticidal alternatives for control are not suitable, was then passed by a vote of 21-18. The full Council approved this resolution at its next regular meeting, November 1971.

In response to these proceedings, comprehensive tests were made to find alternatives for lindane against western bark beetles. The results, now in manuscript form, show that Dursban and Sevin are effective, though generally not comparable to lindane, in preventing attacks, and could be considered for use under certain conditions. Registration of these chemicals for use against bark beetles is expected in the near future.

The continuing demand for the reports prepared for the February 1971 Insect Committee meeting has prompted their publication here. They served as the basis of another brief supporting continued registration of lindane (submitted by the Council to the U. S. Environmental

Protection Agency in May 1972) and a minority report opposing continued use of lindane (submitted in February 1974). As of the date of this publication, lindane registration remains in effect.

This account of the Council's role in the lindane controversy is necessarily brief. Considerable interest has been shown in the process by which the Council handled the controversy. Therefore, details of the discussions, including copies of the various briefs, resolu-

tions, and minutes of the meetings, are available on request to the Project Leader, Forest Insect Research, Pacific Southwest Forest and Range Experiment Station, P. O. Box 245, Berkeley, CA 94701.

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Biological Characteristics of Lindane

Thomas W. Koerber

Abstract--Lindane is an effective insecticide against bark beetles. It is equally toxic to nontarget insects but much less toxic to mammals, birds, and plants. It is moderately stable in soil and bark, but animals and bacteria rapidly metabolize it to nontoxic products, thus preventing significant concentration in living animals and movement in food chains.

The biological properties of a chemical determine how it will affect the organisms that contact it, and how it will behave in the ecosystem. The differences in biological properties between chemicals dictate the differences in their behavior as toxicants and as environmental pollutants.

I consider the properties of an ideal insecticide to be these:

It must be highly effective against the target organism, so that a small dose will produce the desired effect.

It should be nonpersistent under field conditions, rapidly decomposing to nontoxic materials, unless persistence is required to meet the objectives of its use.

It should be immobile, not easily exported from the place of application either by physical means or in food chains.

It should be reasonably safe and not unpleasant to handle.

It should have solubility and stability characteristics that do not require exotic solvents, adjuvants, special mixing or application equipment, or special storage conditions.

Let us consider lindane in relation to the ideal insecticide.

Effectiveness--Lindane's toxicity to various bark beetles has been investigated in laboratory studies by Lyon (1959). He reported contact LD_{50} values of 7.3 mg/kg for *Dendroctonus ponderosae* (monticolae) Hopk., and 0.63 mg/kg for *Scolytus ventralis* Lec. In this series of tests, endrin and dieldrin were somewhat more toxic and DDT much less toxic to *D. brevicornis* Lec. In more recent tests (Lyon

1971), lindane had an LD_{50} of 0.32 mg/kg for *Ips paraconfusus* Lanier. Several materials, including Zectran, Dichlorovos, Enosulfan, and malathion were as toxic or more toxic than lindane when applied topically to *D. brevicornis*. Lindane is equally effective against other insects. Reported LD_{50} values for various species are in the range of 2 to 5 mg/kg (O'Brien 1967).

Nontarget toxicity--The contact toxicity to rats (LD_{50}) is reported to be 900 to 1000 mg/kg, and the acute oral LD_{50} is 88 to 91 mg/kg. Rats fed on a diet containing 10 p.p.m. for 12 months suffered no ill effects (Martin 1968). The acute oral LD_{50} for ducks is reported to be greater than 2000 mg/kg (Tucker and Crabtree 1970), suggesting that lindane is less toxic to birds than mammals.

Upon entrance into an animal body, lindane is distributed to various organs and tissues. It has been found in the blood, liver, spleen, adrenal glands, muscle tissues, brain, kidneys, and fat of treated animals. Storage is greatest in fat, although it is also deposited in the liver and kidneys. Lindane is deposited in tissue lipids at the same concentration as contained in the diet (Counc. Pharm. Chem. AMA 1951).

Menzie (1966) summarizes the available data (much of it in foreign languages) on the metabolism of lindane in animals. There is substantial agreement that lindane, given by several routes to various experimental animals, is broken down to trichlorophenols or 1,2,4-trichlorobenzene and excreted mainly in the urine. These compounds are nontoxic and water soluble. In several studies, experimental animals metabolized and excreted doses as high as 100 mg/kg in 2 to 3 weeks. Parke (1968) quotes a metabolism rate of 5 to 10 percent of the administered dose of lindane per day in rats.

Grover and Sims (1965) investigated the metabolism of lindane by administering 40-mg/kg doses of lindane to rats by intraperitoneal injection every other day. They found the lindane was metabolized to 2,3,5- and 2,4,5-trichlorophenol, which were excreted in the urine.

Because of its minimal storage in animal bodies and rapid elimination, lindane has not caused serious chronic toxicity problems in animals exposed to concentrations used in pest control operations. Rats fed on a diet containing 10 p.p.m. for a year suffered no ill effects (Martin 1968). However, the Council on Pharmacy and Chemistry, AMA (1951) reports liver degeneration and nutritional disturbances in dogs exposed over a long period of time.

Gakstatter and Weiss (1967) exposed four species of fish to water containing 0.03 p.p.m. lindane. Two days after termination of exposure, the fish had eliminated 90 percent of the lindane they had accumulated.

According to Sternberg and Kearns (1956), houseflies receiving sublethal doses of lindane metabolize it to pentachlorocyclohexene. The concentration of pentachlorocyclohexene rises for 2 hours after treatment, then levels off, indicating that it is being further metabolized. Grover and Sims (1965) suggest that lindane metabolism proceeds via pentachlorocyclohexene to trichlorophenols as it does in rats.

Lindane is also metabolized by at least two common bacteria (Allan 1955). The bacteria convert lindane to benzene, monochlorobenzene, and 1,2,3,5-tetrachlorobenzene.

Lindane is considered to be nonphytotoxic at insecticidal dose levels, but high concentrations interfere with germination, suppress growth, and reduce yields (Thomson 1967).

Persistence and stability--Lindane is much more stable in soil than in living animals. In a study in Wisconsin, Lichtenstein and Shultz (1959) applied lindane to a sandy loam soil at a rate of 100 pounds per acre. Three and one-half years later, they were able to recover 23.2 percent of the originally applied material. However, a bioassay showed only 10.7 percent of the original level of toxicity. They concluded that half of the material recovered was actually an inactive breakdown product of lindane. Lindane applied to ponderosa pine bark as a 2 percent oil solution remained effective against two species of *Dendroctonus* beetles for 3 years (Smith 1970), indicating the rate of breakdown and/or loss of lindane from bark is probably no faster than that reported for lindane in soil.

Handling safety and convenience--Lindane is a comparatively safe insecticide to handle. The Council on Pharmacy and Chemistry, AMA (1951) reports an estimated acute oral toxicity of 150 mg/kg for adult humans, (about 7½ grams for an average adult) based on results of attempted suicides and accidental ingestion. There is evidence that inhalation of lindane vapors from thermal vapor dispensers has caused a fatal blood disorder, aplastic anemia (Loge 1965). Workers in mixing and formulating operations where they were exposed to lindane dust suffered dermatitis and irritation of the upper respiratory tract, eyes, and skin (Council on Pharmacy and Chemistry, AMA 1951). There have been no reported problems with lindane as used in forestry. Normal safety procedures have been effective in protecting personnel applying lindane.

Lindane has a higher vapor pressure than the other chlorinated hydrocarbons, but normally it must be heated to release insecticidal concentrations in large volumes, as in a room. It is almost odorless.

Lindane is stable to air, light, heat, and carbon dioxide. It is not attacked by strong acids but is dehydrochlorinated by alkali. It is not corrosive to common packaging materials nor affected by them. Thus it can be stored for long periods in uncoated metal containers in ordinary warehouse facilities. It is soluble in water to the extent of 10 p.p.m., and readily soluble in acetone, aromatic, and chlorinated hydrocarbons (Martin 1968). It is easily formulated as oil-based solutions, water emulsions, and dusts.

Lindane is thus an effective insecticide against bark beetles, killing our common species at dose levels of 0.32 to 7.3 mg/kg. It is equally toxic to nontarget insects, but much less toxic to nontarget mammals, birds, and plants. It is nonpersistent *in vivo*. Insects, mammals, fish, and bacteria rapidly metabolize it to nontoxic products which are quickly excreted. It accumulates in fat at the level contained in the diet. The low accumulation potential, together with its rapid breakdown rate, would largely prevent it from moving in food chains or accumulating in top predators.

It is moderately stable in soil and bark but apparently resistant to removal from the site of application by physical factors. It is not especially hazardous or unpleasant to handle as used in bark beetle control, but may be a health hazard when dispensed by thermal vaporizers. Excellent solubility and stability characteristics permit easy formulation and storage.

As compared with the ideal insecticide for bark beetle control, lindane has two main flaws. It is not as selective as might be desired, killing other insects as readily as bark beetles; and it is more persistent in bark and soil than is strictly necessary. We partly compensate for the lack of selectivity by restricting application to portions of the bark of selected, individual trees. Nevertheless, the broad-spectrum activity of lindane means that parasites and predators in those trees are lost.

The quantity of lindane persisting in bark could easily be reduced. The data showing that lindane treatments are still effective 3 years after application strongly suggest that we are supplying more lindane than is necessary to control beetles emerging from infested logs. What is needed is perhaps 6 months of effectiveness, rather than 3 years. Surely some more dilute solution of lindane can be found to have that period of effectiveness and save money as well.

Lindane is probably not the best insecticide presently available for bark beetles. Several other insecticides, among them malathion, are more toxic to bark beetles than lindane (Lyon 1971). However, I feel that we should not immediately substitute some other insecticide. Candidate replacements for lindane must first be field-tested. They should also be judged by the standard of the ideal insecticide. Lindane, though certainly not ideal, has some excellent properties of safety and biodegradability. Any material considered to replace it should possess these properties and, in addition, have fewer flaws. There is little point in trading one set of undesirable properties for another.

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Lindane Residues in the Environment

George T. Ferrell

Abstract --Lindane residues have been found at low levels in a variety of crops, animals, soils, and waters in the United States, indicating that widespread contamination exists. Lethal or sublethal effects on wildlife have not been found and magnification in food chains has been minimal, probably because of lindane's relatively rapid breakdown and low tendency to be stored in fat in living organisms. Lindane is persistent in certain soils, however, and is relatively volatile and water-soluble. Heavy applications on a broad scale could result in severe environmental contamination.

Lindane (gamma benzene hexachloride) is a broad-spectrum insecticide used internationally to protect apples and other fruits; beans, peas, cole crops, cucurbits, tomatoes, and other vegetables; rice and other cereals; seeds; livestock; households; and logs and lumber. Lindane production in the United States is substantial; it amounted to 7.7, 3.4, and 1.8 million pounds in 1961, 1962, and 1963, respectively (U. S. Dep. Health, Educ. and Welfare 1969). Large amounts are also produced in Europe (statistics unavailable). Primary dependence is placed on benzene hexachloride for insect control on fruit in Japan, India, and Algeria; rice in Asia and South America; cereals in India, United Kingdom, Mexico, Africa, and Turkey; vegetables in India, Japan, Mexico, and Spain; sugar beets in Italy and Turkey; sugarcane in Mexico, Australia, India, and Brazil; and oil seeds (i.e., sesame, soybeans) in India and Japan.

The distribution, concentration, and sublethal effects of persistent organochlorine pesticides in global air, soil, water, and life is of widespread concern. These residues are difficult to identify by gas-liquid chromatography (GLC), the usual method, as many pollutants (including nonpesticides like polychlorinated biphenyls, used as plasticizers) have similar retention times. Confirmation of lindane's identity by mass spectrometry is desirable but may not have been a part of all studies cited in this paper. A degree of skepticism regarding these residue reports is therefore justified. This paper is a brief review of present knowledge of the fate and effects of lindane residues.

AIR

The presence of pesticides in air is a function of their chemical nature, their physical state, the method of application used, and the atmospheric conditions during and after application. Pesticides may be lost from air by gravitational fallout, rain washout, and degradation by sunlight and chemical reactions.

Lindane in small droplets or thin films is about four times more volatile than DDT (Quraishi 1970); its vapor pressure is about 60 times that of DDT (Frear 1955). Organochlorine pesticides have had wide distribution in the global air system and have been detected even in the mid-Atlantic air (Risebrough and others 1968). Rainwater collected over a 12-month period at seven widely distributed sites in England always contained traces of lindane (Tarrant and Tatton 1968), as did 34 of 90 rainwater samples from three sites in Ohio (Cohen and Pinkerton 1966). The persistence of lindane in the atmosphere is not known, but small particles (theoretically including lindane as small crystals adhering to dust particles or water droplets) spend about 30 days in the atmosphere before being washed out by rain, whereas vapors generally stay aloft about 2 to 4 months (Newell 1971).

WATER

Lindane's water solubility is about 10 p.p.m., or about 50,000 times that of DDT (Frear 1955). Pesticide monitoring of 20 rivers in western North America, during 1965-66 (Brown and Niskiocka 1967), showed lindane to be the most

frequently encountered pesticide (46 of 165 positive samples) but in 1967-68 it was much less frequently encountered and spotty in distribution (Manigold and Schulze 1969), occurring in 10 samples in four rivers. Data on contamination of ground water were not available. The average concentration of lindane at the intakes from Lake Michigan to two Chicago filtration plants in April 1969 was 0.015 p/b, while DDT averaged 0.42 p/b (U. S. Dep. Health, Educ. and Welfare 1969). A sampling of many California bays and estuaries for organochlorines only infrequently found lindane contamination (Modin 1969). Data on the persistence of lindane in water were not found.

SOIL

The persistence of residues of a given pesticide in soil is a function of soil variables such as texture, organic content, pH, and chemical composition; climatic factors such as rainfall and temperature; and characteristics of the pesticide such as thermostability, solubility, affinity for soil constituents, and biodegradability. In some soils lindane can persist for many years. Annual disappearance rates have varied from 16 percent (MacPhoe and MacEachern 1960) to 36 percent (loam) (Allen and others 1954). Assuming a 20 percent annual disappearance rate as average, the "half life" in soil would be 3 years. About 3 percent of the lindane originally applied would still be present 15 years after application. After application of lindane three to five times per year for 15 years (1953-68) at the rate of 1.5 lb/acre/yr to a light, sandy soil, the lindane content was about 1.8 lb/acre (Voerman and Besemer 1970). Similar applications of DDT resulted in 4.6 lb/acre after 15 years. Concentrations of both pesticides were believed to have reached a steady state. Evidence of biodegradation of lindane in submerged agricultural soils (rice paddies) was found. Less than 10 percent of applied lindane was left after 90 days in unsterilized soils, whereas residues were much higher when the soil was sterilized (Raghu and MacRae 1966). Because of instability under high pH conditions, lindane would likely break down more rapidly in alkaline than acidic soils. Codistillation of lindane and water vapor from water surfaces and moist soil undoubtedly occurs, but reports of determinations of this were not found in the literature.

WILDLIFE

The persistence of pesticide residues in living tissues is a function of the rate of uptake, as determined by food habits, environmental contamination, and tissue storage; and the rate of loss, as determined by the rate of metabolic breakdown and elimination in urine and feces.

Residues of lindane in wildlife have been widely found, especially in Europe. Hawks found dead or dying in the Netherlands had residues of a number of organochlorines; lindane concentrations were 3.2 to 17.7 p/m (brain) and 89.3 p/m (mesenteric fat) (Kooman and van Genderen 1966). The blubber of a gray whale washed up on a California beach contained 0.2 p/m lindane, 0.2 p/m DDT, and 0.5 p/m DDE (West 1964), indicating river or air transport to marine environments. A survey of Irish wildlife (Eades 1966), including eggs and a variety of adult tissues of land and sea birds, salmon and trout, and one mammal (foxhound), found a variety of organochlorine residues in all samples. Lindane was present in small amounts (0.025 to 0.67 p/m) in all birds examined. The foxhound contained 0.32 to 0.72 p/m; the fish, 0.1 to 0.30 p/m; and all eggs examined had trace amounts of lindane (0.004 to 0.05 p/m). The contamination of sea birds again indicated river or air transport of lindane to the sea.

Nationwide summer, fall, and winter collections of U.S. starlings from 106 sites found lindane residues (0.005 to 1.250 p/m) occurring in summer at 4 sites, in fall at 17 sites, and in winter at 84 sites (Martin 1969). The geographic distribution of lindane residues was widespread but showed little meaningful pattern. Lindane was usually found in birds with the highest fat content. Winter deposition of fat combined with a seasonal shift to a more herbivorous diet may explain the greater lindane residues at that season. A nationwide sampling of mallard and black duck wings found lindane residues at trace level (< 0.05 p/m) in only Washington and Michigan, where lindane had been used for aphid control in apple and pear orchards (Heath 1969).

A survey of herbivorous and carnivorous fishes collected at 50 locations throughout the continental United States in 1967-68 found DDT residues (often above 1 p/m) in all but six of 590 fish samples (five of those lacking DDT were collected at one station in Alaska) (Henderson and others 1969). Lindane was found in 16 percent of the samples, usually at concentrations of less than 0.1 p/m. Lindane was not found consistently at any sampling station over time, as were DDT and dieldrin.

In spite of very limited usage of lindane in South Dakota, a survey of tissues from various big game populations throughout the State found lindane residues in 15 percent of these mammals in average concentrations of 0.04 p/m (Greenwood and others 1967).

Nearly all (40 of 43 samples) adult tissues and eggs of chinstrap penguins, brown skuas, and blue-eyed shags, and livers of a fish (*Nototheria* sp.) collected on Signy Island near Antarctica

contained lindane at 0.001 to 0.006 p/m, and other organochlorine residues at slightly higher levels (Tatton and Ruzicka 1967). Planktonic krill (*Euphausia* spp.), the major food of the penguins, also contained traces of these residues. The collection site is located more than 1000 km from South America. Prevailing wind and ocean currents are from New Zealand, 15,000 km distant. Contamination of Antarctic wildlife far from the nearest regions of application indicates the global scope of the transport of lindane and other organochlorine residues.

Although lindane residues are widespread in wildlife, there is presently no evidence suggesting ill effects. Lindane is not concentrated in living organisms to the extent that DDT and dieldrin are. Laboratory exposure of oysters (filter feeders) to water containing organochlorines at 0.001 to 0.05 p/m for 10 days resulted in magnifications in oyster tissues of 17,000X for heptachlor, 15,000X for DDT, and 60X for lindane (Wilson 1966).

Intensive sampling of various components of the aquatic ecosystem in Lake Poinsett in South Dakota gave results (table 1) indicating both lindane and DDT were concentrated to a greater extent at higher trophic levels in the food chain, although the DDT accumulations in aquatic insects and fish were 333 and 12 times, respectively, greater than those for lindane. When chickens were fed a diet containing 10 to 15 p/m of various organochlorines for 5 days, residues were detectable in body fat and egg yolk for 10 weeks for lindane, 17 weeks for DDT, and 26 weeks for dieldrin, heptachlor epoxide, and DDE (Stadelman and others 1965).

Table 1--Distribution of residues and concentration factors (CF), Lake Poinsett, S.D.

Component	Lindane		DDT	
	P/m	CF	P/m	CF
Water	3×10^{-5}	1	8×10^{-5}	1
Bottom sediment	2×10^{-4}	6.6	22×10^{-4}	30
Plankton	2×10^{-4}	6.6	5×10^{-3}	62
Crayfish	1×10^{-3}	33	2×10^{-3}	25
Aquatic insects	1×10^{-3}	33	.919	11,000
Fish	3×10^{-3}	100	.100	1,200

Source: Hannon and others 1970

Although lindane residues render food repellant to many species, pheasants could be conditioned to accept a lindane-contaminated diet by gradually increasing the concentration. At an average daily dietary intake of 87 p/m, reproductive effects were noted. The dosed birds exhibited a slight decrease in the number of eggs produced, and peak egg production was delayed (Ash and Taylor 1964). Lindane concentrations in the eggs of the experimental birds were 3.4 to 12.6 p/m and averaged 5 p/m in wild birds. Upset of avian reproduction (delayed egg production or thinned eggshells) resulting from DDT residues has been found in a number of species and is thought to be contributing to rapid declines of certain raptors (Peakall 1970). Lindane has been found to stimulate (induce) hepatic microsomal enzymes which enhance the metabolism and excretion of steroid hormones (Koransky and Portig 1962). Such effects are also produced by DDT and some other organochlorine pesticides. The influence of this upon avian reproduction is under current investigation.

Experimental diets containing lindane at 30 mg/kg of body weight/day for 30 days (30-day, empirical, minimum lethal dose, or 30-day EMLD) resulted in one or two of six mallards dying, but more than 2000 mg/kg/day were required to kill three of six ducks (LD₅₀) within 14 days (Tucker and Crabtree 1970). An index of the cumulative toxicity effect of lindane may be calculated: LD₅₀/30-day EMLD = 2000/30 = 67. The authors considered this effect highly cumulative, even for an organochlorine. Similar methods and calculations yielded indexes of 76 for dieldrin; 44.8, DDT; 45, endrin; and 104, aldrin. Some of these indexes are higher than that of lindane, largely because although they have greater acute toxicity (lower LD₅₀), they also have higher cumulative action (lower EMLD) than lindane.

It is well known that broad-spectrum pesticides such as lindane disrupt the trophic relationships within ecosystems by reducing the abundance of nontarget insects, thus reducing the food supply for insectivores. Insectan predators and parasites of pest insects are also destroyed, resulting in a disruption of biological control of pest insects. Experimental concentrations of some organochlorine insecticides in ambient water can reduce the photosynthetic productivity of plankton, which lies at the base of all food chains in these environments. The ecological significance of this effect is doubtful, however, as the chlorinated hydrocarbons in natural aquatic environments have never been observed to reach the experimental concentrations. Controlled, 4-hour exposure of phytoplankton to 1 p/m of aldrin, chlordane, DDT, dieldrin, heptachlor, methoxychlor, and toxaphene reduced productivity by 70 to 94 percent, whereas endrin, lindane, and

mirex caused a 28 to 46 percent reduction (Butler 1963).

Under conditions of heavy use of lindane, the potential for damage to wildlife exists. At rates and amounts presently applied, however, no deleterious effects attributable to lindane have as yet been reported. French workers were unable to find noteworthy changes in the bird populations of a 40-hectare pasture and woodland treated in early spring with BHC containing 10 percent lindane at 50 to 70 lb/acre (Giban and Aubry 1956). Nest boxes for tits had been installed in the woodland the preceding winter. Reproduction, development of young, and nesting mortality were apparently normal compared to control nest boxes.

In Russia, aerial dusting of field margins and forest strips for protection of crops with 12 percent BHC did not appear to have negative influence on the avifauna (Kadochnikov 1951).

CONCLUSIONS

Lindane's relatively low acute toxicity makes it unlikely that wild birds or mammals would suffer mortality from levels now used in agriculture and forestry. Lindane's relatively rapid breakdown in living tissues into readily excreted products of low toxicity and relatively low tendency to be stored in fat and other tissues make magnification in food chains minimal at the levels used in the United States. However, lindane is persistent in certain soils and is relatively volatile and water soluble. If applied frequently in large amounts, it could result in serious environmental contamination. Of 29 articles in the *Pesticides Monitoring Journal* for the period 1967-70 reporting residues of organochlorine pesticides, 25 recorded lindane residues. Although often at low levels, these residues were encountered in a wide variety of crops, animals, soils, and water, indicating widespread contamination.

Since the 1940's, worldwide applications of DDT have exceeded those of lindane by a thousandfold. Greatly increased use of lindane, in amounts approximating the quantities of DDT used in the past, would likely damage the primary productivity of aquatic environments and cause increased environmental contamination, which could lead to reproductive upsets in birds at the top ends of food chains.

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Effectiveness of Lindane Against Bark Beetles and Wood Borers

Richard H. Smith

Abstract--There is strong evidence in the literature that lindane is effective as a remedial and preventive treatment against many species of bark beetles: western pine, mountain pine, black turpentine, southern pine, Douglas-fir, and Engelmann spruce beetles, and several species of *Ips* and *Scolytus*. Hosts include slash, loblolly, ponderosa, sugar, lodgepole, white, and red pines, and Douglas-fir, Engelmann spruce, and elm. Formulations range from 0.25 to 3.0 percent as oil solution or aqueous emulsion; tested dosages range from about 50 to 200 ft² of bark per gallon. Insect population reductions for the materials treated range from 80 to 100 percent. Prophylactic action persists for up to 3 years. Lindane is also effective against cerambycid, buprestid, and ambrosia beetles, as well as against powder-post beetles, old-house borers, and subterranean and nonsubterranean termites; effects generally persist against this latter group for 3 to 7 years.

The field effectiveness of lindane in controlling bark beetles, borers, and other wood-feeding insects has been widely studied. This paper, though not an exhaustive review, covers tests involving a wide variety of insects, hosts, and formulations over a long period of time, in widely separated areas. In every use, the insecticide was closely restricted to narrowly defined targets such as individual trees, logs, and wood products. There were no broadcast applications.

Tests for each species or group of bark beetles can be divided into remedial and preventive types. In remedial tests, the insecticide was applied to infested material and an assessment of results was made from failure to emerge and/or from reduced longevity or capability, such as boring and oviposition, after emergence. In preventive tests the insecticide was applied to uninfested trees or logs which were then exposed to attack after varying periods of time; effectiveness was measured by the absence of attacks. Dosage was expressed in various ways but most often as gallons per square foot or as application to the point of "wetness" or "runoff"; these last two measures can be converted to 1 gallon for approximately 100 and 50 ft² of bark surface respectively. Diesel oil was the usual carrier for oil solutions; aqueous emulsion was always the form of emulsion used. Much of the early

work was done with the gamma isomer of benzene hexachloride, BHC; in these tests some of the other isomers were present. More recent tests used lindane, the pure gamma isomer. However, lindane and BHC produce essentially the same results.

Some of the early testing of lindane with bark beetles utilized a topical application procedure; much of that work has been reviewed by Lyon (1965). In his studies with western pine beetle, mountain pine beetle, fir engraver, and *Ips* engraver, he found lindane often superior to most other chlorinated hydrocarbons. He used the term "uncommonly toxic" to sum up his findings.

The review of test results is arranged by insect species or commonly associated groups of insects. Under each insect, or group, the results are reported as either remedial tests or preventive tests as defined above. Dosage, unless otherwise specified, is for square feet of bark. Brood reduction for remedial use is measured by failure to emerge plus mortality during the first 24 to 72 hours after emergence. Effectiveness for preventive use is measured by absence of attacks when compared with untreated material.

Western Pine Beetle
(*Dendroctonus brevicornis* Lec.)

Field tests were all made on ponderosa pine (*Pinus ponderosa* Laws.) in California.

Remedial

1. 92 percent brood reduction resulted from 1.5 percent lindane in oil, presumably at 1 gal/100 ft²; spray was applied just before the start of emergence (Lyon and Wickman 1960).

2. 87 to 99 percent brood reduction resulted from 1.5 percent lindane emulsion against overwintering brood. Spray was applied to wetness 1 to 5 months before emergence. Variation in percent reduction was largely attributable to time of application (Lyon and Swain 1968).

Preventive

1. 100 percent effectiveness was obtained for 12 months and 3 months with 2.5 percent lindane in oil and lindane emulsion, respectively, at 1 gal/50 ft² (Smith 1967).

2. 74 percent effectiveness was obtained for 7 months with 1.3 percent lindane emulsion applied to fire-damaged ponderosa pine; dosage not given. Reduction in subsequent tree mortality varied from 50 to 100 percent, depending on amount of fire damage^{1/}; that is, some of the more heavily fire-damaged trees which were sprayed died, but at a much reduced percentage.

3. 99 percent effectiveness was obtained for 36 months and 22 months by 2.0 percent lindane oil and emulsion, respectively, at 1 gal/50 ft² (Smith 1970).

Mountain Pine Beetle
(*D. ponderosae* Hopk.)

Field tests were made on both ponderosa and lodgepole pine (*P. contorta* Dougl.) in California and on ponderosa in Colorado.

Remedial

1. 90 percent of the brood was killed in lodgepole pine by 1.5 percent lindane in oil applied 1 to several weeks before emergence, presumably at 1 gal/100 ft². Although some trees were missed, the subsequent infestation was reduced to 25 percent of its former level

on an 85-acre plot (Wickman and Lyon 1962). [In an infestation of this type, it is assumed that the infestation level will be maintained if not treated (Evenden and Gibson 1940; Struble and Johnson 1955)].

2. 92 and 97 percent brood reduction resulted from 0.5 and 1.5 percent emulsion, respectively, applied to wetness about 2 months before emergence from ponderosa pines (Stevens and Mitchell 1970).

Preventive

1. 100 percent effectiveness resulted with 2.0 percent lindane oil solution for 36 months, and 91 percent with a 2.0 percent emulsion for 22 months on ponderosa pine at 1 gal/50 ft² (Smith 1970).

Black Turpentine Beetle
(*D. terebrans* [Oliv.])

Field tests were with slash pine (*P. elliotii* Engelm.) and loblolly pine (*P. taeda* L.) in Florida, Mississippi, and Louisiana.

Remedial

1. 82 to 89 percent brood reduction was obtained in slash pine stumps with 0.5 percent BHC in oil, and 59 to 68 percent with 0.5 percent BHC emulsion, when applied at 1 gal/50 ft² several weeks before emergence.

2. Inconclusive results were obtained on loblolly pine in Louisiana when a 1.0 percent BHC oil solution was applied to runoff to 1-month-old stumps in a 2000-acre cutting area. Two-thirds of the area was treated; one-third was untreated (Kucera and others 1970).

Preventive

1. 100 and 98 percent effectiveness was obtained with 0.5 percent BHC in oil for 4 months and 7 months, respectively, on slash pine at 1 gal/50 ft². About 10 percent of untreated trees were attacked and killed; no treated trees were attacked.

Preventive and Remedial

1. 90 percent effectiveness was obtained in reducing the incidence of attack on untreated, previously unattacked slash pine and

^{1/} Swain, Kenneth M. 1968. Protecting ponderosa pine from bark beetle attack by use of a lindane-water emulsion spray. Report on file, USDA Forest Serv., California Region (R-5), San Francisco. 13 p., illus.

^{2/} Smith, R. H. 1956. Studies of the black turpentine beetle (*Dendroctonus terebrans* [Oliv.]) in slash pine: 1952-1955. Final report on file U.S. Forest Serv., Southeastern Forest Exp. Stn., Asheville, N. C., 75 p., illus.

75 to 80 percent effectiveness in reducing subsequent tree mortality where trees were sprayed within 1 month after being attacked, with 1.0 percent BHC in oil at 1 gal/50 ft²; test was maintained over an 18-month period (Smith 1958).

Southern Pine Beetle
(*D. frontalis* Zimm.)

Remedial.

1. 97 percent brood reduction resulted from both 1.0 percent BHC emulsion and 0.5 percent BHC in oil applied to runoff to bark of loblolly pine 1 to 12 weeks before emergence in summer; 97 and 81 percent, respectively, with the oil and emulsion applied 12 to 16 weeks before emergence in winter (Bennett and Pickard 1966).

Engelmann Spruce Beetle
(*D. rufipennis* Kirby)

Remedial.

1. 93 percent reduction in subsequent attack capabilities was obtained with 0.5 percent BHC emulsion; dosage was not stated but was presumably between wetness and runoff. Effects were determined by individually caging green logs with sprayed and unsprayed Engelmann spruce (*Picea engelmannii* Parry) stumps in Colorado and measuring subsequent oviposition (Massey and Wygant 1954).

Douglas-Fir Beetle
(*D. pseudotsugae* Hopk.)

Preventive.

1. 100 percent effectiveness over a 20-week period was obtained with 200 mg/1 ft² of lindane in oil applied to fresh-cut Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) logs. As an emulsion or suspension, this same dosage was 100 percent effective for about 10 weeks and 99 percent for 20 weeks (Rudinsky and others 1960).

Ips Engraver Beetles
(*Ips* spp.)

Remedial.

1. 100 percent brood reduction of *Ips confusus* Lec., the five-spined California engraver, in ponderosa pine in California was obtained with 1.5 percent lindane in oil (Lyon and Wickman 1960).

2. 89 percent reduction in longevity of emerged *I. confusus* brood from ponderosa pine and 84 percent from sugar pine was obtained with 3.1 percent lindane in oil in California. In addition, there was 75 percent reduction in emergence from ponderosa pine and 85 percent from sugar pine (Stark and Borden 1965).

3. 98 to 99 percent reduction in emergence of *I. pini* from red pine in Canada was obtained by 0.5 percent emulsion sprayed to runoff 4 to 5 weeks before emergence (Thomas 1970).

Preventive on logs.

1. 99 percent effectiveness against *Ips* spp. was obtained for 4 weeks in Florida with 0.5 percent BHC emulsion at 0.4 gal/100 ft² of longleaf pine (*P. palustris* Mill.) and loblolly pine logs (Hetrick and Moses 1953).

2. 90 to 100 percent reduction in egg gallery length of *I. lecontei* Sw. was obtained in ponderosa pine in Arizona by 1 percent lindane emulsion, 85 percent reduction with 0.5 percent, and practically no reduction by 0.25 percent (Ostmark 1969).

3. 100 percent effectiveness was obtained against *I. pini* (Say) in red pine (*P. resinosa* Ait.) with a 0.5 percent lindane emulsion applied to runoff a week before emergence of brood in the area (Thomas 1970).

Scolytus Engraver Beetles
(*Scolytus* spp.)

Remedial.

1. 85 and 94 percent reduction in emergence of *S. multistriatus* Marsh. was obtained with 0.5 and 1.0 percent lindane emulsion, respectively; spray was applied to runoff to American elm (*Ulmus americana* L.) in Connecticut in early spring. A late spring test showed only 78 and 72 percent (Doane 1958b).

Preventive.

1. 96 and 84 percent reduction in the feeding activity associated with disease transmission at 4 and 13 weeks, respectively, was obtained against *S. multistriatus* with 1 percent lindane emulsion applied to runoff to American elm; 0.5 percent was ineffective (Doane 1958a).

Ambrosia Beetles

All tests were preventive on logs.

1. 60 to 100 percent effectiveness was obtained with 0.25 percent BHC oil on southern hardwoods. Insecticide was applied as an instant dip, which is comparable to runoff; *Xylaburus affinis* Eich. and *Platypus compocitus* Say were the most common beetles (Kowal 1949).

2. Highly effective protection was obtained for 3 to 4 months with 0.5 percent BHC oil at 1 gal/100 ft² on southern hardwoods (Johnston 1952).

3. 95 to 100 percent protection was obtained with any concentration greater than 0.1 percent BHC of either oil or emulsion, dosage not given, on red and white pines (*P. strobus* L.) in Massachusetts. Sprays were applied in the spring and exposed to attack until autumn (Becker 1955).

4. 100 percent protection for 20 weeks was obtained with 200 mg/ft² of Douglas-fir bark, as an oil. As an emulsion or suspension, the same dosage was 100 percent effective at 8 to 10 weeks and 99+ percent at 20 weeks (Rudinsky and others 1960).

Borers

(Buprestidae and Cerambycidae)

Remedial.

1. 99 percent brood reduction of *Melanophila californica* Van Dyke was obtained with 1.5 percent lindane in oil applied to wetness to Jeffrey pine (*P. jeffreyi* Grov. & Balf.) from 1 to 6 months prior to emergence; lag time between treatment and emergence had no effect on results (Swain and Wickman 1967).

Preventive.

1. 99+ percent effectiveness was obtained against cerambycids for 4 weeks on cut logs of slash, loblolly, and longleaf pine with 0.5 percent BHC emulsion at 0.4 gal/100 ft² of bark (Hetrick and Moses 1953).

2. 100 percent effectiveness was obtained against cerambycids on logs of red and white pine with > 0.1 percent emulsion BHC; there was 95 percent effectiveness with 0.1 percent but a rapid dropoff with concentration below 0.1 percent; dosage not given. Spraying decks of logs was slightly less effective (Becker 1955).

3. 100 percent effectiveness against buprestids was obtained for 20 weeks with lindane in oil at 200 mg/ft² of cut logs of Douglas-fir (Rudinsky and others 1960).

Miscellaneous

Wood Feeders

In all tests except those for subterranean termites, in which soil treatments were used, lindane was applied as a preventive spray or dip to wood.

1. 100 percent effectiveness was obtained against a powder post beetle (*Lyctus planicollis* Lec.) for 3½ years--the length of the test--with a 0.5 percent BHC oil dip on seasoned oak and hickory; an emulsion was about equally effective when applied to seasoning wood (Johnston and others 1955).

2. 100 percent effectiveness was obtained against subterranean termites for 6 years with a 0.4 percent BHC oil applied at the rate of 2½ gal/10 ft³ of soil in Mississippi; 70 percent effectiveness was obtained at 9 years (Johnston 1958).

3. Lindane at 0.5 percent in oil as a brush or spray is recommended for prevention of old-house borer attacks (*Hylotrupes bajulus* L.) (McIntyre 1961).

4. BHC at 0.4 percent in oil is recommended for remedy of drywood termite infestations (Snyder 1950).

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Lindane: An Undesirable Approach to Bark Beetle Control

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Abstract--Bark beetles have been of concern to foresters for many years. Although much effort has been made, direct control of beetle populations has not been demonstrated. Lindane has been shown to be capable of efficiently killing beetles, but population control on an area-wide basis has never been shown. It is not economical compared to sanitation logging, and its side effects on the natural enemies of bark beetles are unknown. Direct control of bark beetles using lindane is potentially an ecologically unacceptable procedure. The most environmentally sound procedures for bark beetle control appear to be improved stand management and sanitation salvage-logging. The use of lindane should be discouraged.

Bark beetles are the most important forest insects in California and, no doubt, in the Western United States. Because these beetles mass attack and kill individual trees, their damage is readily seen, particularly when a large outbreak occurs. Examples are the outbreak of the western pine beetle, *Dendroctonus brevicornis*, in the Mother Lode region of California in the early 1960's and that of the spruce beetle, *D. rufipennis*, formerly known as *D. obesus*, in Colorado from 1941 to 1952. Bark beetles, unlike defoliators, for example, not only kill the tree but also introduce a blue stain fungus which stains the wood. This fungus does not affect the structural quality of the wood (Whiteside 1951), but the staining affects marketability and there may be some difficulty in painting the stained timber.

WESTERN PINE BEETLE

Concern for control of the western pine beetle has a long history (Miffler and Keen 1960). Attempts have been made recently to study the population dynamics of the beetle and to correlate tree loss with beetle numbers (Stark 1966; Stark and Dahlsten 1970). Even though this insect has received much attention in the past, a satisfactory control for this beetle is still being sought by many forest entomologists. In California, for example, there is a large cooperative effort aimed at control by means of pheromones. The most commonly used strategy for direct control with most bark beetle species is with chemical insecticides; however, in California an indirect sanitation-salvage approach

has been used with *D. brevicornis* and *D. jeffreyi* in the east side pine type.

SANITATION-SALVAGE METHODS

Reduction of stand loss due to bark beetles has been demonstrated by application of the California Risk Rating System or sanitation-salvage logging (Keen 1943; Salzman and Bongberg 1942). By critically analyzing individual trees and removing those trees likely to be attacked in these pine stands, bark beetles were reduced by 70 to 85 percent over a 10-year period (Whiteside 1951). The stand volume was reduced by 15 to 30 percent. This type of cutting can be done at costs only slightly higher than the usual utilization cutting. The technique is applicable only to California east-side Sierra forests, however.

The sanitation-salvage method was also applied to recreation areas in southern California (Hall 1958). Hall tested the sanitation-salvage method to reduce losses of ponderosa and Jeffrey pines to bark beetles, principally *D. brevicornis* and *D. jeffreyi*. However, the California flatheaded borer, *Melanophila californica*, was present in both ponderosa and Jeffrey pines, and the mountain pine beetle, *D. ponderosae*, in sugar and ponderosa pines. The most interesting aspect of Hall's work was the cost analysis. In 1950, 554 beetle-infested trees were cut and burned in a control attempt on 2600 acres, at a cost of \$11,380, or approximately \$20 per tree. There was not enough money available to treat the entire infested

area. (Even if the money were available, the likelihood of detecting every infested tree in an area is remote, although detection and accessibility are easier in recreational areas than in timber-producing areas.) In 1951, the infestation continued at a high level: 1100 trees were detected on 6000 acres. Apparently the previous year's control efforts had little or no effect. The cost in 1951 for felling and burning was about \$22,000. Hall suggested the sanitation-salvage method, and a project was initiated in October of 1953 that lasted 14 months. Approximately 5500 acres were treated. After the treatment, the Forest Service maintained a year-round maintenance control. Infested trees were logged, and trees in inaccessible areas were felled and treated with ethylene dibromide in oil.

A close analysis of the results of this project is quite startling. Losses for 2 years before the sanitation-salvage treatment amounted to more than 200 board feet per acre annually. Unfortunately, check areas were not used; but Hall felt that the annual loss in southern California could be assumed conservatively to be in the neighborhood of at least 150 board feet per acre. At this level, losses were reduced by 92 percent in the first and 90 percent the second year. A side benefit of the treatment was the system of roads built during the operation, which subsequently made possible the salvage of 84 percent (72) of the infested trees in the 1956 season. These infested trees were sold at a nominal stumpage. (Hall never states what nominal stumpage is!) A comment should be made here regarding the sale of beetle-killed timber. These trees should be as marketable and sell for the same stumpage as other trees of the same species. A comparative study of the value of the principal species at the time they were salvaged would be interesting, and also critical to the development of sound control practices.

During 1956, Hall reports, 14 infested trees that could not be logged were treated at a cost near \$280. This represents the total control cost on 5500 acres. This is cheap for a control project, and if credit is taken for the 72 trees that were logged, it cost the Government practically nothing. It appears that these results are at least as good as the results obtained in northeastern California by Salman and Bongberg (1942).

Direct control at \$20 per tree would have cost close to \$190,000. However, using an indirect method, sanitation-salvage, the Government actually made about \$50,000 from the sale of the harvested trees.

DIRECT CONTROL

Direct control of bark beetle populations has never been demonstrated. Although Whiteside

(1951) states that it is possible to effect drastic reductions in western pine beetle populations on a control area for one or more years, data to support this statement are lacking or marginal. On the other hand, he does mention the high cost and the temporary nature of the "control." Direct control in the past consisted of the fell-peel-burn method, and later a chemical, ethylene dibromide (EDB) was used. Lindane, a chlorinated hydrocarbon, has now replaced most other treatments. It was shown to be effective in killing western pine beetle and the California five-spined ips, *Ips paraconfusus* (Lyon and Wickman 1960). In this study, trees were felled and treated with a 1.5 percent lindane-diesel oil spray. Sprayed and unsprayed bolts were brought into the laboratory and put into cages with freshly cut material. This test showed that lindane, indeed, would kill bark beetles. However, by caging the treated logs it may be possible to increase insecticide efficacy, particularly if there is any fumigant action of lindane. Treatment costs were not included in this study, nor were the number or kind of associated organisms recorded. The authors admit that it would be precarious to extrapolate from limited laboratory observations that control was actually attained.

In another test of lindane, this time against *D. ponderosa* in lodgepole pine in a fairly isolated stand, Wickman and Lyon (1962) found they could kill beetles; but tree mortality after treatment left something to be desired. As with the western pine beetle, the effect of lindane on the beetles was tested by caging treated and untreated bolts. They found that 90 percent of the beetles were killed; and, as in their previous study, no evaluation was made of mortality of associated organisms. The actual loss reduction in this isolated stand was 74 percent. The authors conclude that the insecticide was effective but that control was not achieved because of technical failures.

In attempting to find the source of these failures, the authors found that 7 percent of the infested trees were not spotted, but they also state that a 10-to-15 percent spotting error was not uncommon. It must be remembered that this was only an 85-acre isolated stand. In much larger areas with less experienced entomologists or no entomologists at all, the spotting error could be much, much higher.

The trees in this study were felled and jackstrawed, so that the undersides would be accessible to the spray. Normally, trees are treated, then rolled, so that the underside can be treated. This may explain why the control cost in their study was so low. Another technical failure in this project was spray coverage: it was found that 22 percent of the bark surface was left untreated. However, this was calculated from only one bolt with 4.5 ft² of

bark surface. A 5 to 10 percent coverage error for the project was estimated. Some beetles emerged through unsprayed bark, and others emerged through sprayed bark and survived. The 90 percent mortality figure reported would presumably be lower were it not for caging. Thus, a potential 12 to 27 percent of the population could escape treatment, and for most projects this is probably a low figure.

Wickman and Lyon (1962) state that the suppression achieved in their control operation compares favorably with results of other bark beetle control programs in California. Miller and Keen (1960) state that a 75 percent reduction in beetle-caused losses after spraying is frequently the maximum attained. The total cost for control of the Wickman and Lyon (1962) mountain pine beetle experiment was \$4.81 per tree, or \$1,202.65. The authors say that this is at least half as expensive as using penetrating oil sprays (such as ethylene dibromide). This cost figure is so much lower than cost figures listed by Hall (1958) and Swain (1968) that costs must have been determined in a different manner. However, Lyon (1959) claims that the tree need only be lightly coated with a residual-type spray like lindane, as compared to a penetrating oil spray, with which the bark surface must be soaked. Labor, transportation, and material costs are, therefore, much lower with lindane. Stevens and Mitchell (1970) recently corroborated this finding with a study on lindane to control the mountain pine beetle in the Rocky Mountains.

PREVENTIVE TREATMENT

Lyon (1959) suggested that residual-type sprays would have one prospective use that other types of sprays would not have, and that is that they would protect trees from attack. This concept has since received considerable attention, especially in the management of recreation areas.

In laboratory studies, Smith (1970) found that a 2 percent diesel oil solution of lindane applied to ponderosa pine bolts prevented western pine beetle and mountain pine beetle attacks for 3 years.

Swain (1968) tested the effectiveness of a 1.25 percent lindane-water emulsion as a prophylactic spray on standing trees in southern California. The area was ideal for this study, as many of the trees had been predisposed to bark beetle attack by a fire that had previously swept through the area. Only those trees that had the best chance for survival were treated and used as checks. One of the major problems was to get the spray high enough on the bole, but this was overcome by using a boom truck. The method would only be feasible, then, in areas of a relatively flat terrain. Swain

states that trees less than 50 feet in height could be reached with conventional ground equipment.

Only 9 of 100 sprayed trees (84 trees sprayed twice, 3 months apart) were killed by the western pine beetle, and none of the 9 killed trees was attacked on the sprayed portion of the bole (all attacks were above the sprayed portion). Swain concludes that one application prior to the time of overwintering brood emergence will give satisfactory protection from western pine beetle attack on the sprayed portion of the bole during the active bark beetle period (spring through fall). The trees were not attacked for a total of 7 months.

Swain set up cheesecloth catchment nets around the bases of five trees to catch dead or dying insects as they fell from the bole. The results were quite revealing as, of the 316 insects caught, 170 were *D. brevicornis* (53.7 percent), 21 were associated bark beetles (6.9 percent), and 125 were predators (110 *Enoclerus lecontei* and 15 *Temnochila chlorodia*) (39.4 percent). Incidentally, this is one of the few times that animals other than the target insect were counted. It is interesting to speculate what this type of predator mortality means, since both of these beetles are general predators of bark beetles and other wood-inhabiting insects.

The cost figures on the Swain (1968) project are much higher than those listed by Wickman and Lyon (1962). The total cost of Swain's treatment was \$3,208.00 calculated as \$17.16 per tree. This is misleading, however, as 84 of the original 103 trees were treated twice. The total cost of protecting these trees was more than \$31.15 per tree. Swain does state that there was no difference in protection afforded those trees treated twice over those treated once. The author goes on to point out that, in the same area in the preceding year, the mean cost of treating infested trees was \$25 per tree, and that the cost for prophylactic treatment was, therefore, less. Swain makes the statement that the land manager has the advantage of selecting the trees to be protected rather than spend money on treating trees which are already dead.

This last bit of reasoning must be examined. First of all, the land manager can presumably get three-fourths of the cost of a project paid by governmental agencies if his trees are infested, but payments are not made for the protection of trees. The land manager would, therefore, be ahead in paying, in fact, only \$5 to \$6 per tree for control rather than \$17 per tree for protection. Also, how often will trees need to be protected? Even using Smith's data (1970), indicating treatment every 3 years, costs would be unbearable. Secondly, why not

use a sanitation-salvage treatment, as shown by Hall (1958) to be an economical means of handling the bark beetle problem in southern California? Finally, what are the effects of the chemical on the environment? Swain's study (1968) showed nearly 40 percent of the insects killed to be natural enemies. The black-bellied clerid, *E. lecontei*, is known to be an important part of the natural enemy complement in the population dynamics of the western pine beetle (Stark and Dahlston 1970). In the same study, it was shown that some 75 % insects are associated with the western pine beetle. The long- and short-term consequences of using a chemical like lindane in the forest community, as well as on the cryptic community created by the beetle beneath the bark of the pine tree, must be carefully evaluated. To date, these effects are virtually unknown.

SPRUCE BEETLE

The spruce beetle, *Dendroctonus rufipennis*, formerly known as the Engelmann spruce beetle, *D. engelmanni* and *D. obesus*, presents another very different type of problem. This beetle destroyed 4.3 billion board feet of timber in western Colorado from 1939 to 1951 (Massey and Wygant 1954). The infestation was correlated with large blowdown that occurred in June of 1939. This outbreak is interesting from two standpoints: (1) the importance of the bark beetle in the succession of the Engelmann spruce forests and (2) the decision to embark on a large chemical control program near the end of the outbreak in 1950, 1951, and 1952.

Engelmann spruce beetle populations are favored by windfalls and overmaturity of spruce stands (Wygant and Nelson 1949). The windfall initiated this outbreak, and then the beetle populations continued in the overmature spruce, much of which may have blown down because of old age.

Engelmann spruce stands are largely two-storied, even-aged stands, the overstory in this outbreak being overmature and the understory being the suppressed reproduction. When the overstory is killed by the bark beetle, the understory is released. If this were allowed to continue through time, then Engelmann spruce would be maintained in the area largely through the periodic activity of the beetles. Ecologically this is a disclimax or disturbance climax because of the bark beetle. Wygant and Nelson (1949) report that previous outbreaks of this bark beetle occurred so long ago that their exact extent is not known. They do cite instances of several flareups but state that none of these earlier outbreaks approached the destruction of the 1939 outbreak, which continued for more than 10 years. It seems that the beetles play an important role in this forest type. More than likely, it is also clear that the blowdown trig-

gered the massive outbreak. In such an extensive outbreak, salvage would be impossible; but a different approach to the management of such a forest might clearly avert such a disaster. Sanitation cuts and harvest of the most overmature timber may become a necessity.

Much of the outbreak took place during World War II, so that no direct control procedures were attempted. Control was attempted from 1950 through 1952 with orthodichlorobenzene in No. 1 fuel oil--1 part by volume to 6 parts of oil (Massey and Wygant 1954; Massey and others 1953). It was later found that ethylene dibromide was just as effective and that workmen found it less disagreeable (Massey and others 1953). The orthodichlorobenzene-fuel oil solution was used to treat more than a million standing trees before EDB was substituted in 1952. No cost comparison was made between the two materials, nor were any figures given on the cost of the project. The main question is, of course, why was the decision made to control the beetles with chemicals? The effort necessary to get to infested trees and treat them could well have been used to salvage the logs. This is a much more economical approach, as I have pointed out earlier. Although both the materials used killed beetles, there was no evidence that populations were "controlled." In addition, control was not attempted until the tail end of the infestation.

CONCLUSIONS

Each bark beetle species in each situation is somewhat different. In some situations certain bark beetles play an important role in the ecosystem as does the spruce beetle. Where bark beetles are pests, it is clear from much of the literature that improved forest management practices are the key to the solution of the problem (Hopping 1921; Whiteside 1951; Wygant and Nelson 1949). There is no evidence that chemicals (orthodichlorobenzene, EDB, or lindane) have ever controlled a bark beetle population in the true sense of the word. These chemicals do kill beetles readily, and one worker, Swain (1968), demonstrated an effect on natural enemies. Two failures, both with lindane, have been recorded: one with the mountain pine beetle (Wickman and Lyon 1962) and another with the black turpentine beetle, *D. terebrans* (Kucera and others 1970). The study on *D. terebrans* showed that lindane reduced attacks, but did not reduce tree mortality. Two areas in California where control has been attempted are chronically infested with western pine beetle: in Blodgett Experimental Forest no apparent good was achieved, and in the area around Bass Lake, south of Yosemite National Park, chemical control activity has not achieved the desired end after several continuous years of treatment.

Cost figures given for lindane are so variable that comparison is virtually impossible. Jackson (1960) gives a cost of 48 to 60 cents per treated top for logging slash in a small logging unit. Osburn (1962) quotes a figure of \$2.48 per tree for felling, topping some branches, and treating for trees above 7 inches d.b.h. Smaller trees were sprayed standing. Costs as high as \$25 per tree were reported by Swain (1968).

Cancellation of registration of lindane has been under consideration by the Federal Pesticide Regulation Division because this insecticide is a persistent chlorinated hydrocarbon. The question is: Of what use is lindane to the forest manager? Private forest industries in California do not use lindane for killing bark beetles, to my knowledge. Cost is apparently a deterrent factor. In the black turpentine beetle study, for example, a volume of 375 million board feet of saw-timber would have to be threatened in order for an annual expenditure of \$17,000 to be justified (Kucera and others, 1970). Control of beetle populations has not been demonstrated, and there are other alternatives available. Further, the use of persistent insecticides is questionable on the basis of side effects on nontarget organisms alone. There are no studies to show that lindane is not a hazardous material in this respect.

In my opinion, the California Forest Pest Control Action Council has not properly weighed the evidence of past research on forest pest problems. An example of this is the manner in which the direct control programs have been conducted. Person (1940) found that 40 to 90 percent of the bark beetle predator, *Enoclerus lecontei*, moved to the base of the tree and the surrounding duff prior to pupation. Berryman (1967) corroborated this work in his studies of predation on the western pine beetle. As long ago as 1927, it was recommended that stumps and surrounding litter not be burned during fell-peel-burn control of bark beetles (Miller and Keen 1960). Also, it has been suggested that trees be "high-stumped" to preserve these predators (Berryman 1967). Earlier studies had also shown that certain trees had high numbers of parasites, and it was suggested that these trees be spared to serve as a reservoir of natural enemies during control operations (DeLeon 1935). These recommendations were ignored, for the most part, until 1965, when the Council recommended that stumps not be sprayed except where *D. valens* is a problem. There was no mention of sampling for parasites or of "high-stumping," and it has never been demonstrated that *D. valens* is a pest.

In these times of increasing environmental deterioration, alternatives must be sought that are least disruptive to the delicate fiber of nature. Forest management solutions to bark

beetle control appear to be an avenue that should be given increasing attention. In a recent paper, Roe and Amman (1970) state that more effective mountain pine beetle control must consider such alternatives as type conversion, shorter rotations, mixing species, and the development of better size and age class distributions. This is ecological thinking, and the route that all insect control must follow in the future.

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Lindane Registration Should Not Be Retained

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Abstract--The registration of lindane should not be retained for the direct control of bark beetles because of potential adverse side effects. Lindane is a broad spectrum insecticide killing both beneficial and other non-target organisms. The efficacy of lindane has not been demonstrated for area-wide population suppression and furthermore, the strategy of using lindane in direct control of bark beetles could not be justified economically if it were effective. Silvicultural treatments aimed toward suppressing bark beetles provide more effective, economical, and lasting protection for forests than does direct control, whether by salvage or lindane spraying. The economic impact of bark beetles in California commercial forests is questioned.

Lindane has been shown to be an effective insecticide in a number of studies. Cost and ease of application certainly made it more desirable than previously used methods, such as treatment with ethylene dibromide and fell-peel-and-burn techniques. Effectiveness as an insect killer and suitability for control of a certain insect species population are two very different issues, however. It is our contention that control of bark beetle populations with lindane has never been demonstrated adequately. Public agencies, then, should not recommend control procedures until they have been proven effective. This is particularly true in these times of concern for the quality of the environment. It is especially unwise to recommend use of a chlorinated hydrocarbon until it has been shown to be absolutely safe.

The side effects of lindane are not known. Possibly, use of this chemical for bark beetle control may lead to the resurgence of the target species or create other insect problems, such as epidemics of other wood-boring species, by indiscriminate killing of beneficial insects. Until further research is done to show environmental safety for lindane, it should not be used. Even if the direct control procedure is absolutely safe, it should be used only if it is effective in controlling the target insect.

The necessity of using lindane in forest protection is certainly open to question. Our forests were not eliminated before the discovery of lindane. It has been recommended for bark beetle control in California for only the last

11 years (Lyon 1959). It has been recommended only since 1968 for use against overwintering broods of the western pine beetle, *Dendroctonus brevicornis*, (Lyon and Swain 1968).

The question is one of properly evaluating direct control methods. Prophylactic treatments with lindane have been suggested as a major reason why this insecticide is essential for the protection and management of forest lands in California. Protecting trees with a chlorinated hydrocarbon is a questionable procedure, as it is only a stopgap measure and must be continually repeated. If direct control of bark beetles in infested trees is not essential to forest management, then perhaps lindane may not be essential. Hall and Pierce^{1/} state, "The main failings of Direct Control are: high cost of accomplishment, near impossibility of finding all the infested trees before the beetles escape, and the fact that the treatment does little to alter any of the basic conditions which encouraged the outbreak in the first place." Studies conducted to assess the effectiveness of bark beetle suppression show inconclusive results. Swain^{2/}, in the Bass Lake Study, found

^{1/} Hall, R. C., and Pierce, J. R. 1965. Sanitation treatment for insect control. U. S. Forest Service, California Region, San Francisco. 21 p.

^{2/} Swain, K. M. 1966. Analysis of the Bass Lake insect control project. U. S. Forest Service, California Region, San Francisco. 7 p.

that losses on the suppression area were actually greater than in the check plot during 2 of the 5 years studied (in another year, loss on the check plot was only 0.01 percent per board foot per acre greater). Hall and Pierce^{1/}, discussing the case history of the Ranger Peak-Figueroa Mountain Direct Control Units, Los Padres National Forest, indicate that although higher losses were found on the untreated Ranger Peak, "... the 5 percent loss at Figueroa Mountain, however, is 10 times greater than the 0.5 percent level considered acceptable. Direct control alone will not assure that the loss can be reduced to tolerable limits needed to perpetuate the forest." In spite of the "favorable" characteristics of lindane, the California Region, U. S. Forest Service, uses lindane in direct control methods only for temporary suppression, mostly in recreation areas.

In view of these failures of direct control, the sanitation salvage or "thinning" technique should be considered in some detail as an alternative. The concept is not new. Both Hopkins (1909) and Person (1928) noticed that certain trees seemed to be attacked more frequently than others. Salzman and Bongberg (1942) and Keen (1943) advanced the eastside Sierra California Risk Rating System. Hall (1958) applied the technique to southern California recreation areas, and Hall and Pierce^{1/} reviewed certain case histories which firmly support the effectiveness of this method. More recently, Hall and Davies^{3/} state "thinning is an effective management tool in reducing the mortality caused by the mountain pine beetle in overstocked young stands of ponderosa pine." Pierce^{4/} maintains that "silvicultural treatments aimed toward suppressing bark beetles provide more effective, economical, and lasting protection for the forest than does direct control by salvage logging or chemical spraying."

If the foregoing arguments by Hall and others are credible, then it follows that permanent reduction in bark beetle populations could be obtained in California through proper cultural or forest management practices. Sanitation-salvage or thinning technique is operable under a wide variety of forest conditions and, in fact, is the *only control means* that has proven effective. Research in utilizing cultural prac-

tices for the suppression of insect pests was, for the most part, discontinued with the advent of DDT. It was not until the now classical insecticidal malfunctions (that is, resistance, disruption of biological balances, and contamination of food chains) became problems that this line of research was re-emphasized. Today lindane appears on the agenda of forest practices with many of the same credentials that were attributed to DDT in 1945, in that it is claimed to be safe, effective, persistent, cheap, and easy to use.

The major area of U. S. Forest Service bark beetle lindane suppression efforts for the last 10 years has been southern California, where arbitrary values have been placed on individual trees because of high public use. In Barton Flats, San Bernardino National Forest, Hall and Pierce^{1/} made a risk assessment in 1953; and a sanitation-salvage program was carried out. The Ranger District followed this with a direct control suppression program for the next 8 years, during which time losses remained low. When tree loss accelerated in 1961, following a period of prolonged drought, a reassessment of Hall's plots confirmed that many trees had moved into higher risk categories. The District moved into a "symptom treatment" program using direct control; that is, treatment of beetle-killed trees rather than removing high-risk trees. Had the District continued to risk rate and to remove the high-risk trees on an annual basis along with or instead of the annual suppression program, perhaps the 1961 flareup would not have occurred.

The economic impact of bark beetles in California's commercial forest has to be questioned. The Forest Service has had trouble in marketing trees from stand improvement sales. This was especially evident at the McCloud Flats thinning sale in 1968, when stumpage bid prices topped at \$5.95/Mbd.ft. It appears that lumber companies are most interested in the large block, allowable-cut sales and can afford to wait for them. Much of the silvicultural suppression must be done by the "gyppo," or small operator, unless the project is "greened up" with a large block sale of prime timber resulting in a major stand reduction. The marketing policy of the Forest Service, as the major forest landowner in California, influences price structure. In the past only large land areas providing large volumes per acre have been economical to harvest. It is logical to assume that this economic condition restricts the investment that the private landholder can afford in stand improvement at 1970 prices; for instance, chipping tops for *Ips* control is not a feasible practice, nor are thinnings to reduce hazard to bark beetle infestations. We feel that the agencies responsible for direct control of bark beetles should re-evaluate their efforts and take a fresh approach to the entire problem. These agencies should be

^{3/} Hall, R. C., and Davies, G. R. 1968. Mountain pine beetle epidemic at Joseph Creek Basin, Modoc National Forest. U. S. Forest Service, California Region, San Francisco. 22 p.

^{4/} Pierce, J. R. 1968. Western pine beetle infestation, McCloud Flat, California 1968, Shasta-Trinity National Forest. U. S. Forest Service, California Region, San Francisco. 5 p.

looking at causes and not at symptoms. Also, they should evaluate what control procedures are economically feasible and are environmentally safe, and not retain techniques merely because of tradition or ease of handling.

If bark beetles are the threat, as stated in the California Forest Pest Control Action Council's brief (1.2 billion bd. ft. lost annually in California), then perhaps U. S. Forest Service management policy could consider the area of market manipulation. A restriction of annual cuts would drive the price up, and a further restriction would be to make stand improvement cuts first. If the timber supply is so great that the timber industry in this State cannot afford to do anything but harvest the "cream," or if the bark beetle impact has been overstated, then perhaps lindane is not essential.

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Lindane: A Useful Approach to Bark Beetle Control^{1/}

Bruce H. Roettgering Roy Blomstrom Robert W. Gustafson John R. Pierce

Abstract--There is no single method of bark beetle control that is usable and effective under all circumstances. Lindane is one of several tools for bark beetle suppression which may be used singly or in combination with others. It would be unwise to discontinue the use of lindane, and thereby reduce the number of control methods available, without strong justification or before a superior replacement can be found.

The resolution of the Insect Committee states that the brief to EPA in support of continued use of lindane for bark beetle control did not state any attribute of the lindane control program that could not be achieved by other methods now in use, and that there is no evidence that the lindane treatment is an effective method of tree mortality prevention.

It is true that the brief failed to make these points; however, it does not automatically follow that there are in fact other methods now in use that could be substituted for the use of lindane, or that lindane, when used to kill bark beetles, does not prevent tree mortality.

The attributes of lindane are such that when it is used, as it is in the overall bark beetle control program in California, there are no other methods or materials available that could be employed under similar conditions or circumstances. Mechanical or cultural suppression methods, such as peeling and burning and logging infested trees, are frequently suggested as alternatives to the use of lindane. Such methods are not necessarily alternatives, they are, in fact, only other methods. In bark beetle control, the circumstances under which suppression is to be done are considered, and the best method is selected which will accomplish the best job; it is not a matter of arbitrarily selecting one of a number of equally rated methods. For instance, if the circumstances (i.e., tree merchantability, accessibility, and economics) indicate that logging be used to suppress an infestation, then logging is recommended; if the falling and burning

method is practical (and it sometimes still is), then the falling and burning method is recommended. If the circumstances suggest that spraying with lindane is the only practical method, we recommend lindane. Under some circumstances a combination of mechanical, cultural, and chemical control methods may be recommended.

An example of this situation occurred near Lake Almanor on the Lassen National Forest in 1967. In some parts of the infested area it was practical to log the infested trees (cultural control). In other parts of the area, merchantable trees were logged whereas trees below merchantable size, cull logs, and tops were sprayed with lindane. On the islands and along the shore of Mountain Meadow Reservoir it was practical to pile and burn infested trees (mechanical control). The records of bark beetle control operations in California in recent years show that methods other than the use of lindane sprays are recommended most of the time. Only a small fraction of the trees infested by bark beetles were treated with lindane. These represented those instances when the use of lindane, instead of or in combination with other methods, could be justified on the basis of conditions existing at each place where it was recommended.

At present there are no methods or materials with all the attributes of lindane that could be used interchangeably with lindane. Only one other chemical, ethylene dibromide (EDB) is available to the Forest Service for suppressing bark beetles.

EDB is a pesticide which exhibits fumigating activity of rather short duration. For some uses this is a highly desirable trait, but almost always it is not a trait desirable in an insecticide for bark beetle control. Granted that in warm weather EDB applied to the bark of beetle-infested

^{1/} Edited for publication in this volume by the compiler, T. W. Koerber.

trees will kill the developing broods; however, EDB has limited effectiveness in cold weather and because of its short residual life may not render the uninfested portions of treated trees toxic to slash-breeding insects. Thus, on the basis of effectiveness of suppression, lindane almost always tends to rate higher than EDB.

When conditions are such that EDB could be effectively substituted for lindane, the cost of the treatment is higher than spraying with lindane. Furthermore, EDB is notorious for causing skin irritations on direct contact and lung irritations when fumes are inhaled.

Many different tests have demonstrated that lindane mixed with either oil or water to form a 1.5-percent spray solution and applied to the bark of trees harboring beetle broods will on the average cause better than 90 to 95 percent reduction in the surviving emerging beetle population (Lyon & Swain 1968; Teillon and others 1973). It is obvious that bark beetles, either alone or in conjunction with other agents, kill trees. In a given forested area within a given period of time, if all or nearly all of the trees harboring developing bark beetle broods can be located and properly treated with a 1.5-percent lindane spray, the potential beetle population (emerging brood) can be drastically reduced. It follows that in the short run annual tree mortality from bark beetle attack will be reduced (Swain 1963; Wickman & Lyon 1962).

It is agreed that the use of lindane does not provide permanent or even long-term protection of forests from bark beetle attack and that if the conditions which prompted the occurrence of the bark beetle outbreak are not favorably altered, bark-beetle-caused tree mortality should be expected to resume promptly and increase to a higher level. However, cultural

methods (that is, logging just the infested trees) and mechanical, biological, and alternate chemical methods have not been shown to be more effective under the same set of conditions.

On the basis of laboratory screening studies conducted by the Insecticide Evaluation Research Work Unit of the Pacific Southwest Forest and Range Experiment Station, it appears that at least three insecticides are potentially as effective or better than lindane for control of the western pine beetle. Laboratory testing of candidate insecticides should be continued, and field tests of promising compounds should be conducted as soon as practical. When an alternate insecticide which works as well as or better than lindane is registered for use, we will promptly suspend the use of lindane in favor of the alternate material.

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Lindane Registration Should Be Retained^{1/}

Kenneth M. Swain

Abstract--Lindane has been adequately field tested and found effective against bark beetles. However, incorrect operational procedures sometimes result in failure to obtain population suppression. Lindane is rapidly metabolized and excreted by birds, animals, and humans, and the rate of application prescribed for bark beetle control should have minimal, if any, side effects.

Recreational use of National Forest lands in California is the heaviest in the nation, accounting for over 27 percent of all visitor use in 1970. This valuable recreation and timber land must be given the highest degree of protection possible. A major pest problem is bark beetles. To deal with this problem the land manager has a number of tools, among them preventive measures, such as sanitation cutting (the harvesting of high risk trees susceptible to bark beetles), or silvicultural treatment (thinning, release, etc.) to improve stand health and vigor. However, when significant tree loss occurs, direct suppression methods may be recommended. This often involves removing the infested trees from the stand either by logging or fuelwood sales. Sometimes it is not feasible to remove all the infested trees. They may be in an inaccessible location or the amount of site disturbance necessary to remove trees may be unacceptable, as in a recreation area. Often some of the infested trees are unmerchantable under prevailing market conditions. When other methods are not feasible, the infested trees can be treated with an insecticide. Currently, lindane is the most effective registered insecticide.

OPERATIONAL CONSIDERATIONS

The effectiveness of lindane as an insecticide is well documented. In the literature, lindane recommendations are backed up by adequate field testing. It follows that if suppression is not effective in operational use, failure is not the fault of the insecticide, but rather is due to incorrect operational procedure. Any of the following factors could contribute to failure to attain adequate

suppression:

- Poor timing of spray application
- Poor spray coverage (bark not sprayed)
- Missing of infested trees by spotter
- Improper mixing of lindane
- Crystallization of lindane at freezing temperatures
- Application of insufficient spray
- Use of lindane concentrate too low in lindane content

Assuming that the operational procedures are correct, then some degree of control should be obtained. The most obvious error in control projects is spotting. Keen (1960) states that with a three-man crew, after the first of November, about 90 percent of the trees will be found if the work is carefully done. From cruises of 106 sections it has been determined that the standard deviation of marking for any one spotter is plus or minus 20 percent. This is supported by Wickman and Lyon (1962), who found 90 percent mountain pine beetle mortality attributed to lindane at Silver Lake, whereas only 74 percent actual control was achieved because of missed trees and inadequate spray coverage.

Swain^{2/} reports losses on two comparative stands, one treated and the other untreated. In 1961, the loss in the treated stand was 5.5 percent of the stand volume and in the untreated stand the loss was 6.2 percent of the stand volume. The following year the loss was 4.7 percent of the stand volume in the treated stand and jumped to 28.6 of the stand volume in the untreated stand. The losses in the treated

^{1/} Edited for publication in this volume by the compiler, T. W. Koerber.

^{2/} Swain, Kenneth M. 1963. Analysis of the Figueroa Mountain-Ranger Peak insect outbreak. Report of file, Div. Timber Manage., California Region, U.S. Forest Serv., San Francisco, 8 p.

stand were higher than the desired level; however, in the untreated stand the lack of control resulted in catastrophic losses.

Hubbell^{3/} reports on a bark beetle control project against the Jeffrey pine beetle and the California flatheaded borer. The project was in an urbanized recreation area. All trees six inches and over were checked for two years in treated and untreated areas. At the end of this period the number of infested trees in the untreated area had increased by 204 percent ± 95 , whereas the number of trees in the treated area had decreased by 44 percent ± 21 .

EFFECTS OF LINDANE ON BIRDS, ANIMALS, FISH AND HUMANS

A major concern in the use of organochlorine compounds, such as lindane, is the likelihood of transfer in the food chain through a phenomenon called biological magnification. Dr. Francis Gunther (chemist and toxicologist, University of California, Riverside, personal communication) stated that he knew of no instances where lindane went through biological magnification. Dr. Gunther, editor of the 1970 edition of *Residue Reviews*, is a renowned authority on insecticides. Macek (1970) states that lindane and methoxychlor would not be expected to be biologically magnified to any great degree.

Certainly, any insecticide if given in large enough dosages will eventually cause noticeable side-effects or even death to the test animal. At the dosage and rate of application prescribed for bark beetle control in California, however, lindane should cause minimal side-effects, if any. In early testing in California, the California State Department of Fish and Game monitored our use of lindane. The Department's conclusion was that using lindane, in accordance with recommendations made by the U.S. Forest Service, was not harmful to wildlife. However, avoidance of the use of lindane adjacent to streams was suggested.

Birds

In many tests, various birds have been fed a diet containing specific percentages of lindane. Rudd and Genelly (1956) report a 10 percent mortality of pheasants resulted from eating grain treated with 1 2/3 ounces of 75 percent lindane per 100 pounds over a 20-day period. Other investigators, however, were unable to detect noteworthy changes in the bird population of a 40-hectare pasture and woodland

treated with 10 percent BHC (10 percent gamma) at approximately 50-70 pounds per acre. This application is about twice that normally employed. In addition, considerable field observation and experimentation in Germany have led to essentially the same conclusion. The small amounts of BHC that a wild bird could ingest would be insufficient to cause harm, because of the rapid disintegration of BHC within the animal body.

Ash and Taylor (1965) fed pheasants on lindane treated seed. They conditioned birds to low concentrations in the diet to overcome the problem of unpalatability. Eggs analyzed contained 0.4 to 22.1 p/m. Hatching was not impaired. The residues in eggs remained constant on continued feeding and for 5 days thereafter, but then fell rapidly for 15 days. Within 9 days after ingestion ceased, 66 percent of the initial residue had been excreted.

Liska and others (1965) placed young turkeys on treated rangeland immediately after it had been treated. At the end of four weeks the birds had 2.4 p/m of lindane in their body fat. Those placed on the range a week later contained only 1 p/m and those another week later 0.7 p/m.

In summary, the National Academy of Sciences (1969) indicates that field applications of lindane have no toxic effect on birds.

Animals

Groups of 20 rats were maintained for two years on diets containing from 5 to 1600 p/m of the alpha, beta, and gamma isomers of BHC. Gamma BHC (lindane) had the lowest toxicity, beta the highest. Dosages above 100 p/m produced liver injury. Kidney injury also occurred at high dosages. No lesions were produced at or below 50 p/m. (Morrison 1968).

Orr (1948) applied 0.5 percent lindane in acetone to the skin of mice twice a week for 15 months in a vain effort to produce cancerous lesions. Paraffin pellets with 3 percent lindane implanted beneath the skin for 10 months also failed to produce abnormalities.

Truhaut (1954, cited in FAO-WHO 1965) fed groups of 20 young rats on diets containing 25, 50, and 100 p/m of lindane for their entire lives. The highest dosage produced slight liver enlargement and fatty degeneration of the liver. No symptoms or lesions occurred at the 25 p/m level and no increase in the incidence of tumors occurred (Morrison 1968).

According to the Agricultural Board, Division of Biology and Agriculture (1969), mammals metabolize lindane quite rapidly to trichlorobenzenes and phenols, which are excreted.

^{3/} Hubbell, R. J. 1967. The effects of direct control on pine bark beetles in an urbanized forest. Report on file, Calif. Div. For. Dist. VI, Riverside Calif., 5 p., illus.

O' Brien (1967) reports very little lindane is accumulated in the body fat, and in mammals it has a low oral toxicity.

Fish

In our operational use of lindane, precautionary measures are taken to ensure that the spray does not directly, or indirectly, get into streams. Fish are less sensitive to BHC than to DDT, toxaphene, dieldrin, and other new chlorinated hydrocarbons. Brown and rainbow trout were all killed by exposure to 0.05 p/m of lindane, but bluegills have survived 0.45 p/m of 12 percent lindane. However, bass and bluegill fingerlings suffered 50 percent mortality at 0.1 p/m of the same formulation (Rudd 1956). Gakstatter and Weiss (1967) report that four species of fish were exposed to water containing 0.03 p/m lindane. Two days after termination of exposure, the fish had eliminated 90 percent of the lindane.

Generally most insecticides are toxic to fish. The chlorinated hydrocarbons are particularly toxic. However, lindane is considered to be one of the safer chlorinated hydrocarbons (O' Brien 1967).

Humans

Evidently very little work has been done with lindane in relation to human health. Our field procedures on the use of lindane were explained to Dr. Kopping, U.S. Public Health Service, in January 1967. It was his belief that field workers would not show any lindane in the system using current Forest Service procedures. He said that lindane is rapidly eliminated from the body and he would not expect any accumulation unless the patient had been subjected to repeated acute exposure. O'Brien (1967) reports that a Rumanian study showed no ill effects from massive inhalation of DDT plus lindane in a forest spraying operation; some workers inhaled 21 mg/kg of DDT as well as 6 mg/kg of lindane daily for 30 days.

Hayes (1963) states that lindane (gamma isomer of BHC) has the greatest acute mammalian toxicity of all the isomers of BHC. However, it is rapidly excreted by the kidneys and does not accumulate extensively. Lindane has the lowest toxicity on repeated exposure, and therefore is safest for use by workers under long, intensive exposure.

METABOLISM OF LINDANE

There is much concern about the toxic effect of the metabolites of organochlorine compounds. Dr. Francis Gunther (personal communication) said that to his knowledge none of the metabolites of lindane have any toxic side-

effects. One of the more common metabolites is pentachlorocyclohexene (PCCCH), which was confirmed by Yule (1967). This is the common degradation product in soils. (Guenze 1970). In mammals lindane is metabolized quite rapidly to trichlorobenzenes and phenols, which are excreted (Agricultural Board 1969).

RESIDUAL LIFE OF LINDANE

Certainly, as well as its toxicity, the residual life of lindane makes it a desirable insecticide for bark beetle control. Obviously, since bark beetles emerge over a long period of time an insecticide with a short residual life would not be effective.

Lindane applied as a lindane-diesel solution forms a tissue deposit. Lyon (1969) states that tissue deposits of lindane have several advantages over surface deposits: (a) toxicity is higher to the target insect, (b) residual life is longer, and (c) less lindane is available to bark beetle predators and parasites. In contrast, when lindane was applied as a wettable powder at 40 mg actual per square foot, forming a surface deposit, all toxicity was lost in six weeks. (Lyon 1965).

The residual life of lindane as a preventive has been well documented. Smith (1970) reports a 2 percent lindane oil solution applied on ponderosa pine bark remained effective against *Dendroctonus ponderosae* and *D. brevicornis* for three years. Also, according to Swain^{4/} a 1.5 percent lindane-water emulsion gave effective protection against *D. brevicornis* for at least 9 months and probably longer when applied to the bark of standing ponderosa pine.

Dr. William Spencer (personal communication) believes that lindane in soil has very little movement downward. He feels that a 1.5 percent lindane spray on forest soils would volatilize and degrade quite rapidly. And, as long as there is soil moisture, lindane volatilizes readily at 30° C and above. The published vapor pressure of lindane at 30° C and 55° C is 4.5×10^{-5} and 1.45×10^{-3} mm of mercury. Spencer (1960) found the vapor pressure to be 3.5, 2.0, and 2.4 times greater at 20°, 30°, and 40° C, respectively, than the published values. Guenze (1970) reports that lindane degrades in soil to pentachlorocyclohexene, which is more volatile than lindane, and does not remain in the soil to any extent.

^{4/} Swain, Kenneth M. 1968. Protecting ponderosa pine from bark beetle attack using lindane-water emulsion spray. Report on file, Div. Timber Manage., California Region, U.S. Forest Serv., San Francisco, 13 p.

As used in bark beetle control, lindane can have an effective residual life of up to three years. The residual life is dependent upon the concentration, solvent, and type of material being sprayed. From current information it is apparent that lindane is quite variable in its rate of degradation. The current field application of lindane should have a minimum adverse effect on the environment.

FUTURE USE OF LINDANE

Certainly it would be desirable to find alternative methods for treating bark beetles. Hopefully, pheromones will lead to a method of control whereby insecticides will not be needed. New research can help us recognize and conserve the natural enemies of bark beetles. In all probability, however, the need for insecticidal control cannot be eliminated. Now is the time to quit talking about so-called "integrated control" and to put it into practice.

According to Lyon (1971) Dursban, Zectran, and malathion show promise in laboratory tests against the western pine beetle. Let us field test these insecticides. However, until an effective replacement for lindane has been adequately tested, the continued use of lindane is necessary.

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