INDUSTRY BIOSECURITY PLAN
For the Grains Industry

Threat-Specific Contingency Plan

2005

COMMON NAME: **Khapra Beetle**

SCIENTIFIC NAME: ***Trogoderma granarium Everts (Dermestidae)***

SYNONYMS*:* *Trogoderma khapra* Arrow *Trogoderma affrum*

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Warning: This contingency plan contains a considerable amount of information and references out of a report by Rees and Banks (1998). The report is 'Commercial in Confidence, Use of this information requires permission from the Business Manager, CSIRO Entomology, GPO Box 1700, Canberra ACT 2601, Australia. Ento-cbo@csiro.au.

Background

General

Khapra beetle *Trogoderma granarium* Everts has been identified as a serious threat to the whole of the Australian grain industry. If this beetle is not monitored through a targeted surveillance system, the likelihood exists that it could well go undetected for a considerable amount of time, thereby establishing populations which would be impossible to eradicate within the limits of available funds. Khapra beetle and its potential effects have been studied in detail since the 1950's. For example Howe & Lindgren (1957) and Howe (1958; 1963) investigated the potential impact of Khapra beetle in North America (OEPP/EPPO, 1981). By 1966 Khapra beetle was successfully eradicated from where it occurred in California, Arizona and New Mexico (Pasek, 1998).

Host range

Unlike most Dermestidae (Scholtz & Holm, 1985) this species feeds by preference on grain and cereal products (particularly wheat, barley, oats, rye, maize, rice, flour, malt, and noodles) and can be a serious pest of such commodities in store. The damage is done in the larval stage as the adults do not normally feed (Freeman, 1980). Khapra beetle will attack almost any kind of material (Cotton, 1956) such as dried blood, dried milk, fish meal, wool, goat skins and many more (Dillon, 1968). They can feed on products with as little as 2% moisture content and can develop on animal matter such as dead mice, dried blood, and dried insects.

Pasek (1998) and CPC (2005) list the primary seed and cereal grain hosts. These are (alphabetical order on scientific name): *Avena sativa* (oat), *Cicer arietinum* (garbanzo), *Glycine max* (soybean), *Hordeum vulgare* (barley), *Lens culinaris* (lentil), *Oryza sativa* (rice), *Pisum sativum* (garden pea), *Sorghum bicolor* (grain sorghums), *Triticum aestivum* (wheat), *Vigna unguiculata* (cowpea), and *Zea mays* subsp. *mays* (corn). Preferred animal feeds and concentrates include: rolled and ground barley, ground corn, ground dog food, rolled oats, dried orange pulp, ground rice, and cracked and ground wheat bran. Nuts that may serve as primary hosts include: *Arachis hypogaea* (peanut), *Carya illinoensis* (pecan), *Juglans* spp. (walnut), and *Prunus dulcis* (almond). Grocery commodities that sometimes serve as hosts include: bread, dried coconuts, cornmeal, crackers, white and whole wheat flour, hominy grits, baby cereals, pearl barley, and wheat germ. Larvae can feed, but not fully develop on seeds of *Medicago sativa* subsp. *sativa* (alfalfa), noodles, *Phaseolus lunatus* (lima bean), and raisins.

Part of plant/commodity affected

The young larvae feed on debris or damaged kernels of grain. Whole grain is only attacked by fourth instar or older larvae. Feeding is usually concentrated over the surface of infested materials and down the sides of bins, but may penetrate 6 metres or more into bulk storage (Dillon, 1968).

BIOLOGY

Identification

General

For Australia it is important to;

1. Know and identifying the range of native *Trogoderma* species.
2. Document the taxonomic differences between native and pest *Trogoderma* species.
3. Develop a rapid DNA technique to distinguish pest *Trogoderma* specimens from native specimens.
4. Examine the likelihood of pest *Trogoderma* existing in native bush and re-infesting grain storages.

As mentioned earlier sophisticated methods are needed to reliably distinguish between Warehouse and Khapra beetle. In Australia considerable investigation has been done on this topic. It is possible to identify adults, larvae and cast skins down to species level, but it requires skill and training, as well as good equipment (microscope) and appropriate identification keys (Banks, 1994). For preliminary identification visit the Pest and Diseases Image library at http://flyaqis.mov.vic.gov.au/padil/T_granarium.htm.

(From left to right) egg, final instar larva, pupa in skin of final instar, and adult beetle about to escape from the cuticle of the pupa
Photo: Degesh America

A description of the different life stages follow:

Eggs

Initially milky-white, later pale-yellowish; typically cylindrical, 0.7 mm long and 0.25 mm broad; one end rounded, the other more pointed and bearing a number of spine-like projections, broader at the base and tapering distally (OEPP/EPPO,1981). Laid loosely and singly in the host material (APHIS, 1984).

Larva

Total length of the first-instar larva is 1.6-1.8 mm, a little more than half of which consists of a long tail, made up of a number of hairs borne on the last abdominal segment. Body width is 0.25-0.3 mm, and colour uniformly yellowish-white, except for the head and body hairs which are brown. The head bears a short antenna of three segments. A characteristic feature of the larva is the presence of two kinds of body hairs: simple hairs, in which the shaft bears many small, stiff, upwardly directed processes; and barbed hairs, in which the shaft is constricted at regular intervals, and in which the apex consists of a barbed head. This brown or yellowish-brown head is as long as the combined lengths of four of the preceding segments. Simple hairs are scattered over the dorsal surface of the head and body segments. The tail consists of two groups of long simple hairs, borne on the 9th abdominal segment. Barbed hairs are found in pairs of tufts, borne on certain abdominal tergites. As the larva increases in size, the colour changes progressively from the pale yellowish-white of the first-instar larva to a golden or reddish-brown. The density of the body hairs increases but these hairs and the tail become much shorter in proportion to the length and breadth of the larval body, and in the 4th instar the hairs give the appearance of four dark transverse bands. The mature larva is approximately 6 mm in length and 1.5 mm in breadth (OEPP/EPPO,1981).

Morphologically, the mature larva of Khapra beetle can be separated from that of *T. versicolor* by the absence of a dark pretergal line on the 7th and 8th abdominal segments, such a line being faint or absent on the 7th segment and never present on the 8th segment in Khapra beetle. (OEPP/EPPO,1981). Three pairs of legs (APHIS, 1984).

Pupa

At the last ecdysis, the larval skin splits, but the pupa remains within this skin for the whole of its life. The pupa is of the exarate type; male smaller than female, average lengths being 3.5 mm and 5 mm, respectively. (OEPP/EPPO,1981). Whitish colour (APHIS, 1984).

Adult

Oblong-oval beetle; about 1.6-3.0 mm long by 0.9-1.7 mm wide; males brown to black, with indistinct reddish-brown markings on the wing covers; females are slightly larger than males, and lighter in colour; antennae are 11-segmented; head is small and usually
deflexed.

Several other species also occur in grain and other stored products, sometimes in large numbers, and they may be confused with Khapra beetle. It is important that any field identification should be checked in the laboratory. For more information, see Hinton (1945), Beal (1956; 1960), Faber (1971).

Khapra and Warehouse beetles are similar in many ways, and they can only be distinguished by dissection of the genitalia or by DNA methods. For obvious reasons the presence of Warehouse beetle in Australia increases the risk of Khapra beetle establishing here.

Dorsal and lateral view of the adult Khapra beetle

Photos: Department of Agriculture, Western Australia

Symptoms

The most likely stage to be seen during inspection is the hairy larva and the most usual evidence is cast larval skins. Special attention should be given to any produce from the areas where the pest is indigenous, especially oilseeds and oilseed products, pulses, cereals and gums, as well as used and new sacks and hessian from these areas. Examine malt from temperate areas carefully. In warehouses which are suspect, examine cracks and crevices and look behind any panelling against walls. In ships, look also under rust scale, under timber coverings of tanks, on ledges, etc. In dry cargo containers, look between floor boards and behind linings. Larvae are most likely to be seen during the hour before dusk since they tend to be more active at such periods (OEPP/EPPO,1981).

LIFE HISTORY

The adults are short-lived, mated females living 4-7 days, unmated females 20-30 days and males 7-12 days. They do not fly and feed very little, if at all. Mating occurs about 5 days after emergence. The beetle can lay a full complement of eggs following a single mating, but a second mating greatly increases the total number of eggs produced: once-mated females lays about 60 eggs, whereas twice-mated individuals laid about 60 and then 500 eggs after the respective matings. Delay in mating of 15-20 days results in up to 25% reduction in fecundity. The preoviposition period, which is not affected by humidity, is negligible at 40°C, 1 day at 35°C, 2 days at 30°C, 2-3 days at 25°C, and, at 20°C, no eggs are produced. Under optimum conditions, the female lays an average of about 50-90 eggs loosely in the host material. The eggs hatch in 3-14 days (OEPP/EPPO,1981). Optimum conditions for development are 33-37°C, 45-75% r.h. (Howe, 1958). Khapra beetle is able to survive short periods at 60°C, and at -15°C for several hours. The upper limits are considered to be in the vicinity of 46°C. At 70% r.h., minimum temperature of development is about 22°C.

On hatching the larvae are about 1mm long. There are five molts in the development of the larvae, and the cast skin is shed following each molt (Morschel, 1972). Both short- and long-lifecycle larvae can develop. Larvae may enter diapause under certain conditions, which then make it difficult to control them chemically. OEPP/EPPO (1981) mentions that if the temperature falls below 25°C for any period of time ,and, sometimes, if the larvae are very crowded, they may enter diapause and development ceases. The larvae are cold-hardy, surviving temperatures below -8°C. Diapause often occurs at constant temperature, below 30°C. In diapause, the larva can moult but is relatively inactive and rarely feeds. It tends to seek out crevices in the fabric of buildings. A larva can remain in this state for several years, but the provision of a new consignment of food, especially in warm conditions, may stimulate renewed development and pupation. Young larvae are unable to feed on whole grains and depend on damaged grains or grain products for food (they readily attack softer foods such as nuts). Such damaged grains are always present in practice in lots of stored grain. Older larvae can feed on whole grains. The amount and condition of the food present affects the speed of development, but larvae can survive long periods (at least 13 months) without food. These starving larvae pupate within a week on the return of favourable conditions such as high temperature and availability of food. Starvation of dormant larvae for 3 months, followed by a brief period of feeding, results in the production of 40% of the normal number of eggs. However, this percentage is ample for the survival of the pest. One to 3 months of starvation does not affect the pupation rate of dormant larvae. For more information, see Hinton (1945), Howe (1952), Hadaway (1956), Burges (1959; 1963), Faber (1971), Karnavar (1972), Nair & Desai (1972).
Complete development takes place within the range 21 to over 40°C. The life cycle from egg to adult takes an average of 220 days at 21°C, 39-45 days at 30°C and 75% RH and 26 days at 35°C, the optimum. Development can take place at a relative humidity as low as 2%, at which the life cycle is prolonged. OEPP/EPPO (1981). The rate of increase of populations at 33-37°C is about 12.5 times per month: this compares with 20 times at 32-35°C (minimum RH 30%) for *Rhyzopertha dominica* and 25 times at 27-31°C (minimum RH 50%) for *Sitophilus oryzae*, the principal competitors of Khapra beetle as pests of whole grain. In the zone where Khapra beetle is indigenous, where mean temperatures are consistently above 25°C, the larvae develop rapidly into the pupal stage, e.g. in 15 days at 35°C (OEPP/EPPO,1981).

ESTIMATE OF ECONOMIC IMPACT ON PRODUCTION, ALLIED INDUSTRIES AND NATIVE ECOSYSTEMS

General

The khapra beetle is principally a serious pest of stored products under hot dry conditions; complete destruction of grain and pulses may take place in a short time. In humid climates, the rates of increase of its competitors are so much greater that it has difficulty in establishing itself. However, in such areas, it lives at the inner edge of the expanding hot zone of stacks or bulks, in which heating has been induced by the activity of other species. In the EPPO region in the 1970s, Khapra beetle was rated as of considerable economic importance in Cyprus, Tunisia and Turkey. Khapra beetle, depending upon existing conditions, may cause losses to stored grain of 5 to 30 percent and losses have been known to reach as high as 74 percent. The most favourable conditions for multiplication and damage is in bulk grain under extended storage. Despite this, it is likely that direct losses to stored grains in Australia by susceptible Khapra beetle strains would be limited. This is because current phosphine treatments used to control endemic grain pests would also control non-resistant Khapra beetle populations.

Estimate impact on trade

International grain markets are becoming more discerning and for the Australian industry to continue to be successful, it is essential that we adapt to these changing markets especially given that 75% of our annual harvest is exported. Customers continue to demand grain that is completely free of grain insects. Especially in the case of Khapra beetle it would be of the utmost importance for Australia to be able to claim freedom of this pest.

When Australia was erroneously listed as "Khapra beetle"country in the late 1940's, it took over 15 years of lobbying and publication to have this stigma removed (Emery, 1999). Many Australian export markets could disappear immediately if Khapra beetle is found to be present (Butcher & Dean, 1995). Under 4 scenarios in an assessment of the potential economic impact of Khapra beetle in Western Australia, costs associated with export market losses ranged from $46 million/year to 117 million/year, while the present value of costs over a 30 year period ranged from $200 million to $1.6 billion (McElwee, 2000). These costs did not include the possibility that adequately treated grain might be accepted by Khapra beetle-free export destinations. It is possible (although considered unlikely by many grain pest experts) that Khapra beetle could be controlled to acceptable levels by existing (phosphine) or additional (methyl bromide, heat, controlled atmospheres, irradiation) control measures. In this case the costs of Khapra beetle to Western Australia would be substantially less than the estimates quoted above. Conversely, it is possible that even countries listed as Khapra beetle countries may decline Western Australian wheat because they do not want a particular strain of the beetle or because of market or political pressures.

Environmental Impact

Apart from the destruction of grain products by Khapra beetle, ingesting products contaminated with body parts, setae and cast larval skins can result in gastro-intestinal irritation. Asthmatics and sensitised individuals are also at risk, as contaminants are highly allergenic.

Since infestations would most likely be confined to grain storage facilities and other buildings, this pest is not expected to have significant impacts on natural environments or endangered / threatened species (Pasek, 1998).

The use of methyl-bromide or other fumigants to eradicate or control Khapra beetle will likely produce adverse effects to the environment and human health. Methyl bromide is an ozone-depleting substance, and human exposure to high concentrations can result in the failure of the central nervous and respiratory systems (Pasek, 1998).

GUIDELINES FOR THE SELECTION OF CHEMICAL CONTROL TREATMENTS

Introduction

Worldwide, the fumigant of choice for quarantine treatment against Khapra beetle is methyl bromide. This is despite its known high level of tolerance to the fumigant, particularly when in diapause. Recommended dosage rates against the pest tend to be twice as high or more than against typical stored product pests (eg. Bond 1984). Practical problems with fumigating some oily, high risk commodities (eg. expeller cake) with methyl bromide further compounds the difficulties.

In the survey by Rees & Banks (1999) the following insecticidal treatments are considered particularly:

- Fumigation - (methyl bromide and phosphine)
- Controlled atmospheres
- Heat
- Irradiation

Despite the importance of Khapra beetle to a number of quarantine authorities there is remarkably little modern (post 1960) literature on the response of the pest to insecticidal measures. This is particularly so for the response of diapause larvae - assumed here to be the main form of the pest requiring quarantine control. Many of the available scientific studies do not take adequate precautions to ensure the at least part of their test samples is well established in diapause. There is a risk that these studies will give rise to dosage schedules that will not eliminate diapause larvae, though they may well control the more susceptible active larvae and other developmental stages.

The Australian Department of Health, a predecessor of AQIS, commissioned studies in the UK to remedy the lack of reliable data on diapause larvae. Extracts (Rees & Banks, 1999) from these studies (Spratt *et al*. 1985, Bell *et al*. 1983, 1985) are included below.

Methyl bromide

Historically, dosage recommendations for control of Khapra beetle have been based on 'double the normal dosage' for typical stored product pest control. The latter are often aimed at ct = 200 g h m^{-3} at 20°C, implying ct = 400 g h m^{-3} at 20°C for Khapra beetle. This is close to the value of 480 g h m^{-3} for 100% kill at 20°C given by Bell *et al* (1985), but less than the Russian quarantine dosage implied by Mordkovitch and Sokolov (1992) of 600 g h m^{-3}. Bogs (1976) give a dosage of 600 g h m^{-3} for >15°C, which may be the origin of this recommendation.

During the apparently successful Khapra beetle eradication campaign in the 1950s in USA, the dosage recommendations finally adopted correspond to a minimum ct of about 1200 g h m^{-3} at unspecified temperatures (initial dosage 80 g m^{-3}, 32 g m^{-3} remaining after 24 hours) (calculated from Armitage 1958).

Exposures exceeding ct = 400 g h m^{-3} are easily obtained at 20°C with dosages of 48 g m^{-3} for 24 hours with most commodities in well sealed enclosures. Oily and finely divided commodities may need additional dosage or topping up to achieve target ct-products and as a result residual bromide levels may exceed established tolerances (eg. 50 ppm in cereals, Australian MRL). There is also a risk of taint or quality change in some materials. Alternative treatments may be considered more appropriate despite long history of methyl bromide use in such situations.

Phosphine

Phosphine fumigation is not currently approved by AQIS as a quarantine treatment against Khapra beetle. Reasons for this appear to be historical - with suitable precautions to prevent leakage and exposure times of 12 or more days, depending on conditions, data available for phosphine action on Khapra beetle, until recently, supported consideration of its use as an alternative to for this pest. However, as noted below, resistance development may now have rendered this former option inappropriate.

Khapra beetle, even as a larva in diapause, is quite sensitive to phosphine. Australian dosage rates for control of *Sitophilus* species are sufficient to control normally-susceptible Khapra beetle at >20°C, and appear to be so too for resistant Khapra beetle so far encountered. Data on the latter is insufficient to establish a firm recommendation.

The best studies on action of phosphine against Khapra beetle are those of Bell *et al.* (1983,1985) and Hole *et al* (1976). There are numerous other studies (e. g. Lindgren *et al*. 1960, El-Lakwah et al. 1989, Punj and Girish 1969, Dhaliwal and Rattan 1973), but as these are carried out under conditions where diapause is absent or not adequately proven, they are, at best, indicative only of the relative susceptibility of Khapra beetle to phosphine.

All data available to us shows that phosphine dosages recommended currently for control of stored product pests in stored grain, including *Sitophilus* species and resistant *Rhyzopertha dominica* (currently known strains, 1998) will be more than adequate to eliminate normally-susceptible Khapra beetle. This applies to the most tolerant stages of the pest known, ie. diapause larvae below 25° and egg stage above this.

Australian recommendations for phosphine use against phosphine-tolerant species of stored grain pest (Winks *et al*. 1980) specify commodity temperatures must exceed 15°C. The data of Bell *et al*. (1985) shows that phosphine could be used down to 10°C against Khapra beetle provided an adequate exposure time was allowed (16 days at 10°C).

Other fumigants and fumigant mixtures

Data on the effectiveness of other fumigants and for fumigant mixtures is insufficient to base recommendations for quarantine treatment on. Almost all studies do not adequately show that larvae in diapause have been tested. An exception is Bell *et al*. (1985) who tested a methyl bromide / methyl chloroform mixture. However methyl chloroform is no longer available, as it is an ozone-depletor.

Controlled atmospheres

Carbon dioxide-based atmospheres (< 70% CO_2) are less effective against Khapra beetle than most other stored product pests, requiring much prolonged exposure for control of diapause larvae. Annis (1987) concluded that 16 days exposure at 80% CO_2 (20-30°C) was required to eliminate Khapra beetle (data of Spratt *et al*. (1985), Verma and Wadhi (1978) and Le Torc'h (1983)).

Low-oxygen atmospheres however appear to be quite effective against Khapra beetle, including eggs and diapause larvae (Verma and Wadhi 1978), requiring the same exposures as other tolerant stored product insect pests. Annis (1987) suggests 0.1% oxygen at 20-29°C for more than 20 days.

High pressure CO_2 may be effective with only brief exposures (a few hours). No data is available to us on effectiveness of the new technique on Khapra beetle.

In summary, some CA treatments are effective against Khapra beetle at exposure periods only slightly longer than required for phosphine. While the difficulties and costs associated with CA application in large structures and containers may limit its use there, small-scale packaging in nitrogen or CO_2 in barrier film packs may be assumed to be fully insecticidal against Khapra beetle inadvertently included, provided temperatures exceed 20°C (no data available below this), exposures exceed 20 days and the atmospheres in the packs do not exceed 1% O_2.

Heat

Heat treatment appears to be a potentially useful technique for quarantine treatment of heat tolerant commodities against Khapra beetle. There is a surprising quantity of data available to substantiate this. Much of it is antique, but of good quality. For instance, Husain (1923) studied heat disinfestation of wheat from Khapra larvae. As expected the resulting temperature/time relationship is of the form typical of heat/time curves shown by many stored product pests (Banks & Rees, 1999).

Overall the data shows that, unexpectedly, Khapra beetle is not the most heat tolerant common stored product pest. Some stages of *R. dominica* are more so (Husain 1923), and heat dosages aimed at complete kill of *R. dominica* can be expected also to eliminate Khapra beetle. This is despite the known unusual tolerance of Khapra beetle to moderately high temperatures, around 41°C, lethal to many species, and its unusually high optimum developmental temperature. Note, however there are some inconsistencies in the data between authors that give rise to some concern and additional studies are required for conclusive development of recommendations.

In summary, most of the available laboratory data show temperatures above 55°C are lethal to all stages of Khapra beetle in less than 15 minutes. However response data for diapause larvae is very limited. The USDA recommendation of 7 minutes at 66°C seems unnecessarily stringent, but may actually include some allowances for time that heat takes to penetrate to the actual target pest through structures, commodities or residues.

It is suggested (Rees & Banks, 1999) that a conservative heat dosage of at least 120 minutes at 55°C at the site of the infestation would be adequate to eliminate Khapra beetle. Due allowance for time to heat the site to the required temperature would need to be added to any specification.

Irradiation

Rees & Banks (1999) refer to many laboratory-based studies on use of irradiation to sterilise Khapra beetle for its control. Most of these studies are directed at adult insects, often not the stage of concern in quarantine treatments.
Studies on effectiveness of irradiation on apparently diapause larvae are not adequate to base a sound assessment on, but they suggest diapause larvae are very tolerant to irradiation at low temperatures (< 20ºC). Data is available in Rahalkar and Nair (1968).

Other

In India, the use of deoiled neem (*Azadirachta indica*) seed powder mixed into wheat seemed to be an effective and cheap method to control the pest in stored wheat (Singh & Kataria, 1986).

RESISTANCE

Resistance to phosphine

While susceptible Khapra beetle, even as diapause larvae, appear to be controllable with standard dosage rate and exposures to phosphine, there is evidence that resistance to phosphine has already developed in this species. Prolonged exposures at substantial phosphine concentrations are required to control the tolerant strains so far identified. There has been no substantial recent survey of resistance levels to phosphine in Khapra beetle. However, judging from the resistance levels in some other species of stored product pest from the Indian subcontinent, resistance levels may be substantial and even to a level to jeopardise achievement of control to quarantine standards by normal high dosages for prolonged periods (eg. 1.0 g m^{-3} for 12 days at 20-30°C as given for *Sitophilus* control by Anon. (1993).

At present there are no data which suggests that any of the resistant strains found to date would not be controlled by '*Sitophilus*' dosages for phosphine. However, the known presence of substantial resistance to phosphine together with the continued widespread poor use of phosphine in some Khapra countries suggests that phosphine is probably not now a fumigant of choice for quarantine use against Khapra beetle.

Introduction of a strain of Khapra beetle tolerant of phosphine into Australia would be a particularly challenging disaster, since phosphine would be one of the most important tools which typically would be used in an eradication or control attempt.

Resistance to methyl bromide

Methyl bromide is not at present used repeatedly and rarely as a fumigant against established Khapra beetle populations. Consequently, presence of other than a natural variation of tolerance to methyl bromide in the field is unlikely. This contrasts with the known situation for phosphine.

Slightly increased levels of tolerance to methyl bromide can be selected for in the laboratory with levels of 2x resistance achieved after many selections (Mordkovich and Sokolov 1992). While this resistance level is low, it would jeopardise control with standard, already high dosages used currently with methyl bromide for quarantine purposes.

BIOLOGICAL CONTROL

Infestations by dermestids are usually controlled by treatments with insecticides. However, insecticides may cause hazards to man and the environment. Especially in the storage of small subsistence farmers in the tropics the use of insecticides may be dangerous and their costs prohibitive. Hence, there is a need for the development of alternative methods such as biological control, an efficient component in integrated pest management. Al-Kirshi *et al.* (1997) considers the potential or the larval parasitoid *Laelius pedatus* (Say) to control the Khapra beetle in cereals. The parasitoid wasp has desirable characteristics to control Khapra beetle. However, the advantages of biological control for Khapra beetle in the high valued grain industries of Australia would be limited.

TECHNICAL INFORMATION FOR PLANNING SURVEYS

General

The entry potential of Khapra beetle is considered to be very high, since the larvae can survive for several years without food. They have a very wide host range, and since they may hide in such diverse items as hessian cloth, crude rubber, wool, vermiculite, timber and cotton waste, the chance of an undetected incursion substantially increases. Asia, the Middle East and African countries are high risk regions and considered to be endemic for Khapra beetle. Establishment potential is considered to be potentially high, since the climate, especially under bulk storage conditions, are suitable for Khpra beetle, and detection may go unnoticed in instances where the continuous identification in the presence of Warehouse beetle is not practised.

Trapping

Trapping is used to monitor the presence of Khapra beetle in warehouses and other storage facilities. In Russia, traps with maize or wheat have been used (Saplina, 1984) and gave better records than visual observations. A trap has been developed for USDA/PPQ (OEPP/EPPO,1981) which combines a feeding attractant for larvae and a pheromone for adult males (Barak, 1989).

A complete survey protocol whereby the absence or presence of *Trogoderma* spp. (not Khapra beetle specific) can be verified, has been drawn up for Western Australia (Poole, 1999). The method consists of using sticky traps and a pheromone lure Biolurehttp://www.insectslimited.com/wbkbbiol. . However, these traps are placed in a suspended position, and therefore only flying *Trogoderma* are trapped. With the non flying Khapra beetle not being able to enter suspended traps, such traps show only the presence of other *Trogoderma* spp., results which may then be used to derive some estimates on Khapra catches in wall mounted traps. This information would be particularly useful, since (as mentioned before) distinguishing between Warehouse and Khapra beetle is a difficult and time-consuming task. As for targeted surveillance, the suspended trap can thus be used as an indicator of other *Trogoderma* spp., but any reference to Khapra beetle specific traps, implies the use of the ***wall mountable*** type, better known as the Biolure box trap.

Once Khapra beetle has been found, adjacent areas as well as areas suspect of being on the continued pathway (see next section) should be identified for targeted surveillance. Such surveillance needs to be auditable/quantifiable and designed in order to meet the standards as set by the trading partners. Results should be thoroughly data-based, and substituted with clear mapping of all Trogoderma catches. See APHIS (1984) for the survey procedures used in the United States Action Plan.

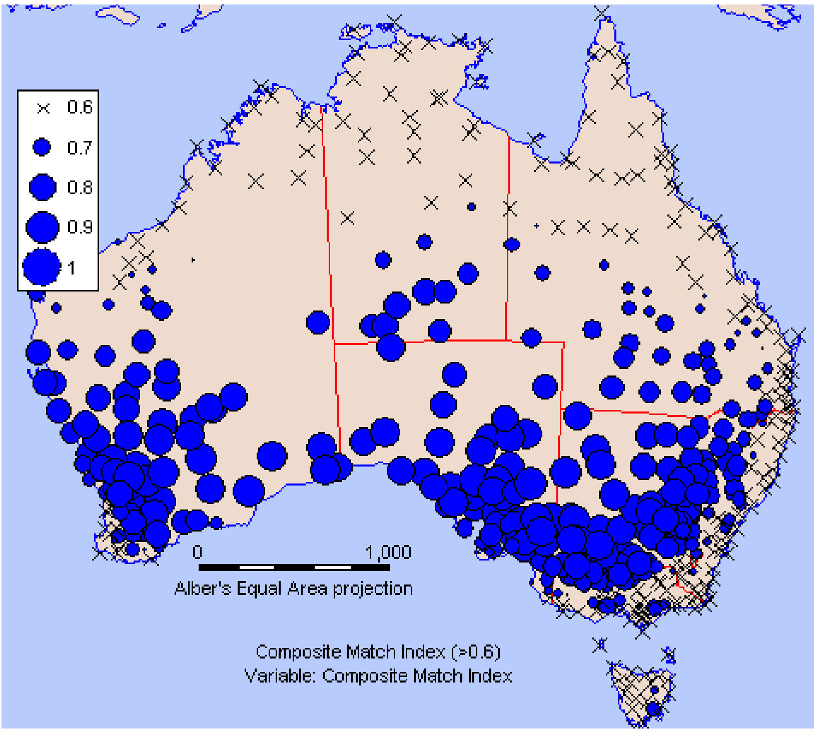
CURRENT DISTRIBUTION

It is very important to distinguish between records which relate to introductions and those of established infestations. Khapra beetle is established within an area broadly limited north by the 35° parallel, south by the Equator, west by West Africa and east by Myanmar; i.e. the warm dry regions along the Suez route from the Indian subcontinent to Europe. Khapra beetle has been introduced into areas of similar climatic conditions elsewhere, especially the alternative route between India and Europe around Africa. Initially, these introductions caused severe damage but outbreaks have been local and have, in most cases, been eradicated. In general, Khapra beetle is only successful in competition with other major stored product pests in conditions of low humidity. It has also established in some areas of unfavourable climate, in protected environments only, for example in Western Europe and Japan. (OEPP/EPPO,1981).

Khapra beetle is a native of the Oriental region, but has become established in a number of Asian, Middle East and African countries, as well as some European countries. In the USA a Khapra beetle infestation in 1954 resulted in a successful eradication program (Dillon, 1968). The USDA now regulates the importation of certain items from 25 countries.

Potential distribution in Australia

Khapra beetle is typically a pest of hot, dry climates or of commodities stored elsewhere in hot dry conditions. Banks (1977) showed that much of the interior of Australia, including some grain growing areas provide suitable conditions for this pest. Coastal population centres with the exception of Adelaide appear unsuitable. Given the localities where it has established elsewhere, it is likely that Khapra may also get a foothold in Western Australia, especially in areas such as Dalwallinu, Mullewa and Southern Cross. While bulk grain is usually unloaded and inspected at a few coastal ports at probably relatively low risk, full container lots (FCLs) and less than container lots (LCLs) could land up just about anywhere. Observations on environmental suitability are based on ambient weather conditions. Actual conditions in a grain bulk or store may be quite different. The spread and rapid establishment of Khapra beetle in the south west USA, provides a warning about the potential of the pest and the cost and difficulty of getting rid of it (Rees & Banks, 1999). Larvae tend to be gregarious and large numbers together can cause the commodity to heat, further assisting their rate of development. Regarding Western Australia, studies by Howe (1958) indicated how interspecific competition may lead to eg. Khapra beetle and *Rhyzopertha dominica* being the dominant species in a climatic region such as Merredin, whilst *Sitophilus granarius* may be dominant in Fremantle.



Potential distribution of Khapra beetle based on using the "Match climates" function in CLIMEX (Sutherst *et al*., 1999) and the occurrence of Khapra beetle in in the south-west of USA.

Dispersal

The natural spread of this pest can be considered as limited. Adults are short-lived and do not fly. Small larvae, being light and hairy, may be blown about in the wind. Both adults and larvae can walk limited distances (Rees & Banks, 1999).

Khapra beetle is readily transported with agricultural products in packaging (especially second hand bags), shipping containers, vessels, or vehicles carrying agricultural produce. Some larvae may hitch a lift on birds, rodents or farm animals, but it is transportation by humans (also on clothing) that allows them to cover long distances quickly (Rees & Banks, 1999).

RISK MITIGATION PROTOCOLS THROUGH DEVELOPMENT OF QUARANTINE ZONES AND MOVEMENT CONTROLS

National strategy for Australia

Khapra beetle is considered a QPA (Quarantine Pest Australia). Agricultural produce from countries where Khapra beetle is established require careful inspection, and in some cases mandatory fumigation. It is important to evaluate possibilities for improvements in Post Entry Quarantine (PEQ).

State and Territory actions for Australia

Identify possible weaknesses and recommend improvements in the frequency of trapping grids for Khapra beetle. For Western Australia the Department of Agriculture in 2000 identified the most likely pathways, simultaneously valuing the importance by suggesting the number of wall mountable traps (BioLure box traps) to be used.

Phytosanitary risk elsewhere

Khapra beetle is an A2 quarantine organism for EPPO (OEPP/EPPO, 1981), and is also of quarantine concern for CPPC, COSAVE, JUNAC, NAPPO and OIRSA. The continued occurrence of Khapra beetle on produce imported from countries where it is indigenous, and the potential for spread due to increasing use of dry cargo containers and roll-on roll-off road transport, make it a continued threat to EPPO countries. This not only applies to the risk of establishment in heated buildings in areas of unfavourable climate, but also to parts of Greece, Italy, Spain and Russia on the fringes of the natural range, where it is not known to be established. A minimum period of 4 months with an average temperature of 20°C is considered necessary for Khapra beetle to be a pest. Although EPPO does not in general consider pests of stored products to be quarantine pests, because of the ease with which they are spread around the world and their ability to survive in protected storage environments, an exception is made in the case of Khapra beetle. In addition, it should be recalled that other continents take severe measures against Khapra beetle; the presence of the pest in an EPPO country would be a significant additional constraint to its exports (OEPP/EPPO,1981).

Phytosanitary measures elsewhere

EPPO recommends (OEPP/EPPO, 1990) that it is preferable not to require a phytosanitary certificate for stored products, but rather to inspect consignments on import and take appropriate post-entry action, for example treatment following EPPO Quarantine Procedures Nos 12 or 18 (OEPP/EPPO, 1982; 1984).

ERADICATION

Feasibility

Given the total farm value of commodities which have been described as suitable for Khapra beetle, it is likely that it would be feasible to spend at least a few million dollars on eradication. Eradication has been shown to be a viable option in U.S.A. and Mexico (see "The Americas" in Rees & Banks, 1999). Surveys in grain warehouses in 1954 and early 1955 revealed infestations at at least 151 sites in 23 counties in the three states California, Arizona and New Mexico. These Khapra beetle infestations were eradicated by 1966 at a cost of over US$11 million (Pasek, 1998). Surveillance should be viewed as a pre-emptive venture needed to lessen costs at the stage when an incursion materialises. When an infestation is found at an early stage and when only one or a few localities are found to be infested, the eradication campaign would be similarly less expensive.

Eradication Program

The reader is referred to the section on ***Chemical control Measures***. Besides immediate quarantine to prevent further spread, fumigation with methyl bromide at a rate of 2.4 kg per hundred cubic metres, applied as a hot gas, injected from several points outside the building and diverted to points within the building/ infested material (Dillon, 1968) would probably still be the best control option. The usual treatments for rats and common pests do not kill Khapra beetles, because the pest is extremely resistant to normal dosages of fumigants. Dosage rate and duration of fumigation would vary with temperature.

Other possibilities towards eradication include combinations of phosphine and methyl bromide, treatment with specific controlled atmospheres at temperatures above 20°C, cold & heat treatment, and irradiation (Rees & Banks, 1999).

See APHIS (1984) for the eradication procedures used in the United States Action Plan.

TECHNICAL DEBRIEF AND ANALYSIS FOR STAND DOWN

When an incursion response and related cost sharing activities are terminated, certain generic procedures need to be followed. These are described in Merriman and McKirdy (2005). The debriefing report would vary depending on the reasons for stand down, and will need to reflect the changed status of action. In addition to the preparation of an appropriate debriefing report in relation to operational issues, the technical issues that need to be evaluated in the event of an eradication attempt being unsuccessful include;

Containment of the infestation

If a delimiting survey properly identifies those areas infested with Khapra beetle then the aim should be to contain the pest. It also means that whenever an infestation is found, infested properties should be placed under immediate quarantine. In WA a containment strategy is followed for the Warehouse beetle. This approach was chosen because an extensive survey showed that the warehouse beetle was already established over too wide an area to allow eradication to be a practicable option. By 1993 Warehouse beetle was found to be present in Perth, Pithara, Carnamah, Corow, Wongan Hills, Dalwallinu, Three Springs, Goomaling, Northam, Clackline, Kellerberrin, Williams and Wickepin. For Warehouse beetle the Agricultural Protection Board (APB) and Department of Agriculture's Program Evaluation Unit (PREVU) did a Benefit: Cost analysis which indicated that the total cost of a containment campaign over thirty years at 1994 dollar values amounted to approximately A$4.7 m (Butcher& Dean, 1995). Since Khapra beetle does not fly, and the climate in WA is far from ideal for optimum development, it is foreseen that a containment strategy would have some value.

Research on control options

The reader is referred to the section on ***Chemical control Measures***. For Australia Rees & Banks (1999) have thoroughly addressed the presently available and known control options for the near future.

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