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## PALM PROTECT Report Summary

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### Final Report Summary - PALM PROTECT (Strategies for the eradication and containment of the invasive pests *Rhynchophorus ferrugineus* Olivier and *Paysandisia archon* Burmeister)

#### Executive Summary:

Palm protect aimed to develop methods for the early detection, control and containment of the the red palm weevil *Rhynchophorus ferrugineus* and the palm borer moth *Paysandisia archon* for use at origin, point of entry, in transit and on-site. Both these invasive pests are a major problem around the Mediterranean region and have been responsible for the loss of over 100 000 palm trees with estimated annual costs of several hundred million euros since their introduction into Europe.

Palm Protect has provided a comprehensive understanding of the biology of *R. ferrugineus* and *P. archon*. The relationships between pest species, host palm species, climate and the dispersal capabilities of these pests have been established. Important odorants and vision properties that contribute to, or disturb mate and host plant finding, as well as the parasitoids that are able to infest *P. archon* have been identified. This data, together with a critical overview of previous work, has contributed toward the development of new, improved and original tools for the detection and control within the project and for the stakeholder community.

Palm Protect developed detection techniques for use at trade points and open areas. For detection of individual palms in quarantine/at trade point two protocols were successfully demonstrated based on olfaction and acoustics. Dogs were trained to detect infestations of both the red palm weevil and the palm borer moth, the accuracy of detection was high, but dependent on the palm host. Acoustic monitoring was able to detect *R. ferrugineus* larvae inside young palms shortly after infestation, and long before any visual symptoms appear.

In open areas the use of attractants and traps and a location aware/decision support system were developed. Baited traps were found to be useful as a monitoring tool for *R. ferrugineus*, and the within the project the best trap (Picusan®) was selected as well as the optimal lure and trap distribution in both palm plantations and urban areas. A location aware system (CPLAS) and decision support was developed for use in urban and agricultural areas. This is a useful tool for the management of red palm weevil, providing information and classification of on infestations symptoms, risk assessment and control recommendations.

Control methods for quarantine treatment of palms in transit and in the field were developed. All live stages of *R. ferrugineus* were killed with aluminium phosphide, a treatment that could be easily applied in sealed containers used to prepare and ship palms overseas.

An injection device specifically for palm trees that quickly and efficiently delivers insecticide into the palm's trunk with minimal damage to palm tissues was developed and used in the assessment of the mobility and persistence of pesticides in palms. Stipe injection resulted in better distribution and higher persistence of pesticide compared with frond injection and, especially crown spraying, suggesting that stipe injection could be a good alternative for the control of *R. ferrugineus*.

Different strains of entomopathogenic fungi from *R. ferrugineus* and *P. archon* from around the Mediteranean basin were identified. Using laboratory, semi-field, and field assays for one of these strains from *Beauveria bassiana* have demonstrated the enormous potential that entomopathogenic microorganisms have for controlling these palm pests.

Semiochemical-based control methods included mass trapping and attract and infect precedures, using a Picusan® trap and emtomopathogenic fungi. In field trials, the attract and infect device was found to be more effective at protecting palms than trapping alone.

Palm Protect also evaluated risks and impacts of *R. ferrugineus* and *P. archon*. A model has been developed to compare the spread and impact of the red palm weevil under current management measures with the projected spread and impact using new control and management measures developed within the project.

#### Project Context and Objectives:

*Rhynchophorus ferrugineus* and *Paysandisia archon*, invasive pests of palm trees

Palm trees in EU Member States are under serious threat from the red palm weevil, and the palm borer moth, two invasive species that have been accidentally introduced into Europe through the import of infested palm trees. The larvae of both these insects bore into palm trees and feed on the succulent plant material of stems and/or leaves. The resulting damage is often only visible long after infestation, and by the time the first symptoms of the attack appear, they are so serious that, in the case of *R. ferrugineus*, they generally result in the death of the tree. The red palm weevil is native to southern Asia and Melanesia, and is reported to attack more than 20 species of palms worldwide, including date (*Phoenix dactylifera*), and coconut (*Cocos nucifera*) palms, as well as the Mediterranean fan palm (*Chamaerops humilis*), a native European palm, which is protected in some regions of Spain [1-6].



#### a. The red palm weevil

Since its first detection in Spain [7], where it was believed to have arrived with date palms imported from Egypt, *R. ferrugineus* has spread along the coastal fringe of the Mediterranean basin, where it is particularly prevalent, and through the Canary Islands. It is now present in every EU Member State where susceptible palm trees are grown outdoors [3]. This pest is also spreading world-wide; and is now a major pest in the Middle Eastern region, Asia, regions of Oceania and North Africa, the Caribbean, and North America [3, 8, 9, 10].

Many preventative and curative procedures have been implemented with variable degrees of success to eradicate and contain *R. ferrugineus* [2], but these have been hampered by environmental concerns relating to the use of pesticides and legislation restricting their use (EU directive 91/414) [11]. Furthermore, the larva, which is the destructive stage of this insect, is concealed within the palm tree, thereby limiting effective delivery of pesticides, often resulting in their frequent and prolonged applications [12].

All EU Member States are required to take protective measures against the introduction and spread into the Community of harmful organisms, such as *R. ferrugineus*, as described in Article 16(2) of Directive 2000/29/EC [14].

The high rate of spread of *R. ferrugineus* is most likely due to a combination of factors that have resulted in the inadequate eradication and containment of this weevil, including the lack of effective early detection methods, and the transportation of infested date palms from contaminated to clean areas have had a major impact.

In 1996, in response to the appearance of *R. ferrugineus* in the south of Spain, the Spanish government banned the import of palms from countries where Rhynchophorus spp had been recorded. This was partially successful up until 2000 when restrictions to palm movement were partially lifted, leading to massive imports of infested palms and a massive spread of *R. ferrugineus* into other regions of the country [13]. By 2007 the spread of this invasive pest had become uncontrollable, which resulted in the adoption of emergency measures [15] by the Commission to prevent its further introduction and spread [15]. These measures included the restricted import and movement of susceptible palms, the establishment of demarcated areas, official annual surveys for the presence of *R. ferrugineus* or evidence of infestation on plants of the Palmae family and provide notification to the Commission and other Member States.

Of the Member States, Italy and Spain are the worst affected by the red palm weevil, accounting for ca. 90% of the total number of outbreaks reported. The red palm weevil is also prevalent in France with the number of recorded damaged palms trees rising from 80 in 2006 (year of first detection) to over 1000 in 2010 [16].

Although reports of infested imported palms declined after the introduction of emergency measures to combat *R. ferrugineus*, further policy changes have since been made by the Commission [31] for a variety of reasons:

- The application of measures of Decision 2007/365/EC were not fully effective against *R. ferrugineus*.
- Additional species of Palmae were found to be susceptible.
- New recommendations on methods for control, containment and eradication of *R. ferrugineus* from a Commission Expert Working Group, comprising experts from Member States, which met in January 2010, and from the International Conference on Red Palm Weevil Control Strategy for Europe, held in Valencia, Spain, May 2010.
- Evidence suggests that the spread of *R. ferrugineus* through the import of susceptible plants from third countries could not be adequately mitigated by current preventative treatments, especially from susceptible plants which are infested but show no symptoms.

The working group and conference highlighted the serious situation of *R. ferrugineus* in the European Union and the need for further action against this invasive pest:

- Eradication of *R. ferrugineus* in many areas is unlikely, containment is more realistic.
- Strict compulsory eradication measures for first outbreaks of *R. ferrugineus* in non-infested areas should be a priority.
- Better enforcement of EU legislation for intra-community trade and imports from third countries is required to prevent further spread of *R. ferrugineus* within EU member states.
- There is a necessity for research and development of programmes focused on the early detection, control and eradication of the red palm weevil.

A successful eradication programme of the red palm weevil was undertaken in the Canary Islands to protect the native *P. canariensis* after this insect was detected in the resorts of Fuerteventura and Gran Canaria in 2005. This included a ban on the importation of any palms from outside the Islands and a programme of work including monitoring for the pest; inspection of palm trees and nurseries; accreditations for transplants and movement of palm trees; elimination of infected trees; plant health treatments and mass trapping; and an awareness campaign including a web site; talks and seminars, and courses, newsletters and leaflets. In 2007 an outbreak was reported on Tenerife, but since 2008 no additional weevils have been detected [17, 18].

#### b. The palm borer moth

The palm borer moth *P. archon*, native to South America, was first reported in Europe in France and Spain in 2001, but is believed to have been introduced before 1995 on Palm trees imported from Argentina. It has since spread to other EU member states (Italy, Greece, Cyprus) with isolated reports in the UK, Bulgaria, Denmark, Slovenia and Switzerland, on Palms imported from Spain and Italy [19-23]. This pest appears to have a large host range, including the native Mediterranean fan palm which is very susceptible to *P. archon* attack. Although *P. archon* has not been reported to be a significant pest in South America, with the exception of reports from Buenos Aires [24], and rarely kills date or canary palms, it has been the cause of serious damage and plant mortalities, mainly in ornamental Palm nurseries, in France, Italy and Spain [19, 25]. It may also increase the risk of *R. ferrugineus* spread by creating primary damage to palm trees, which will attract the weevil. In the absence of suitable control methods, this insect presents a risk, particularly to nursery and amenity palms throughout the Mediterranean region. In 2009 the Commission recommended measures to limit the further spread of this invasive species within the community [14].

#### Impact of *Rhynchophorus ferrugineus* and *Paysandisia archon*

There is little information on the socio-economic impact of *R. ferrugineus* and *P. archon* in Europe, but the effects of these pests and the measures required to eradicate and control them are having significant, and potentially devastating, impacts on the palm tree populations and landscape in the Mediterranean basin. In southern Europe, exotic palm trees have become an essential component of the Mediterranean urban landscape. They are planted in large numbers for ornamental purposes along streets, in public parks, golf courses, hotel grounds and in private gardens. There is also great concern that the native palms, *P. canariensis* and *P. theophrasti* of the Canary Islands and Crete respectively, as well as palm groves such as those of Elche in Spain, a UNESCO World heritage site, will eventually succumb to infestations of these pests. These are important for tourism, as are the palm trees on the French Riviera and on the Italian Adriatic coast (Palm Riviera). In addition, a number of palm plantations, primarily the date palm, including those of Elche, and the numerous nurseries throughout the Mediterranean basin that supply exotic palms, are of great economic value. In Spain alone, over 50,000 palm trees have been destroyed in the fight against the red palm weevil between 1996-2010 and > 90% of these occurred between 2005 and 2010 [26]. However, the eradication and control of *R. ferrugineus* (and *P. archon*), especially over large areas, is hampered by the huge costs required and budget limitations, which are compounded by the difficulties in the eradication on private properties, resulting in re-infestation of "cleaned" areas.

The key aspects of protective measures against *R. ferrugineus* and *P. archon* are to:

- Rapidly and accurately detect these invasive pests in imported Palms, or Palms being moved within the Community.
- Rapidly detect new infested areas.
- Take appropriate measures to eradicate the pests.
- Take appropriate actions to contain and control the pests within areas where eradication is unlikely, to prevent further spread within the Community.

However, these invasive pests pose significant threats because:

- One or both of these pests are already present where susceptible palms are grown.
- *R. ferrugineus* appears to be spreading uncontrolled.
- Previous measures have proved insufficient and often ineffective.
- There are difficulties in eradicating in "uncontrolled" areas such as private gardens.
- Re-infestation of "clean" areas can occur due to a single untreated palm tree.
- Infestations in some rural areas may be undetected.
- Continued import of palms from third countries which themselves have *R. ferrugineus* and *P. archon* infestations.
- The expansion of the EU adding new border countries.
- The impact of climate change on the range of these invasive species and their host palm trees.

Although there are no specific studies on the economic impact of the problems due to *R. ferrugineus* or *P. archon*, *R. ferrugineus* has had an economic pest on coconut and sago palms for > 1 century [2]. Estimates place annual losses due to these invasive species in the multi-billion Euro range. The direct costs include the value of the destroyed trees and their potential (date) crops, the cost of trapping and other quarantine methods, and the huge budgets allocated to the various chemical treatments. The indirect costs are also substantial. The most significant of these is the restricted movement of trees, resulting in drastic cuts in trading not only among countries but also between different regions of the same country.

In Spain, one of the worst affected Member States, the region of Murcia has spent €7M on various measures to combat *R. ferrugineus*, mainly on the removal of infested trees. From 2004 – 2009, in the Autonomous Community of Valencia, around 20,000 palms, mostly *P. canariensis*, have been killed by *R. ferrugineus*, with an estimated cost of €800 per tree [27]. Similar scenarios have been reported all around the Mediterranean basin, including an estimated €27M in the Valencia region on eradication and control measures, over this same period [28]. It is estimated that more than €45M has been spent on the eradication and control of *R. ferrugineus*, since it was first detected in Spain, as a whole. Most of this spend (> 95%) has been incurred during the last 5 years. Up until now, the eradication programme enforced in infested areas in Spain has only been successful in the Canary Islands, where in 2010, the first areas were declared pest free after 3 years of not detecting any infested palms and no captures of *R. ferrugineus* in traps.

In Israel, dates are one of the most economically important crops. It is estimated that there are 4,000- 4,500 hectares of date palm plantations, comprising around 500,000 trees, producing 27,000 tons of fruit per year, as well as more than 2,000 hectares of ornamental palms, which are under threat from *R. ferrugineus* [29]. The sale and export of palms and dates for 2009 produced an income of over €118M.

In central Italy, *P. archon* infestation rates of sampled young potted *C. humilis* ranged from 25% to 98%, and 25% to 54% on sampled lots of *C. humilis* crops, whereas infestation of *P. canariensis* crops is approximately 24% (Riolo et al., pers. comm).

The impact of these pests is a worldwide problem, for example palm trees are of huge economic importance in the USA, where *R. ferrugineus* has first detected in 2011. In 2007, the gross sales for palms from nurseries in the USA were \$203 M, predominantly in Florida (\$127 M) and in California (\$70 M). The USA date palm production encompasses about 3,200 hectares, primarily in California and Arizona, and date palms are also an important part of the landscape in tourist areas of the southern USA [30].

Clearly, the economic impact of *R. ferrugineus* (and *P. archon*) infestations to palms around the world is devastating.

Despite EU legislation and measures taken to eradicate and contain these invasive pests, *R. ferrugineus* remains the most damaging pest of palm trees, and *P. archon* has become established in the Mediterranean basin. The main options for the eradication, control and containment of these quarantine insects are through integrated pest management, relying on innovative early detection, effective mass and monitoring trapping, preventative and curative treatments, alongside quarantine and education procedures.

#### **Palm Protect**

The EU project Palm Protect (strategies for the eradication and containment of the invasive pests *Rhynchophorus ferrugineus* Olivier and *Paysandisia archon* Burmeister) was commissioned to develop reliable methods for the early detection, eradication, control and containment of the red palm weevil and the palm borer moth through, thereby helping to minimise the economic and environmental impact of these pests through:

- providing a more comprehensive understanding of the biology of *R. ferrugineus* and *P. archon* to facilitate decision making for risk assessment and optimisation of monitoring and control methods.
- combating the spread and establishment of *R. ferrugineus* and *P. archon* by the development of technologies for the early detection and monitoring of these pests.
- developing methods to eradicate, control and contain *R. ferrugineus* and *P. archon*, to restrict their further invasion of EU territories.
- Valuing what is at risk and estimating impacts

#### References

Available as a separate attachment.

#### Project Results:

Figures and table listed in this report are available as a separate attachment.

#### **Biology of *Rhynchophorus ferrugineus* and *Paysandisia archon***

For the biology of the red palm weevil (*Rhynchophorus ferrugineus*) and the palm borer (*Paysandisia archon*) the aims were to determine:

1. the capacity of adults for dispersal
2. the duration of the life cycles and the host palm tree range
3. the new key-odorant molecules that trigger the olfactory-guided behaviours
4. the natural enemies that feed on *P. archon* under European environmental conditions to support decision making for risk assessment, improvement and optimisation of monitoring and control means, and regulation

Experimental results produced by Palm Protect have provided additional knowledge about the biology of *R. ferrugineus* and *P. archon*. The traits of their life histories that made them able to successfully invade the European-Mediterranean region, in spite of earlier actions and regulations to eradicate and control them, have been documented. Previous data available at the beginning of the project was collated to provide a comprehensive analysis of their biology. Palm protect established the quantitative relationships between pest species, host palm species, climate and the dispersal capabilities of these pests. It also identified some important odorants and vision properties that contribute to, or disturb mate and host plant finding, as well as the parasitoids that are able to parasitize *P. archon*. A critical overview of the available data was provided that contributed toward the development of new, improved and original tools for the detection and control within the project and for the stakeholder community. The main outcomes in relation to the biology of *R. ferrugineus* and *P. archon* are described below.

#### **1. Capacity of adults for dispersal under European-Mediterranean conditions**

Various technologies to track and measure flight of both palm borer pests, under closed semi-field or open field conditions, were used and evaluated, including electronic micro-transmitters and portable detectors, active tags and passive radio-frequency identification (Figure 1). The flight performances of wild *P. archon* and *R. ferrugineus* were also evaluated in the laboratory using flight mills with tethered insects (Figure 2), to compare sexes as well as virgin and mated individuals and correlated to the risk for their dispersal and spread.

#### a. Palm Borer Moth

The flight capability greatly varied from one individual to another. Overall females flew longer distances than males and virgin individuals tended to fly longer than mated ones. Using flight mills, most flights covered a distance of 50 - 200 metres, but the longest flight recorded was 2.9 km. Using radio-tracking (open field) most tagged females flew more than 500 metres and could not be recovered within the 30-hectare experimental area. Males never moved beyond a 4 hectare area and 250 metres during their life. Most flights were observed above 28°C and at the highest illumination, around midday. Considering the short life span of *P. archon* and its relatively low fecundity, the risk posed by this pest due to its dispersal capability appears limited, when compared to its large size and the apparent strength of its flight.

#### b. Red Palm Weevil

The adult red palm weevil demonstrated a significant dispersal capability. Flight was very variable between individuals and although females were significantly (~10%) larger than males, size did not correlate to flight performance. In contrast, age was strongly correlated to frequency of flight, which occurred from 2-97 days of age, with 96% of flights being undertaken by 13-19 day old adults. Weevils aged up to 2 months could cover a distance of 10 km within a single flight, and 20% of weevils were still able to perform long flights after 2 months of age. On average, males flew as many times, as long and covered the same distances as females. Overall, 41% of flying individuals were able to cover a mean distance of 5 to 10 km per flight. One individual flew 48 km in a single flight and one covered a distance of 250 km during its life. Mated males performed more flights and flew longer distances than virgin ones, which together with a longer life than females, make them an overlooked risk as they can signal palms to other weevils by the pheromone they emit. Over a 2 year period under semi-natural conditions (green-house) the movement and flight behaviour of *R. ferrugineus* was monitored using automated video recordings and was compared to climate conditions (temperature, humidity and illumination). Adult *R. ferrugineus* did not move below 15°C. Walking movement increased from 16.5 to 38°C, then dramatically decreased to almost nil at 44°C, with optimum walking between 34 to 38°C. Flight occurred within a narrower window; spontaneous take-off was observed over the temperature range from 18.5 to 42°C, with maximum flight activity occurring between 30 and 34°C. These data were in agreement with measures made of the speed of vision, which is highly correlated to the thermal optimum in insects, and with literature reports for flight based on pheromone traps from the Middle-East and the Mediterranean regions.

### 2. To assess the duration of the life cycles of *R. ferrugineus* and *P. archon* and their palm tree host range under European environmental conditions

#### a. Host range

Regional and international literature was reviewed and local surveys, together with experimental assays, were undertaken to determine the susceptibility of important palm species (e.g. the Canary Islands date palm *Phoenix canariensis*, the Mexican Fan Palm *Washingtonia robusta*, the Cretan date palm *Phoenix theophrasti*, and the Mediterranean Fan Palm *Chamaerops humilis*) to these two pests. For example, *P. canariensis*, is the palm species by far the most susceptible to *R. ferrugineus* in the Mediterranean. By comparison *P. theophrasti*, although susceptible, was not as readily infested and larval development within this palm was slower. Hence the risk to *P. theophrasti* is moderate and the *R. ferrugineus* infestation in this palm is easier to detect and control.

Surveys and choice experiments conducted in France and Italy showed that *P. archon* most readily infests and damages *C. humilis*, *Trachycarpus fortunei* (windmill palm) and *W. robusta*. However, larvae tended to develop more efficiently and rapidly on *P. canariensis* as compared to the other species, where development rates were similar. In other choice assays, gravid females were attracted to *T. fortunei* and *P. canariensis*. Virgin females preferred to land on the fronds while the mated ones preferred the stem where they lay eggs, and females did not avoid palm where eggs had previously been deposited. The odours from the leaves are currently being analysed to identify the attractive compound(s).

However, it is clear that none of the palm species abundant in the Mediterranean landscape are resistant to either *R. ferrugineus* or *P. archon*. The Canary Islands date palm (*P. canariensis*) is by far the most attacked and killed palm species by *R. ferrugineus* and is also attacked by *P. archon*. In Eastern and Southern Mediterranean the date palm, *Phoenix dactylifera*, is severely attacked and killed by *R. ferrugineus*, whereas *T. fortunei* and *C. humilis* are not attacked by *R. ferrugineus*, but they are severely attacked and killed by *P. archon*. The two *Washingtonia* species (*W. filifera* and *W. robusta*) are attacked and killed by both pests though they possess obvious defence mechanisms against the insects. It is likely that attacks, especially by *R. ferrugineus* are favoured by injury, which aids egg-laying, and *P. archon* damage can attract *R. ferrugineus* which is seeking such damage to lay eggs. There are many other palm species, which are rare in the Mediterranean, but found in parks and gardens (e.g. *Jubaea chilensis*, the Chilean Coconut palm) and which are also susceptible to *R. ferrugineus*. Hence the risk to almost all palm species in the Mediterranean is high. There is no reliable evidence of a plant other than a palm being a host for either pest species.

#### b. Survivorship capacities and fecundity of *R. ferrugineus* exposed to winter conditions

Virgin weevils were exposed to conditions that mimicked Mediterranean winters and compared to normal control temperatures (27°C). Mortality, feeding and mating activities were recorded weekly and eggs, larvae, pupae and adults produced were monitored. Compared to normal control conditions, chill (winter) temperature (15°C) reduced fecundity/fertility by at least 50%, but survival increased. This was attributed to the cold period delayed aging proportionally with the duration of chilling; for example over a 32 week period the half survival time was 275 days at 15°C compared to 81 & 120 days for females and males respectively at 27°C. Weevils fed and slightly moved at 15°C and some females remained fertile even after 7 months at this temperature. Between 15 and 10°C *R. ferrugineus* stopped feeding and did not mate, which reduced longevity and fertility, especially if exposed to periods of 1 month at 10°C. Pupae were very sensitive to low temperatures; adults only emerged from 4% of pupae that had been exposed to 5°C for 2 weeks.

#### c. Recording/modelling of the thermal differences between the inside of the palm stem and the surrounding air

Insect development depends on temperature. As both palm pests are borers and can live deep in the palm tissues, they are particularly well protected against extremes and fluctuations in temperature during both the summer and winter periods. To accurately use ambient temperature to predict population dynamics with a development model, the buffer effect on internal temperatures of palm tissues and the possible impact of feeding larvae causing local heating due to fermentation of chewed tissues, must be taken into consideration. Over a two year period the internal and external temperatures of infested date palms in Egypt and healthy Canary Islands date palms in the South of France, were simultaneously recorded using electronic loggers.

In the healthy Canary Islands date palms over a one year period, temperatures recorded 25 cm inside living tissues where larvae would normally develop, were on average 2°C higher than ambient temperature measured. The inner temperature was directly dependent on, and could be accurately predicted from, the air temperature measured over a preceding 10 day period. In the drying, more external tissues, the inner temperature followed the same pattern as ambient temperature, but the buffer effect was lower (0.5°C on an average over 1 year). In autumn the air temperature was lower than that inside the palm, whereas in spring air temperature was warmer.

In date palms in Egypt, internal temperatures were approximately 2.0 to 4.5°C greater in infested than healthy palms depending on the season and the level of infestation.

This information, coupled to the determination of the thermal thresholds and optima for flight and mortality, enables standard meteorological data based on air temperatures to be used in a model to predict emergence and flight probability of the red palm weevil. These parameters are currently being compared to actual available information for validation.

### 3. New key odorant molecules that modulate the major olfactory guided behaviours and vision

Semiochemicals are important tools for pest management, either for luring the pests to traps, or for disrupting mate or host plant location. New semiochemicals were identified and their effects against both palm borers were evaluated. As vision interacts with olfaction to contribute to optimal behavioural responses, its properties were investigated for the development of visual lures.

#### a. Pheromone systems in the Palm Borer Moth

Conflicting data were available about the existence of pheromones in *P. archon*. Comprehensive morphological, electrophysiological and behavioural studies were used to clarify whether this moth produced a female sex pheromone in common with most moth species.

#### Female sex pheromone

Thorough studies of the morphology and organisation of the ovipositor and of the antennae of both sexes were carried out by light, scanning and electron microscopy.

Ovipositor preparations did not show any aperture or projection in the outer cuticle at the intersegmental membranes. Furthermore, none of the associated epidermal cells, or those of neighbouring tissues, exhibited the shape and organisation of the cells typical of a pheromone gland.

The antenna of *P. archon* is thin and club-shaped without any evident sexual dimorphism except for club size. Based on the comprehensive description of the external morphology and organisation, and of the sensillum (sensory hairs) equipment, the antenna appeared very similar to that found in butterflies (Papilionoidea and Hesperioidea). Overall no sexual dimorphism was observed, and of particular note was the absence of any morphological differences in the sensory organs (sensilla trichoidea), that are used to detect the female sex pheromone by male moths.

Behavioural bioassays carried out in a large screened cage with virgin moths that had their antennae removed so they could not detect smell, showed that *P. archon* could find a mate and copulate. Attraction to and copulation attempts with dummy adults by intact adults were also observed, although in lesser numbers than with live *P. archon*. Airborne volatile collected from females and solvent extracts of the ovipositor, legs and wings of both sexes were prepared and evaluated by gas chromatography coupled to electroantennograph (EAG) recordings (which measures the response of the antennal olfactory glands to volatiles), but no compound tested triggered a response. It would therefore appear that long distance mate location for copulation is not dependent on olfaction.

Overall the data collected from *P. archon* definitively showed the absence of a female sex pheromone gland that is typical of moths. This result agrees with the absence of a dimorphic olfactory system, which together with the vision properties (see below), imply that *P. archon* is closer to a butterfly, where vision plays an important role in mate location, than to a moth. However, recent open field and large wind tunnel assays carried out in France nevertheless do support the existence of a long range chemical sex attractant. The mate location system of *P. archon* therefore is not yet fully elucidated, but likely relies on unusual properties, including pheromones.

#### Male sex pheromone

Previous studies based on EAG recordings reported that males produce a pheromone in the tarsal androconia of the mid-legs, which is detected by female antennae. This chemical has a molecular structure like other moths' (Cossidoidea and Sesidoidea) female sex pheromones. It was found to attract virgin females in the vicinity of males. However, experiments carried out in Palm Protect using synthetic pheromone showed that this chemical did not have long-range attraction for females, hence its potential for pest monitoring appears weak.

#### b. Palm kairomones and pheromone synergists for *R. ferrugineus*

Optimal pheromone trapping of *R. ferrugineus* relies on the interaction/synergy between the aggregation pheromone (main component: ferrugineol) and natural compounds emitted by the host palms or plant material. Ethyl acetate has previously been shown to enhance pheromone attraction, but is not as effective as natural odours from palms which synergise the pheromone response. More than 100 volatiles emitted by various tissues (green leaves, male inflorescence, healthy meristem and decaying tissues of infected palms) from the Canary Islands date palm, *P. canariensis*, were extracted or collected and identified by gas chromatography mass spectrometry. Around 70 of these compounds were assessed by electroantennography (EAG) activity of male and female *R. ferrugineus* and compared with the activity of the ferrugineol. Various esters, acetoin and 2-phenylethanol triggered EAG responses comparable to ferrugineol. Selected molecules were then evaluated, together with ethyl acetate, to determine whether they could enhance the attraction of ferrugineol to weevils under laboratory conditions and compared to ethyl propionate, which is known to enhance pheromone attraction.

Ethyl acetate synergized ferrugineol, whereas the responses to natural odours were variable. From more than 1,500 tests, some mixtures had a positive effect by either increasing the *R. ferrugineus* response to the pheromone or the variability in the response was dramatically reduced although the response didn't increase. Furthermore, all components identified by EAG screening did not greatly enhance the pheromone attraction, suggesting some synergizing components were not retained or identified from palm tissues by the methods used.

Ethanol was also shown to increase trap captures when added to the attraction pheromone + ethyl acetate.

#### c. Repellents or masking odours against Palm Borers

Volatiles from plants and fungi that have previously been reported to be repellent to various arthropods, were tested on both *R. ferrugineus* and *P. archon* under laboratory and open field conditions.

*R. ferrugineus*- Candidate antifeedents and oviposition deterrents against *R. ferrugineus* were evaluated in the laboratory. Four molecules caused a moderate to significant reduction in the numbers of eggs laid in treated substrate compared to the controls, and some compounds reduced feeding in females. In a screened cage under semi-field conditions, dispensers of putative repellents were placed on potted palms. Pheromone traps were added beside each palm and *R. ferrugineus* released into the cage. After 24 hours, the numbers of *R. ferrugineus* caught in traps associated with candidate repellents were significantly lower than in traps associated with control palms that had no chemical.

*P. archon*- The two most active repellents/deterrents against *R. ferrugineus* were evaluated against *P. archon*. Various doses and modes of presentations were applied on palm trees placed under semi-natural (large wind tunnel) or natural environments. The number of landings and eggs laid by females were compared between treated and untreated palm trees. Overall high doses of both chemicals reduced both landing and oviposition compared to controls.

In conclusion four molecules showed interesting disrupting effect on feeding, attraction or oviposition behaviour of *R. ferrugineus* and also *P. archon*. These chemicals require additional investigation to evaluate field potential for palm protection and practical and regulatory field implementation.

#### d. Vision in the Palm Borers

The visual cues to attract pests to traps were investigated, through electrophysiology and anatomical studies, and the colours and patterns related to palms and the two species were evaluated to direct choices for visual lures and traps.

*Paysandisia archon* has ocelli and two compound eyes with apposition optics, typical of butterflies, but not moths. Its vision is therefore related to butterflies, in agreement with the absence of an abdominal female sex pheromone gland and antennal morphology. Electroretinography (ERG), measuring electrical responses to light, and single cell recordings (SCR) showed that *P. archon* possessed highly developed colour vision based on a typical insect trichromatic scheme (UV-blue-green photoreceptors) plus an orange photoreceptor. The latter receptors are more pronounced in the male. The wings possess a conspicuous orange reflectance with a marked UV peak, suggesting that this colouration is used for same species visual recognition. The palm leaves have no specific colour and can therefore be visually recognized only by the typical pattern. A visual trap made of super-luminescent LED was designed based on the behaviour evidence for visual detection of the same species, and the physiology of vision. However *P. archon* responded poorly to this lure although some did orientate towards dead moths (Figure 3).

*R. ferrugineus* has two compound eyes with apposition optics. Based on ERG and SCR recordings the eyes possess many cells with a broad wavelength of sensitivity, most likely belonging to the achromatic system for motion detection. The other cells are capable of trichromatic colour discrimination: UV, green and orange-red. The 'orange' receptors detect the specific colour of the body of *R. ferrugineus*. This weevil therefore is most likely to discriminate between the UV-enriched sky and the green foliage or dark silhouettes such as traps. This vision property suggests that *R. ferrugineus* would be able to detect, and therefore be attracted to, dark (black) or red traps against light UV-rich backgrounds rather than lighter traps, the colours of which are not perceived.

### 4. Identification of local natural enemies which parasitize *P. archon* under European environmental conditions.

To identify natural enemies that parasitize *P. archon* two strategies were undertaken:

a. 'Sentinel eggs' patches were prepared from laboratory reared Lepidoptera. These were placed in palm trees in the field in various locations in France and Italy during the oviposition period for *P. archon*. After various exposure times, the eggs were recollected, along with naturally laid eggs, and incubated in the laboratory to check for parasitoid emergence. However, this approach was not successful because no parasitoids emerged from eggs. It nevertheless did however show predation of *P. archon* eggs in the wild, presumably by ants.

b. Fifteen strains of *Trichogramma* spp (parasitic wasps) originating from Europe and which parasitize other moth species were evaluated under two conditions: in tubes in the laboratory and in potted palms in a confined area.

i. In tubes:

One *P. archon* egg was exposed to various numbers of selected parasitic wasps, acquired from standard laboratory colonies reared on other moth eggs (from the Mediterranean Flour Moth *Ephestia kuehniella* and the Eri silkworm, *Philosamia ricini*). The mortality of eggs incubated in the presence of parasitic wasps was higher (73% - 100%) compared to control eggs (41%). Dissection of eggs revealed the presence of 2 to 25 nymphs per egg in those which were parasitized (Figure 4).

The most promising strains from the in-tube screenings were evaluated on *P. archon* eggs deposited on potted palm trees set in a closed room.

ii. In potted palms:

The parasitoids were released from boards containing 1,000 nymphs attached at various positions on the palm tree. Efficiency was measured as the mortality induced by *Trichogramma* (actual parasitism) and by the presence of parasitoid nymphs in the host egg, compared to natural egg mortality.

Three parasitoid strains caused higher egg mortality than in control eggs (not exposed to parasitic wasps). For one strain, parasitism could be increased 10-fold by a 2-fold (from 1,000 to 5,000) increase in the number of *Trichogramma* nymphs released. Overall parasitism efficiency was dependent on the parasitoid strain. Hence, *Trichogramma* could potentially be used for the biological control of *P. archon*, but these results have to be confirmed by releases in the field.

*P. archon* eggs were also exposed to two generalist parasitoids, *Trissolcus basalis*, and *Ooencyrtus telenomicida*, under laboratory conditions, but no successful parasitism was observed. Similarly the generalist predators, the mealybug ladybird *Cryptolaemus montrouzieri* and the mirid bug *Nesidiocoris tenuis* did not feed on *P. archon* eggs. Therefore, these species show little promise for the biocontrol of *P. archon*.

### Detection of *Rhynchophorus ferrugineus* and *Paysandisia archon*

This work focused on early and effective detection of palms infested with the red palm weevil (*R. ferrugineus*) or the palm borer moth (*P. archon*) in two domains; trade points and open areas. At trade points or ports individual palms can be inspected, while in open area (natural, urban or agricultural), where not all palms are accessible, or even identified, other modes of inspections are required.

The main objective was to develop methods to help prevent the spread and establishment of *R. ferrugineus* and *P. archon* within and between countries by the development of non-invasive tools for (early) detection of infested palms in consignments and in open areas.

The aims were:

- i. The development of a quarantine detection system for *R. ferrugineus* and *P. archon* in individual palm trees
- ii. The development of a Location Aware and Decision Support System for area wide control of *R. ferrugineus*.

### 1. Development of detection protocols for individual palm trees in quarantine

Three modes of detection were evaluated for detection: dogs, acoustics and thermal imaging.

a. Detection using dogs

This task was divided into five stages:

1. Selection of dogs for training.
2. Development of training protocol for detection of *P. archon* and *R. ferrugineus*, using different developmental stages of both pests.
3. Evaluation of detection abilities in artificially infested palms of different species.
4. Validation of the training protocol.
5. Evaluation of dog persistence, working ability, conditions and precision.

After testing five dogs of three breeds: German Shepherd (two dogs), Golden Retriever dog (one dog) and Labrador Retriever (two dogs), a Labrador Retriever and a Golden Retriever were selected based mainly on their olfactory abilities and their remarkable docility (Figure 5).

A four stage training protocol was developed:

- i. Mental activation to stimulate dog's senses.
- ii. Obedience tests.
- iii. Training olfactory detection capability and communicating it by sitting-down.
- iv. Detection efficiency evaluation as a percentage of true positive & true negative responses.

Each of these stages lasted at least a month. The training protocol involved different developmental stages of *R. ferrugineus* and *P. archon*.

The detection efficacy was tested using a variety of palm species for *R. ferrugineus*. In addition, the specificity of the dog's detection and discrimination abilities between target and non-target insects was evaluated. Young larvae and adults of two different beetles, the rice weevil and the rust-red grain beetle, and an Indian meal moth were used as non-target insects. For each work session the dog's responses were recorded and categorized. The protocol included a grid of palms, some artificially infested and others used as controls. Canary Islands date palms, *P. canariensis*, which are the major host of *R. ferrugineus*, were used to test detection of young *R. ferrugineus* larvae while Mediterranean fan palms, *Chamaerops humilis* (the major host of *P. archon*) were tested for detection of *P. archon* larvae.

Dogs' responses were categorized as:

- i. True positive indication (TP) when the dogs successfully located target odours.
- ii. False negative (FN) when the dogs did not detect the target odours
- iii. True negative (TN) when the dog correctly didn't respond to the non-target odours
- iv. False positive response (FP) when the dog responded to the non-target odours.

The dogs were able to detect early infestation of *R. ferrugineus* and *P. archon* in artificially infested palms, although with different accuracy levels dependent on the host palm species. The accuracy in the major host, the Canary Islands date palm, was 96% true positive detection and only 6% as false negative.

In experiments in field conditions (nursery), dogs were able to detect early infestation (only 1 young larva/palm) of *R. ferrugineus* in artificially infested Canary Islands date palms. The accuracy of *R. ferrugineus* detection was 86% and 99% for true positive and true negative responses respectively, recorded only 5 days after artificial infestation with one larvae. The accuracy of *R. ferrugineus* and *P. archon* detection in semi-field conditions (greenhouse) expressed as true positive responses was 96% to 99%.

The average time required for the dog to inspect a palm is 3-4 seconds indicating that theoretically the dog can explore 100 palms in a working session. In practice dogs become tired and require rest periods. The resting requirements are highly affected by the working conditions. On average, after 30 minutes of activity dogs require a resting period of at least 15 minutes, allowing them to play, run and to rest as needed. Resting requirements dictate that more than one dog is needed for inspection of large areas.

Experience from one trained dog that did not lose its searching ability after a 3-month non-participatory period suggests that dogs may not require continuous training to maintain their skills even if a break in working occurs. The influence of the environmental conditions on the searching ability of the dogs was also recorded. There was no difference in working ability observed over temperatures ranging from 22 to 32°C. However, windy days often reduced the accuracy of the responses.

b. Acoustic detection

This task consisted of five stages:

1. Comparison of Acoustic devices;
2. Equipment selection (recording devices and software);
3. Monitoring diurnal acoustic activity of *R. ferrugineus*;
4. Optimizing acoustic algorithm for *R. ferrugineus*.
5. Recording *P. archon* acoustic activity.

Three acoustic devices were tested:

- i. Larval sound detector (NIR-W. Weinard, Germany).
- ii. Commercial detector and recording system (Marantz professional)
- iii. Digital laser vibrometer.

Comparison of these recording devices on potted Canary Islands date palms pre-infested artificially with 2-4 *R. ferrugineus* larvae (Figure 6) revealed that the detection of an infested palm was similar with the help of recordings taken by a tactile microphone (devices i and ii) or by laser vibrometer. Despite apparent advantages of the laser vibrometer in detecting larval activity in palms from a distance, this method has its disadvantages. The cost of the laser vibrometer is too high to consider it as a practical tool and the use of the laser allows the sound energy on the outer surface of the trunk to be sensed. By comparison, the tactile microphone could be inserted into the trunk, thus possibly improving the signal to noise ratio.

Regular recordings were conducted from infested and not infested palms. Two main types of *R. ferrugineus* larval feeding sounds were identified:

- i. Basic, very short 'clicks' or 'snaps' lasting 1-4 milliseconds with energy between 1 and 8 kHz.
- ii. Longer lasting sounds termed 'rasps' or 'bites' that were seemingly fused from short sound events. Their maximum energy was < 3 kHz.

Automatic acoustic detection was comprised of two phases, learning and classification. For the learning phase two sets of acoustic clip files were composed. One set acquired from non-infested trunks, and the second set was a collection of active sounds clips. The clips were cleaned using software to remove any extraneous sounds, such as sounds that could be the result of leaves movement, to ensure that the operator clearly identified the boring larvae.

The automatic classification split sounds into those "produced by larvae" or "clean" and these were stored in a database.

To evaluate the specificity and the sensitivity of acoustic detection of *R. ferrugineus* infestation in the two most susceptible palm species (Canary Islands date palm and date palms), experiments were conducted on potted palms in a quarantine greenhouse. Data clearly indicated that acoustics is a sensitive method to detect *R. ferrugineus* infestation in quarantine despite potential interference from external sounds. The efficacy depends on the palm species and larval age. Larger larvae apparently create more distinctive sounds.

The acoustic detection of *R. ferrugineus* in Canary Islands date palms was better than in date palms. With the selected equipment both the trained listener and the computer (machine monitoring) were able to accurately detect the activity of *R. ferrugineus* larvae inside young Canary Islands date palms shortly after infestation began (less than 3 weeks), and long before any visual symptoms appear. Although human detection was somewhat better than machine detection (100% v 80% true positive respectively), both a trained listener and machine detection have potential to be used in quarantine for young palms, especially in Canary Islands date palms, for the detection of *R. ferrugineus* infestation.

In date palms the acoustic detection of *R. ferrugineus* was less efficient; the observer achieved 100% true positive detection later during the infestation while machine detection at this stage was only 50%, but was able to reach 100% as larvae grew older. These data indicate that automatic/machine detection still requires improvement, but is expected to perform much better under quiet ambience conditions. Moreover interference due to wind movements and friction of fronds need to be taken into consideration. The difficulties with acoustic detection in date palms are probably due to the fact that young palms usually have offshoots which become infested rather than in the main trunk where the microphone is directly attached. Continuous recording of *R. ferrugineus* larvae activity showed that larvae are not always active but did not indicate any specific activity pattern.

Experiments on *P. archon* detection were conducted under laboratory conditions, comparing signals from infested and uninfested potted Mediterranean fan palms. The acoustic activity of *P. archon* larvae was clearly detectable, especially in the late afternoon. However, due to high signal interference acoustic characterization and algorithms for automatic detection of the sound emitted by the boring larvae still need to be developed.

In conclusion, comparing all the tested detection methods for quarantine detection, using dogs appears to be a realistic and sensitive approach for the detection of both pests if only professional training is implemented. Manual acoustic monitoring can also provide accurate early detection. The machine detection of *R. ferrugineus* in date palms requires improvement. Development of automatic/machine detection of *P. archon* is feasible but will require further signal characterization. Thermal detection is less suitable for very early detection when the damage to the stem tissue is low (as will be discussed below).

## 2. Development of an area-wide detection

Unlike evaluation of individual palms in quarantine locations, area wide detection demands the creation of a dedicated aware system, fed by monitoring data of the pest populations. This part of the project focused on detection of *R. ferrugineus* infestation. The data comprises pest trapping information and pest risk assessment of palm condition based on visual inspection of suspected areas and trees as well as aerial/satellite images, natural infrared and thermal ranges and visual inspections of palm trees to evaluate their condition.

### a. Evaluation of synthetic attractants/dispensers and traps.

This task consisted of three stages:

#### i. Selection of the best trap

A standard protocol for trap and lure evaluations was established. The local traps, currently in use by growers, were compared with traps tested within the project (Figure 7) in pairs or sets (depending on a number of trap types compared). The traps were distributed at a distances of approximately 25 meters apart and away from palm trees, with the distance of at least 50 meters between the tested sets/pairs. Using this protocol the efficacy of a new black pyramidal trap design (Picusan®) was evaluated, and in most cases it performed better than common traps of different designs (Table 1).

#### ii. Determination of optimal pheromone release

The optimal release of *R. ferrugineus* pheromone (ferrugineol + ferrugineone) was studied by five partners in four countries, Israel, Greece, Italy and Spain, implementing the same standard protocol using the same trap type and attractant. Due to local environmental conditions pheromone release did however differ, the emission range was between 0.60 to 50.9 mg/day. It was determined that the optimal ferrugineol emission threshold should be 5 mg/day. Moreover, it is clear that higher emission levels up to the 50 mg/day do not significantly affect *R. ferrugineus* trappings.

#### iii. Development of synthetic plant kairomone to substitute palm tissue and molasses.

Work focused on evaluation of the mixture of ethyl acetate/ethanol components of fermentation odour that showed that Picusan® traps baited with pheromone and the ethyl acetate/ethanol mixture (1:3 ratio, released at 100 - 300 mg/day) performed significantly better than pheromone alone, and as effective as the standard complete bait, comprised of pheromone, 10% molasses and *P. canariensis* palm stem pieces.

In general, traps baited with pheromone and synthetic kairomone (ethyl acetate/ethanol) in one dispenser performed significantly better than pheromone alone, thereby improving trap efficacy, and one dispenser was as effective as using two dispensers. By comparison, ethyl acetate alone does not significantly improve the attractiveness of the aggregation pheromone.

In most of the locations, the synthetic kairomone can be at least as effective as the use of complete bait (pheromone/plant material/molasses). The advantage of using a synthetic kairomone is the reduction in the labour required to service the traps baited with plant material and molasses that are not standard and must be replaced frequently.

### b. Optimal trap distribution

The objective of this task was to establish guidelines for optimal distribution of monitoring traps within urban areas and date plantations for early warning of *R. ferrugineus* risk. The distribution and the abundance of the *R. ferrugineus* catches were mapped using geographic information system software and analysed using geostatistic methods. The major conclusions were:

#### i. In date palm plantation:

Based on monitoring over a two year period, traps should be distributed in the plantations at a density of at least one trap per 0.35 ha (60X60 m). In addition, traps should also be distributed around the plantations (along their borders) in distances of 30 m. There is some indication that these traps function as barrier.

ii. In urban areas:

Based on monitoring data covering a full year in an urban park environment, traps should be distributed at a density of one trap per 0.5 ha or no less than 75 m one from another.

### 3. Pest risk assessment of palm condition in open areas

#### a. Pest risk assessment by visual inspection

The most obvious approach to infestation detection is visual examination of a tree. Visual symptoms of red palm weevil activity depend on the infestation stage, on the site of infestation, and on the physiological age and species of the infested palm. For example, if the red palm weevil develops in the lower part of the trunk, which is common in date palms, oozing wounds may be observed where offshoots have been removed. On the other hand, in Canary Islands date palms, where crown infestation is common, oozing does not occur but changes in crown symmetry are usually visible. In coconut palms (*Cocos nucifera*) and Canary Islands date palms inner crown fronds tend to wilt. This symptom is less common in date palms.

For risk assessment and development of a protocol for manual visual detection a literature search and data was collected and collated. Data on symptoms of *R. ferrugineus* infestation in Canary Islands date palms and risks collected was summarised in English and translated into Arabic.

The palm inspection should be regularly conducted in the area at risk (weevils were trapped in pheromone traps in the area and/or infested trees were already found in within a radius of about 10 km). Each inspected palm should be mapped by GPS. The palm should be thoroughly inspected from bottom to the top. In case of the tall palms it is advised to use binocular for crown inspection. Special emphasize should be put to the shape of crown the intactness of the stipe and leaves, any oozing from the palm tissue or cocoon remains at the base of the palm. For the follow up development of symptoms it is important to take at least one or more pictures of a palm at each inspection session. In case of suspected infestation in the palm crown, construction of an inspection window by cutting some leaves is required to enable access to the centre of the crown for proper evaluation of palm condition.

Symptoms of infestations in Canary Islands date palm include (examples shown in Figure 8):

- i. The crown is not of typical shape, but appears somewhat flatten
- ii. There is a gap between the inner and outer leaves
- iii. Holes in one or more leaves
- iv. Some holes or chewing symptoms in inner leaves
- v. Extensive chewing symptoms of ">" shape
- vi. Some leaves collapsed
- vii. Asymmetric inner leaf growth
- viii. Crown partially collapsed
- ix. No new inner leaves
- x. All the crown leaves collapsed into an "umbrella" shape
- xi. All the crown leaves collapsed into an "umbrella" shape and are dry
- xii. Collapse of the palm tree with RPW stages detected in the stipe

#### b. Determining the effect of *R. ferrugineus* infestation on the canopy temperature

For developing remote thermal detection of infested palms, the physiological changes associated with damaged vascular system of the palms were investigated in Canary Islands date palms (in a greenhouse) and date palms in a greenhouse and in two date plantations.

Thermal imagery proved to have potential as a tool for assessing *R. ferrugineus* infestation in palm trees in quarantine and open areas. As expected the detection accuracy was higher at later stages of infestation, and was correlated with larval damage. However this method it is not suitable for covered facilities as palm leaf exposure to a direct sun light is a prerequisite for thermal imaging. Time of day appears to be critical for detection accuracy. Highest differences between infested and uninfested trees were obtained between 11:00 to 14:00. The method is also limited to the warm season.

Detection accuracy with thermal detection was lower when compared to the detection accuracy obtained by acoustic means or using dogs. This is probably associated with the level of damage of the infested palms in controlled experiments, effective only if causing substantial water stress that can be detected by thermal images. In commercial plantations infested trees were detected by ground and aerial thermal images with high accuracy and reliability before visual symptoms were observed.

For large scale screening aerial thermal imaging has an advantage over other detection methods that were developed for *R. ferrugineus* infestation, such as dogs and acoustics, since the latter require screening every tree. Identifying and mapping suspected infested palm trees within commercial plantation through thermal imaging is a complicated task. When covering a large area, the water status of trees is not a specific indicator of *R. ferrugineus* infection and can be highly variable due to differences in irrigation, age, sun exposure or diseases. These factors may cause inaccurate detection of *R. ferrugineus* infestation. On the other hand, thermal imaging can be used for large scale screening of palms in order to detect wide range of anomalies making this methodology more cost effective. The problem of specificity could be solved if thermal detection would allow identifying of specific trees as suspected candidates, followed by specific examinations using other detection means. Additionally, the accuracy and reliability of the thermal detection is crop water stress index threshold-dependent. Thus, it is necessary to further develop an algorithm for adaptive selection of the crop water stress index threshold for optimal detection of the *R. ferrugineus* infested trees.

#### c. Location Aware System and Decision Support system

In Palm Protect, a Location Aware System CPLAS (by Bytelogic) has been modified for use in the early detection and monitoring of *R. ferrugineus*. This upgrade of CPLAS provides the capability to operate in larger areas than was previously possible in its preliminary application (i.e. urban, agricultural and natural environments) as well as under more complex scenarios such as analysing large numbers of palm trees and different palm species, traps, and treatment options. In addition, several functions of the system were improved including monitoring, the network, web and communication functions, data handling, and ease of use. CPLAS integrates a geographic information system (GIS), a decision support system and multimedia technology; it implements location aware services for monitoring, risk assessment of the *R. ferrugineus* dispersal/infestations and decision support for the control of the pest. During the project CPLAS was used in real time conditions in five study areas: the Park Pedion Areos and the National Garden of Athens in Greece, Bahai Gardens in Haifa, Israel, and two date palm orchards in Maale Gamla and Ramot/Majrasa, Israel, and the Preveli palm tree forest of *P. theophrasti* in Crete. The upgraded CPLAS provides a web mapping site where the background GIS information layers of the study areas, the collected data (including trap captures and photographs) and interpolation infestation risk analysis maps are available.

The following have been developed:

1. Semi-automatic procedures for faster mapping of palm trees using high resolution aerial/satellite imaging, development of data collection tools for trap captures, and CPLAS data synchronization with server using web services.
2. Spatial-Multimedia DSS for efficient assessment of infestation risk in real time for two palm tree species: Canary Islands date palms (*P. canariensis*) and the date palm (*P. dactylifera*).
3. Web site with GIS information layers and spatial data for all study areas (<http://209.126.77.75/cplas/>)

The upgraded CPLAS has already been recognised as a useful tool by Bytelogic as well as other stakeholders.

Control of *Rhynchophorus ferrugineus* and *Paysandisia archon*

The main objectives were to

1. Provide a critical review and new research on the identification, development and validation of different control methods aimed at the containment and/or eradication of *R. ferrugineus* and *P. archon* under European/Mediterranean conditions
2. Develop scientifically based protocols for
  - a. Quarantine treatment of palms in transit.
  - b. Eradication/containment including preventative and curative techniques.
  - c. Proper disposal of infested material.

#### 1) Review of existing control methods for *R. ferrugineus* and *P. archon*.

A full review of all available information on control methods for *R. ferrugineus* and *P. archon* was completed in June 2012. At the end of the Palm Protect Project, this information was updated and together with the main accomplishments obtained within the project have been the basis for the chapters of a book dealing with the biology and management of *R. ferrugineus* and *P. archon*, which is currently in preparation. This information will probably be the most recent and reliable compendium for anyone interested in the control of these important palm pests.

#### 2) Development and evaluation of a suitable method for quarantine purposes of *R. ferrugineus* in palms in transit.

An assay extending for two complete growing seasons studied the feasibility of a quarantine treatment for Canary Islands date palms. Palms were naturally infested and placed in a sealed container. Infested palms were exposed to aluminium phosphide for 48 h. The infested and treated palms were inspected over short (immediately after exposure) and long (after one year of physical containment as required by EU legislation) periods for the presence of all stages of *R. ferrugineus* (Figure 9). Treated palms were also assessed long term for any phytotoxic effects of aluminium phosphide. Treatment completely eliminated all live stages of *R. ferrugineus* (i.e. 100 % efficacy) and no phytotoxic effects of aluminium phosphide were observed for up to 1 year after exposure to aluminium phosphide. This treatment, which could be easily applied in sealed containers used to prepare and ship palms overseas, could therefore be recommended to significantly reduce the enormous risks that palm imports impose at this moment worldwide.

#### 3) Assessment of movement and distribution of insecticides within palms

Different assays carried out in Spain (for Canary Islands date palm) and Israel (for date palm) identified the main advantages and drawbacks of this technique. An improved injection device developed within Palm Protect was used in these assays (Figure 10). This prototype (which is now patented) allowed a reduction of the number of injections per treatment (from three to one) and reduced the injection zone. These two features are very important to minimize the mechanical impact of the injection and, as a consequence, the possibility of subsequent infections with opportunist pathogens of palms. A combination of field and laboratory assays were used to determine the toxicity of different insecticidal molecules (both commercial and experimental) and assess their movement within the palm and the different behaviours of these molecules which preferentially accumulated in different parts of the palm (e.g., imidacloprid in the palm crown and abamectin in the palm fronds). These differences could explain field results and help refining chemical control of *R. ferrugineus* and *P. archon* in the near future.

#### 4) Identification and evaluation of new synthetic products based on natural products.

New molecules belonging to the groups of fusion proteins and fungal secondary metabolites have been obtained and tested against *R. ferrugineus* in the laboratory and under semi-field conditions. These molecules, which have a better eco-toxicological profile than conventional insecticides, proved effective in the laboratory against both immature stages and adults of the weevil. However, they had a limited impact when injected into palms, probably due to distribution problems. Further work would be necessary to improve the mobility of these products within the palm.

#### 5) Inundative biological control with entomopathogenic fungi against *R. ferrugineus* and *P. archon*.

During the three years period of Palm Protect Project, all partners have collected samples of specimens of both *R. ferrugineus* and *P. archon* showing symptoms of fungal disease. The processing of these samples has allowed the identification of more than 20 different strains of entomopathogenic fungi (including the genera *Beauveria*, *Lecanicillium* and *Metarrhizium*) that may be used against these two pests in the future. Furthermore, the molecular characterization of these strains has revealed the adaptation mechanisms of resident Mediterranean strains of these fungi to invading *R. ferrugineus* and *P. archon* in this region. Full characterization of one of these strains from *Beauveria bassiana*, including laboratory, semi-field, and field assays, have demonstrated the enormous potential that entomopathogenic microorganisms have for controlling these palm pests. A formulated product including spores of this strain has been used against *R. ferrugineus* exploiting different application technologies: (a) as a direct spray in field conditions, (b) vectored by artificially infested sterile males in the field, (c) in an "attract-and-infect" device exploiting semiochemicals developed in Palm Protect in open field conditions, and (d) as an endophyte in semi-field conditions. Promising results have been obtained in all cases, but further work is necessary to refine the application methods and obtain efficacies comparable to other commercially available (predominantly synthetic chemicals) options.

#### 6) Semiochemical-based control methods against *R. ferrugineus*.

Semiochemical-based control methods included mass trapping, attract and infect and push/pull procedures. Mass trapping and attract and infect was implemented in a perimetral design aimed at reducing *R. ferrugineus* populations (Figure 11). Field trials demonstrated that the use of a synthetic kairomone (made of ethanol/ethyl acetate in a 3:1 ratio) significantly enhanced trap catches. Therefore, optimization of the pheromone dispensers (release rate and the use of the right proportion of the attracting blend) should reduce the costs of applying mass trapping against *R. ferrugineus* and thus contribute to a more sustainable control of this pest in the near future.

Picusan® traps baited with pheromone, palm tissues and water (in ratios optimized in related tasks in the project) were placed along the perimeter of a 5 hectare palm nursery. Reduction of captures in the centre of the plot and number of affected palms was recorded. Over a one year period, 184 palms located at less than 25 meters from any trap located in the outer perimeter of the nursery were killed by the weevil. Within the perimeter only 40 palms were infested.

A field trial was also carried out to investigate whether a trap density of 1 per hectare could reduce the number of weevils reaching the centre of a trap grid. One Picusan® trap was placed in the corners of a 1 ha plot. Weevil captures in the centre of the plot were compared with those of traps located 400 m away. A 57-87 % capture reduction was observed in the centre of the mass trapping grids relative to traps 400 m away from the plots. The 5 traps of the grid captured between 1.5 and 6 times more weevils than isolated traps.

Mass trapping at 1 trap per hectare can reduce weevil population but does not avoid palm infestation.

For attract and infect (with entomopathogenic fungi) techniques, a trap with an infective device that remains active in field for around 2 months was designed. A field trial was carried out with these devices to study: (a) how the fungus affected weevil populations and (b) palm infestation reduction. *Beauveria bassiana* (EABb 07/06-Rf) fungal spores were formulated and placed in an infective-Picusan® trap. Four infective traps were placed in the corners of each 1 hectare plot (figure 11). Four sentinel palms were located in the center of each plot. Trials were replicated in Ibiza and Valencia (Spain). Weevils reaching the center of the plot were captured and the incidence of the disease on the weevil population and the reduction of palm infestation were studied.

Between 40 and 80% of the adults captured in the plots treated with infective traps were infected with fungi, and traps remained effective for over 75 days. Moreover, infected adults were able to move distances over 300 m from the trap, helping to spread fungi to other weevils. Only 42% of the sentinel palms in the centre of infective trap plots were infested by weevils, compared to 100% infestation in mass trapping plots.

The push and pull procedure was tested in a field trial to study if laboratory active repellent substances could reduce palm infestations. However, the repellent compounds, at the doses tested were not able to reduce palm infestation in the field.

#### Valuing what is at risk and estimating impacts

Within the overall aim of valuing what is at risk from *R. ferrugineus* and *P. archon*, two invasive pests of palms in the Euro-Mediterranean region. The target objectives were to:

- (i) Describe the market for palm products, e.g. dates, originating in the Eastern Mediterranean and to describe the ecosystem services provided by palms in the Euro-Mediterranean region.
- (ii) Estimate the value of ornamental / amenity palms around the Euro-Mediterranean region from an ecosystem services perspective.
- (iii) Identify and describe the potential socio-economic impacts of the palm pests, *R. ferrugineus* and *P. archon*, using appropriate economic methods given risk based scenarios for pest spread.
- (iv) Estimate costs of implementing alternative pest management options that emerge from WP 3 and WP 4 and applying them to future scenarios so as to inform strategies for the control and containment of the pests.

A review of the literature and collection and analysis of data were carried out which identified the markets for palm products, and which described the ecosystem services derived from palm amenities which are diminished by pest damage to palms. The review highlighted that date production in partner countries such as Egypt and Israel is a major economic activity, employing thousands of people and which supply products sold in both domestic and export markets including the EU. For example, the EU imports over 70,000 tonnes of dates from the near East and North African nations bordering the Mediterranean annually, worth almost €140 million.

Palm trees within the Euro-Mediterranean region provide a variety of ecosystem services within the themes of provisioning services, regulation & maintenance services and cultural services. Values for provisioning services were estimated using conventional economic production data, e.g. value of date production; in Spain this is around 5,000 tonnes of dates each year, worth around \$16 million. Benefits from regulating & maintenance services by palms include improvements in air and water quality, the provision of shade leading to lower ambient air temperature, reductions in ultraviolet radiation, the production of oxygen and reduction of carbon dioxide, and lower levels of noise and dust. Although it is recognised that palms provide significant cultural services, e.g. in the form of palms in urban environments, lining streets and town squares, in public parks, botanical gardens, heritage palm groves and private gardens, placing an economic value on such services is very challenging for economists, explaining why so few data reporting palm values were found during the literature review.

A variety of approaches are used by environmental economists to estimate particular ecosystem service values within the framework of total economic valuation. Through a worldwide review of literature we found that most studies that placed economic values on urban trees and palms operated at a large scale, and placed values on the "urban forest", i.e. the sum of all trees in an urban vicinity, and did not place values on individual species. Nevertheless, some estimates did report the values of palms. A US study in a city with a Mediterranean type climate suggested that palm species have individual values that range from at least an average of \$220 for *Arecastrum romanzoffii* (Queen palm) up to \$530 for *Archontophoenix alexandrae* (Australian palms). Such values reflected only the cost of palm replacement and the values would increase if they also included the palms contribution to carbon sequestration and storage, air quality improvement and cultural significance, aspects that are recognised as contributing significantly to the total value of an individual. A study in Spain estimated that 1.4 million trees in Barcelona (a large proportion of which would have been palms) provided multiple benefits including removal of 305.6 tons of air pollution, valued at €1 million and carbon sequestration, estimated at 5,422 tonnes/year.

*Rhynchophorus ferrugineus* and *P. archon* degrade palms and hence lower the value of ecosystem services provided by infested palms. To better understand and predict the costs involved in taking action against the pests to protect palms, the regions within Europe and around the Mediterranean Basin where the pests are most likely to find environmental conditions suitable for establishment and where consequently impacts may occur were described and identified. For example, the bio-climatic modelling software CLIMEX was used to generate a map indicating areas suitable for establishment of *R. ferrugineus* (Figure 12).

To estimate baseline economic impacts over a ten year period to 2023, a bioeconomic model integrating the spread and impact was developed, assuming that current EU emergency phytosanitary measures, designed to inhibit spread, were fully implemented across member states affected by the pest infestations. Given the uncertainties about the spread and current impact, Monte Carlo simulations were used to predict future impact. The model projected impacts of over €146 million in Spain, €73 million in Italy, €60 million in Greece and €35 million in France in 2023. In all cases, the two largest components of costs were (i) replacement values for felled trees, and (ii) inspection costs. Given the magnitude of such impacts, there is a great and urgent need to develop and implement alternative efficient pest control methods to inhibit the spread of harmful palm pests to prevent such huge losses. Hence WP5 next researched and estimated the total economic costs of implementing control measures and management strategies which may emerge from other work packages of Palm Protect. The bio-economic model was used to estimate costs in three future spread scenarios (A, B and C) in which improved detection and control methods were used. Scenario A assumed the enhanced detection methods would improve detection of infested palms by 10% each year from 2015 and using trunk injection of insecticide would reduce the need to fell palms that are irreversibly damaged by 20%. Scenario B assumed the enhanced detection methods would improve detection by 20% and earlier trunk injections of insecticides would still reduce felling by 20%. Scenario C assumed the enhanced detection methods would improve detection by 30% and earlier trunk injections would reduce the need to fell palms by 30%. In addition it was assumed there would be a 10% reduction in trap inspection costs, due to efficiencies gained from experience.

In each scenario, improved detection methods resulted in increased costs in the early years as the area found to be infested increases resulting in greater surveillance and monitoring costs. However, as a consequence of earlier detection the number of palms that can be treated with systemic insecticides increases and there is a concomitant reduced amount of felling required. This leads to cost savings from reduced felling, disposal and replacement of infested palms. Mean costs incurred by case study countries range from €18.5 million (France) to €48.6 million (Spain) in scenario A; from €20.1 million (France) to €40.6 million (Spain) in scenario B, and from €19.1 million (France) to €55.6 million (Italy) in scenario C. The overall outcome of the effect of improved detection and reduced management costs varies depending on a number of factors including, the proportion of land suitable for establishment of the pest that is already infested, the density of susceptible palm species and the total area infested before new methods and strategies are adopted. By implementing the technologies developed within Palm Protect, and assuming that the technologies operate as described in scenarios, then nominal baseline aggregate costs could be reduced from approximately € 316.5 million in 2023, to between € 266.1 million (Scenario B) and €284.9 million (Scenario C) respectively, a net saving of between € 50.4 million and € 31.6 million. In each scenario improved detection efficiency of infested palms will initially increase costs due to further monitoring and treatment activities around newly identified infested sites but this will usually lead to having to fell fewer palms that cannot be recovered, as the infestation has been detected sufficiently early, whilst there is also an increase in the cost of treating infested palms that are recoverable.

Results lead to conclude that no single scenario suits all case study countries. With respect to pest management regimes across the EU, the implication is that a harmonized, i.e. single unified approach, may not always be appropriate, and that countries may find alternative approaches benefit them most economically. Impact estimates remain conservative due to a lack of data (lack of previous studies) estimating the value of all ecosystem services provided by palms in the EU. Given the considerable magnitude of impacts, there is a need for management policies to minimise the impact of invasive pests, taking into account the costs of prevention, and policies that minimise the damage they consequently cause, bearing in mind costs of control or eradication. However, there are challenges when allocating appropriate resources to control invasive pests due to the high level of uncertainty surrounding the extent of potential economic, environmental and/or social impacts potentially caused by the species.

#### Potential Impact:

##### Dissemination Strategy Overall

- The joint dissemination, exploitation of project results and management of intellectual property will be covered in a PALM-PROTECT project consortium agreement that will have to be agreed by each partner organisation and the project management committee.

- A work package was committed to dissemination of the project results, which has the following objectives:

- To disseminate project results to stakeholders.
- To train stakeholders in EU and third countries.
- To organise a website, a final workshop and symposium.
- To coordinate wider dissemination of information by cooperation with other projects and organisations

##### Dissemination of project results:

- Regular reports will be made to National EU Plant Protection Organisation representatives and via them, the EC Desk Officer, to the EU Standing Committee on Plant Health.

- A project publicity leaflet was produced at the start of the project outlining the aims and objectives, and an annual newsletter was produced describing the latest results and activities of Palm Protect partners.

- A database of key stakeholders was compiled and the brochure and newsletters were sent to stakeholders throughout the project.

- Wider dissemination of the findings of the project was made to relevant agencies, stakeholders and civil society in all EU member states through the project website.

- An international workshop was held at the end of the project to which stakeholders were invited. Presentations and demonstrations of project results and outcomes were made.

- Presentations were made at relevant scientific meetings with publications in conference proceedings throughout the project.

- Project results were published in peer-reviewed international scientific journals.

- Training of stakeholders within Europe, through workshops, were given, including detection techniques and the use of injection techniques for pesticide delivery.

#### Stakeholder Groups:

- The stakeholder groups are the extensive contacts of the project consortium and Advisory Panel Members and a wide range of EU member states. They were established from academia, the policy community, industry and the NGO community
- A database of > 350 stakeholders was created from industry and end-users from European countries, Egypt and Israel. A link on the website also allowed the public/companies etc to register their interest in Palm Protect to receive publicity materials. A mailing list of these stakeholders was also been created for electronic distribution of publicity material.

#### Palm Protect Events:

The Palm Protect project has a wide range on dissemination activities, including presentations, posters, demonstrations and publications. The following list shows the Palm Protect events, which will be detailed later:

- [23-24/01/2012](#) The first project kick-off meeting at Fera, York
- [11-13/09/2012](#) The second Palm Protect Project Meeting, Tel Aviv, Israel
- 12/09/2012 The first Palm Protect stakeholder workshop, Tel Aviv, Israel (sponsorship supplied by local chemical companies and growers)
- [28-30/05/2013](#) The third Palm Protect Project Meeting, Montpellier, France
- 29/05/2013 The second Palm Protect stakeholder workshop, Montpellier, France
- 26/11/2013 The fourth Palm Protect Meeting, Brussels, Belgium
- [19-23/05/2014](#) The fifth Palm Protect Project Meeting, Palermo, Italy
- 21/05/2014 The third Palm Protect stakeholder workshop, Catania, Italy
- [19-20/11/2014](#) The fifth Palm Protect Project Meeting, Las Palmas, Spain
- 21/11/2014 The final dissemination conference and stakeholder workshop, Las Palmas, Spain

At each stakeholder event local interested parties were invited to the meeting/ demonstrations and were able to the network with the project partners. Experts from the field of industry/ growers/ gardens were also in attendance to feedback from an industry perspective.

The consortium partners have been a very proactive group and have attended and participated in a wide range of conferences and promotional activities. See below:

#### Palm Protect Local Workshops and Events

August 2012: Dr V. Soroker (ARO) ran a workshop on red palm weevil problems and challenges to gardeners and extension workers in Tel Aviv, Israel.

December 2012: Dr F. Karamaouna gave an update on Palm Protect to working visit of the BIO CIRCLE to the Benaki Phytopathological Institute (BPI), Athens, Greece.

January 2013: Dr V. Soroker (ARO) gave an update on red palm weevil problems and research progress at the annual date growers meeting in Israel.

January 2013: Llorenç Baronat and Lluís Olibet (EV) participated in a training workshop on the control of Red Palm Weevil using trunk injection and sanitation in Galicia, Spain

February 2013: Llorenç Baronat and Roger Busquets (EV) participated in a meeting in Terrassa, Spain entitled "Using Endoterapia to control different pests", focused on palm trees to prevent and control red palm weevil.

March 2013: Dr D. Rochat (INRA) gave instruction on red palm weevil biology and semiochemical trapping in the city of Hyères-les-Palmiers to French Agricultural Ministry personnel who implement quarantine regulations.

April 2013: Llorenç Baronat and Lluís Olibet (EV) participated in a training workshop on the control of Red Palm Weevil using trunk injection and sanitation in Galicia, Spain.

May 2013: Dr D. Kontodimas and Dr A. Michaelakis (BPI) participated in a workshop on the control of palm tree insect pests for the Municipality of Maroussi, Athens, Greece.

May 2013: Dr D. Rochat (INRA) delivered a lecture entitled "New pests, new challenges: red palm weevil and palm borer moth" at the French Academy of Agriculture.

June 2013: Dr V. Soroker (ARO) attended a meeting on the use of neonicotinoids in agriculture: neonicotinoids implementation against red palm weevil.

July 2013: Dr E. Quesada ran a workshop for the Plataforma Ciudadana por los Parques, los Jardines y el Paisaje de Sevilla at the Universidad de Cordoba, where he discussed the Palm Protect project and demonstrated his research on the red palm weevil.

July 2013: Dr D. Kontodimas (BPI) participated in a workshop on quarantine pests, other diseases and insect pests at the Technological Institute of Crete, School of Agriculture, Heraklion, Crete.

July 2013: Fera attended the Royal Entomological Society's insect festival in York, where they displayed the Palm Protect poster, distributed newsletters and engaged the public in discussions about Palm Protect.

October 2013: Fera presented the Palm Protect poster at the annual Fera science conference, York.

November 2013: A Public Meeting of the Academy was held with a panel discussion on: "The Red palm weevil: New acquisitions and the possibility of population control". A talk on Methods for monitoring infestations of Red palm weevil was presented by Pompeo Suma, a Palm Protect partner from the University of Catania.

November 2013: Endoterapia Vegetal's (EV) team: Joan Manel Barroso Martinez, Josep Maria Riba and Roger Busquets Huix visited Israel to demonstrate their injection apparatus to the Israeli Palm Protect team and local stake holders and how it could be used for treatment of Canary palms in Urban area and Date palms in plantations.

January 2014: CPLAS exhibit by BPI at the "From Science to Technology", Exhibition at the Democritus Research Centre, Athens, Greece,

January 2014: Workshop of FruityNet: held at the Agricultural University of Athens. Oral presentation 'A Location Aware System for the integrated management of Rhynchophorus ferrugineus in urban landscapes' by Costas Pontikakos (BPI)

April 2014: Presentation by Dimitrios Kontodimas (BPI) "Biological control of the red palm weevil, present status, experience and pest management in Greece" at a workshop of the Research programme "Ecological and molecular studies, and integrated management of the red palm weevil Rhynchophorus ferrugineus and the palm-borer moth Paysandia archon of Cyprus", Lemessos, Cyprus .

September 2014: European Researchers' Night, York. Fera presented Palm Protect to the public

December 2014: One day Workshop 'The Tree and the City' organized by the Union of Geotechnical Professionals and the Enterprises on Green, Athens; 'Insect infestations' by Dr Dimitrios Kontodimas.

Potential impact, including the wider societal implications of the project so far.

Estimates of potential pest impacts add to the body of work describing impacts of invasive species and support the revision of EU phytosanitary regulations so as to reduce the likelihood and frequency of such invasions occurring in future. Despite emergency phytosanitary regulations being in place, *R. ferrugineus* continues to spread with a potential impact worth millions of Euros. Implementing new detection and surveillance strategies that operate as described in the scenarios envisaged could save tens of millions of Euros and protect hundreds of thousands of palms from destruction. If new strategies are adopted that require much more preventative measures being implemented, such as trunk injection of insecticides, then companies involved in such work will grow and provide greater employment opportunities.

Global climate change has the potential to increase the area in Spain where date palms can be grown for commercial production with an estimated 18.72 million to 22.86 million ha being suitable by 2100. However, WP5 (valuing what is at risk and estimating impacts) has shown that climate change scenarios can also make much of Spain more suitable for the establishment of *R. ferrugineus*. It is important that new methods for the control of *R. ferrugineus* are established so as not to allow the pest to stifle the emergence of a valuable emerging cropping system.

In seeking to identify estimates of the various factors of worth that contribute to the total economic value of palms, WP5 has shown that there are still significant knowledge gaps that need filling. Palms are currently not fully valued, i.e. they are undervalued, and to better understand the true worth of such important, culturally significant components of southern European habitats environmental economists need to undertake further valuation studies. Palm Protect therefore provides the basis on which to build the case and justification for such further studies.

WP5 described the aims and results as they emerged during the project at all stakeholder meetings held at the time of project meetings, e.g. in Israel (Sept. 2012), France (Montpellier, May 2013), Italy (Sicily, May 2014) and Spain (Canary Isles, Nov. 2014). Feedback from stakeholders was noted during the meetings and additional information collected to inform the background to the research.

A major development within WP5 was the creation of a mathematical simulation model that has the potential to be adapted and used to simulate the spread and impact of other invasive species in future. The model operates in Excel, which is the most widely used spreadsheet software, hence no specialist programming knowledge is required. The model also contains Monte Carlo simulation and can therefore output results to take uncertainty into account. There has been dialogue between WP5 researchers and a US economist and modeller to explore possible collaboration and further development of the model to enable greater exploitation of outputs.

Future dissemination and exploitation  
Principal outputs from this project are:

#### Tree injection devices

**Endoterapia Vegetal** is a company involved in the application, commercialization and advice of therapeutic treatments by means of the Vegetal Endotherapy technique on ornamental trees. This is a method for treatment of trees through the injection of plant protection products directly into the vascular system of the plant.

During the Palm Protect project, Endoterapia Vegetal developed a new injection device prototype and formulation specifically for palm trees for improved and less intrusive delivery of pesticides. The devices were designed to be user friendly and ergonomic, lightweight and robust, and for quick and safe use.

The aim beyond the project is to sell the device to countries where management of pests of palms is a problem (mainly around the Mediterranean area and South America). Interest in the injection devices has been received from a variety of pesticide supply companies, and negotiations are ongoing.

#### CPLAS

In Palm Protect, BPI has upgraded the Location Aware System CPLAS (by Bytelogic) for use in the early detection and monitoring of *R. ferrugineus*. The upgrade of CPLAS provides the capability to operate in larger areas than was possible in its preliminary application (i.e. urban, agricultural and natural environments) as well as under more complex scenarios such as larger number of palm trees and palm species (e.g. *P. canariensis*, *P. dactylifera*), traps, treatment options etc. In addition, several functions of the system were improved including monitoring, network, web and communication functions, data handling, and ease of use. CPLAS integrates a geographic information system (GIS), a Decision Support System (DSS) and multimedia technology; it implements location aware services for monitoring, risk assessment of the *R. ferrugineus* dispersal/infestations and decision support for the control of the pest. During the project CPLAS was used in real time conditions in five study areas: the Park Pedion Areos and the National Garden of Athens in Greece, Bahai Gardens in Haifa, Israel, a date palm orchard in Maale Gamla, Israel, and the Preveli palm tree forest of *P. theophrasti* in Crete. The upgraded CPLAS provided a web mapping site where the background GIS information layers of the study areas, the collected data (including trap captures, photographs etc) and interpolation infestation risk analysis maps are available. The CPLAS web site (<http://209.126.77.75/cplas/>) is currently accessible to the project coordinator and the partners involved in the CPLAS application (BPI and ARO) and will be available for another 3 months after the end of the project. In a commercial CPLAS edition, the web mapping site should be accessible to authorised users with restricted access to their data. Given the aforementioned advantages, the upgraded CPLAS has already been recognised as a useful tool by Bytelogic as well as stakeholders (e.g. at the Final Project Conference in Las Palmas). In this context, the new CPLAS is a marketable 'foreground' deliverable of the project. Therefore, BPI is negotiating with Bytelogic an agreement to have the upgraded version of CPLAS on the market.

#### Dogs trained to detect red palm weevil in palms trees

Based on the ability of dogs to detect infestations of *R. ferrugineus* and *P. archon* in young palm trees demonstrated within Palm Protect, this method could have an important impact on the management of the palms. Such early detection of pest infestation could help decide whether to treat the palm or eliminate the tree before it becomes a source of infestation at trade point and/or in open areas (e.g. nursery). This method has been developed for use at origin, point of entry, in transit and on-site to combat these invasive pests of palm trees and also to support stakeholders and end-users in the implementation of the Council Directives (e.g. 2000/29/EC, 2007/365/EC, 2008/776/EC, 2009/77/EC and 2010/467/EU). Several benefits can be obtained adopting this method within an integrated control programme of these pest infestations. The dogs are able to search an entire palm plot (of more than 100 palm trees) in nursery conditions, working accurately and efficiently; a regular pro-active inspection programme can reduce the possible financial impact and damage to the brand reputation; if the pests are detected, that specific palms can be treated or disposed to prevent the spreading of the infestation. An inspection following a treatment can confirm that all the insects have been eliminated. Currently, there is a general willingness of all stakeholders involved in the management of these pest infestations to exploit this promising approach. Indeed, a key point is that exploitation of this method requires low investments that can easily justified an adequate return also on non-monetary investment (e.g. the reduction of usage of insecticide treatments). The project team was recently contacted by several private and institutional entities (e.g. dog training centres, regional plant protection services, palm growers) requesting more details about the practical application of this method. Hence, operation of trained dogs currently entrusted to their trainers will continue beyond the project.

#### Attract and Infect devices for the control of red palm weevil

A device to apply the "attract and infect" technique has been developed during the Palm Protect project by the Universitat Politècnica de València (UPV). For this purpose, the Spanish company SanSan Prodesing SL, which manufactures the Picusan® trap (best of the commercial traps tested during the project), with advice from UPV and Universitat Jaume I, has developed a new device based on the Picusan® trap including an infective tunnel. Weevils are attracted to the trap where they are infected with fungal spores as they go through the tunnel. Weevils are then allowed to escape in order to spread fungal conidia to the wild population.

The optimal pheromone release rate used in these traps has been determined by UPV and this data is being used by SanSan Prodesing SL to develop pheromone dispensers with a release rate near the optimum value. A publication about the use of synthetic kairomones (ethanol and ethyl acetate mixture) has attracted interest from companies in relation to in adding kairomone mixtures to dispensers to increase trap efficacy.

#### Training manual on sanitation pruning of palms

A training manual was produced by Endoterapia Vegetal giving a step-by-step guide to the pruning of red palm weevil for sanitation purposes. This manual was produced for stakeholders involved in the growing and maintenance of palm trees (e.g. pest control companies, nurseries, growers). The manual is available as open access via the palm protect website ([palmprotect.eu](http://palmprotect.eu)).

#### Review of control methods for the red palm weevil and the palm borer moth

A review on the control methods currently available for the red palm weevil and palm borer moth is available as open access via the palm protect website ([palmprotect.eu](http://palmprotect.eu)). This review gives an overview of the problems caused by these pests, and discusses the pros and cons of the available control methods.

#### Book on the biology and management of red palm weevil and palm borer moth

A book on the biology and management of the red palm weevil and palm borer moth is currently being produced. This will be published by John Wiley and Sons Ltd, with Dr Victoria Soroker (ARO) and Dr Stefano Colazza (UNIPA) as editors. All Palm Protect partners will contribute to this book, which include the scientific outcomes of the project. The final draft of the book is in preparation.

#### Peer reviewed publications

A variety of publications have been produced during the time frame of Palm Protect (listed above in the publications section). It is anticipated that further publications will include data from Palm Protect. These will be listed on the Palm Protect website or made available if open access.

#### Future funding opportunities

Continued funding of Palm Protect was discussed by partners at the final project meeting. One potential opportunity would be via Euphresco funding.

Individual partners will make enquiries with their Country's Euphresco contact.

#### Palm Protect website

The palm protect website domain name was purchased for 4 years. The website will remain functional until December 2015.

#### List of Websites:

[www.palmprotect.eu](http://www.palmprotect.eu)

Contacts: Dr Neil Audsley (Coordinator) - [neil.audsley@fera.gsi.gov.uk](mailto:neil.audsley@fera.gsi.gov.uk) or Claire Charlton (EU Bids & Tenders) - [claire.charlton@fera.gsi.gov.uk](mailto:claire.charlton@fera.gsi.gov.uk) or [palmprotect@fera.gsi.gov.uk](mailto:palmprotect@fera.gsi.gov.uk)

## Subjects

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