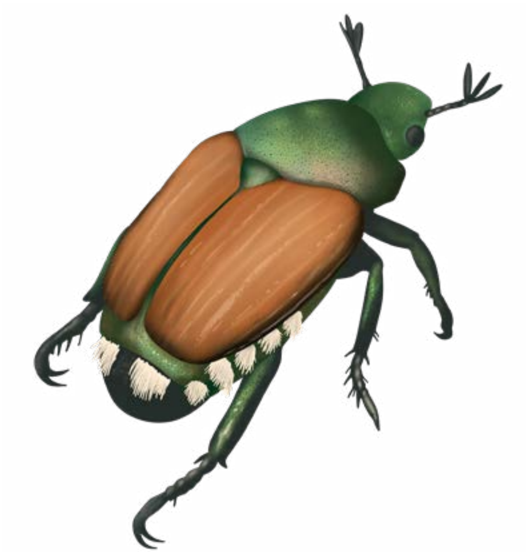
IPM Popillia
Integrated Pest Management of Japanese Beetle

VADEMECUM

POPILLIA JAPONICA

A new threat to European Agriculture



A comprehensive and clear guide for the EU, Plant Protection Organizations, farmers, and professionals involved in the management of *Popillia japonica*.

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SPOTTERON Citizen Science and Monitoring App Toolkit Platform

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A BRIEF INTRODUCTION

POPILLIA JAPONICA

Popillia japonica Newman, 1841 (Coleoptera: Scarabaeidae), commonly known as the Japanese beetle, is a species native to East Asia, namely Japan and Kunashir Island (RU). Since the beginning of the last century, the beetle has spread to two other continents, North America and Europe, where it has become invasive and caused significant economic and ecological damage.

P. japonica adults feed on leaves, flowers, and fruits, causing severe damage to plants, while the larvae, developing in the soil, primarily feed on roots, disrupting the growth of crops, meadows, pastures, and turfgrass. (Potter & Held, 2002; EPPO, 2020; Gotta et al., 2023)

***POPILLIA JAPONICA* FEEDS ON OVER 400 HOSTPLANTS**

Find the full list of host plants: www.popillia.eu/hostplants

Due to its ability to fly and its highly polyphagous nature, which allows it to feed on over 400 plant species, *Popillia japonica* can rapidly invade large areas (Potter & Held, 2002; Poggi et al., 2022; Gotta et al., 2023).

It is estimated that in the United States, where it arrived in 1916, more than $450 million are annually spent for the direct control costs and replacement of damaged plants (Potter & Held, 2002). In the Azores, *P. japonica* was introduced in the 1970s to Terceira airport, where it has rapidly spread throughout the archipelago. However, the overall economic impact on the Azores is less severe than in other invasive areas (EPPO, 2020). In Italy, *P. japonica* was first detected in the Ticino Valley Natural Park in 2014. Since then, the infestation has spread rapidly, reaching approximately 20,000 km^2 by 2023, infesting major agricultural areas (Gotta et al., 2023).

In **Europe**, *P. japonica* is classified as the **second most harmful priority pest**, based on its economic, social, and environmental impact (Sánchez et al., 2019).

In Switzerland, *P. japonica* was first reported in the Ticino Canton in 2017 and has since been closely monitored and control measures have been applied. Nevertheless, from that moment on, some occurrences have been detected in other parts of the country (Sanchez et al., 2019).

Adults

POPILLIA JAPONICA

Adults of *P. japonica* measure 8-12 mm long and are characterised by a distinctive, brightly coloured appearance. The head and pronotum are of a shiny metallic green, while the elytra are bronze-coloured. A key identifying feature is the presence of five white tufts of hairs along each side of the abdomen and two larger tufts located at the posterior end of the body (Fleming, 1972; EPPO, 2024).

Larvae

POPILLIA JAPONICA

Larvae of *P. japonica* are white and assume a distinctive 'C' shape. During their development they undergo three instars, growing from a length of about 2 mm in the first instar to approximately 30 mm in the last instar (EPPO, 2024).

IDENTIFICATION OF
POPILLIA JAPONICA
ADULT

The unique colour combination and the lateral hair structures facilitate species identification (Potter & Held, 2002).

Fig.1. Adult of *Popillia japonica*
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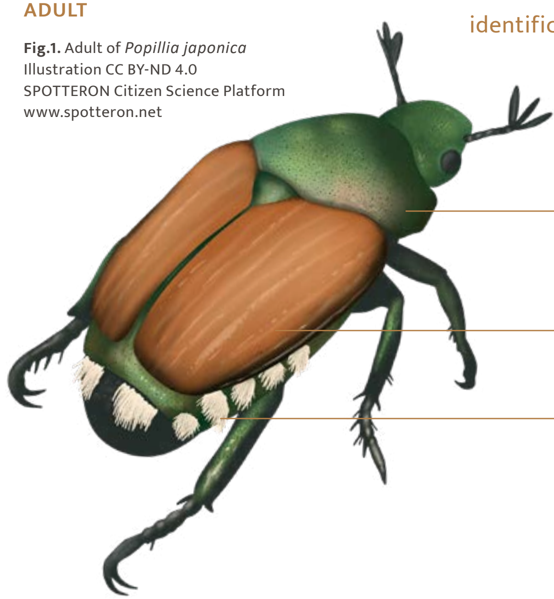

IDENTIFICATION OF
POPILLIA JAPONICA
LARVAE

The raster, an area of spines, hairs, and bare areas on the underside of the last abdominal segment just in front of the anal slit, has two rows of small spines arranged in a V-shape. That pattern helps distinguish *P. japonica* grubs from similar species. (Fleming 1972)

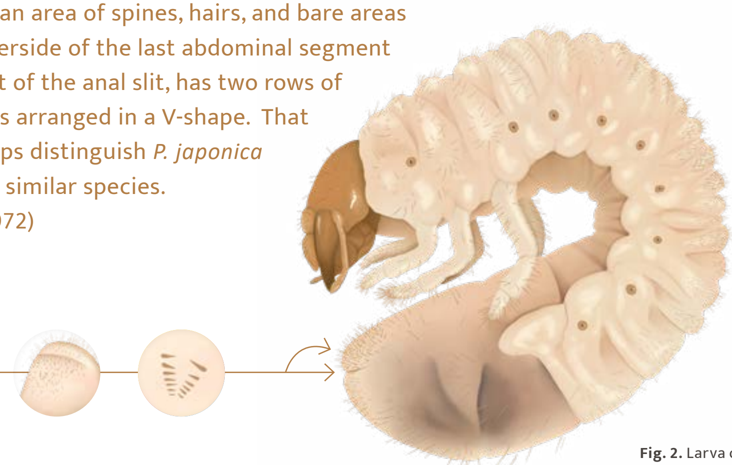

Fig. 2. Larva of *Popillia japonica*
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Life Cycle

POPILLIA JAPONICA

Popillia japonica follows an annual cycle (univoltine), completing one generation each year except in colder regions of North America where the cycle can extend over two years due to low temperatures (Potter & Held, 2002).

Adults emerge from the soil from beginning of June till August, with a peak of activity in July. During this period, mated females lay eggs in the soil. Each female can lay 40-60 eggs during its lifetime (Potter & Held, 2002; Gotta et al., 2023). Eggs hatch after approximately 10-14 days, giving rise to larvae that feed on plant roots and reach the third instar by late summer or early autumn. During the colder months, the larvae move deeper into the soil (about 10- 20 cm) and form an earthen cell (Fleming, 1972; Potter & Held, 2002). In spring, as temperatures rise, the larvae move upwards from the soil to feed until pupation in late May or early June. (Potter & Held, 2002; Fleming, 1972; EPPO, 2020).

LIFE CYCLE
POPILLIA JAPONICA

Adults

Adults emerge from the soil from the beginning of June till August, with a peak activity in July. They are active from June until September.

Pupation

Pupating occurs in a small cell after a few weeks of feeding in springtime.

Larvae

The larvae grow and feed on fine roots and organic material 2.5-5 cm below the ground. The larvae moult twice and feed until late autumn.

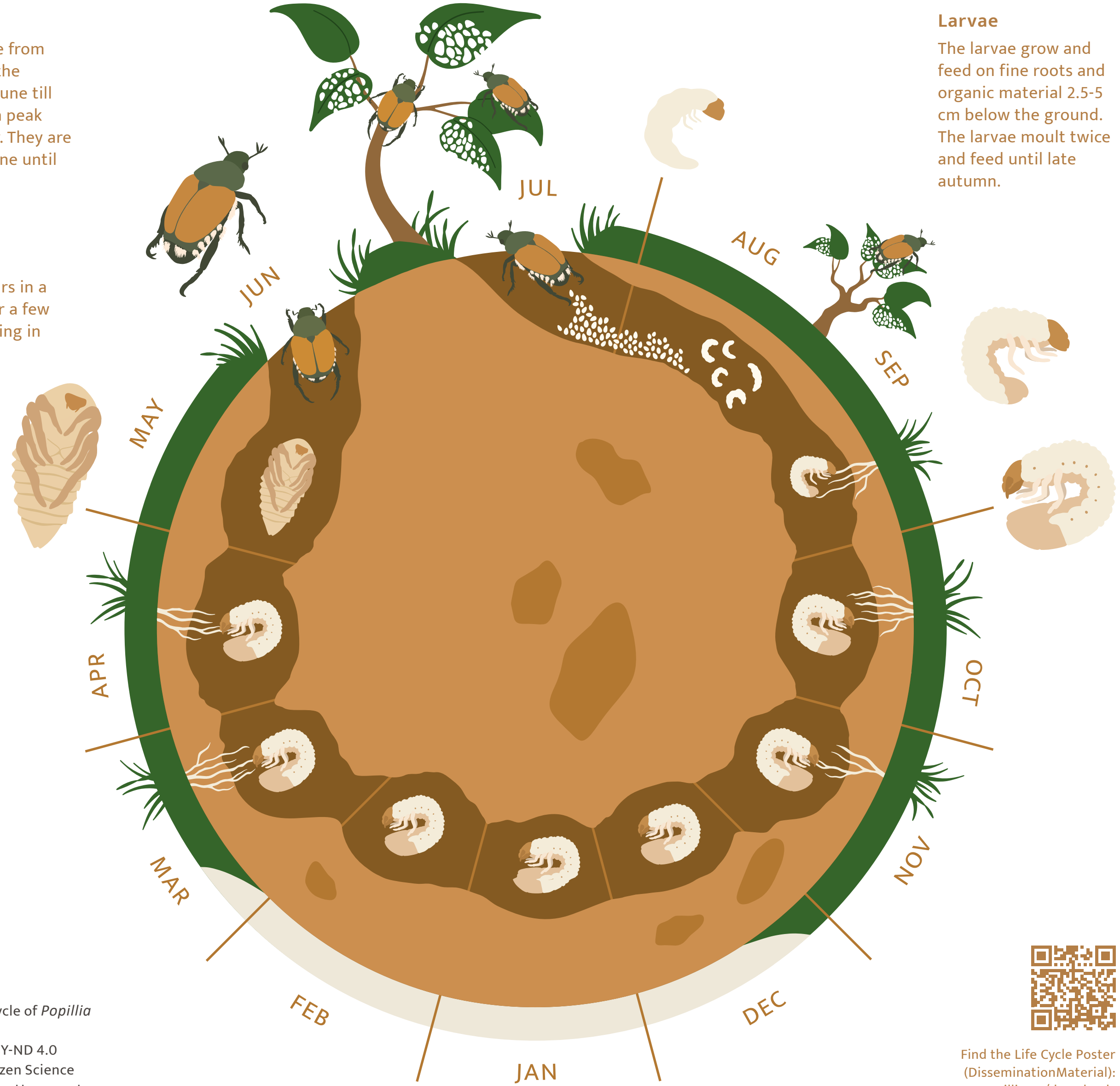


Fig. 3. The life cycle of *Popillia japonica*

SPOTTERON Citizen Science Platform www.spotteron.net

Find the Life Cycle Poster (DisseminationMaterial): www.popillia.eu/downloads

Distribution

POPILLIA JAPONICA

Popillia japonica populations were accidentally introduced into the eastern United States from Japan. Since their discovery there in 1916, they have spread throughout most of the USA east of the Rocky Mountains, and into southeastern Canada (Fleming 1972, Potter and Held 2002).

Eradication efforts are being directed against satellite infestations in the Pacific Northwest. The Azorean and Italian populations originated from two independent introduction events, both stemming from the North American invasive population (Strangi et al., 2024; Nardi et al., 2024).

Scan the QR-Code or follow the link to see migration routes and possible new invasion areas in the Supplementary material on our website.
www.popillia.eu/migrationroutes

2

SURVEILLANCE AND MONITORING METHODOLOGIES

POPILLIA JAPONICA

To complement the measures outlined in the official surveillance framework (COMMISSION IMPLEMENTING REGULATION (EU) 2023/1584), further to the visual inspections and the common funnel traps, a new digital device can be employed to detect *P. japonica* adults. Moreover, the engagement of citizens through citizen science can improve the ability to detect and track the spread of the Japanese beetle in a specific area.

Trap Systems

POPILLIA JAPONICA

FUNNEL TRAPS

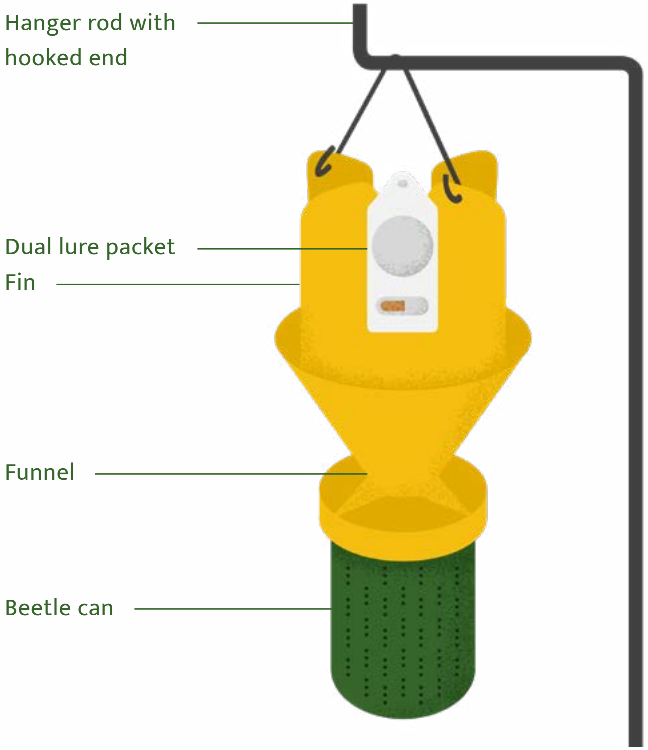
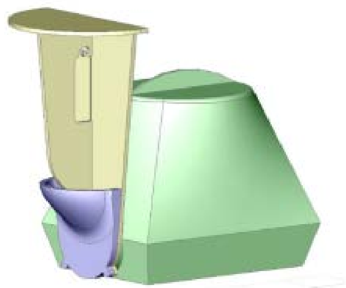


Fig. 4. Detailed description of different trap components, Infographic CC BY-ND 4.0 SPOTTERON Citizen Science Platform www.spotteron.net

Funnel traps, are baited with a dual semiochemical lure (a combination of phenethyl propionate, eugenol, geraniol, and the synthetic sex pheromone “Japonilure”). These traps require manual identification of the captured insects by an operator (Ladd et al., 1981) (Fig. 4).

i-SCOUT DEVICE



The i-SCOUT device, also uses the dual semiochemical lure but incorporates a camera that captures images of the insects. Using artificial intelligence and convolutional neural networks (CNNs), the device can automatically identify the species with 98% accuracy (Rojic, 2024).

Fig. 5. Prototype of iSCOUT device

Trap Placement Guidelines

POPILLIA JAPONICA

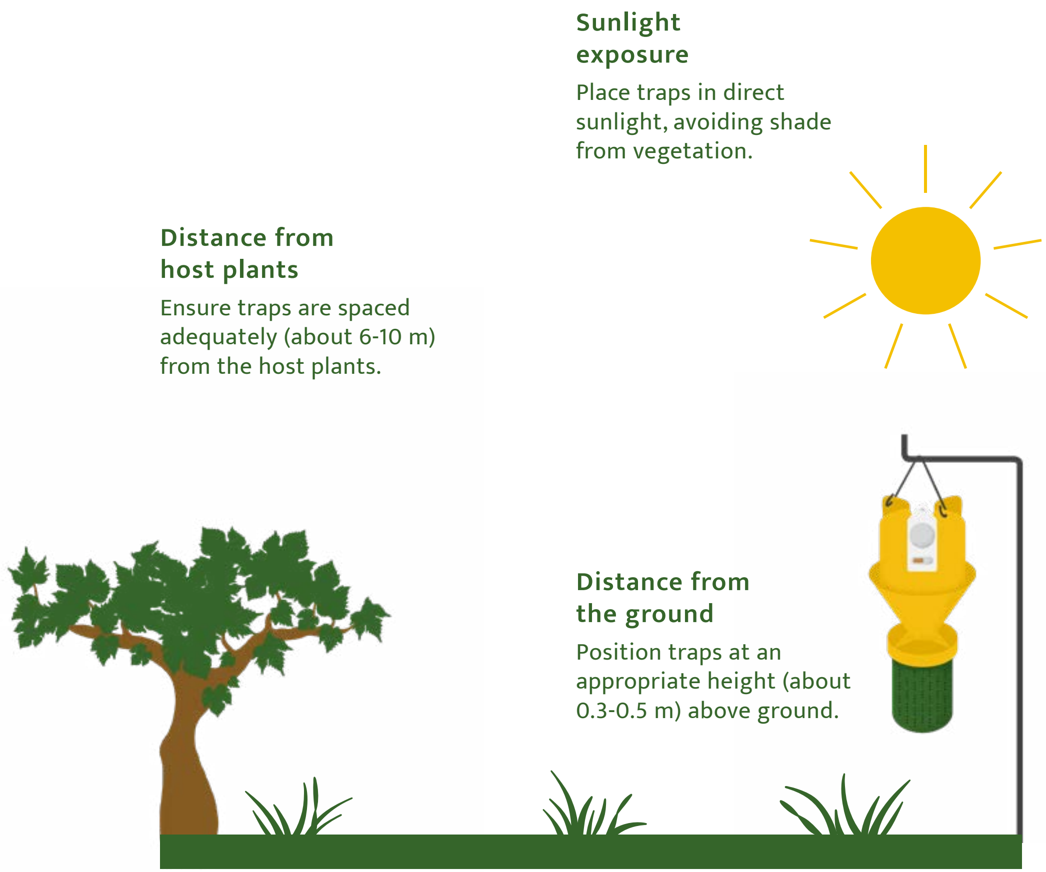
Proper trap placement is important for effective surveillance/monitoring of *P. japonica* (EPPO, 2016):

- **DETECTION AND DELIMITING SURVEYS**
  Traps should be placed no closer than 200 m apart.
- **MASS TRAPPING OR DENSITY MONITORING**
  Traps should be placed 50 m apart within infested areas (EPPO, 2016).
- **HEIGHT**
  - General placement: 0.5 m above ground level.
  - Turf or turf combined with high-growing hosts: 0.3-0.5 m from the trap funnel rim to the ground.
  - Turf with low-growing hosts: Place traps at host level (EPPO, 2016).
- **LIGHT CONDITIONS**
  Traps should be placed in direct sunlight (all-day sun or at least midday sun).
- **DISTANCE FROM HOST PLANTS**
  Traps should be placed 6-10 meters away from host plants.
- **AVOID OBSTRUCTION**
  Traps should not be placed under foliage or in locations that interfere with lawn-care equipment.

⚠ Ensure that the use of these devices is carried out in consultation with the appropriate National and Local authorities (NPPO), as the bait may attract *P. japonica* adults, even in areas still classified as free from infestation. Moreover, the trap's attractant is so potent that, in areas with a high density of insects, it lures significantly more individuals than the trap can capture, leading to severe damage to the vegetation surrounding the trap's placement area.

THE RECOMMENDED POSITIONING OF TRAPS

Fig. 6. Recommended placement of traps. Infographic CC BY-ND 4.0 CREA and SPOTTERON Citizen Science Platform www.spotteron.net



Field Monitoring via Mobile Apps & AI

CITIZEN & EXPERT INVOLVEMENT

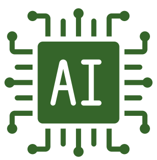
When there is a potential outbreak, it is essential to get data from the region. Both in an early situation and in a confirmed infestation, the spread, number of beetles, and damage can provide valuable information. For such occurrence monitoring, the IPM App Toolkit is available to stakeholder partnerships as a modern and feature-rich platform for both expert monitoring and public reporting ("Citizen Science").

THE IPM APP TOOLKIT CONSISTS OF:

- Mobile Smartphone Apps for Android & IOS
- Interactive Map Application for Browsers
- Admin Interface & Data Access for partners

The App enables the intuitive reporting of *Popillia japonica* sightings in a visually appealing and reliable mobile interface. All data submissions come with their GEO coordinates and additional data attributes such as the number of beetles observed, visible plant damage, host plant selection, weather parameters, and more. App users can also upload photos of the observed beetle and short descriptions alongside the data submission.

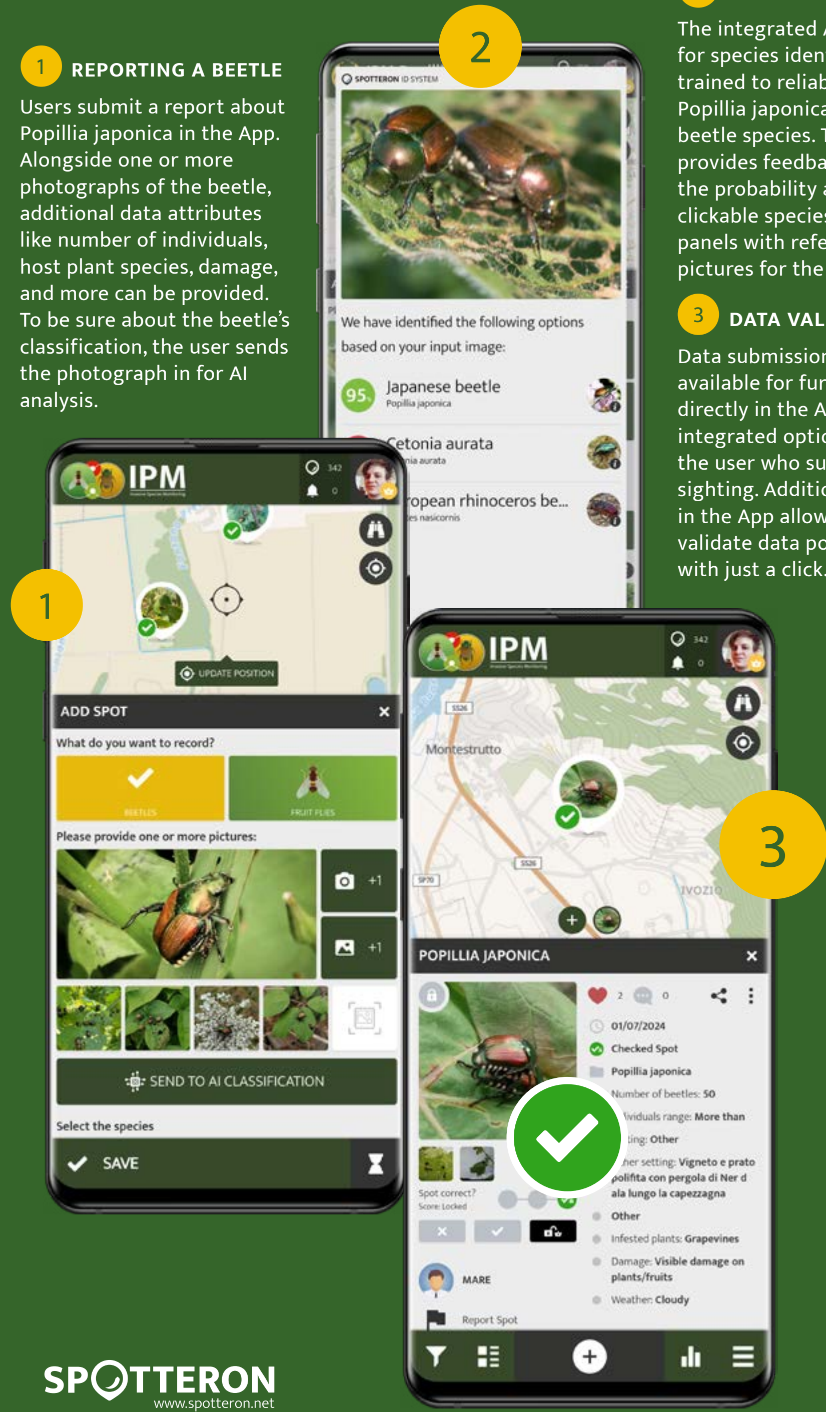
INTEGRATED AI SPECIES IDENTIFICATION



All photographs of beetles can be AI-analyzed directly in the App by every user. The AI system is trained for reliable identification of Popillia japonica and similar beetle species. With its direct accessibility in the data submission dialog via a button, the AI Species Identification can dramatically reduce the number of wrong data submissions by the public.

1 REPORTING A BEETLE

Users submit a report about Popillia japonica in the App. Alongside one or more photographs of the beetle, additional data attributes like number of individuals, host plant species, damage, and more can be provided. To be sure about the beetle's classification, the user sends the photograph in for AI analysis.



2 AI SPECIES ID

The integrated AI system for species identification is trained to reliably recognize Popillia japonica and similar beetle species. The interface provides feedback about the probability as well as clickable species information panels with reference pictures for the user.

3 DATA VALIDATION

Data submissions are available for further review directly in the App with integrated options to contact the user who submitted the sighting. Additional tools in the App allow experts to validate data points manually with just a click.

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IPM Stakeholder Toolkit Co-Use

COLLABORATION OPTIONS FOR NATIONAL STAKEHOLDERS

The IPM App Toolkit is available for co-use by national and international stakeholders. The software platform allows full partnerships for plant health agencies, research institutions, government agencies, and other stakeholders to use the App in a partner's own country/region for both data submissions by the public and expert monitoring in the field.

Using modern technologies such as AI species identifi-cation, communication tools, data visualizations, push notifications, and more are being already integrated, national partners can utilize a feature-rich App Toolkit that works reliably in practical use.

AUTOMATED SIGHTING REPORTS & DATA CONNECTORS

Reported sightings of *Popillia japonica* or other invasive pest species are available via a range of data connectors for national partners. From manual data download to live API access, the App can be fully integrated into currently existing data flows. The IPM App Toolkit can be configured to automatically report new validated *Popillia japonica* sightings to the local competent authorities via e-mail notifications.

INDEPENDENT FULL DATA & MANAGEMENT ACCESS

A new national partner gets full access via exclusive national admin accounts, enabling full independent use. The administration interface allows instant data download, as well as integrated communication and outreach tools to send custom media messages to the App users in their own country or region.

THE IPM STAKEHOLDER TOOLKIT INCLUDES:

- Innovative mobile Apps for enabling streamlined data reports for *Popillia japonica* and other invasive pest species
- Browser-based data submissions via embeddable online map
- Data Administration for own country, including data export options, API documentation, and supportive tools
- Integrated communication tools for sending push messages to reach out to all national users or distinct target groups
- Ability to set up expert users with data moderation/data validation possibility

The IPM App Toolkit offers a cost-efficient and high-quality option for professional expert data recording and public data submissions (SPOTTERON, 2024). With the modern and always-maintained IPM App, users can easily report sightings and provide additional information from photographs to GEO locations and data attributes. Supportive tools like AI species identification or automated reports are seamlessly integrated, and data connectors are available for national partners to access live data.

IPM APP TOOLKIT CO-USE

For national stakeholders, please get in contact to register for co-using the IPM App Toolkit in your country/region: www.popillia.eu/couse

3

BEST PRACTICES FOR CONTROL

POPILLIA JAPONICA

To address the invasion of *P. japonica*, various control strategies have been implemented to eradicate, limit and reduce its populations. These strategies encompass chemical, physical, and biological control methods (Fig. 7) and are reported in Table 1. Please make it sure that the following measures meet your national Member State regulation:

www.eppo.int/ACTIVITIES/plant_protection_products/registered_products

Fig. 7. Flow chart of measures to be taken in case of outbreak.
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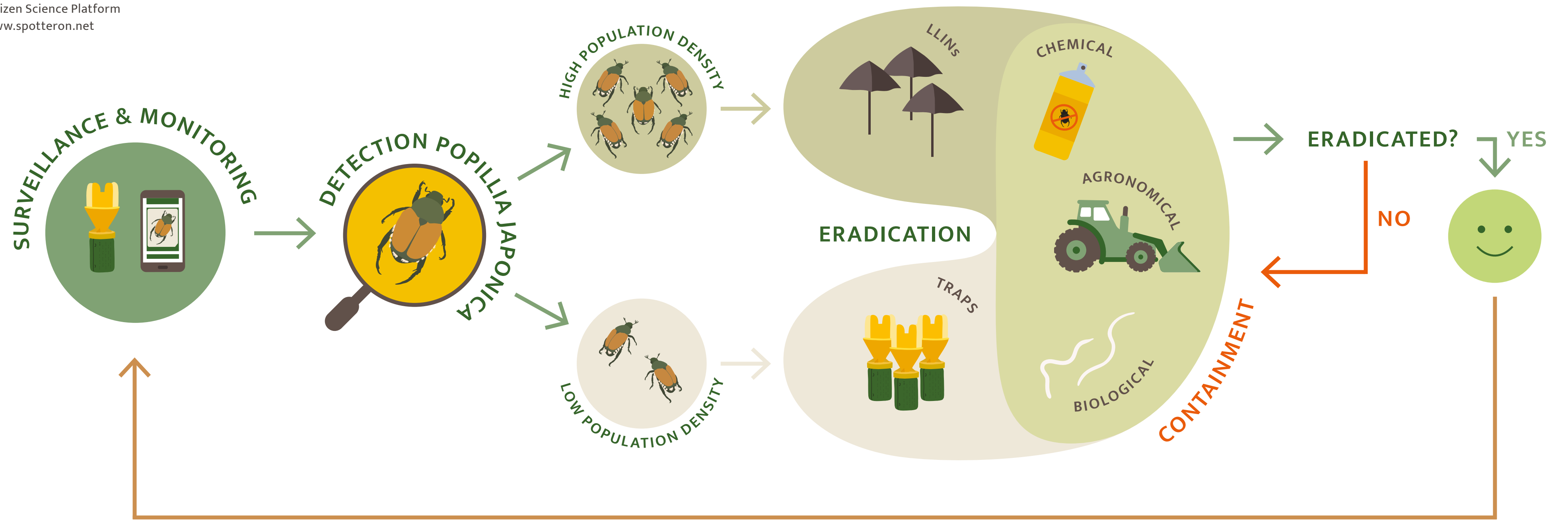

Chemical Control

POPILLIA JAPONICA

Table 1: chemical, agronomical and biological control measures

SYSTEM	ACTIVE SUBSTANCES	TARGET AND PERFORMANCE	TYPE OF ENVIRONMENT / CROP
Conventional (spray)	Pyrethroids and their derivatives (e.g., deltamethrin, lambda-cyhalothrin, etofenprox)	**Against adults:** they show high effectiveness, but use with care because pyrethroids are also toxic to beneficial insects including pollinators and natural enemies (predatory mites, lady beetles, and others) that help keep other pests in check (Bosio, 2024; Redmond et al., 2020; Gotta et al., 2023).	vineyards, corn, nurseries
	Acetamiprid	**Against adults:** it shows very high effectiveness as a contact insecticide. It has cytotropic-translaminar activity and highly systemic, protecting even newly grown plant organs.	vineyards, nurseries
	Chlorantraniliprole	**Against adults and larvae:** highly effective against adults on plants and larvae in the soil, with low impact on bees, predatory insects and mites, and other beneficial species (Larson et al. 2012, Redmond and Potter 2020). Acts mainly through ingestion, with some contact activity.	vineyards, nurseries, turf
Low-impact	Attract-and-Kill devices (A&Ks) made with Long-Lasting Insecticide-treated Nets (LLINs)	**Against adults:** LLINs are insecticidal nets impregnated or coated with pyrethroids, assembled in A&Ks (Paoli et al., 2023). They kill beetles and reduce the local population density with a minimal environmental impact. A single net per hectare is an effective ratio to reduce adult populations in 20-hectare infested areas (Paoli et al., 2024). This method is recommended when labour costs associated with mass trapping become excessive. Ensure that the use of these devices is carried out in consultation with the appropriate National and Local authorities (NPPO), as the bait may attract *P. japonica* adults, even in areas still classified as free from infestation. Moreover, the trap's attractant is so potent that, in areas with a high density of insects, it lures significantly more individuals than the trap can capture, leading to severe damage to the vegetation surrounding the trap's placement area.	all environments

Agronomical and Physical practices

POPILLIA JAPONICA

PRACTICE TYPOLOGY	TARGET AND ADDITIONAL NOTES	TYPE OF ENVIRONMENT / CROP
Crop rotation / intercropping	**Against larvae:** this can reduce crop damage. Continued cultivation of the same crop preferred by *P. japonica* in the same field increases the risk of heavy infestations. Crop rotation with non-host species can help prevent high pest populations (Fleming, 1976). Soybeans intercropped with sorghum reduce beetle abundance compared with soybean monoculture (Althoff & Rice, 2022).	corn, soybean
Early and late planting	**Against adults:** some maize varieties can be sown early or late in the season to ensure that silking occurs either before or after the peak flight period (Fleming, 1976).	corn
Irrigation	**Against larvae:** by managing irrigation, particularly by limiting or halting it during peak beetle flight, it is possible to reduce larval infestations. This may reduce subsequent larval population densities (Potter et al., 1996), as female *P. japonica* prefers moist soil for oviposition (Dalthorp et al., 2000).	turf

Kaolin-based foliar spray (Aluminum Silicate)	**Against adults:** it decreases vine infestations through a repellent action. Its use is recommended under specific weather conditions (Gotta et al., 2023).	vineyards
Mass trapping	**Against adults:** it is useful both for surveillance and monitoring. It can be used for eradication in the case of low-density populations. See Chapter 2 for the correct placement of the traps. ⚠ Be aware that the use of mass traps must be done in agreement with the local competent authority. While a single trap baited with the pheromone can attract individuals from an area of up to 78.5 hectares, the optimal number of traps require**d for effective control may vary depending on factors such as pest density and environmental conditions (Wawrzynski & Ascer**no, 1998). Mass trapping alone may suppress new, small, or isolated infestations, but is unlikely to eliminate established high populations.	all environments, except nurseries
Mulching	**Against adults:** among various weed mulching products, coconut mulch was the most effective in reducing oviposition (Mori et al., 2022).	nurseries (e.g. potted plants)
Nets barrier	**Against adults:** Anti-hail and insect-proof nets are effective in protecting nursery plants (Gotta et al., 2023; Burkness et al., 2022).	nurseries (e.g. potted plants), small fruit crops (e.g. bluebarry, raspberry)
Tillage	**Against larvae:** several types of tillage can reduce the density of larvae in the soil (Fleming, 1976).	corn, soybean, nurseries

Effective biological control agents

POPILLIA JAPONICA

BIOCONTROL AGENTS	SPECIES NAME	TARGET AND ADDITIONAL NOTES	TYPE OF ENVIRONMENT / CROP
Effective biological control agents	*Heterorhabditis bacteriophora*	**Against larvae:** indigenous *Heterorhabditis bacteriophora* strains (e.g., strain POP16 for Northern Italy), applied at a rate of 2.5 billion individuals per hectare, have demonstrated higher efficacy compared to commercial strains. This is likely due to their superior adaptation to local ecological conditions and extended soil persistence. **Optimal Timing:** application is recommended in August or September, when first and second instar larvae, the most susceptible life stage, are prevalent. **Application Method:** *Heterorhabditis bacteriophora* should be applied using appropriate spraying equipment. To minimize exposure to harmful UV radiation and high temperatures, which can reduce EPN viability, applications should be timed for early morning or late evening. To enhance EPN performance, the soil should be watered before and after application.	turf
		Against larvae: *Heterorhabditis bacteriophora*, is effective when applied at three times the manufacturer's recommended dosage. This higher concentration provides greater coverage and significantly increases the likelihood of a successful larval infection.	nursery (e.g. potted plants)

Optimal Timing: *Heterorhabditis bacteriophora* can be used for both preventive and curative treatments against *Popillia japonica* larvae.

For preventive treatments, *H. bacteriophora* must be applied to the soil of potted plants just before the adult beetle emerges.

For curative treatments, *H. bacteriophora* must be applied about 60 days before the desired marketing or movement of treated plants.

In controlled nursery environments, preventive treatment, which limits the vitality of newly hatched larvae, appears to be the most effective method for preventing the passive spread of the pest.

Application Method: *Heterorhabditis bacteriophora* should be applied using suitable equipment, ensuring that the application process strictly adheres to the instructions provided by the manufacturer on the label

In addition to the measures that tested effective, the promising techniques, which are either not yet availlable in the EU or still need to be developed before being ready to use, are listed in the Table 2.

Promising techniques that are either not yet available in Europe or still need to be developed

POPILLIA JAPONICA

Table 2: Promising techniques for the future

TREATMENT TYPOLOGY OR BIOCONTROL AGENTS	ACTIVE SUBSTANCE / SPECIES NAME	TARGET AND PERFORMANCE	TYPE OF ENVIRONMENT / CROP
Conventional (endotherapy)	Acetamiprid	**Against adults:** it involves injecting active ingredients into plants through drilling. The injected solution is then absorbed by the plant and transported to the leaves, where insects feeding on them are subsequently poisoned.	lindens
Low-impact chemical control	Iron chelate	**Against adults:** it is a leaf fertilizer, achieving 70% adult mortality in laboratory tests, that enables organic growing by creating a film that suffocates adult insects (Bosio, technical communication). Its field effectiveness still requires accurate evaluation.	vineyards
	Saponins	**Against adults:** extracted from alfalfa (*Medicago sativa*), saponins are biologically active molecules with antifeedant and insecticidal properties against *P. japonica*. They act as a food deterrent, significantly reducing the consumption of treated leaves. Additionally, when used at a concentration of 3%, they increase the mortality rate of *P. japonica* adults. (Iovinella et al., 2023).	nursery

	Bacillus thuringiensis var. *galleriae (Btg)*	**Against adults:** it significantly reduces defoliation and achieves approximately 80% adult mortality on roses. Unfortunately, its effect is not persistent. At higher concentrations, *Btg* can reduce defoliation by up to 90% on *Tilia cordata*. However, ingestion of *Btg* residues on leaves can be harmful to some species of caterpillars (Redmond et al., 2020).	nurseries (e.g. roses, lindens)
	Metarhizium spp. *or Beauveria* spp.	**Against adults:** under laboratory conditions, *Metarhizium brunneum* reached 100% mortality by 19 days after treatment. This fungus could be also used also in all environments for the attract-infest-release strategy, which consists in luring the beetles through the semiochemicals and forcing them to walk on a fungal-infected substrate. As a consequence, the insect gets infected by contact. Once infected, the beetle can spread the fungus within the pest population through both mating and direct contact, as *P. japonica* tends to congregate (Benvenuti et al., 2019).	turf / all environments
Parasitoids	*Tiphia* spp	**Against larvae:** some *Tiphia* species, such as *Tiphia vernalis* or *T. popilliavora*, are ectoparasites of *Popillia japonica* larvae (Althoff & Rice, 2022). The establishment of these wasps in a specific area may be aided by availability of nectar sources (e.g., *Paeonia lactiflora* or *Prunus serotina*) or aphid honeydew, leading to higher parasitism rates (Balock et al. 1934, Rogers and Potter 2004, Mclaughlin et al. 2022).	all environments
	Istocheta aldrichi	**Against adults:** this fly lays eggs on the adult's prothorax; then, larvae drill through the exoskeleton and, after their first molt, fly larvae move to the internal organs (Fleming, 1976).	
Parasites	*Ovavesicula popilliae*	**Against larvae:** if ingested, this microsporidian may reduce the larval survival of *P. japonica* by about 75% (Piombino et al., 2020). Adults of *P. japonica* developed from larvae infested with *O. popilliae* may have a fecundity reduction by up to 50% (Smitley et al. 2011).	turf

Scheduled Control Measures

POPILLIA JAPONICA

Fig. 8. Scheduled control measures to manage *Popillia japonica*
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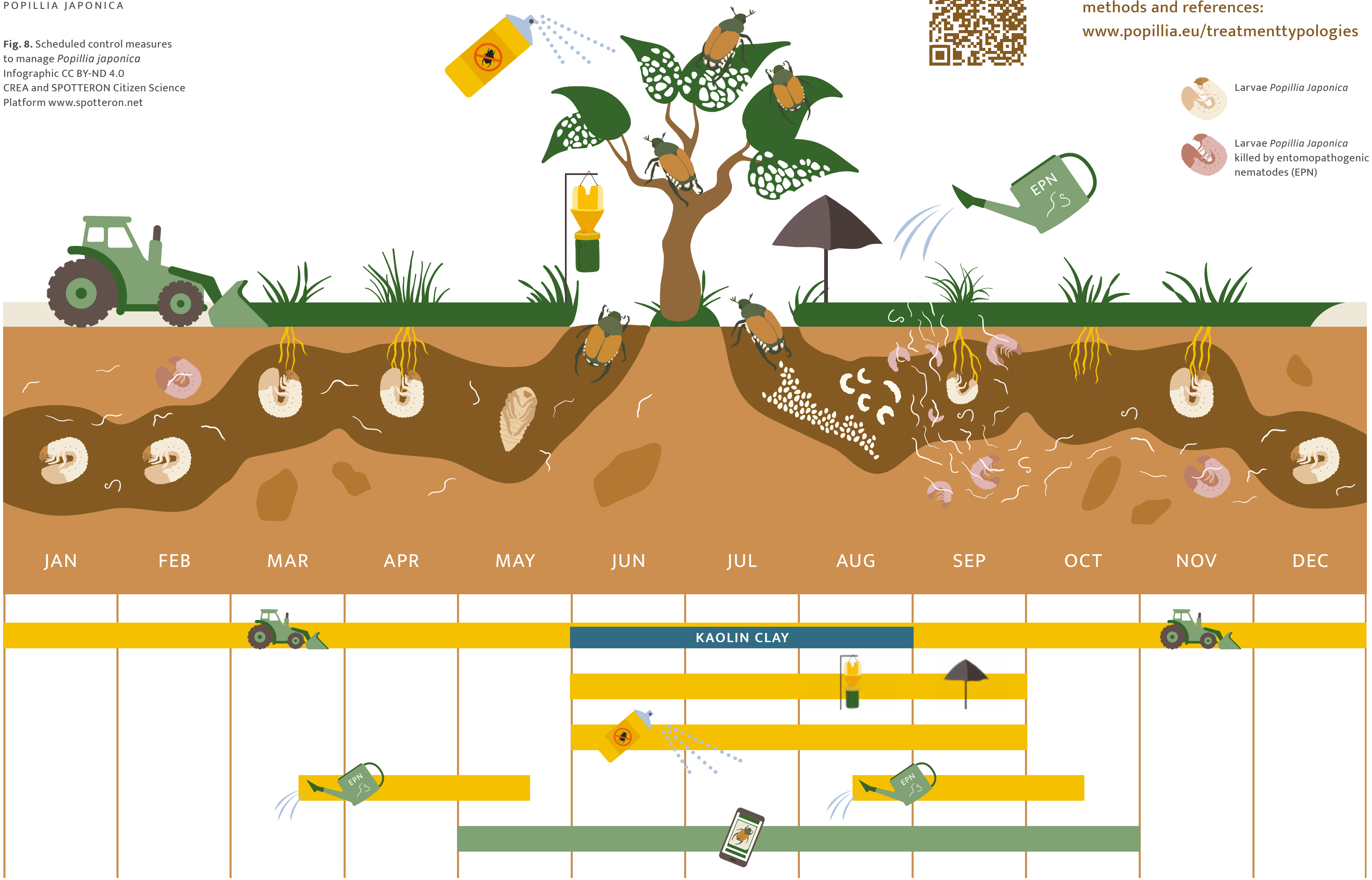
Detailed insights into treatment methods and references:
www.popillia.eu/treatmenttypologies



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INVASIVE SPECIES *Popillia japonica / Japanese beetle*

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