5 POTENTIAL DISTRIBUTION AND EFFICACY OF PESTS ASSOCIATED WITH BIOCONTROL AGENTS

5.1 BIOCONTROL AGENTS ASSOCIATED WITH POTATO AND VEGETABLE PESTS

5.1.1 *Copidosoma koehleri* (Blanchard 1940)

Synonyms: *Arrenoclavus koehleri* (Blanchard 1940)
Copidosoma uruguayensis (Tachikawa 1968)

Taxonomic position: Insecta, Hymenoptera, Encyrtidae (Encyrtinae)

Authors: V. Canedo, P. Carhuapoma, E. López, & J. Kroschel

Hosts

Potato tuber moth, *Phthorimaea operculella* (Zeller) (primary host); Andean potato tuber moth, *Symmetrischema tangolias* (Gyen); Guatemalan potato tuber moth, *Tecia solanivora* (Povolny); Tomato leafminer, *Tuta absoluta* (Meyrick)

Morphology

Egg

The ovarian eggs of *Copidosoma koehleri* are dumbbell-shaped, consisting of the bulb, neck, and enlarged basal portion measuring approximately 0.17 mm in total length. *C. koehleri* is a polyembrionic species as common in the family Encyrtidae (i.e., two or more); in *C. koehleri* up to 40 embryos develop from a single fertilized egg. The embryo is divided into two forms: one that will develop into an adult and the other that becomes a soldier responsible for eliminating other species of parasitoids that are in the host.

Larva

Juvenile L1 larvae are transparent and colorless, but then change to a creamy-white opaque appearance after the ingestion of host tissue (Photo 1A). The potato tuber moth larva spins its silken cocoon as the parasitoids consume its adipose tissue. Parasitized potato tuber moth larvae are unable to pupate because the vital organs are consumed by the internal parasitoids. The parasitized host becomes flaccid and unhealthy in appearance. When the parasitoid larvae devour the contents of the host's ventricles, their color changes from creamy-white to orange. The host larva is now essentially only a shell surrounding the brood of parasitoids. This host carcass is called a "mummy" (Photo 1B).

Pupa

At the end of larval development, the larva secretes a cocoon sheath to pupate. The pupa is at first entirely white (Photo 1C), but in about 24 hr the eyes become colored with a brick-red pigmentation. Later melanization begins, and the abdominal tergites are the first structures to turn black.

Adult

The small wasps (1.1–1.4 mm, including the ovipositor) have an enlarged pair of middle legs used for jumping. The wings are covered with short hairs. Head and thorax are dark with a metallic green sheen. Antennae from female are long and slender in shape, with a 3-segmented oval clava, whereas the male antenna is always 7-segmented (Photo 1D).

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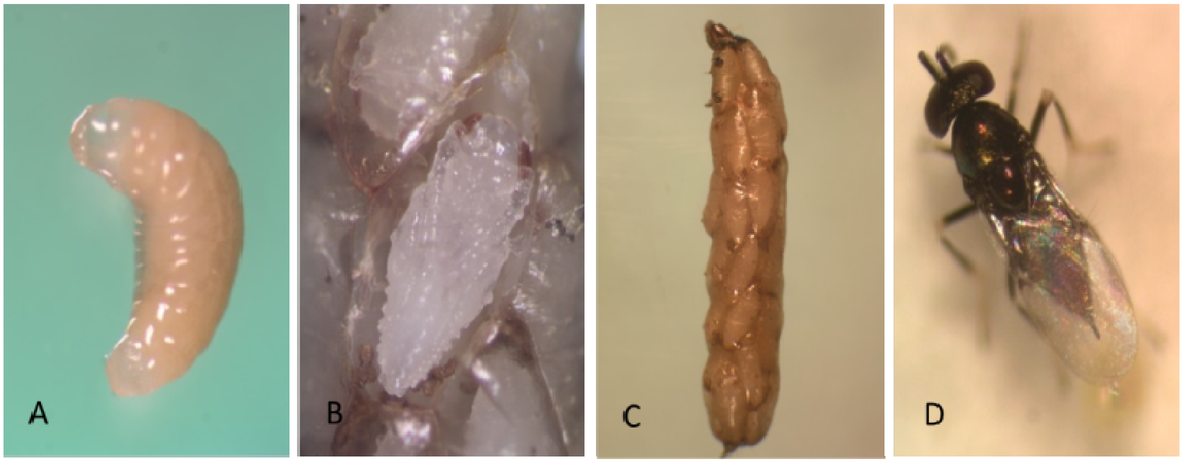


Photos 1. The development stages of *Copidosoma koehleri*: (A) larva, (B) pupa, (C) mummy with up to 72 individuals, and (D) adult. Photos: Courtesy of CIP.

Biology

Parasitism

C. koehleri is an egg parasitoid of species of the potato tuber moth complex. The female parasitizes moth eggs of all ages but prefers freshly laid eggs. Parasitized host larvae hatch and grow, and inside develop through polyembryony an average of about 35–40 genetically identical *C. koehleri* wasps from a single-laid *C. koehleri* egg. Toward the end of host larval development, *C. koehleri* larvae feed actively on the host tissue and kill the host. Wasp pupation takes place inside the host cuticle (the mummy) from which adult wasps emerge.

Temperature-dependent development

C. koehleri completes its development from egg to adult at temperatures of 20°–30°C. Total development at 20°C was almost 2.3 times longer (50 days) than at 30°C (22 days). Its total life cycle was not completed at constant temperature of 14°C. The highest mortality of parasitized larvae of *P. operculella* and mummies were 49% and 52% at 20°C, respectively. Female longevity decreased with high temperatures, from 26 days at 20°C to 12 days at 30°C. The optimum temperature for reproduction ranged from 20° to 25°C. The maximum fecundity of 113 offspring was observed at 20°C. The sex ratio is affected by temperature, with a predominance of males at 30°C (female:male ratio of 1:3.4) and a ratio of 1:1 at 25°C.

The established functions were used to estimate the life-table parameters of *C. koehleri* and to build an overall stochastic phenology model. Negative r values under 15°C indicate that the population size is decreasing at these temperatures; positive r values between 18°C and 32°C indicate an increase of the population. The finite rate of increase peaked at 22°C (λ=1.0739) and was smallest at 15°C (λ=0.956) and 35°C (λ=0.919), respectively; $\lambda<1$ indicates that the population is decreasing. Highest values for the gross reproduction rate and net reproduction rate (R_o) were found at 22°C. The shortest mean generation time (T) was observed at 26°C (48.98 days); the shortest population doubling time (Dt) at 22°C (9.73 days). The optimum temperature for overall population growth ranged from 20°C to 24°C (see Annex 7.4.1).

Economic impact in pest control

For inundative biological control of the potato tuber moth, *C. koehleri* was released, in combination with other parasitic wasps like *Apanteles subandinus* or *Orgilus lepidus* in several countries (e.g., Australia, South Africa, Zimbabwe, Zambia, and others). *C. koehleri* complements well with these parasitoids (see sections 5.1.2 and 5.1.3). Classical biological control was very successful in Zimbabwe. After its establishment in Australia, it started to play an important role in *P. operculella* control after the introduction of a potato integrated pest management program with fewer pesticide applications.

Geographical distribution

Possible region of origin: South America: endemic in Peru, Argentina, Brazil, Uruguay, Chile, Ecuador, and Bolivia

Introduced and established: Australia (including Tasmania), Cyprus, Kenya, India, Mauritius, USA (California), South Africa, St. Helena, Zimbabwe, and Zambia

Introduced but establishment not confirmed: Bermuda, Colombia, Greece, Israel, Italy, Japan, Madagascar, New Zealand, Yemen, Seychelles, Tanzania, Venezuela, and DR Congo (Fig. 1).

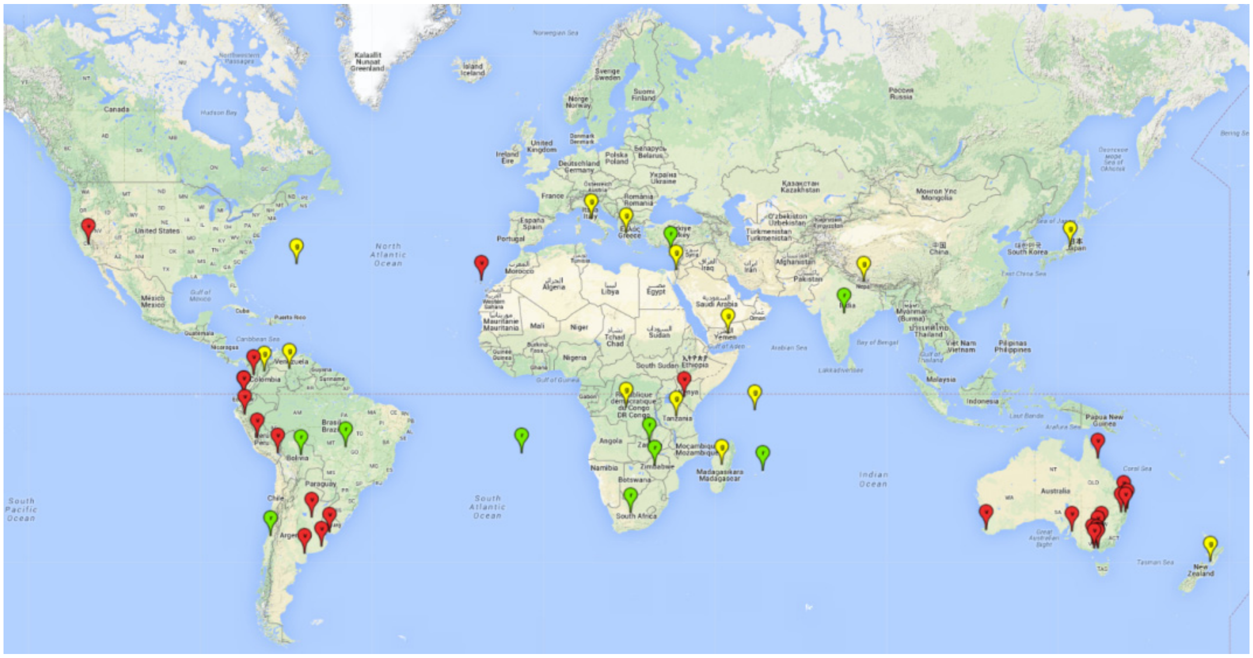


Figure 1. Global geographical distribution of *Copidosoma koehleri*. Green points indicate countries with reported natural occurrences including successful establishments after releases; red points are georeferenced distribution data; and yellow points indicate countries where releases have been undertaken but where establishment is not confirmed.

Potential establishment and efficiency under current and future climates

Changes in global establishment and future distribution

In potato production regions globally, the potato tuber moth, *P. operculella*, is potentially established at an establishment risk index (ERI)>0.7 (see section 4.1.1). Potential release regions for *C. koehleri* are those potato production regions where the potato tuber moth has been established, causing significant economic damage in potato fields and stores. Therefore, the establishment index (EI) for the parasitoid *C. koehleri* is only displayed for those regions where *P. operculella* can potentially establish. An EI=1 indicates survival of the parasitoid throughout the year—that is, the likelihood of long-term establishment for classical biological control is very high in these regions. However, *C. koehleri* has also been established in regions with an EI of 0.5–0.6 (indicated by light-cream zones in Peru, Argentina, and Australia in Figure 2; compare with Fig. 1).

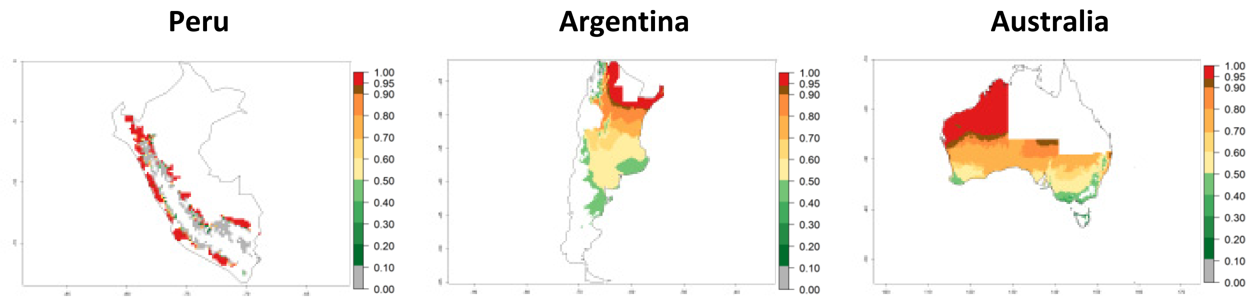


Figure 2. EI of *Copidosoma koehleri* in countries and regions where establishment has been reported according to model predictions of the year 2000. An EI>0.5 (light yellow to red zones) indicates regions with permanent establishment.

Many regions can be identified where *C. koehleri* has high EI>0.95 (Fig. 3A). These are in countries and potato-growing regions of South America (Venezuela, Colombia, Ecuador, Peru, Argentina, southeast of Brazil, Bolivia); Central America (Guatemala, Costa Rica, Honduras, Mexico); West and East Africa (Senegal, Cameroon, Sudan, Kenya, Uganda); Asia (India, Indonesia, Nepal, South China); and northwest Australia. Global predictions for 2050 indicate that the establishment of *C. koehleri* will potentially increase in potato-growing regions of North Africa (Egypt, Morocco, Tunisia); South America (Chile, Argentina, south of Brazil); South Africa; and southern Australia (Fig. 3B). In contrast, a slight reduction in the establishment potential is predicted for some potato-growing regions of Australia, India, and Indonesia, but which will not affect its establishment (Fig. 3C).

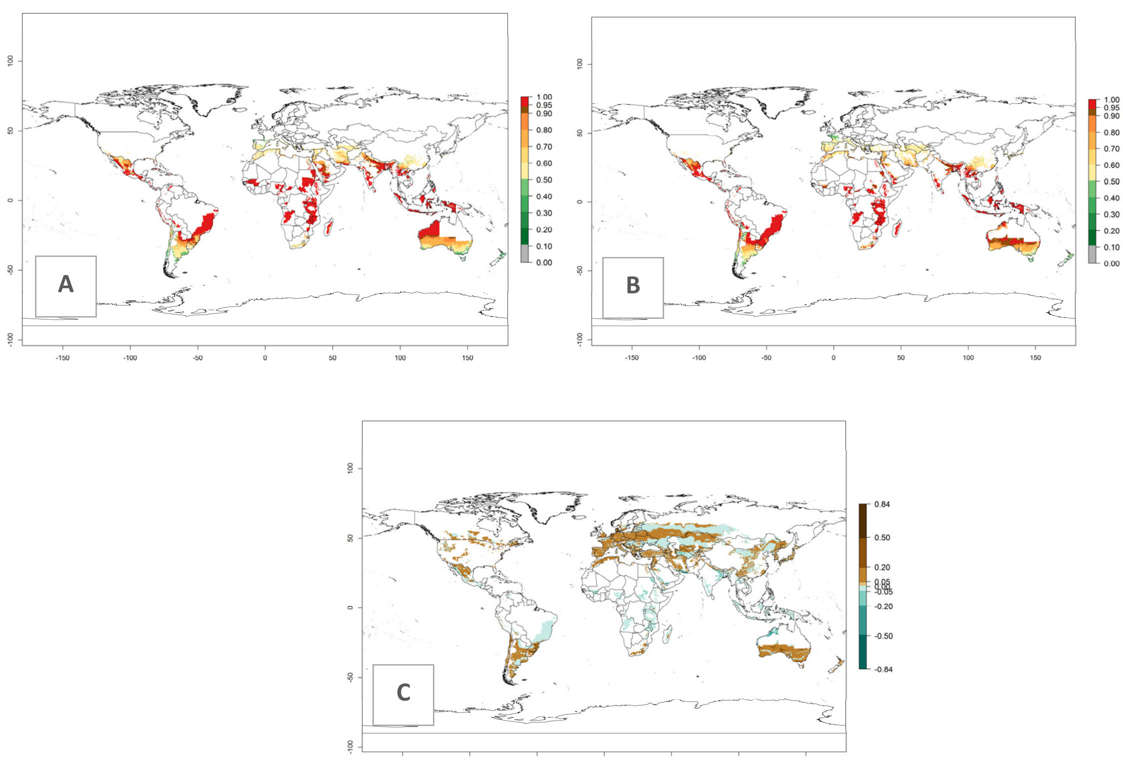


Figure 3. Establishment and potential distribution worldwide of *Copidosoma koehleri,* parasitoid of *Phthorimaea operculella*, according to model predictions, using the EI for the years 2000 (A) and 2050 (B), and changes of the EI between 2000 and 2050 (C), displayed for potato production regions with an ERI>0.7 of its primary host *P. operculella*. An EI>0.5 indicates regions with potential permanent establishment.

Changes in global abundance

The generation index (GI) reflects the abundance of the population, and it estimates the mean number of generations that may be potentially produced within a given region per year (Fig. 4A, B). The number of generations per year in countries where *C. koehleri* is established today ranges from 6 to 9. For the year 2050, in some tropical areas of America the GI indicates a potential increase of 1 generation per year (Chile, Argentina, Uruguay, and south of Brazil). In other regions fewer generations will be produced, such as in southeast Brazil, Africa, Asia, and northwest Australia (Fig. 4C).

The activity index (AI) highlights not only the establishment but also the potential spread and efficiency of *C. koehleri* to control its host. The AI for the year 2000 reveals an activity of *C. koehleri* of 4–6 in countries where the species is present today. For potato production regions of Zimbabwe, where the parasitoid was very successful in biological control, an AI of up to 10 was estimated (Fig. 4D, compare with Fig. 1). Predictions of change for the 2050 climate change scenario show a slight increase in the potential growth by a factor of 1–3 in some potato-growing areas of Peru, Bolivia, Chile, and southeast Brazil in South America; in countries of southeast Africa (e.g., Mozambique), and south of Australia. In contrast, a reduction of the potential growth will be expected in Indonesia (Fig. 4E, F).

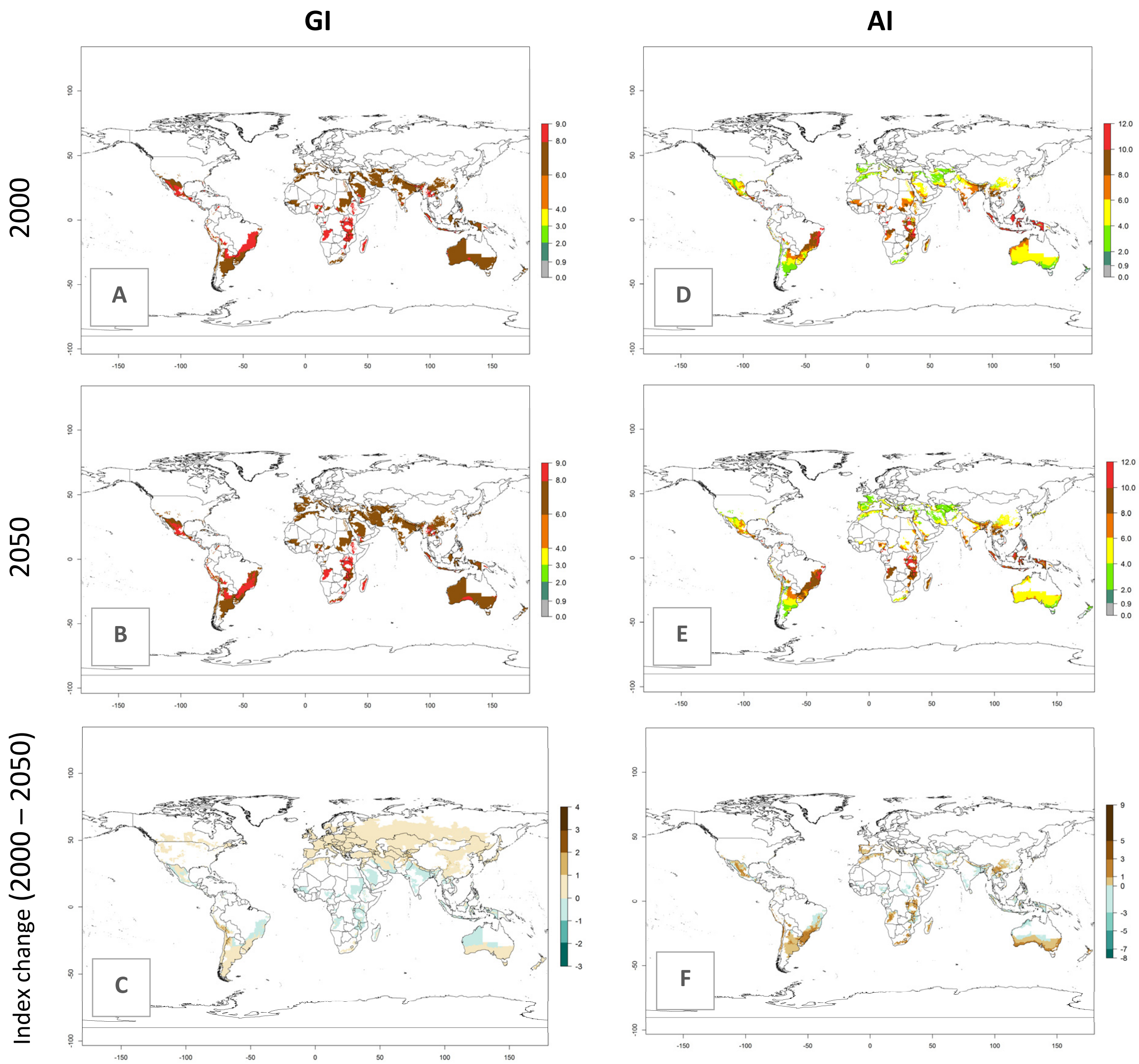


Figure 4. Changes in abundance (GI, number of generations/year) and activity (AI, potential population growth) of *Copidosoma koehleri* in potato production regions worldwide according to model predictions, using the GI (A, B) and the AI (D, E) for the years 2000 and 2050, and the absolute index change (C, F), displayed in potato production regions with an ERI>0.7 of its primary host *Phthorimaea operculella*.

Changes in regional establishment and distribution in Africa

In Africa, *C. koehleri* has been introduced and established in Kenya, South Africa, Zimbabwe, and Zambia. It has also been introduced into Madagascar, the Seychelles, Yemen, Tanzania, and DR Congo; but establishment was not further validated and confirmed. According to the mapping results, however, it could have been expected to establish successfully in all these countries (Fig. 5A).

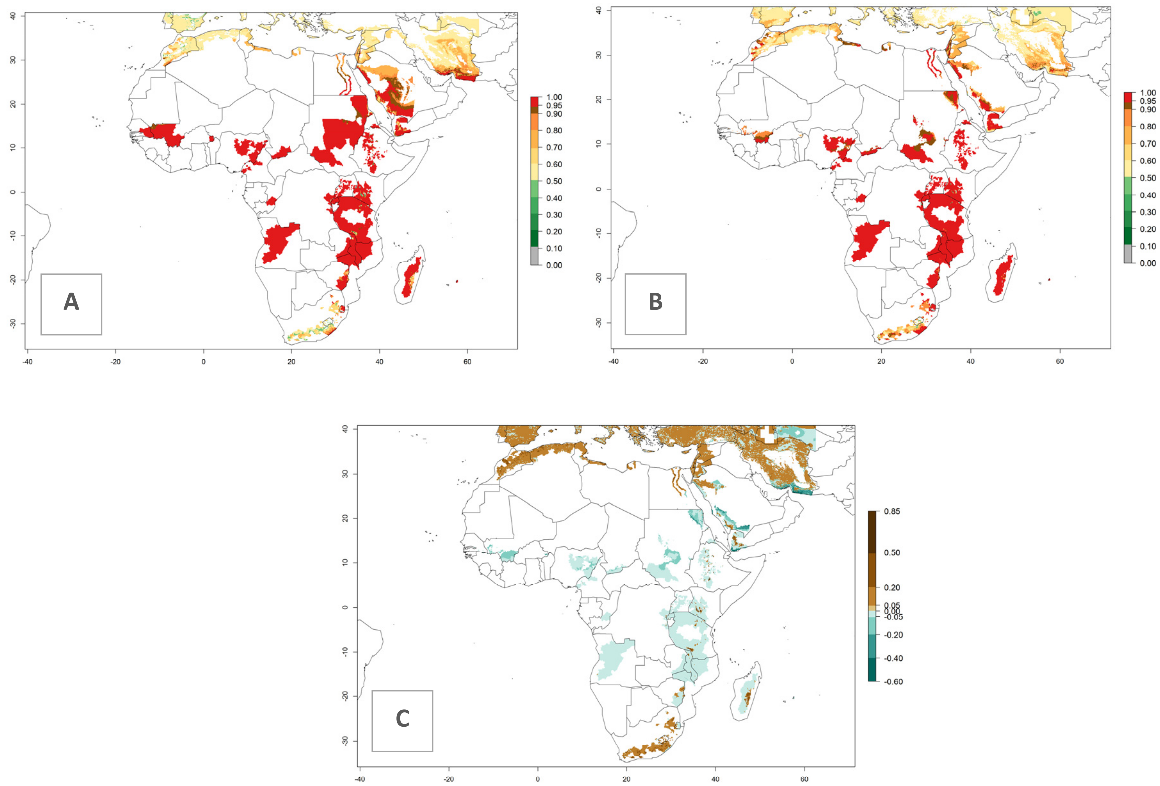


Figure 5. Establishment and potential distribution of *Copidosoma koehleri* in Africa according to model predictions, using the EI for the years 2000 (A) and 2050 (B), and changes of the EI between 2000 and 2050 (C), displayed for potato production regions with an ERI>0.7 of its primary host *P. operculella*. An EI>0.5 indicates regions with potential permanent establishment.

In tropical eastern Africa, an EI>0.95 indicates that *C. koehleri* could potentially establish according to the prevalent temperature conditions in the potato-growing regions of Angola, Ethiopia, Chad, Congo, Kenya, Madagascar, Malawi, Mali, Mozambique, Nigeria, Rwanda, Senegal, Sudan, Uganda, Zambia, Zimbabwe, and Tanzania (Fig. 5A). Climate change is expected to increase the establishment potential in South Africa and countries of North Africa (Fig. 5B, C).

Changes in regional abundance in Africa

In many potato-growing areas of Africa, the GI reveals 6–9 generations per year (Fig. 6A). Predictions for the year 2050 indicate an increase in generation numbers per year in potato highland production regions of East Africa, South Africa, and some parts of Madagascar. In contrast, the number of generations could potentially reduce in countries of the Sahel such as Senegal and Sudan (Fig. 6B, C). The activity and spread potential of the parasitoid is expected to increase in potato-growing areas of East and South Africa. Especially for Angola, Ethiopia, Kenya, Madagascar, Malawi, South Africa, Tanzania, and Uganda, a high *C. koehleri* activity of AI>8 is projected (Fig. 6D–F).

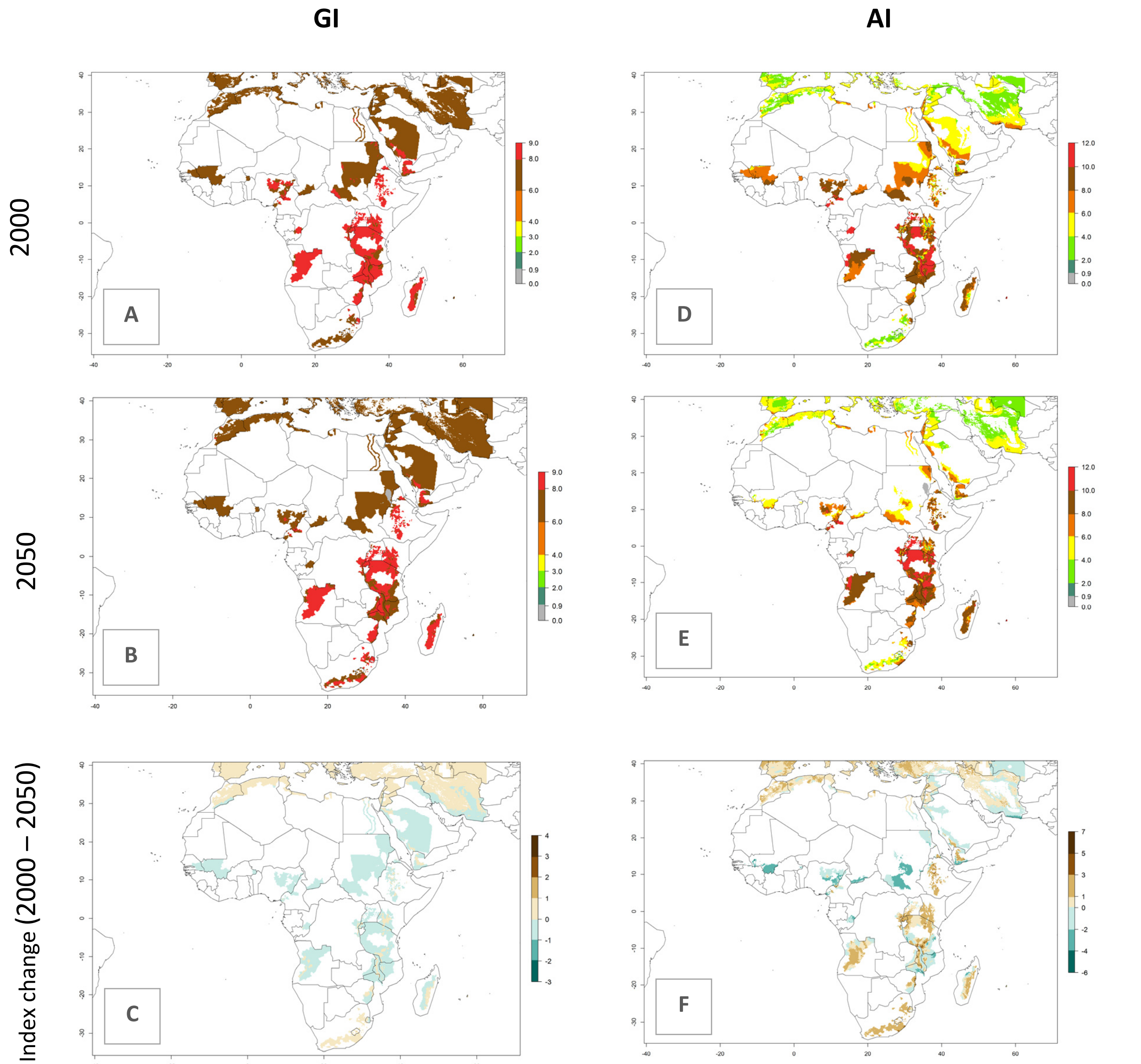
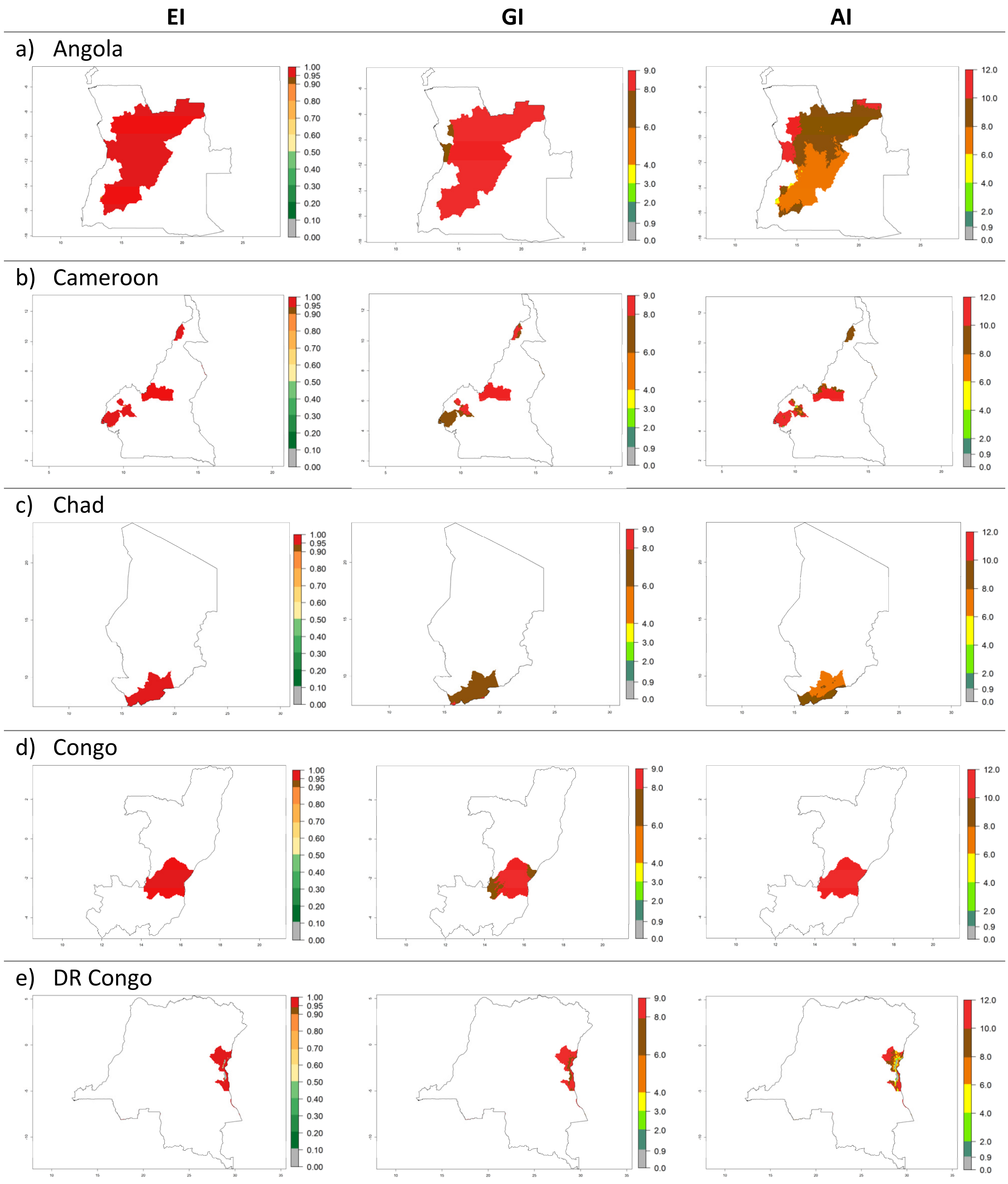


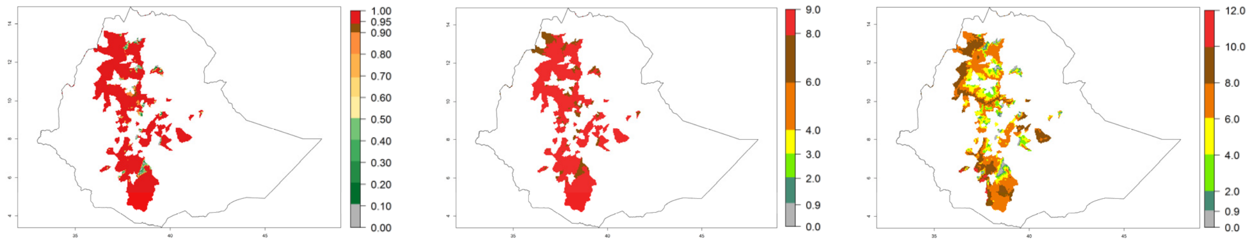
Figure 6. Changes in abundance (GI, number of generations/year) and activity (AI, potential population growth) of *Copidosoma koehleri* in Africa according to model predictions, using the GI (A, B) and the AI (D, E) for the years 2000 and 2050, and the absolute index change (C, F), displayed in potato production regions with an ERI>0.7 of its primary host *Phthorimaea operculella*.

Potential release areas in Africa

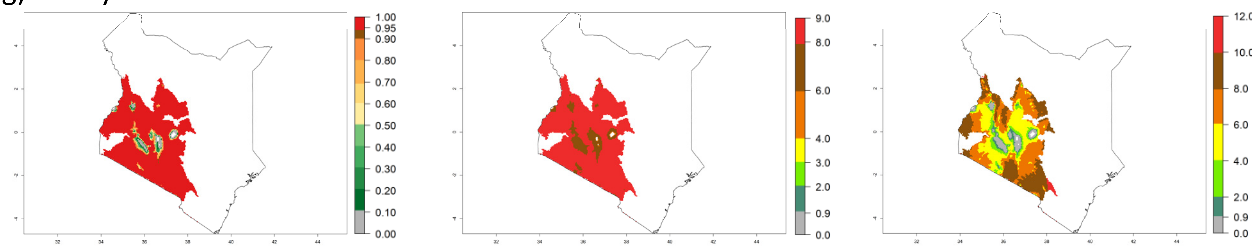
Considering an ERI>0.7 for *P. operculella* (section 4.1.1) in potato-growing areas of Africa, the potential countries to release *C. koehleri* under the current climate are Angola, Cameroon, Chad, Congo, DR Congo, Ethiopia, Kenya, Madagascar, Malawi, Mali, Mozambique, Nigeria, Rwanda, Senegal, South Africa, Sudan, Tanzania, Uganda, Zambia, and Zimbabwe (Fig. 7). *C. koehleri* has been shown to establish at an EI>0.5; in all suggested countries the likelihood of establishment is expected to be higher in almost all potato-growing regions with an EI>0.95. This high establishment potential is associated with a GI>8 (i.e., more than 8 generations per year) and an AI>8.


EI
GI
AI
a) Angola
b) Cameroon
c) Chad
d) Congo
e) DR Congo

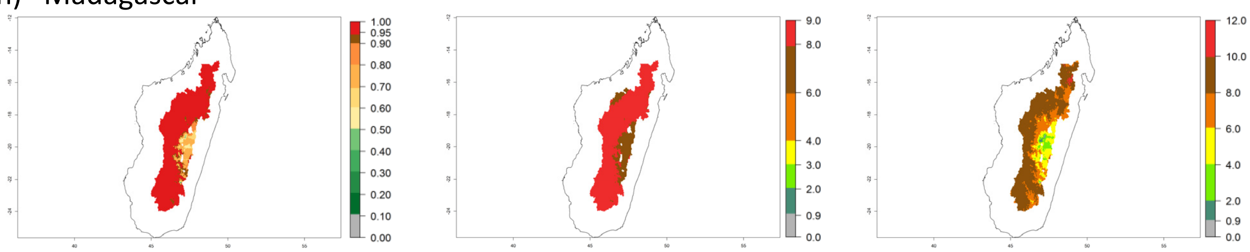
f) Ethiopia



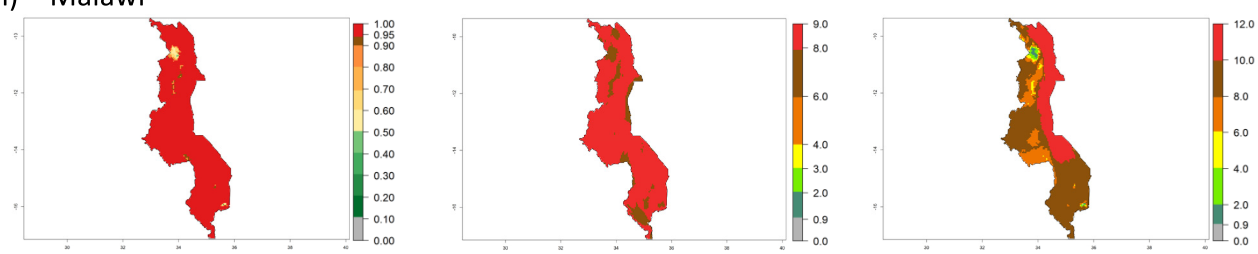
g) Kenya



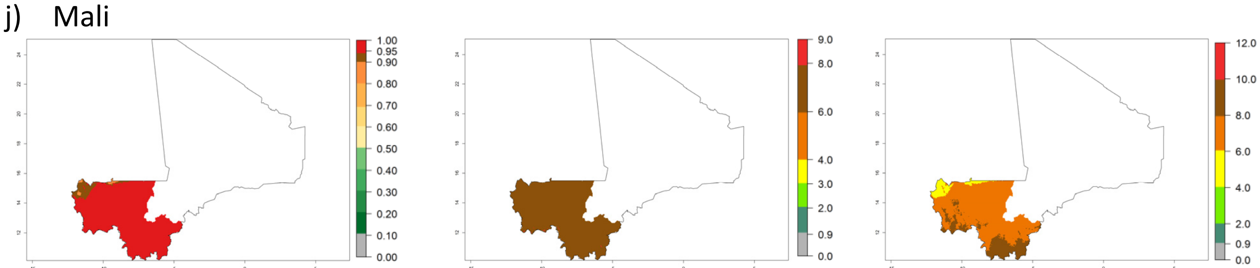
h) Madagascar



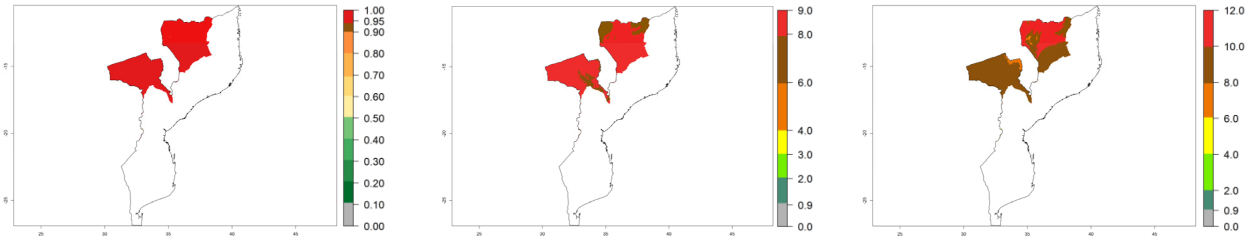
i) Malawi



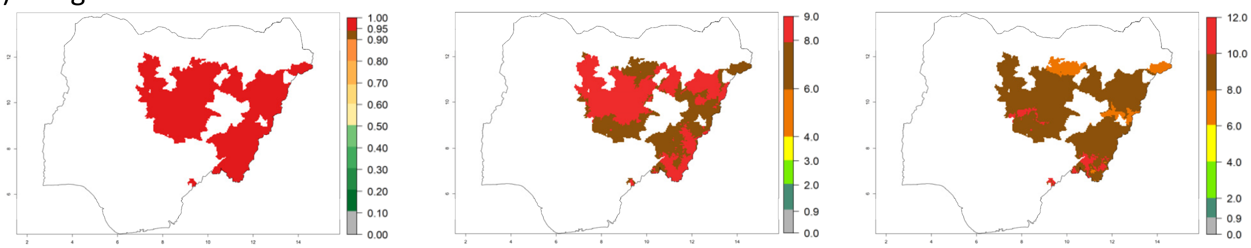
j) Mali



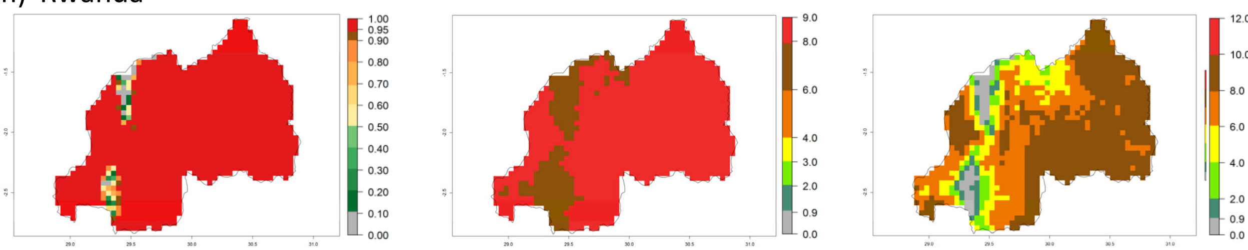
k) Mozambique



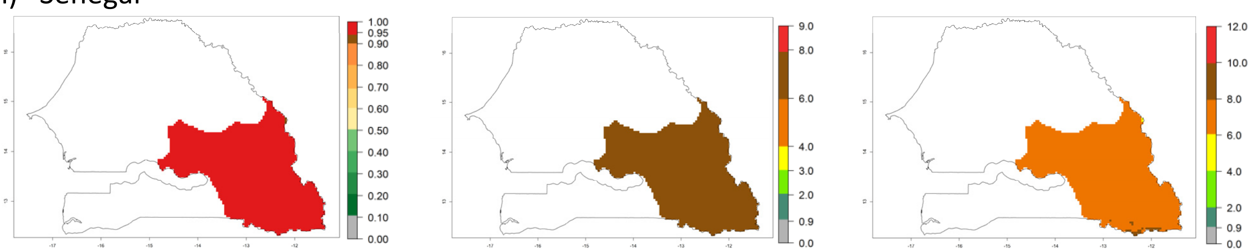
l) Nigeria



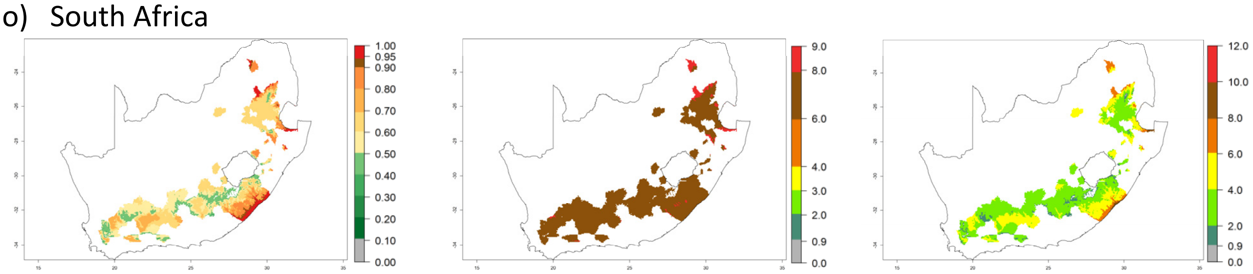
m) Rwanda



n) Senegal



o) South Africa



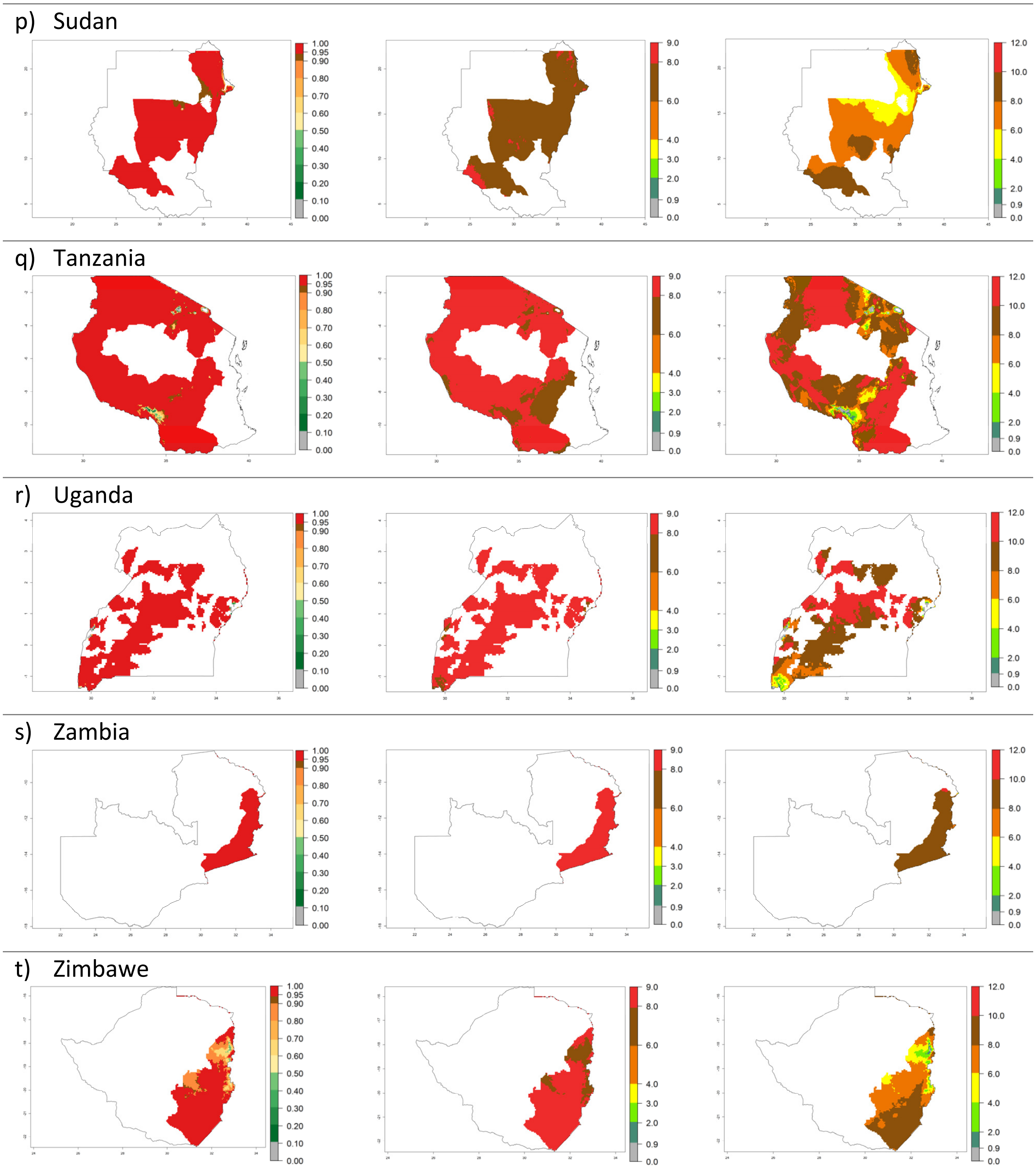


Figure 7. EI, abundance (GI, number of generations/year), and activity (AI, potential population growth) of *Copidosoma koehleri* in selected African countries according to model predictions for the year 2000, displayed in potato production regions with an ERI>0.7 of its primary host *Phthorimaea operculella*. An EI>0.5 indicates regions with permanent establishment.

Risks to no-targets

No risks are reported. The three potato tuber moth species *P. operculella*, *S. tangolias*, and *T. solanivora* are the only known hosts of *C. koehleri*. In regions where *P. operculella* has been accidently introduced, generally local parasitoids specific to *P. operculella* are absent. In such situations, local parasites comprise oligo- or polyphagous species in general. *C. koehleri* might dominate local species because of its high specificity to potato tuber moth species.

Further reading

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