Available online at www.agrifarming.org

DOI: http://dx.doi.org/10.18782/2582-7146.242

ISSN: 2582 – 7146

Curr. Rese. Agri. Far. (2024) *5*(6), 48-59

Current Research in Agriculture and Farming

Review Article

Peer-Reviewed, Refereed, Open Access Journal

From Scavengers to Pollinators, A Comprehensive Review of Beneficial Insect's Ecological Services

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Received: 11.10.2024 | Revised: 24.11.2024 | Accepted: 5.12.2024

ABSTRACT

The review paper delves into the various applications of beneficial insects in agriculture and their vital functions in advancing environmentally friendly agricultural methods. It has been acknowledged that beneficial insects, such as pollinators, parasitoids, and predators, contribute to agricultural yield, biodiversity preservation, and integrated pest management (ipm). The efficacy of these insects in managing pest populations and augmenting pollination services has been underscored by a review of several research and case studies. Despite known obstacles like habitat needs and species-specific conservation initiatives, beneficial insects nevertheless have a substantial potential to improve environmental health and global food security. The goal of this review is to present a thorough understanding of the functions of beneficial insects while promoting more study and application to maximize their application in sustainable agriculture.

Keywords: *Beneficial Insects, Entomology, Ecology, Pollinators.*

INTRODUCTION

In Greek, the word "entomology" can also Entomo signifies insects, and logy implies study. The study of arthropods and their impact on living organisms, including humans, animals, and plants, is known as entomology(Abdi–Soojeede) Damage from insects can take place in two forms. The first is direct harm to people, farms, and livestock. The second method involves indirect harm, such as acting as a disease vector or aiding in the spread of illness. Beneficial insects, also known as Keystone species in the ecosystem. ,are also present. Keystone refers to the fact that their existence is essential to the ecosystem of communities, which includes the feeding cycle, environmental cleaning, organic matter decomposition, soil fertility enhancement, etc (Abdi–Soojeede).

Cite this article: Aslam, I., Saeed, R. M. F., Anjum, M., Fatima, Qasim, M., Ali, A., Hussain, U., & Ahmad, M. (2024). From Scavengers to Pollinators, A Comprehensive Review of Beneficial Insect's Ecological Services, *Curr. Rese. Agri. Far.* *5*(1), 48-59. doi: http://dx.doi.org/10.18782/2582-7146.242

Introduction to beneficial insects:

Beneficial insects are those which provide regulating ecosystem services in many ways to agriculture such as Pollination and the natural regulation of plant pests. It aims to enhance insect-derived ecosystem services from a conservation perspective (Getanjaly et al., 2015) There are many insects on agricultural land that serve as natural enemies, pollinators, productive insects, scavengers, weed killers, and soil builders—in other words, they do not pose a threat to crop productivity and human health. Currently, farmers have a one-sided goal of making the most money possible while disregarding the effects on beneficial insects (Getanjaly et al., 2015)

Ecology of beneficial insects:

Beneficial insect communities on farms are influenced by site- and landscape-level factors, with pollinator and natural enemy populations often associated with semi-natural habitat remnants. They provide ecosystem services essential for all agroecosystems (Arnold et al., 2021) As a tactic to improve biological control and pollination in agroecosystems, providing floral resources to boost beneficial insect populations has shown potential. There has never been an experimental comparison of the two approaches, one of which provides a single flower species and the other several flower species (Pontin et al., 2006)

Uses of beneficial insects:

Many insects that are present in agricultural areas serve as natural enemies, pollinators, productive insects, scavengers, weed killers, and soil builders. These insects do not pose a threat to the production of crops (Getanjaly et al., 2015) These beneficial insects have produced natural goods, controlled the population of numerous dangerous pest species, disposed of garbage, and recycled organic nutrients, among many other benefits that have kept human cultures and civilizations intact (Getanjaly et al., 2015)

Role of the insects in pollination:

Pollination is the process of moving pollen from anther to the location where the female land. Seed development and fertilization follow if it is effective{Frankel, 2012 #76} By including the management of ecosystem services, such insect pollination, into farming operations, the sustainability of agriculture can be increased (Fijen et al., 2018) The need for food security is developing as a result of the risks that come with an expanding human population. Worldwide, crops depend on insect pollinators to produce fruits or seeds fit for human use from three out of every four plants. Numerous crops of fruits and vegetables, including broccoli, cherries, melons, almonds, apples and blueberries, rely on insect pollination services{Tanda, 2022 #72}Animal pollination is beneficial to fruit or seed establishment and yield for up to 75% of crop species{Bartomeus, 2014 #75}Along with other animal pollinators like bats, birds, beetles, moths, hoverflies, wasps, thrips, and butterflies, as well as external vectors like wind and water, bees are an important insect for crop pollination (Khalifa et al., 2021) The value of honey and beeswax produced by honey bee pollinators is 143 times greater than that of the honey they generate (18.9 billion vs. 140 million). The following is a list of commodities derived from seeds that require bee pollination: fruits, nuts, seeds, fiber, and several commodities that are indirectly dependent on bee pollination (USDA, 1981) (Levin, 1983) The markets for pollination services provided by honey bees in the United States are the largest in the world. The conduct of migrant beekeepers, who make honey and serve as a substitute for ecosystem pollination services, is significantly influenced by these markets (Rucker et al., 2012) In order to provide pollination services for fields and orchards, farmers have been importing colonies of European honey bees (Apis mellifera) for generations. However, because to illnesses, pesticides, and other factors, these colonies are becoming fewer and farther apart. Pollination services are also rendered by native bee colonies; however, it is unknown how much and how this varies with land management approaches (Kremen et al., 2002) a healthy pollinator population may increase the production or quality of several crops that are significant to the local economy{Richards,

2001 #73}The most efficient method of pollinating plants with insects is the use of managed pollinators. This method is widely utilized in industrialized nations for more than 15 important crops and has grown into a well-established industry. Managed pollinators include bumblebees, honeybees (especially Apis mellifera), and, more recently, a few species of solitary bees including Megachile and Osmia{Shivanna, 2015 #74}

Role of the insects as scavengers:

Scavengers are insects that consume dead and decomposing plant and animal debris. Scavengers and decomposers, insects contribute to the biogeochemical cycling of the nutrients, for instance, bark beetles (Getanjaly et al., 2015) Ants were the most obvious invertebrate scavengers that were seen in the current investigation feeding on insect cadavers that included entomopathogenic nematodes and their symbiotic bacteria (Baur et al., 1998) Since various species groups oviposit in a precise order, blowflies are the first insects to arrive to a dead body and are useful in forensic medicine for determining the moment of death(Heath, 1982) By eliminating corpses and related pests, scavengers maintain the functional health of ecosystems and benefit agricultural landscapes (Jameson et al., 2024) A wide and incredibly diversified assemblage of different arthropods, nematodes, and molluscs are among the invertebrate scavengers of terrestrial and aquatic carrion. While crustaceans play this role in maritime ecosystems, insects—especially flies—are by far the most functionally significant animals in terrestrial ecosystems. However, most corpses in most settings support a multi-trophic foodweb made up of several invertebrate taxa (Anderson et al., 2019) Carrion is the primary decomposer of large carcasses in terrestrial settings, and blow flies (Calliphoridae) and Necrodes beetles (Silphidae) compete for it (Matuszewski & MĄdra-Bielewicz, 2022) It has been proposed that grasshoppers' scavenging of arthropod tissue has a significant role in both their diet choices and the spread of pathogens (O'Neill et al., 1993) Carrion-associated beetles are crucial to an ecosystem's ability to recycle organic materials (Zanetti et al., 2015) While some secondary beetles have low P levels that may allow them to take advantage of less effective fungus or a wider range of species with variable efficiency, others have high P contents and necessitate efficient P supply via fungi. This co-occurring scavenger has the lowest documented phosphorus content of any invertebrate, feeding on the nutrient-poor bark beetle frass (excrement/boring leftovers) (Six & Elser, 2020) Decomposition is the primary process involved in an ecosystem's ability to function properly.Because they remove dead animal meat and carrion from the ecosystem, decomposers and scavengers are vital to it (Mashaly et al., 2019) In addition to providing food for scavengers, carrion is a source of reproductive material for many insects. For instance, vertebrate carrion is necessary for the reproduction of burying beetles belonging to the Nicrophorus genus (Coleoptera: Silphidae) (Hall et al., 2011)

Insects as food:

The term "entomophagy" refers to the consumption of insects.Insects have long been ingested in various cultures, especially in sub-Saharan Africa, south and southeast Asia, and Latin America (Penedo et al., 2022) Eggs, larvae, pupae and adults of certain insect species have been components of the human diet for thousands of years, be it as a regular food item or sustenance during famines, as an ingredient of medicines or part of ritual practices and even novelties (Mozhui et al., 2021)In addition to meat, other sources of protein must be sought after. This has increased people's curiosity about edible insects. These insects are a good source of vital nutrients, minerals, vitamins, and proteins and are included in the diets and traditions of many Asian and African nations. Moreover, it has been observed that they are sustainable (Raheem et al., 2019) Insects are considered to have great nutritional value due to their high presence of essential proteins, healthy fats, and several micronutrients such as iron, copper, magnesium, riboflavin, and biotin (Pali-Schöll et al., 2019) Numerous environmental, health,

social, and livelihood advantages come with entomophagy. A good source of fat, protein, vitamins, and minerals is insects. Almost 1700 bug species are edible worldwide; eighty percent of the ingested species belong to the four insect orders in rank order that are most commonly consumed by humans: Coleoptera, Hymenoptera, Orthoptera, and Lepidoptera. Ants, termites, caterpillars, beetle grubs, and grasshoppers are all consumed in Africa (Chakravarthy et al., 2016) Protein, fats, carbs, certain vitamins, and minerals including calcium, iron, and zinc are all easily obtained from insects. In general, insects have an energy level that is similar to that of meat (Zielińska et al., 2015) In his book "Les Oeuvres de Pierre Belon," which was released in 1555, the French physician and herbalist Pierre Belon (1517–1564) also discussed eating insects. Belon gave an account of how the people of Turkey and other Eastern nations consumed grasshoppers, ants, and other insects. He also suggested consuming ants as a treatment for dyspepsia (Olivadese & Dindo, 2023) Given that insects possess the greatest reservoir of antimicrobial peptides of any animal, more research is necessary to determine the nutritional and health benefits for both people and animals. Another way to improve plant health is to use residual substrates that contain chitin as fertilizer (Van Huis, 2020) Animals have always included insects in their diet. Their goods have positive results in palatability tests and are recognized by having a very good nutritional value (high protein content, necessary amino acid and fatty acid levels, especially lauric acid) (Kępińska-Pacelik & Biel, 2022) There is a large range of insect-based pet diets available; nevertheless, there is debate on the nutritional value of insects for cats and dogs, as well as the safety, health, and legal aspects of using them as feed or ingredients. The primary insect-based materials utilized are meal and fat derived from adult house crickets, mealworm larvae, and black soldier fly larvae. There aren't many research on the topic, and the most of them focus on certain elements of using insects in pet food. It has been stated that they are well-tolerated, acceptable, and have no negative effects on health (Valdés et al., 2022)

Aesthetic value of insects:

Many insects have been appreciated by humans throughout history for their inventiveness, beauty, amazing shapes, and unique behaviorsMany musicians and songwriters have been influenced by the melodies, noises, and other characteristics of insects. Many insects make noises that can be heard directly and used as inspiration for composed music (Hogue, 2009)We are always drawn to the coloration, beauty, and way of life of insects. Many coleopterans' colored wings and elytra are utilized as jewelry, needlework and ceramics. Butterfly is one of the insects with the most aesthetic value; collectors and museums give it the most attention, making it a valuable commodity in the market (Lokeshwari & Shantibala, 2010) The use of odononota, or damselflies, for leisure and enjoyment has a long history in several Asian nations, including China and Japan. Dragonfly lovers in modern Japan, like birders elsewhere, take great satisfaction in being able to identify a wide variety of Odonata. In reality, Japanese dragonfly lovers have access to a multitude of symposia, festivals, and sanctuaries (Lemelin, 2007) A number of cultural services provided by insects have an everyday impact on our society. These services include those that are connected to art, leisure, and the formation of customary beliefs (Duffus et al., 2021) Numerous insects have been praised for their creativity, grace, amazing forms, and unique habits. There are times when using insects as totemic images evokes strong feelings of awe and admiration because they may represent human connection or lineage with these species. Many composers and musicians have been influenced by the melodies, noises, and other characteristics of insects (Hogue, 2009) Because of their exquisite beauty, butterflies are often known as flying flowers. Because of their beautiful wing colors, these insects improve the aesthetic value of their surroundings (Ghazanfar et al., 2016) Due to their mimetic, thermal, and sexual tactics, 496

species of butterflies inhabit Europe. Their enormous morphological range in wing patterns, forms, and colors provide a rich substrate for aesthetic attractivity (van Tongeren et al., 2023) Everyone is familiar with and has encountered insects on a regular basis, therefore seeing them may evoke a variety of emotions. Insects may be the source of great anxiety for some societies, possibly due to their evolutionary psychology, while for others they are symbols and objects of celebration (Klein & Brosius, 2022) Owing to their significance in Japanese culture, fireflies were frequently included in artwork. Throughout the seventeenth and twentieth centuries, it was common to create paintings and woodblock prints known as ukiyo-e, or "pictures of the floating world," which depicted daily life, entertainment, or leisure activities. Mass-produced color woodblock printing also became a significant industry, particularly in the Tokyo area (Prischmann-Voldseth, 2022) Japanese people have always had a fondness for fireflies, from using them as beautiful topics in poetry and art to trapping and selling them as commodities (Haugan, 2019)

Insects as biocontrol agent:

The definition of biological control is the decrease in pest populations caused by natural enemies, usually with human participation. Controlling the population of insect pests is part of it. Chemical pesticide consumption is reduced when biological control is used. Biological control platforms are used to depress populations of pest organisms below the ETL level, reducing pests but not eliminating them (Holmes et al., 2016)There are two approaches in this senerio one is predatory insects and another is parasitoids. Predators are the big sized insects which feed on small insects and cause mortality (Curio, 2012).

Predatory insect species:

A large number of insect predators hunt actively. the mature forms of several ants (Formicidae), ground beetles (Carabidae), and tiger beetles (Cicindellidae). Many walking predators are also there, such as lacewing larvae (Chrysopidae), syrphid fly larvae (Syrphidae), ladybird beetles (Coccinellidae), and predatory bugs (Hemiptera) (Weseloh & Hare, 2009) The free-living ladybird beetle attacks a vast number of prey throughout its existence. Aphids are among the several pests that ladybird beetles of various kinds have the ability to biocontrol (Mushtaq et al., 2015) Praying mantis, or mantodea mantis, are a key predator in the ecology. They mostly eat grasshoppers, moths, butterflies, flies, and beetles, and they are skilled at mimicking and camouflaging their surroundings (Hiral et al., 2018) Aphids, adult Coleoptera, and caterpillars of Lepidoptera can all be controlled by the predatory bugs (Heteroptera: Hemiptera). These insects are able to successfully tame their prey because to changes in their morphology, physiology, and biochemistry (de Carvalho et al., 2020) The green lacewing is A potential polyphagous predator, Chrysopa formosa is frequently employed in the biocontrol of a variety of pests (Li et al., 2023) Chrysopidae, or green lacewings, are thought to be some of the best all-around aphid predators (Sarwar, 2014) Due of their considerable predation on mosquito larvae, dragonfly/damselfly naiads have the ability to reduce mosquitoes and, in turn, the illnesses they transmit (Priyadarshana & Slade, 2023) The larvae of damselflies (Anisoptera) and dragonflies (Zygoptera) are two of the most significant predatory insects in wetlands, since they feed on a variety of macroinvertebrates, including young mosquitoes (E1-Rayah, 1975, Corbet, 1980, Quiroz-Martinez and Rodriguez-Castro, 2007) One of the biggest and most physiologically varied families of hemipterans is the Reduviidae, or "assassin bugs." All insects are predators (a subfamily called Triatominae feeds on the blood of vertebrates and is the vector of Trypanosoma cruzi, the parasite that causes Chagas disease), and the majority of them are quite general predators (Ambrose, 2001)Assassian bugs also hunt spiders. Spiders are caught by Stenolemus giraffa as they are resting in their webs (Soley, 2016).

Parasitoid insect species:

Parasitoids are the biological control agents which lays eggs inside the host organism and reproduces inside the host by laying eggs inside it and gets over the host system and ultimately kills the host organism (Jervis & Kidd, 1986) Upon depositing their eggs on or within the bodies of other insect species, parasitoids mature into larvae that feed on their host, ultimately leading to the host's death (Godfray, 1994) Certain parasitic Hymenoptera, most notably Metaphycua helvolus (Comp.), pierce their hosts with their ovipositor and consume their bodily fluids as adults, killing their hosts in addition to growing inside them as larvae (Flanders, 1953) The tiniest parasitoids are those found in the Trichogrammatidae family (Hymenoptera: Trichogrammatidae); they feed mostly on the eggs of lepidopterans. The most well-known ones are Trichogramma and Trichogrammatoidea species, which are mostly suitable for mass production in laboratories on fictitious hosts such as flour, rice, and paddy moths (Nagaraja, 2013) Only parasitoids of wood-boring beetle and wood wasp larvae are found in the symphytan superfamily Orussoidea (Polaszek & Vilhemsen, 2023). Within the Lepidoptera, Chacoela (Pyralidae) parasitize Polistes wasps as larvae or pupae; Sthenauge (Pyralidae) feeds on saturniid larvae as ectoparasites; and Epipyropidae parasitize hemipteran nymphs or lepidopteran larvae (Heraty, 2017) The host range of dipteran parasitoids is larger than that of hymenopteran or coleopteran parasitoids combined (Eggleton & Belshaw, 1992) Trichogramma and other egg parasitoids are the most often generated and utilized natural enemies worldwide. In order to manage several insect pests, Trichogramma evanescens and numerous other species have also been extensively studied in a variety of crops, including maize, cotton, rice, and sugarcane (Masry & El-Wakeil, 2020) The parasitoid fly Ormia ochracea lays its larvae in two different ways on its hosts, the field crickets Gryllus integer and Gryllus rubens: (1) directly on the host, and (2) surrounding the host. In the field, super-parasitization affected 3.2% and parasitization affected 12.7% of male crickets (Adamo et al., 1995) Aphid nymphal-adult parasitoids, Diaeretiella repae; cabbage butterfly larval parasitoids, Hyposoter ebeninus; and Cotesia glomerata also cause mortality of these insects (Firake et al., 2013).

Insects as medicine:

Entomotherapy, the practice of using insects for therapeutic purposes, has been employed for centuries in numerous countries across the globe (Siddiqui et al., 2023) Insects are the most abundant category of living things in terms of species. Approximately 70% of all creatures are insects, with over a million species having been identified to date (Raven & Giordano, 2009) Scientific research has demonstrated that insects' bodies include immunological, analgesic, antibacterial and antirheumatic qualities. Insects and the compounds derived from them have been employed as healing resources by human societies across the globe. In addition to their medicinal use, these creatures have also held mystical and magical significance in the treatment of various ailments in diverse cultures (Costa-Neto, 2005) Currently, there are over 300 species of therapeutic insects spread throughout 70 genera, 63 families, and 14 orders. Roughly 1700 prescriptions for traditional Chinese medicine involve crude medications made from insects or insects used for therapeutic purposes (Feng et al., 2009) Bee products serve as apitherapeutic agents, abundant in hundreds of bioactive chemical compounds responsible for their diverse biological activities, including antioxidant, anti-inflammatory, immunomodulatory, neuroprotective, and antimicrobial properties (El-Seedi et al., 2022) It has been observed that insects of the orders Orthoptera, Hemiptera, Coleoptera, Lepidoptera, Diptera, and Hymenoptera contain bioactive substances with anti-inflammatory properties (Dutta et al., 2019) Numerous peptides derived from insects that have been isolated and described show great promise in the treatment of major human illnesses such as leukemia, herpes simplex

virus (HSV), and HIV (Slocinska et al., 2008) The raw extracts of various edible insects, along with their active compounds like sericin, cecropin, solenopsin, melittin, antimicrobial peptides, and fibroin, exert anti-cancer and immunomodulatory effects through diverse mechanisms (Sinha & Choudhury, 2024) The possibility that insects create cytokine-like substances that alter fundamental immune system systems in humans points to a potential source for biopharmaceuticals with anti-infection and anticancer properties (Chernysh et al., 2002) The larvae of Lucilia sericata, the medical maggot, have been used for a variety of purposes. These include aiding in forensic analyses and investigations as well as treating chronic, non-healing wounds (larval treatment) (Nigam et al., 2010).

Insects as bioindicators:

Bioindicators are frequently defined as species whose presence or abundance clearly reflect some aspect of the nature of the ecosystem in which they are present{McGeoch, 1998 #77}Bioindicators can be created to assess ecosystem well-being, gauge human impacts and interventions, evaluate human health, and measure sustainability{Burger, 2006 #78}Among insects, the coleopterans are the primary group used as bioindicators for metal and soil contamination. Foliage-bearing indicators may include arctiid moths, chrysomelid leaf beetles, and ants{Sajjad, 2020 #79}Pollution in the environment poses a major danger to ecosystems, environmental monitoring is essential for managing and forecasting their future. Numerous possible members of the class Insecta can serve as environmental bioindicators {Shrivastava, 2018 #81}.

Terrestrial insects as bioindicators:

Bioindicators have been attracting significant attention in environmental pollution studies. Among the terrestrial insects beetles are highly responsive to a variety of ecological factors, respond swiftly to changes in their surroundings, and are inexpensively and readily sampled using a variety of techniques {Ghannem, 2018 #80} In Australia, Ants have been recognized as a successful bioindicator as it decreases its population due to SO_2 emissions {Andersen, 2002 #82} Carabids are often utilized as bioindicators of altered environment. They have been applied in grasslands and boreal forests where it has been shown that species abundances and/or numbers vary along a gradient of habitat disturbance {Rainio, 2003 #83} Notonectidae, Vellidae, Hydrophilidae, Gyrinidae, and Dytiscidae Families are found in most settings and throughout the year, reflecting changes in the environment and in geography, which contributes to their position as a protected species{Mahanta, #84 }Nearly all terrestrial ecosystems depend on pollinators and pollination to function. In that they may be used to track environmental stress, pollinators are bioindicators both as individuals and as population {Kevan, 1999 #11} In terrestrial environment honeybees can serve as environmental pollution detectors in a variety of ways, such as through increased bee mortality rates from ingesting toxic chemicals from the environment, pesticide residues in honey, and heavy metal residues in other goods {Hajam, 2021 #12}.

Aquatic insects as a bioindicator:

Bioindicators, or biological indicators, are helpful for quick and affordable ecosystem evaluations {Kietzka, 2019 #17} In aquatic habitats, aquatic insects can detect even a slight change in the environment and play a significant part in the food chain {Priawandiputra, 2018 #14} Despite making up over half of all freshwater animal species, aquatic insects have received little attention in analyses of climate change, especially in tropical environments. Ephemeroptera, Plecoptera, and Trichoptera (EPT) are well-known aquatic insect species that function as bioindicators of environmental changes {Souza, 2024 #13} It has been discovered that water factors in the northern part of Peninsular Malaysia affect the community structure of the Ephemeroptera, Plecoptera, and Trichoptera as their mortality occurs and their population decreases {Ab Hamid, 2017 #15} The adult odonate community can offer a quick and efficient method for assessing the quality of

the environment {Júnior, 2015 #16} For determining the spread of cadmium in maritime surface waters, sea skaters are a good bioindicator {Parikh, 2021 #18} In water management, aquatic insects such as caddisflies (Trichoptera), stoneflies (Plecoptera), and mayflies (Ephemeroptera) are frequently utilized as markers of environmental quality due to their widespread public recognition {Let, 2022 #19}.

Acknowledgement:
I would like to sincerely thank my co-authors for their support and kind gesture to complete this manuscript in time.

Funding: NIL.

Conflict of Interest:
There is no such evidence of conflict of interest.

Author Contribution
All authors have participated in critically revising of the entire manuscript and approval of the final manuscript.

CONCLUSION

The examination of beneficial insects has brought attention to the important functions that they play in managing ecosystems and promoting sustainable agriculture. It has been demonstrated that the beneficial insects, which include pollinators, parasitoids, and predators, increase agricultural yields, lower pest populations, and support biodiversity preservation. The usefulness of these insects in integrated pest management (IPM) techniques has been shown by a number of case studies and research findings, which has decreased reliance on chemical pesticides. Moreover, the demonstrated economic advantages of utilizing beneficial insects highlight their significance in advancing ecologically sustainable agricultural methods. Benefiting insects have the potential to assist agricultural sustainability, even in spite of implementation problems related to species conservation and habitat management. To effectively utilize their potential, more investigation and knowledge are required.

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