Advances in Vertebrate Pest Management

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SUMMARY

Vertebrate pests (VPs) are complex group of animals that pose significant risks to human activities, as their populations can rapidly expand and cause damage to livestock as well as native species. The emergence of VPs is a growing concern due to their increasing impact on ecosystems and agriculture. These pests contribute to substantial economic risks by impeding crops, transmitting different pathogens as well as damaging natural habitats, resulting in a significant need for potent management practices to ameliorate their severe effects. Recent advances in VPs management have produced remarkable improvements in our ability to control lethal species that are affecting agriculture, ecosystems as well as human welfare. Efficient trapping, genetic control strategies and the integration of advanced data analytics exhibit potent innovations that provide a useful advancement in mitigating the impact of VPs on global biodiversity as well as agricultural yields. This chapter examines advancements in VPs management incorporating a variety of traditional as well as contemporary methods. Furthermore, this chapter examines chemical as well as physical control approaches for their potential in reducing pest populations. Moreover, it emphasizes the significance of these innovations in the development of more sustainable and environmentally friendly VPs management techniques. Besides, the primary focus of this chapter is integrated pest management an efficient approach integrating different approaches to enhance pest control. Besides, biological Control Approaches, incorporating natural predators as well as pathogens are analyzed in this chapter.

INTRODUCTION

Vertebrate pests are organisms with a backbone that can instigate challenges as they can cause destruction to the environment (Littin et al., 2004). This complex group of animals incorporates mammals such as rodents and deer, as well as birds and reptiles which possess the capability to destroy agricultural lands and the spread of various pathogens. Their capability to adapt quickly and reproduce intensively enhances their impact on the human population and the well-being of local wildlife species (Singh & Gajadhar, 2014)

It is reported that VPs instigates substantial damage to agriculture, human health as well as natural resources (Witmer, 2007). While different species in all vertebrate cohorts have been involved in inducing harm, birds and mammals are reported as the primary contributors to causing significant damage (Bomford, 2008). The incorporation of agroecosystems has opened up new ways for these vertebrates to exploit, transforming them into serious agricultural pests (Zotti et al., 2018). In response, humans have taken different approaches to protect their resources (Bryan et al., 2013). This conflict has intensified with the proliferation of the human population, enhanced efforts to accelerate productivity from conventional croplands and the conversion of marginal lands into agricultural areas (Bomford, 2008; Cui et al., 2021). Furthermore, the increasing human population has resulted in the advancement of human settlements into wildlife habitats, leading to more frequent human-wildlife interactions and intensifying conflicts between them (Cui et al., 2021).

On the global scale, the type of destruction induced by wildlife is primarily influenced by the life history strategy of every species, with specific species and crops affected differently around different regions of the world (Skendžić et al., 2021). The root of many conflicts arises when wildlife desires to save sufficient food resources to accomplish their nutritional needs by foraging on resources recognized to be essential. This phenomenon is observable worldwide via various examples i.e., carnivores preying on livestock, prized game animals and endangered wildlife (Khanal et al., 2020); grain losses caused by flocking, seed-feeding avian species, grassland rodents and lagomorphs consuming seeds and green foliage primarily intended for livestock (Abercrombie et al., 2019); herding ungulates trampling as well as consuming crops and seedlings reported substantial for reforestation; aquaculture damages owing to fish-eating birds and the transmission of pathogens from wildlife to humans (Dolbeer et al., 1994). Besides, another significant global risk revolves around the consumption as well as contamination of stored foodstuffs by rodents. This endorses the diverse group of

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situations in which human-wildlife conflicts occur, highlighting the requirement for effective strategies to manage these challenges (Gratz, 2018).

In light of the rising risks posed by human-wildlife conflicts on a global level, the crucial need for effective VPs management approaches becomes apparent. Furthermore, potent management of these pests is vital to ameliorate their economic and ecological effects which is necessary for a crucial equilibrium between conservation actions and the protection of human resources. Therefore, in this chapter, we will explore the latest advancements necessary for the management of VPs.

UNDERSTANDING VERTEBRATE PESTS

Overview of common vertebrate pest

Vertebrate pests which are characterized by the presence of a backbone possess the potential to inflict remarkable harm on crops, natural habitats and human well-being. Common culprits incorporate rodents (e.g., rats and mice), birds (e.g., pigeons and crows) and larger mammals (e.g., deer and rabbits). Therefore, a complete knowledge of the different types of VPs is crucial for the development of successful pest management approaches (Fig 1).

Rodents, owing to their excessive reproductive abilities emerge as persistent pests, inducing destruction to crops as well as acting as vectors for pathogens. Birds frequently attracted to agricultural lands, can destroy crops, leading to significant economic losses. On the other, larger mammals can negatively impact ecosystems as well as agriculture through extensive grazing and resulting in habitat degradation (van Klink et al., 2015).

Ecological and economic impacts of vertebrate pests

The complex relationship between VP, their ecological as well as economic impacts is a multifaceted web that extends across certain ecosystems (Haines-Young & Potschin, 2010). In the ecological zone these pests i.e., rodents, insects as well as birds exert their impact by destroying biodiversity, modifying habitats and facilitating the expansion of different pathogens (Medan et al., 2011). Concurrently, their economic impacts manifest via agricultural damage, infrastructure destruction as well as influence on human well-being (Kenis et al., 2009; Sekercioglu, 2010)

In the ecological sphere, VPs serve a noticeable role in destroying the delicate equilibrium of ecosystems (Sekercioglu, 2010). One of the integral ecological influences which is posed by VPs is biodiversity disturbance. Pests prey on other species for resources resulting in a decrease in the diversity of plant as well as animal well-being (Kenis et al., 2009). This disturbance in the natural equilibrium can have adverse impacts on the ecosystem which influences everything from the abundance of certain species to the structure of the ecological community (Battisti et al., 2016). Habitat modification is another ecological impact of VPs activity. Whether through burrow excavation or nest building, these pests alter their surroundings potentially modifying the structure of the ecosystem and affecting the distribution of other species. Such changes can cause the displacement of native fauna, as alterations in habitat architecture may no longer modulate their survival or reproductive needs (Kremen et al., 2007).

Furthermore, VPs contribute to the expansion of pathogens in ecosystems. Acting as vectors, certain pests possess the ability to carry and transmit pathogens to other organisms or even humans, which not only instigate direct damage to the health of affected organisms but can also cause a wide range of ecological impairments (Elmberg et al., 2017). Disease-induced declines in population sizes or alterations in the behavior of influenced individuals can further disturb the complex relationships in the environment (Hawley & Altizer, 2011). The transformation from ecological to economic effects, VPs prompt an extensive threat to agriculture (Turcotte et al., 2017). Their voracious veracity as well as feeding habits can wreak destruction on crops, ultimately resulting in subsided yields along with economic losses for farmers. Insects, rodents and birds contribute to the degradation of stored food supplies, escalating post-harvest damages. The economic value of agricultural loss extends beyond instant losses which interrupt food supply chains, livelihoods as well as the stability of rural economies (Tibaingana et al., 2022). Infrastructure instabilities are another characteristic of the economic impact of VPs. Some pests owing to their nesting behaviors can instigate harm to buildings, roads as well as other structures. This results in further economic instabilities for repairs as well as maintenance. Human health is not protected from the financial consequences of VPs. Pests that possess the ability to carry pathogens can directly affect human well-being, resulting in up-surged medical expenses along with reduced productivity owing to illness. The economic burden includes costs correlated with healthcare services, medication and the severe loss of income for individuals affected by pest-borne disorders (Rani et al., 2021).

Behavioral aspects influencing pest management strategies

VPs illustrate specific dietary preferences, with rodents preferring grains and seeds, while birds target fruits and crops as per their dietary preferences. Modifying regulatory approaches to accommodate these particular feeding habits accelerates their effective capability. It is reported that different pests i.e., rodents, exhibit rapid reproductive rates, emphasizing the importance of practical control approaches. Understanding their breeding seasons along with reproductive biology enables the application of targeted methods to limit population growth. In response to environmental incentives. Birds may display roosting propensities in specific locations or undergo seasonal relocations (Kvakkestad et al., 2021)

TRADITIONAL PEST MANAGEMENT TECHNIQUES

Chemical control methods

Rodenticides are chemicals that possess the ability to disrupt the physiology of rodents, instigating death. The influence of rodenticides extends beyond targeted pests (Munawar et al., 2023). Secondary poisoning is a process that can occur when predators or scavengers consume poisoned rodents, ultimately resulting in unintended harm in non-target species. The ecological consequences of rodenticide use highlight the importance of considering the broader influence on ecosystems. While rodenticides can potentially reduce rodent populations, their usage necessitates a remarkable approach to diminish harm to non-target species and avoid long-term ecological imbalances. Rodenticides including brodifacoum are designed to control rodents by deteriorating their physiology, ultimately leading to high mortality. While effective to counteract rodent populations, the use of rodenticides instigates ecological risks. Secondary intoxication can take place when predators or scavengers consume poisoned rodents, instigating unintended harm to non-target species (Blažić et al., 2018).

Insecticides serve as a major element to ameliorate pest numbers that act as vectors for different pathogens. These chemicals, available in different forms i.e., sprays, dust as well as baits and are designed to disrupt the life cycle of different targeted insects. In agriculture, insecticides are extensively used to protect crops from insect damage. The role of insecticides in VP management is essential for regulating food security, presents challenges related to ecological impacts (Begum et al., 2017). For instance, Malathion is an insecticide that plays an essential role in managing pests that serve as disease vectors or damage crops. Harm to beneficial insects i.e., pollinators and the development of resistance in targeted pest populations require a careful approach to their usage (Khan et al., 2023).

Physical Control Methods

Physical control methods provide a non-chemical strategy to managing VPs. Traps, designed to capture pests alive or cause instant mortality, provide a targeted means of controlling them (Smith & Meyer, 2015). Barriers i.e., fences and netting, prevent pests from accessing certain areas or resources. Traps and barriers, while effective when properly designed and regulated, necessitate a significant understanding of pest behavior (Weintraub, 2009). The success of these physical control approaches depends on factors i.e., the choice of trap type, proper placement and continuous monitoring. In agricultural lands, barriers play an essential role in protecting crops from pest damage (Romeh, 2019). Following are examples of some traps along with their work principles.

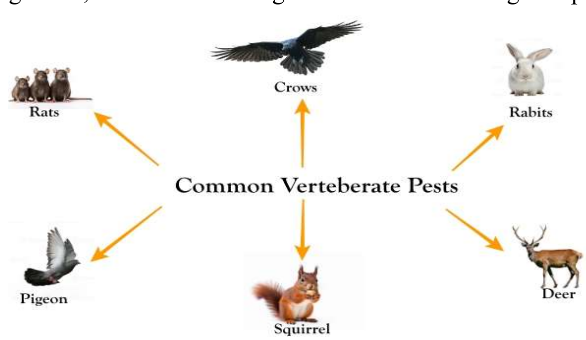

Fig 1. The most common vertebrate pest

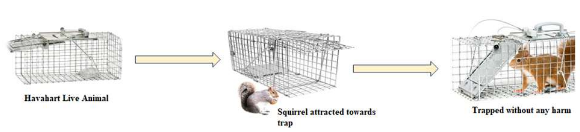

Fig 2. Havahart live animal trap

The Havahart live animal trap works by attracting the pest into a cage-like structure with bait. Once inside, the door closes without causing harm, allowing for safe and humane capture. This trap is effective for smaller VPs i.e., squirrels, providing a non-lethal solution for relocation [Bosson et al., 2012 (Fig 2)]. The Victor snap trap contains a spring-loaded mechanism set with bait. When a rodent interacts with the bait, the trap snaps shut, delivering an instantaneous and humane kill. Widely utilized for rodents, this trap is very helpful and designed for quick pest control (Takács et al., 2018). Glue traps such as catchmasters employ adhesive surfaces to capture pests. Placed strategically along with pest pathways, these boards trap rodents and insects upon contact. This cost-effective and simple solution is substantially helpful for various pests, providing ease of use and disposal (Schoenberger et al., 2023). The rat Zapper Ultra uses electronic technology to deliver a humane, high-voltage shock to rodent secrecies. The bait inside the trap lures the pest, and upon entry, a quick and humane electric shock is administered, ensuring a swift and potential solution to rodent infestations. Furthermore, habitat modification incorporates altering the environment to make it less favorable for pests. This strategy involves the removal of potential shelters or manipulation of food sources (Gurr et al., 2017).

BIOLOGICAL CONTROL APPROACHES

Biological control is a significant strategy for managing VPs, based on the principles of ecological balance (Heimpel & Mills, 2017). Biological control provides various advantages i.e., reduced dependence on chemical pesticides, minimal impact on non-target organisms along with the potential for long-term pest control. By using the power of natural predators and parasites, biological control together with the principles of IPM helps in regulating the ecosystem equilibrium across the globe.

Predatory species play an essential role in biological control. Animals such as raptors, snakes and carnivorous mammals naturally prey on VPs. For example, barn owls are renowned for controlling rodent populations which makes them remarkable partners in agricultural lands [Zaitzove-Raz et al., 2020 (Figure 3)]. Parasites are organisms that live on or within a host organism, often inducing harm to the host. In the framework of VPs management parasitic species can target pests and ultimately reduce their populations. Parasitoid wasps, for example, lay eggs on or inside pests and their larvae develop by consuming the host from the inside (Fatouros et al., 2020). Furthermore, microorganisms including bacteria, viruses and fungi also contribute to biological control. Bacillus thuringiensis is a bacterium, that produces toxins lethal to various insect pests, providing a targeted and environmentally friendly method of control (Rosas-García, 2009).

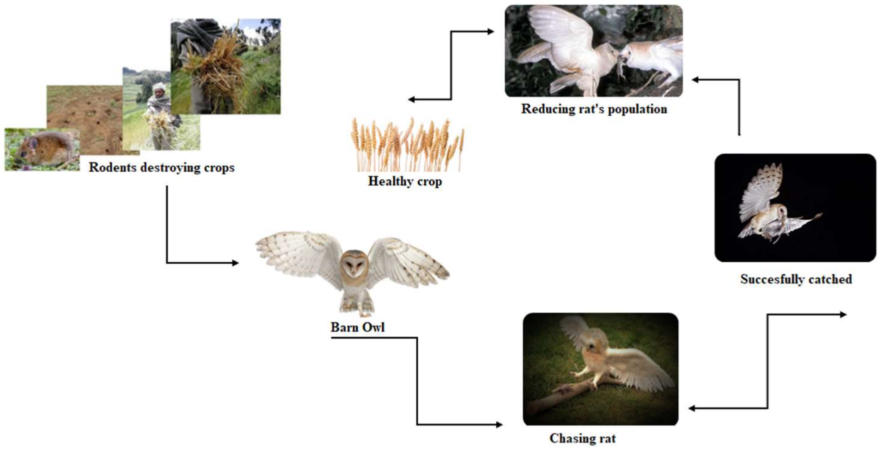

Fig 3. Barn owls are controlling rodent populations in agricultural lands

It is reported that in Australia, the introduction of cane toads in the mid-20th century led to environmental imbalances and harm to native species. To counter this invasive pest, the cane toad tadpole-killing virus was reported as a potential biological control agent. It is demonstrated that its efficacy in reducing cane toad populations manifests the success of a biological control approach (Cushman, 2017). Moreover, it is revealed that in aquaculture, bacterial pathogens pose a considerable threat to fish populations. Traditional approaches often involve antibiotics but concerns about resistance have resulted in the exploration of biological control alternatives. Phage therapy, which utilizes viruses that infect as well as kill specific bacteria, has shown promise in managing bacterial infections in fish farms, providing a targeted and environmentally sustainable solution (Almeida et al., 2009).

TECHNOLOGICAL INNOVATIONS IN VERTEBRATE PEST MONITORING AND MANAGEMENT

In the framework of VP management advanced technological approaches are playing a pivotal role in increasing selective, efficiency as well as substantial sustainability (Huang et al., 2008). Satellite imagery and geographic information system (GIS) has developed innovative methodologies through which pest animals can be monitored as well as managed throughout the world. These advanced tools can provide actual data on land use, vegetation health status as well as environmental circumstances. Integrating this information with VPs population data results in more targeted as well as on time monitoring (Huang et al., 2008). Furthermore, aerial vehicles are commonly recognized as drones, have reported as substantial tools for aerial investigation. Equipped with cameras along with specialized sensors, drones can capture high quality images and collect data. The property to cover large areas quickly makes these tools an efficient approach for regulation as well as on time detection (Vanegas et al., 2018).

Camera traps are particularly equipped with specialized sensors and play an indispensable role in the monitoring of VPs in their natural environment. These devices automatically capture high resolution images or videos when generated by any sort of movement. This technology is particularly remarkable for indefinable and nocturnal species. Acoustic sensors help in the detection as well as evaluation of sounds in the environment which provide a non-intrusive way for monitoring VPs species. Specific algorithms can differentiate pest calls from background noise which helps in the actual identification of organisms as well as their activity patterns (Schuller et al., 2023).

In addition to this, the biotelemetry approach encompasses the use of GPS-enabled tags to VPs which helps in the tracking of their movements as well as behavior. This innovation has explored new ways for the evaluation of migration patterns, pest habitat preferences as well as interactions with their environment. GPS tracking has been reported as the most significant approach for the evaluation of the spatial dynamics of pests (Bidder et al. 2015). Radiofrequency identification (RFID) technology is employed in tracking different pests in controlled environments. By using RFID tags or collars equipped with RFID chips it is possible to monitor the movement along with the behavior of pests (Parsons et al., 2015).

Automation has garnered great attention in the current times for pest control with the development of automated traps as well as bait stations. These special devices use specialized sensors to monitor the existence of pests and can dispense baits as well as capture mechanisms. Automation accelerates the efficiency of monitoring and control efforts while minimizing the need for manual intervention (Preti et al., 2021). Besides, variable rate technology (VRT) in agriculture allows for the targeted use of pest control approaches based on actual data. By modulating the rate of pesticide or bait use according to pest density and distribution VRT diminishes the use of chemicals as well as reduces environmental danger (He, 2022).

Additionally, bioacoustics monitoring incorporates the use of acoustic recordings for the detection of natural predators in an environment. With the help of automated listening methodologies, scientists can recognize the sound signatures of predator animal species. This information is valuable for the assessment of the potent working of biological control methodologies and alleviating ecological equilibrium. Involving automation systems can aid in the development of such systems that can release biocontrol agents i.e., predatory insects or sterilized pests in a targeted manner. These systems are equipped with specialized sensors that estimate environmental factors and pest population dynamics that have the optimal release timings (Blumstein et al., 2011).

GENETIC AND BIOTECHNOLOGICAL ADVANCES

Recent investigations have reported that CRISPR-Cas9 operates by employing RNA molecules to guide the Cas9 protein to a specific target particularly a gene in the DNA of a living organism. The Cas9 protein then serves as a molecular scissors that have the ability to cut the DNA at the specific location specified by the RNA guide. This process leads toward the addition, deletion or replacement of specific DNA sequences with unmatched accuracy (Jiang & Doudna, 2017) as de described in Table 1.Top of Form

In the context of VPs management, one of the major advantageous factors of CRISPR-Cas9 is its potential nature for species-specific recognition. By recognizing and targeting particular genes that are essential for the survival or reproduction of a specific pest, we can generate modifications that decrease the fitness or fertility of the different animals (Hayat et al., 2024). For example, essential genes involved in reproductive success i.e., those responsible for sperm-egg interaction and development, become primary targets (Akbar & Ijaz, 2024). Modification of these genes can cause sterility or reduced reproductive success which represents a powerful way for the management of pest populations without resorting to a wide range of approaches (Scott et al., 2018; McFarlane et al., 2018).

The accuracy provided by CRISPR-Cas9 is not only beneficial for targeting specific pest's animals but also for the reduction of environmental impact. Contrary to the conventional chemical control methods, which may have unplanned consequences on non-target animals, CRISPR-Cas9 possesses the ability to modify interventions with a level of accuracy that reduces damage (Courtier-Orgogozo et al., 2017).

Additionally, gene drives are mechanisms that exhibit the potential to impact the inheritance of a specific gene and allow it to rapidly expand throughout a population of animals (Oye et al., 2014). In the field of pest management, gene drives can be created for the introduction of traits that destroy the pest's capacity to reproduce. This technology displays tremendous potential for effectively decreasing pest populations and ameliorating biological outcomes (Wilkins et al., 2018). Transgenic Sterility, specifically through the sterile insect technique (SIT), incorporates the release of various sterile insects into the natural ecosystem that exhibits the ability to mate with the wild population, thereby diminishing reproduction rates (Wilkins et al., 2018). Biotechnological advancements enable the formation of transgenic insects that can carry self-limiting or dangerous genes. Once released, these genetically modified insects mate with their wild counterparts ultimately resulting in a frequent reduction of pest populations across successive groups (Beech et al., 2012). Radiation-induced sterility is a component of the traditional SIT, it is the process where insects are sterilized via exposure to radiation (Morrison et al., 2010).

INTEGRATED VERTEBRATE PEST MANAGEMENT (IVPM)

It is reported that in IVPM, pests such as rodents, birds and mammals play an indispensable role in ecosystems. The aim is not to get rid of them solely but to control their numbers in a specific way that diminishes harm while keeping the ecological equilibrium substantially intact. This approach is based on certain ecological principles and recognizes that these animals are part of complex ecosystems (Witmer, 2007). A key property of IVPM is combining specific control methods i.e., biological, cultural, mechanical and chemical strategies. Biological control uses natural predators or parasites for the management of different pest. For example, the introduction of predators i.e., barn owls or using bacteria to control rodent populations can be substantially effective and ecosystem friendly that regulates sustainable as well as organic farming principles. Cultural methodologies incorporate changing human practices to make agricultural lands least attractive to pests. This could incorporate shifting planting patterns, rotating crops, or modifying irrigation practices. By destroying the habitat and resources that sustain pests, farmers can generate the least suitable ecosystem that halts pests from settling (Van den Berg et al., 2006).

Mechanical control methodologies use physical barriers, traps and restraints to manage pest populations. Farmers may apply netting to protect crops from birds, erect fences to keep out mammals or use traps strategically to capture rodents. While these strategies can be labor-intensive, they are highly useful when combined with other approaches (Van den Berg et al., 2006). Chemical control, though not the major focus, it is still part of IVPM. It is used very carefully to overcome environmental influence. Targeted as well as selective

Table 1. Technological innovations in vertebrate pest monitoring and management

Technology	Benefits	References
Satellite Imagery and GIS	Real-time, targeted monitoring with environmental data integration	Huang et al., 2008
Unmanned Aerial Vehicles (Drones)	Efficient aerial surveillance for pest and crop monitoring	Vanegas et al., 2018
Acoustic Sensors	Non-intrusive pest monitoring with sound analysis	Schuller et al., 2023
Data Analytics and AI	Predictive models for early warnings in proactive management	Guimapi et al., 2022
Machine Learning for Image Recognition	Automated real-time pest identification with algorithms	Guimapi et al., 2022
Biotelemetry (GPS-enabled tags)	GPS tracking for insights into pest movements and behavior	Bidder et al., 2015
Radio Frequency Identification (RFID)	RFID tracking for studying social dynamics within pest populations	Parsons et al., 2015
Automation	Sensor-based traps and bait stations for efficient control	Preti et al., 2021
Variable Rate Technology (VRT)	Targeted pest control	He, 2022
Bio-acoustic Monitoring	Acoustic predator detection for ecological balance	Blumstein et al., 2011

pesticides are selected to avoid disturbing non-target species and they are applied in a specific way that maximizes potential while curtailing residues (Witmer, 2007). Employing IVPM necessitates a deep understanding of the local ecosystem, incorporating pests along with their interactions with other species. This knowledge forms the basis for farmers and land managers to adapt control approaches to specific circumstances. Monitoring as well as regular assessment of pest populations are substantially crucial for adaptive management that responds to changing conditions and prevents unintentional outcomes (Van den Berg et al., 2006).

Community engagement is integral to IVPM's success. Local communities of people i.e., farmers along with researchers must collaborate to share knowledge, experiences as well as resources. In addition to this, educational approaches serve as essential elements in promoting the execution of IVPM. Different farmers need access to the required information, training on the principles as well as practices of these necessary approaches (Braun et al., 2006). Extension services involving agricultural agencies, and non-governmental organizations can also play an indispensable function in spreading knowledge and providing support to enable the shift to integrated pest management (Bottrell & Schoenly, 2018).

CONCLUSION

Taken together this chapter extensively illustrates traditional and modern strategies for VP management determining ecosystem friendly solutions. It critically evaluates the effectiveness of chemical as well as physical control methods, highlights the potential of genetic and biotechnological advances and emphasizes the efficacy of integrated pest management. By assessing biological control approaches for their ecological accuracy and sustainability, this chapter provides a thorough overview, supporting the development as well as the implementation of sustainable practices for the management of the challenges posed by VPs in agriculture, ecosystems as well as human well-being.

REFERENCES

Abercrombie ST, JL Koprowski, MH Nichols et al., 2019. Native lagomorphs suppress grass establishment in a shrub-encroached, semiarid grassland. Ecology and Evolution 9:307-17. https://doi.org/10.1002/ece3.4730

Akbar A & MU Ijaz, 2024. Pharmacotherapeutic potential of ginkgetin against polystyrene microplastics-instigated testicular toxicity in rats: A biochemical, spermatological, and histopathological assessment. Environmental Science and Pollution Research 31:9031-44. https://doi.org/10.1007/s11356-023-31662-7

Almeida A, Â Cunha, NC Gomes et al., 2009. Phage therapy and photodynamic therapy: low environmental impact approaches to inactivate microorganisms in fish farming plants. Marine Drugs 7:268-313. https://doi.org/10.3390/md7030268

Battisti C, G Poeta, G Fanelli et al., 2016. Role and Effects of Disturbances in Natural Systems. In: An Introduction to Disturbance Ecology. Environmental Science and Engineering. Springer, New York, USA, pp:13-29. https://doi.org/10.1007/978-3-319-32476-0_3

Beech CJ, M Koukidou, NI Morrison et al., 2012. Genetically modified insects: science, use, status and regulation. Collection of Biosafety Reviews 6:66-124.

Begum A, SN Alam, M Jalal Uddin et al., 2017. Management of pesticides: Purposes, uses, and concerns. Pesticide Residue in Foods: Sources, Management, and Control (Khan M & M Rahman eds): Springer, New York, USA, pp: 53-86. https://doi.org/10.1007/978-3-319-52683-6_4

Bidder OR, JS Walker, MW Jones et al., 2015. Step by step: reconstruction of terrestrial animal movement paths by dead-reckoning. Movement Ecology 3:1-16. https://doi.org/10.1186/s40462-015-0055-4

Blažić T, G Jokić, M Götz et al., 2018. Brodifacoum as a first choice rodenticide for controlling bromadiolone-resistant Mus musculus. Journal of Stored Products Research 79:29-33. https://doi.org/10.1016/j.jspr.2018.08.006

Blumstein DT, DJ Mennill, P Clemins et al., 2011. Acoustic monitoring in terrestrial environments using microphone arrays: applications, technological considerations and prospectus. Journal of Applied Ecology 48:758-767. https://doi.org/10.1111/j.1365-2664.2011.01993.x

Bomford M, 2008. Risk assessment models for establishment of exotic vertebrates in Australia and New Zealand. Invasive Animals Cooperative Research Centre, Canberra, Australia.

Bosson CO, Z Islam, R Boonstra et al., 2012. The impact of live trapping and trap model on the stress profiles of North American red squirrels. Journal of Zoology 288:159-169. https://doi.org/10.1111/j.1469-7998.2012.00941.x

Bottrell DG & KG Schoenly, 2018. Integrated pest management for resource-limited farmers: challenges for achieving ecological, social and economic sustainability. The Journal of Agricultural Science 156:408-426. https://doi.org/10.1017/S0021859618000473

Braun A, J Jiggins, N Röling et al., 2006. A global survey and review of farmer field school experiences. A Report for the International Livestock Research Institute, Wageningen, Netherlands

Bryan E, C Ringler, B Okoba et al., 2013. Adapting agriculture to climate change in Kenya: Household strategies and determinants. Journal of Environmental Management 114:26-35. https://doi.org/10.1016/j.jenvman.2012.10.036

Courtier-Orgogozo V, B Morizot & C Boëte, 2017. Agricultural pest control with CRISPR-based gene drive: time for public debate: should we use gene drive for pest control? EMBO Reports 18:878-80. https://doi.org/10.15252/embr.201744205

Cui Q, Y Ren & H Xu, 2021. The escalating effects of wildlife tourism on human-wildlife conflict. Animals 11:1378. https://doi.org/10.3390/ani11051378

Cushman GT, 2017. Guano, Intensive Agriculture, and Environmental Change in Latin America and the Caribbean. In Oxford Research Encyclopedia of Latin American History. Oxford Research Encyclopedia of Latin American History. Retrieved 18 Jul. 2024. https://doi.org/10.1093/acrefore/9780199366439.013.113

Dolbeer RA, NR Holler, DW Hawthorne et al., 1994. Identification and control of wildlife damage. In: Research and Management Techniques for Wildlife and Habitats (Boolcout TA ed.): Bethesda: The Wildlife Society pp: 474-506.

Elmberg J, C Berg, H Lerner et al., 2017. Potential disease transmission from wild geese and swans to livestock, poultry and humans: a review of the scientific literature from a One Health perspective. Infection Ecology and Epidemiology 7:1300450. https://doi.org/10.1080/20008686.2017.1300450

Fatouros NE, A Cusumano, F Bin et al., 2020. How to escape from insect egg parasitoids: a review of potential factors explaining parasitoid absence across the Insecta. Proceedings of the Royal Society B 287:20200344. https://doi.org/10.1098/rspb.2020.0344

Gratz NG, 2018. Rodents and human disease: a global appreciation. In: Rodent pest management (Parkash I, ed) CRC Press, Florida, USA, pp:101-69. https://doi.org/10.1201/9781351076456-7

Guimapi RA, S Niassy, BT Mudereri et al., 2022. Harnessing data science to improve integrated management of invasive pest species across Africa: An application to Fall armyworm (*Spodoptera frugiperda*)(JE Smith)(Lepidoptera: Noctuidae). Global Ecology and Conservation 35:02056. https://doi.org/10.1016/j.gecco.2022.e02056

Gurr GM, SD Wratten, DA Landis et al., 2017. Habitat management to suppress pest populations: progress and prospects. Annual Review of Entomology 62:91-109. https://doi.org/10.1146/annurev-ento-031616-035050

Haines-Young R & M Potschin, 2010. The links between biodiversity, ecosystem services and human well-being. In: Ecosystem ecology: A new synthesis (Raffaelli DG & CLJ Frid, eds): Cambridge University Press, UK, pp: 110-139. https://doi.org/10.1017/CBO9780511750458.007

Hawley DM & SM Altizer, 2011. Disease ecology meets ecological immunology: understanding the links between organismal immunity and infection dynamics in natural populations. Functional Ecology 25:48-60. https://doi.org/10.1111/j.1365-2435.2010.01753.x

Hayat MF, M Zohaib, MU Ijaz et al., 2024. Ameliorative potential of eriocitrin against cadmium instigated hepatotoxicity in rats via regulating Nrf2/keap1 pathway. Journal of Trace Elements in Medicine and Biology 84:127445. https://doi.org/10.1016/j.jtemb.2024.127445

He L, 2022. Variable rate technologies for precision agriculture. In: Encyclopedia of Smart Agriculture Technologies (Zhang Q, ed): Springer, New York, USA, pp: 1-9. https://doi.org/10.1007/978-3-030-89123-7_34-1

Heimpel GE & NJ Mills, 2017. Biological control. Cambridge University Press, Cambridge, UK. https://doi.org/10.1017/9781139029117

Huang Y, Y Lan, JK Westbrook et al., 2008. Remote sensing and GIS applications for precision area-wide pest management: Implications for homeland security. In: Geospatial Technologies and Homeland Security (Sui DZ, ed): Springer, Dordrecht, USA, pp: 241-255. https://doi.org/10.1007/978-1-4020-8507-9_12

Jiang F & JA Doudna, 2017. CRISPR-Cas9 structures and mechanisms. Annual Review of Biophysics 46:505-29. https://doi.org/10.1146/annurev-biophys-062215-010822

Kenis M, MA Auger-Rozenberg, A Roques et al., 2009. Ecological effects of invasive alien insects. Biological Invasions 11:21-45. https://doi.org/10.1007/s10530-008-9318-y

Khan BA, MA Nadeem, H Nawaz et al., 2023. Pesticides: impacts on agriculture productivity, environment, and management strategies. In: Emerging Contaminants and Plants: Interactions, Adaptations and Remediation Technologies (Aftab T, ed): Springer International Publishing, Florida, USA, pp: 109-34. https://doi.org/10.1007/978-3-031-22269-6_5

Khanal G, C Mishra & KR Suryawanshi, 2020. Relative influence of wild prey and livestock abundance on carnivore-caused livestock predation. Ecology and Evolution 10:11787-97. https://doi.org/10.1002/ece3.6815

Kremen C, NM Williams, MA Aizen et al., 2007. Pollination and other ecosystem services produced by mobile organisms: a conceptual framework for the effects of land-use change. Ecology Letters 10:299-314. https://doi.org/10.1111/j.1461-0248.2007.01018.x

Kvakkestad V, ÅL Steiro & A Vatn, 2021. Pesticide policies and farm behavior: the introduction of regulations for integrated pest management. Agriculture 11:828. https://doi.org/10.3390/agriculture11090828

Littin KE, DJ Mellor, B Warburton et al., 2004. Animal welfare and ethical issues relevant to the humane control of vertebrate pests. New Zealand Veterinary Journal 52:1-10. https://doi.org/10.1080/00480169.2004.36384

McFarlane GR, CBA Whitelaw, SG Lillico et al., 2018. CRISPR-based gene drives for pest control. Trends in Biotechnology 36:130-3. https://doi.org/10.1016/j.tibtech.2017.10.001

Medan D, JP Torretta, K Hodara et al., 2011. Effects of agriculture expansion and intensification on the vertebrate and invertebrate diversity in the Pampas of Argentina. Biodiversity and Conservation 20:3077-100. https://doi.org/10.1007/s10531-011-0118-9

Morrison NI, G Franz, M Koukidou et al., 2010. Genetic improvements to the sterile insect technique for agricultural pests. Asia-Pacific Journal of Molecular Biology and Biotechnology 18:275-95.

Munawar N, T Mahmood & DW Galbraith, 2023. Chemical control of rodents and its impact on rodent infestations during subsequent cropping season. International Journal of Pest Management 69:140-9. https://doi.org/10.1080/09670874.2020.1861362

Oye KA, K Esvelt, E Appleton et al., 2014. Regulating gene drives. Science 345:626-8. https://doi.org/10.1126/science.1254287

Parsons MH, RJ Sarno & MA Deutsch, 2015. Jump-starting urban rat research: conspecific pheromones recruit wild rats into a behavioral and pathogen-monitoring assay. Frontiers in Ecology and Evolution 3: 146. https://doi.org/10.3389/fevo.2015.00146

Preti M, C Moretti, G Scarton et al., 2021. Developing a smart trap prototype equipped with camera for tortricid pests remote monitoring. Bulletin of Insectology 74:147-60.

Rani L, K Thapa, N Kanojia et al., 2021. An extensive review on the consequences of chemical pesticides on human health and environment. Journal of Cleaner Production 283:124657. https://doi.org/10.1016/j.jclepro.2020.124657

Romeh AA, 2019. Integrated pest management for sustainable agriculture. In: Sustainability of Agricultural Environment in Egypt: Part II. The Handbook of Environmental Chemistry (Negm A & M Abu-hashim, eds): Springer, Floraida, USA, pp: 215-34. https://doi.org/10.1007/698_2018_267

Rosas-García NM, 2009. Biopesticide production from *Bacillus thuringiensis*: an environmentally friendly alternative. Recent Patents on Biotechnology 3:28-36. https://doi.org/10.2174/187220809787172632

Schoenberger JM, BJ Prendergast, KR Luchins et al., 2023. Preference of escaped mice for live capture or glue traps and relevance to pest control programs. Journal of the American Association for Laboratory Animal Science 62:38-47. https://doi.org/10.30802/AALAS-JAALAS-22-000073

Schuller BW, A Akman, Y Chang et al., 2023. Ecology and computer audition: Applications of audio technology to monitor organisms and environment. Heliyon 10:23142 https://doi.org/10.1016/j.heliyon.2023.e23142

Scott MJ, F Gould, M Lorenzen et al., 2018. Agricultural production: assessment of the potential use of Cas9-mediated gene drive systems for agricultural pest control. Journal of Responsible Innovation 5:98-120. https://doi.org/10.1080/23299460.2017.1410343

Sekercioglu CH, 2010. Ecosystem functions and services. In: *Conservation Biology for All* (Sodhi NS & PR Ehrlich, eds): Oxford Academic, Oxford, UK, pp: 45-72. https://doi.org/10.1093/acprof:oso/9780199554232.003.0004

Singh BB & AA Gajadhar, 2014. Role of India's wildlife in the emergence and re-emergence of zoonotic pathogens, risk factors and public health implications. Acta Tropica 138:67-77. https://doi.org/10.1016/j.actatropica.2014.06.009

Skendžić S, M Zovko, IP Živković et al., 2021. The impact of climate change on agricultural insect pests. Insects 12:440. https://doi.org/10.3390/insects12050440

Smith RH & AN Meyer, 2015. Rodent control methods: non-chemical and non-lethal chemical, with special reference to food stores. Rodent Pests and their Control 2:81-101. https://doi.org/10.1079/9781845938178.0101

Takács S, AE Musso, R Gries et al., 2018. New food baits for trapping house mice, black rats and brown rats. Applied Animal Behaviour Science 200:130-5. https://doi.org/10.1016/j.applanim.2017.11.011

Tibaingana A, G Makombe, T Kele et al., 2022. Smallholder Maize Farmers Need Better Storage for Food Security: An Exploratory Study over the Storage Types Used in Uganda. New Advances in Postharvest Technology. IntechOpen. https://doi.org/10.5772/intechopen.109172

Turcotte MM, H Araki, DS Karp et al., 2017. The eco-evolutionary impacts of domestication and agricultural practices on wild species. Philosophical Transactions of the Royal Society B: Biological Sciences 372:20160033. https://doi.org/10.1098/rstb.2016.0033

Van den Berg H, PK Das, A von Hildebrand et al., 2006. Evaluation of the integrated pest and vector management (IPVM) project in Sri Lanka: WHO mission report, July 2006.

Van Klink R, F van der Plas, CGE Van Noordwijk et al., 2015. Effects of large herbivores on grassland arthropod diversity. Biological Reviews 90:347-66. https://doi.org/10.1111/brv.12113

Vanegas F, D Bratanov, K Powell et al., 2018. A novel methodology for improving plant pest surveillance in vineyards and crops using UAV-based hyperspectral and spatial data. Sensors 18:260. https://doi.org/10.3390/s18010260

Weintraub PG, 2009. Physical control: An important tool in pest management programs. In: Biorational Control of Arthropod Pests (Ishaaya I & A Horowitz, eds) Springer, Dordrecht, USA, pp: 317-324. https://doi.org/10.1007/978-90-481-2316-2_12

Wilkins KE, TA Prowse, P Cassey et al., 2018. Pest demography critically determines the viability of synthetic gene drives for population control. Mathematical Biosciences 305:160-9. https://doi.org/10.1016/j.mbs.2018.09.005

Witmer GW, 2007. The ecology of vertebrate pests and integrated pest management (IPM). In: Perspectives in Ecological Theory and Integrated Pest Management (Kogan M & P Jepson eds): Cambridge University Press, Cambridge, UK, pp: 730. https://doi.org/10.1017/CBO9780511752353.013

Zaitzove-Raz M, O Comay, Y Motro et al., 2020. Barn owls as biological control agents: potential risks to non-target rare and endangered species. Animal Conservation 23:646-59. https://doi.org/10.1111/acv.12576

Zotti M, EA Dos Santos, D Cagliari et al., 2018. RNA interference technology in crop protection against arthropod pests, pathogens and nematodes. Pest Management Science 74:1239-50. https://doi.org/10.1002/ps.4813