A Proposed Framework to Investigate the Interactions Between Barn Owls and Anticoagulant Rodenticides in an Integrated Pest Management Program

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ABSTRACT: Due to the economically and environmentally beneficial rodent control services birds of prey (raptors) provide, many property owners in North America and around the world install artificial nest boxes to attract breeding populations of barn owls as part of an integrated pest management (IPM) strategy. However, anticoagulant rodenticides (ARs) and barn owl biocontrol are often concurrently used to limit damage from rodent pest species in agricultural ecosystems which could lead to secondary poisoning of these beneficial predators. Substantial global effort is currently underway to determine the efficacy and cost effectiveness of this IPM approach, while better defining the risk to barn owls from potential AR exposure. While these issues have received increased attention, there is little data describing the circumstances in which barn owls interact with AR compounds, as well as the potential sublethal effects of AR exposure in these settings that may hinder a barn owl's ability to adequately control pests in agroecosystems. By incorporating research techniques that can relate AR application to barn owl diet, movement, development, and secondary AR exposure frequencies, we can begin to understand the nature of employing chemical and biological control together in an IPM program. To understand the interactions between ARs and barn owls in IPM, we propose that studies investigate the frequency and severity of secondary poisoning in barn owls that are providing biological control on farms.

KEY WORDS: anticoagulant rodenticides, barn owl, integrated pest management, pest control, raptors, rodent control, *Tyto furcata*

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INTRODUCTION

Integrated pest management (IPM) is a science-based pest control strategy that relies on the use of multiple methods, including biological, chemical, cultural, and physical controls, working in tandem. A primary objective of this strategy is to maximize efficacy and minimize environmental risk by relying on chemical compounds such as pesticides only when needed. In northern California, a common IPM strategy for rodent pests in agroecosystems is employing a combination of biological control [e.g., American barn owls (*Tyto furcata*)] and chemical compounds [e.g., anticoagulant rodenticides (ARs)] to suppress rodent populations (Kross et al. 2018). This IPM approach is reliant on attracting barn owls to agricultural settings via nest box networks installed in and around agricultural fields. While this IPM system is popular with many farmers in the central valley of California, an investigation of the non-target interactions between barn owls and ARs is needed. Two important questions remain to be explored: 1) Does secondary exposure to ARs reduce the pest control services provided by barn owls, and 2) do barn owls in agroecosystems experience sublethal effects from exposure to ARs? To effectively implement an IPM program utilizing both barn owls and ARs, a better understanding of the interaction between AR application and barn owl ecology is needed.

It is currently unknown if an IPM strategy utilizing ARs and barn owls to manage rodent pests is more successful than either management strategy alone. Figure 1 shows conceptional interactions and outcomes of using barn owls and ARs in an IPM system. This model assumes that the exclusive use of barn owls or ARs would reduce rodent populations, and their combined use would create an IPM system that would meet or exceed efficacy observed for any of these approaches alone, while relying on less AR use than if only ARs were employed. However, the interaction between these two control methods and their effect on decreasing rodent populations have not been thoroughly researched, which leaves many unknowns in the effectiveness of such a potential owl+AR IPM program. In addition, an understanding of aspects of barn owl ecology and behavior that make them susceptible to secondary poisoning from ARs could help inform strategies that mitigate negative impacts of ARs on barn owls. Thus, more studies are needed to identify each outcome and their interactions in combination.

We initiated a multi-year study between 2018 and 2021 aimed at understanding the prevalence of secondary AR exposure, exposure pathways, and lethal and sublethal effects of AR exposure in barn owls. We

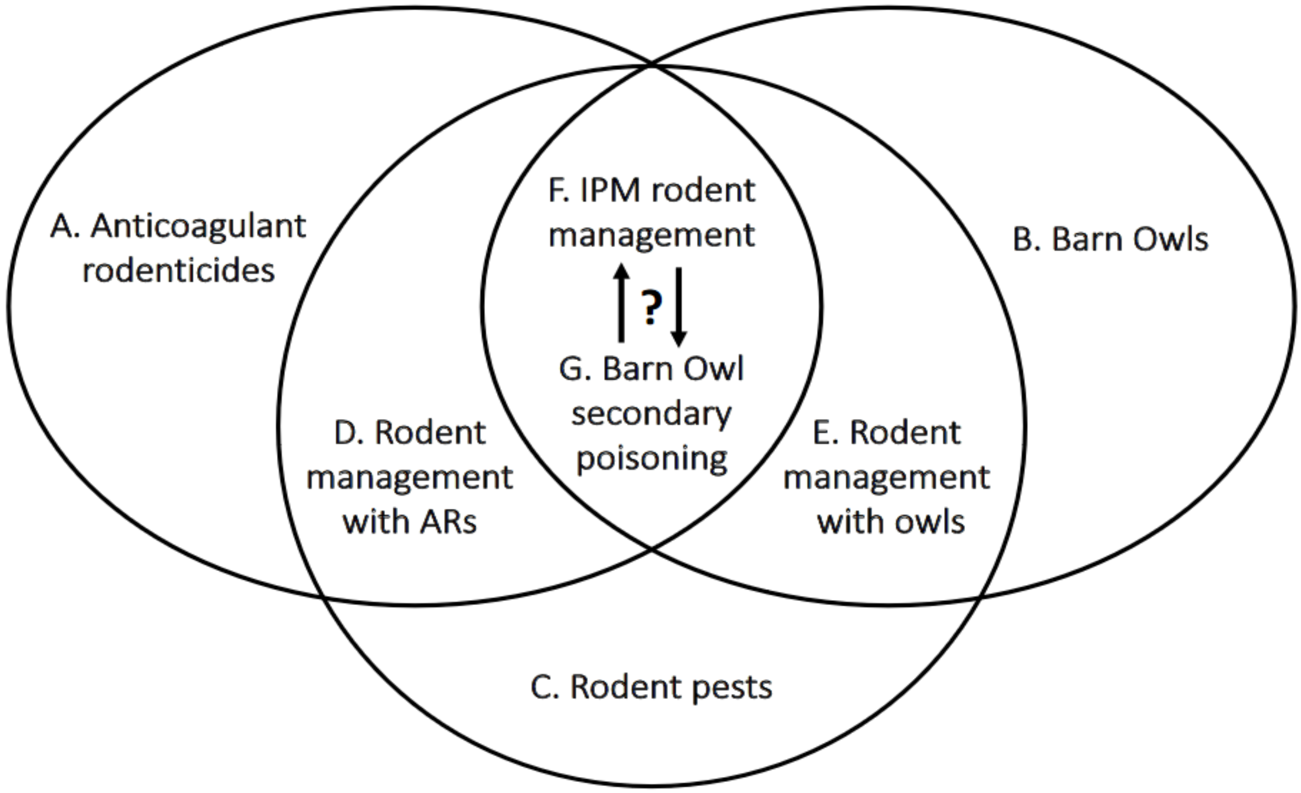

Figure 1. This conceptual Venn diagram illustrates interactions between the pest management strategies (A and B) and their effects (D-F) on controlling rodent pest populations (C). Each of the letters (A-G) represent a part of the pest control strategies and descriptive information (below diagram) that is important to identify during studies to gain a better understanding of the interactions between management strategies and pests. Although we assume the combined use of ARs and barn owl biocontrol should reduce rodent pest populations (F), their combined use could lead to AR exposure to barn owls from ingesting poisoned rodents (G). This potential nontarget effect should be investigated further.

proposed to obtain information on AR applications from farmers and facility managers; described barn owl diet via pellet dissections; analyzed barn owl foraging habits using GPS telemetry; surveyed rodent distribution and abundance; and assessed sublethal effects on barn owl development through growth rate measurements of nestlings on two large-scale vineyard operations. We used this research to develop the following objectives: 1) outline a repeatable framework for systematically studying the interactions between barn owls and ARs in agroecosystems around the world, and 2) highlight challenges and areas for improving this framework.

METHODS

We analyzed two approaches for investigating the effects of ARs on barn owls in agroecosystems: 1) an opportunistic approach where researchers passively observe and record when/where rodenticide applications are being applied, or 2) an experimental approach where researchers designate specific times, locations, and compounds used. AR applications on neighboring properties are relevant given the large home range of breeding barn owls (Castañeda et al. 2021, Huysman and Johnson 2021) and efforts to gather AR-use data surrounding the study site are important. Additionally, laws and regulations regarding the use and application of AR compounds should be noted, as this can change by state or region (Gomez et al. 2022). For example, in California, second generation ARs are only allowed to be used in and around buildings and related structures, while first-generation AR compounds can be used in agricultural fields, as well as in and around buildings and related structures.

Opportunistic Approach

The benefit of an opportunistic approach is that it allows researchers to understand realistic patterns of AR exposure as they would occur in active commercial agroecosystems. Under opportunistic studies, it is important to consider that researchers do not have direct control over the timing and spatial extent of AR applications. Therefore, it is necessary to frequently gather information from land managers to ensure an accurate understanding of AR use in the study system. Because land managers are adapting to on-the-ground situations regarding pest damage, they may change their field chemical application methods throughout a research project's timeline based on fluctuations in rodent populations. With an opportunistic approach, it is important to consider that barn owl AR exposure will be influenced by pest management decisions in real-time. Due to the limited time ARs can be detected in a sample taken from a live bird (e.g., blood samples have an approximate one to two-week window for AR detection; Salim et al. 2014 b), researchers should time AR exposure screening in live barn owls to coincide with the period in which detection is possible. For example, if researchers are interested in determining peak exposure, screening for ARs in a barn owl population two or more weeks post exposure may misrepresent the true peak exposure rates associated with a pulsed AR application.

Experimental Approach

The benefits of the experimental approach include controlling when and where ARs are applied. An experimental approach can help to address a mismatch between AR application and timing of AR exposure screening as described above. For an experimental approach, it is important that researchers replicate standard AR application strategies to the extent feasible to ensure results are applicable and valid to current pest management practices. For example, experimentally applying ARs when and where no pest problem may exist will not always accurately represent pest management in agroecosystems, thus confounding results. Researchers wanting to take this approach should consider obtaining funding to cover the costs of ARs and a Pest Control Applicator license to apply ARs themselves given that commercial farming operations might not be incentivized to operate outside of normal business practices. Researchers may or may not be able to implement experimental designs in commercial agricultural landscapes where production is prioritized. Therefore, we suggest research takes place on a landscape where the primary focus is not production, such as at an agricultural research station. Under this approach, it is still necessary to survey neighboring properties for AR-use as much as possible because off-site exposure can influence results.

RESULTS

For an IPM system using barn owls and ARs to work effectively, it is important to understand how the different control methods work together. While exposure to lethal doses of ARs in barn owls will result in death, exposure to sublethal doses is associated with other negative impacts including growth deficiencies (Naim et al. 2010) and possibly a reduction in immune functionality (Rattner et al. 2014b). Identifying frequency and severity of AR exposure in barn owls can help researchers understand the interactions between AR applications and these bio-control agents to determine how they may affect the overall IPM system.

Measuring the Frequency of Secondary Exposure to ARs

There are three common approaches for detecting secondary exposure of ARs in barn owls: blood samples (Vudathala et al. 2010, Salim et al. 2014b), fecal pellets (Eadsforth et al. 1991, Gray et al. 1994, Elliott et al. 2014, Salim et al. 2014a), and liver tissue (Sheffield 1997, Rattner et al. 2014a, Stansley et al. 2014, Wiens et al. 2019). Using blood–while invasive–is an important method for identifying secondary exposure of ARs because it can give an acute timeline of exposure in a living animal. Blood samples can detect recent exposure of ARs from the past one to two weeks depending on the dose and compound ingested (Salim et al. 2014b, Horak et al. 2018). Researchers then can relate exposure to land-use practices. Blood can be collected from barn owl nestlings older than four weeks for quantifying AR exposure per UC Davis IACUC guidelines, which require any blood collections to be less than 1% the body mass of the individual (Monks and Forbes 2007). While a maximum two-week detection period is a limited window of time, it allows for at least two collections per nestling for a larger period of detection.

Depending on the compound, ARs in pellets can be detected for up to a week after initial ingestion (Eadsforth et al. 1991, Gray et al. 1994). The half-lives of ARs vary greatly between compound and animal, and the half-life of ARs in barn owls' tissues and pellets is unknown (Horak et al. 2018). Pellets account for prey consumed, and barn owls produce on average 1.7 pellets per day (Marti 1973). Hypothetically, if found in or around a nest box, pellets can provide an unlimited source for testing for ARs as this passive method is not physically invasive. It should be considered a minimally invasive method because a high frequency of visits to the nests would be necessary to collect enough whole pellets from inside the nest box which could create a stressful environment for the nestlings. The only non-invasive approach would be to collect pellets below the nest box. By collecting from outside the nest box, researchers must assume that all pellets collected came from the nestlings or adults from that nest box. This could account for inaccurate results if the pellets are not from the target individuals.

Analysis of liver tissue is the most common method for testing AR exposure in barn owls through live animals brought into wildlife rehabilitation centers and dead animals collected from highways and roads (Murray 2017, 2018). This method yields the greatest ability to detect AR exposure given the long half-lives of ARs in liver tissue (Fisher et al. 2003). While useful, researchers cannot tie land-use practices to the carcass because of unknown exposure time or location. Furthermore, some samples may result in potentially biased results given the greater likelihood of detecting AR exposure from an individual that already shows clinical symptoms of illness or disease (e.g., barn owls brought to rehabilitation centers).

Measuring the Effects of Secondary Exposure to ARs

There are many known effects of secondary exposure to ARs in birds including anemia, delayed/stunted development, and mortality (Knopper et al. 2007, Naim et al. 2010, Hughes et al. 2013, Salim et al. 2014a). Sub-lethal effects are more difficult to assess in wild animals because the most likely effects are related to the individual's fitness and immune responses (Rattner et al. 2014b). For barn owls used in IPM systems, researchers can measure sub-lethal effects connected to lowered immunity and fitness including barn owl nestlings' development. These can be measured by comparing frequency of exposure to ARs and measuring growth of nestlings via morphometrics such as feather, talon, and beak growth, and weight increases (Naim et al. 2010). Collecting morphometric data are helpful, but this minimally invasive method requires consistent methodology, thorough documentation, and consideration of other factors, such as temperatures influencing nest growth, to ensure the additional time and effort are worth pursuing, from a cost/benefit perspective.

Another solution is to pair survival and mortality rates of barn owl nestlings to blood and liver tissue samples taken from carcasses found in active nest boxes. This would identify recent and lifetime AR exposure for nestlings that have yet to leave their nest box. This method may be time consuming given frequent visits to active nest boxes to collect carcasses, but the effort can pay off with the potential of identifying exposure in the liver in an individual or nest that may have been missed using pellet or blood samples.

DISCUSSION

One of the main goals of introducing barn owls as biological control into IPM programs in agroecosystems for the control of rodent pests is to reduce negative environmental impacts of ARs, including decreasing non-target exposure (Kross and Baldwin 2016, Kross et al. 2016, Huysman et al. 2018, Johnson and St. George 2020, St. George and Johnson 2021). A significant part of a barn owl's diet consists of rodent species that are often targeted with ARs, especially mice and rats (Van Vuren et al. 1998, Hindmarch and Elliott 2014, Browning et al. 2016, Kross et al. 2016). As such, they are at increased risk for secondary exposure to these compounds. Understanding rodent ecology is fundamental for studying the interaction between ARs and barn owls given spatial variability in rodent reproductive rates, preferred food resources and foraging habitats, and variable types of damage caused by rodents across agricultural systems. Similarly, parameters positively affecting barn owl reproduction and occupancy of nest boxes are important because of the potential pest control services provided by parents feeding their nestlings. Thus, it is important to thoroughly review all factors for the proposed research to identify best management practices for rodents and to accurately identify AR exposure pathways for barn owls.

Barn Owl Diet

Barn owls experience secondary exposure to ARs when they prey upon a rodent that has consumed ARs (Erickson and Urban 2004, Rattner et al. 2014b, Geduhn et al. 2016, van den Brink et al. 2018). Collecting egested pellets is a simple method for analyzing barn owl diet, and identifying prey remains from pellets has been shown to accurately represent an owl's diet (Lenton 1984, Moore et al. 1998, Marti 2010, Hindmarch and Elliott 2014, Lemos et al. 2015, Browning et al. 2016, Kross et al. 2016, Horváth et al. 2018, St. George and Johnson 2021). Barn owl pellets can be easily collected from inside active nest boxes or around nest boxes used for roosting and perching. Diet analyses typically rely on whole pellets (Marti et al. 2007), although collecting whole pellets from active nest boxes before they become trampled by nestlings can be a challenge. Larger prey items such as rabbits are also difficult to identify in pellets. The use of motion activated or continuously recording video cameras can document nestling diet by recording prey deliveries to active nests (St. George and Johnson 2021). Video recordings may capture prey items that are not present in pellets and can solve the issue of lost data due to trampled pellets. However, implementing video cameras in a field setting can be time consuming and costly. Using pellet dissections and video recordings together can provide a more complete understanding of a barn owl's diet. Because describing diet composition alone does not give an indication of AR exposure, the timing of diet sampling should align with other AR exposure monitoring methods and active AR applications.

Conducting rodent surveys can identify rodent abundance and distribution on the landscape. Researchers can gain an understanding of prey selection in barn owls by comparing what is detected in their diet to prey availability (Paz et al. 2013). Understanding prey selection in barn owls can help give an indication of whether they are commonly consuming species that are targeted by ARs (Geduhn et al. 2016). It is important to consider that non-target prey species may also be exposed to ARs (Nakayama et al. 2019), and different species are targeted with ARs in different scenarios (e.g., different crops, field vs. structural AR-use, different seasons). Surveying for rodents may require the use of multiple methods due to differences in crop type, rodent biology, and the trapping success for different species (e.g., Sherman live traps, Whisson et al. 2005; open-hole method, Engeman et al. 1993; and motion sensor cameras Klemens et al. 2021). Additionally, the large home range of barn owls may span multiple land-use types (Castañeda et al. 2021, Séchaud et al. 2021). Thus, identifying species composition and density across multiple land-use types and with multiple rodent survey methods can become time intensive.

Barn Owl Movement Ecology

Documenting barn owl movement can help explain exposure pathways in agroecosystems. For example, telemetry data can provide information about home range, habitat selection, and the distance/duration barn owls are hunting (Castañeda et al. 2021, Huysman and Johnson 2021, Séchaud et al. 2021). Telemetry is a common tool used to help understand spatial patterns of foraging in wildlife species, which entails capturing and attaching a transmitter to an individual that can collect location and behavior data (Meyburg and Fuller 2007, Huysman and Johnson 2021, Séchaud et al. 2021). With the knowledge of AR applications and movement data, researchers could identify if owls hunted near pesticide targeted areas and can relate barn owl foraging locations with the dietary trends from the nest. In combination with nest cameras, researchers may discern where the prey items originated from on the landscape.

There are various forms of telemetry available (e.g., VHF and GPS), although the weight and battery life of the transmitter need to be considered. Per the United States U.S. Geological Survey's Bird Banding Lab and Institutional Animal Care and Use Committee (IACUC) guidelines, transmitters on birds must weigh no more than 3% of an individual's total body weight (Erickson et al. 2007, Boal et al. 2010). This consideration currently limits the use of many commercially available GPS transmitters on lighter individuals and potentially males, although this may become less of a problem as technology progresses. Many transmitters are powered by solar panels to decrease weight and to increase battery life, although the use of solar charging is not compatible with a species that is only active at night. Due to limited battery life on transmitters that can be affixed to nocturnal raptors, once batteries are depleted a significant effort should be made to retrieve the transmitter (Castañeda et al. 2021). Retrieved transmitters can be recharged and redeployed which can be an important way to increase sample sizes. VHF telemetry is another option for tracking barn owl movement, although this technique may require increased field presence to collect data (Walls and Kenward 2007). Further considerations for deploying transmitters on any raptor include state and federal permit requirements to handle these protected birds while conducting this type of research activity and the specialized training required prior to attaching transmitters.

CONCLUSION

There is a need for long-term research projects to investigate the interactions between IPM programs using both chemical controls (anticoagulant rodenticides) and biological controls (barn owls). Without this information, it is difficult to understand how well these pest control methods work together given the potential negative impact that ARs can have on barn owls. It necessary to first ensure that barn owls and ARs can be safely utilized together, without minimizing the effectiveness of barn owls as a biocontrol agent, for the success of any IPM program in an agroecosystem. We have provided a conceptual outline and comprehensive approach for studying the interactions between barn owls and ARs in agroecosystems globally. We also provided insights into challenges and areas for future studies to improve on our framework. Many of our proposed methods are at least minimally invasive, we must emphasize the importance of identifying the project scope and objectives early on to minimize environmental stress and unnecessary visits to the nest boxes.

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