Structural Pest Control Board
Research Advisory Panel

Niamh Quinn Proposal

"Following the Trail: Can Mitigation Measures Reduce Rodenticide Exposure in Coyotes?"

2025

Represented University:
UC Agriculture and Natural Resources

Funds Requested: $329,970

Term: January 1, 2026 through December 31, 2028

University *of* California
Agriculture and Natural Resources

Contracts and Grants

ANR Office of Contracts and Grants
2801 Second Street
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(530) 756-1148 fax
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OCG: ocg@ucanr.edu
http://ucanr.org/contractsandgrants

Letter of Institutional Support of Project Entitled: "Following the Trail: Can Mitigation Measures Reduce Rodenticide Exposure in Coyotes"
Principal Investigator – Niamh Quinn, UC Cooperative Extension Advisor, Orange County
Period of Performance: January 01, 2026 – December 31, 2028
Requested budget: $329,970

July 30, 2025

Kristina Jackson-Duran
California Department of Consumer Affairs
Structural Pest Control Board
2005 Evergreen Street, Suite 1500
Sacramento, CA 95815

Dear Ms. Jackson-Duran,

It is our pleasure to present for your consideration the above-referenced proposal in response to your Structural Pest Control Board Research Proposal Solicitation Notice No. SPCB-25-01. The project efforts at the University of California, Agriculture and Natural Resources will be conducted under the supervision of Dr. Niamh Quinn, Cooperative Extension Advisor, Orange County.

Any questions of a programmatic nature should be directed to Niamh Quinn at nmquinn@ucanr.edu. Questions of a contractual nature may be directed to Heidi von Geldern at hvongeldern@ucanr.edu or by phone at 530-750-1304. Correspondence may be sent to the attention of Heidi von Geldern, University of California, Agriculture and Natural Resources, Office of Contracts & Grants, 2801 Second Street, Davis, CA 95618-7717.

Sincerely,

Kimberly Lamar

Kimberly Lamar
Interim Director, Contracts and Grants

UNIVERSITY OF CALIFORNIA
Agriculture and Natural Resources

UCCE, Orange County

29th July, 2025

California Department of Consumer Affairs
Structural Pest Control Board

Dear Structural Pest Control Board and Research Advisory Panel.

I am pleased to submit the attached proposal, *"Following the Trail: Can Mitigation Measures Reduce Rodenticide Exposure in Coyotes?"*, for your consideration under the SPCB-25-01 Research Solicitation. This project will evaluate how anticipated mitigation measures, including pulsed anticoagulant rodenticide applications, influence non-target wildlife exposure in California's structural pest control environment, generating empirical data to support the Department of Pesticide Regulation's reevaluation process.

Anticoagulant rodenticides remain a critical tool for managing commensal rodent populations, yet their persistence and bioaccumulation continue to present ecological and regulatory challenges. Despite recent statewide restrictions, AR exposure remains nearly ubiquitous among urban coyotes and other predators, raising concerns about current practices and the need for robust, empirical evaluations of mitigation measures. This project will leverage a novel tool developed by the Quinn Lab (isotopically labelled anticoagulant rodenticides (iLARs)) to trace rodenticide movement through trophic pathways with unparalleled precision. By pairing iLAR detection in coyote feces and hair with GPS collar tracking and validated rodent population indices, we will generate the first comprehensive, real-time assessment of how pulsed baiting and increased-frequency deployments influence exposure risk while maintaining rodent control efficacy.

Our research team brings extensive experience in AR exposure monitoring, wildlife ecology, and applied pest management. Previous projects led or co-led by our team have quantified coyote AR exposure statewide (Stapp et al., 2024), validated behavioral monitoring tools for commensal rats and developed a standardized rat activity index (Bosarge, 2024), and examined how non-target wildlife interact with bait stations in urban environments (Burke, 2018). Together, these studies have built the methodological foundation of non-invasive fecal testing, validated rat population indices, and landscape-based wildlife monitoring, that will ensure the success of the proposed research. Our interdisciplinary team includes specialists in wildlife toxicology, spatial and movement ecology, and structural pest control operations, ensuring that outcomes are both scientifically robust and directly applicable to industry and regulatory needs.

7601 Irvine Blvd, Irvine, CA 92618   (949) 653-1810

UNIVERSITY OF CALIFORNIA
Agriculture and Natural Resources

UCCE, Orange County

The long-term outcome of this research is the development of a scalable, science-based framework for ongoing monitoring of non-target AR exposure, not only in coyotes but also in raptors and other mesopredators. This framework will provide DPR and SPCB with actionable evidence to refine structural pest control guidelines, reduce ecological risk, and uphold the principles of Integrated Pest Management without compromising the pest control tools upon which California's urban and industrial sectors rely.

Thank you for considering this proposal. I am confident that the innovative approach and experienced interdisciplinary team will deliver results that inform policy and practice statewide. Please feel free to contact me at nmquinn@ucanr.edu with any questions regarding the proposal.

Sincerely,

Niamh Q

Niamh Quinn, PhD
Human-Wildlife Interactions Advisor
Principal Investigator, UCANR

ATTACHMENT 1

REQUIRED ATTACHMENT CHECKLIST

A complete proposal will consist of the items identified on the list below.

Complete this checklist to confirm that all items are contained with your proposal. Place a check mark or "✓" next to each item that you are submitting to the State. For your proposal to be responsive, in addition to your proposal, all required attachments must be returned. This checklist should be returned along with your proposal.

It is essential that the Cost Proposal be complete, thorough, and comply with content sequence requirements. The proposal must be typed and double-spaced on 8½ X 11 paper. All pages shall be consecutively numbered. All elements shall follow the sequence presented on the following checklist:

✓ Check	Attachment #	Attachment Name/Description	Form Provided	Completion Required
	Attachment 1	Required Attachment Checklist	YES	YES
	Attachment 2	Cost Proposal/Budget Display Sheets	YES	YES
	Attachment 3	Budget Narrative Form and Explanation of Costs	YES	YES
	Attachment 4	Proposer's References	YES	YES
	Attachment 5	Sample Agreement a) Project Summary and Scope of Work b) Schedule of Deliverables c) Key Personnel d) Authorized Representatives and Notices e) Use of Pre-existing Intellectual Property f) Current & Pending Support g) Third Party Confidential Information (if applicable) h) Budget Justification	YES	YES
	Attachment 6	Resumes (Curriculum Vitae) for Proposer, Proposer's staff involved in project, and all Subcontractors	NO	YES
	Attachment 7	Narrative of Research Objectives, as described in Rating/Scoring Criteria	NO	YES
	Attachment 8	Narrative of Project Direction (Work Plan and Work Schedule), as described in Rating/Scoring Criteria	NO	YES
	Attachment 9	Narrative of Qualifications, as described in "Minimum Qualifications for Proposers" and Rating/Scoring Criteria	NO	YES
	Attachment 10	Copy of current business license, professional certificates, or other credentials	NO	YES

ATTACHMENT 2

COST PROPOSAL/BUDGET
DISPLAY RESEARCH PROPOSAL

YEAR 1 – (for first 12 months)

Period of award
01/01/2026-12/31/2028

Period of award: January 1, 2026-December 31, 2026
Contractor: The Regents of the University of California, ANR
Project Title/Description: Following the Trail: Can Mitigation Measures Reduce Rodenticide Exposure in Coyotes?_______

Description	Hours	Rate	Total
PERONNEL SERVICES			
1. Staff Research Associate I	25% FTE	$58,700 *escalation each FY	$14,969
2. Classification			
3. Classification			
		Total Salaries	$14,959
		Total Benefits	$8,874 (59.28%)
		Total Personnel Services (A)	$23,843
SUBCONTRACTOR SERVICES			
1. USDA/National Wildlife Research Center			$9,570
2. Classification			
3. Classification			
		Total Subcontractor Services (B)	$9,750
OTHER SERVICES			
1. Classification			
2. Classification			
3. Classification			
		Total Other Services (C)	
OPERATING EXPENSES			
1. Supplies and Expense			$138,650
2. Travel In-State			
3. Travel Out-of-State			
4. Equipment			
5. Other Costs			
		Total Operating Expenses (D)	$138,650
Total Personnel and Operating (Add A through D)		$172,063	
Indirect Costs (detail) (25% MTDC)		$43,016	
TOTAL COSTS – Year 1 (for the first 12 months)		$215,079	

ATTACHMENT 2, Cont.

COST PROPOSAL/BUDGET
DISPLAY RESEARCH PROPOSAL

YEAR 2 – (for months 13 thru 24)

Period of award
01/01/2026-12/31/2028

Period of award: 01/01/2027-12/31/2027
Contractor: The Regents of the University of California, ANR
Project Title/Description: Following the Trail: Can Mitigation Measures Reduce Rodenticide Exposure in Coyotes?______

Description	Hours	Rate	Total
PERONNEL SERVICES			
4. Staff Research Associate I	25% FTE	$61,048 *includes escalation each FY	$15,567
5. Classification			
6. Classification			
		Total Salaries	$15,567
		Total Benefits	$9,228 (59.28%)
		Total Personnel Services (A)	$24,795
SUBCONTRACTOR SERVICES			
4. USDA/NWRC			$12,715
5. Classification			
6. Classification			
		Total Subcontractor Services (B)	$12,715
OTHER SERVICES			
4. Classification			
5. Classification			
6. Classification			
		Total Other Services (C)	
OPERATING EXPENSES			
6. Supplies and Expense			
7. Travel In-State			
8. Travel Out-of-State			
9. Equipment			
10. Other Costs (DNA Detection)			$17,900
		Total Operating Expenses (D)	$17,900
Total Personnel and Operating (Add A through D)		$55,410	
Indirect Costs (detail) (25% MTDC)		$13,853	
TOTAL COSTS – Year 2 (for 12 months)		$69,263	

ATTACHMENT 2, Cont.

COST PROPOSAL/BUDGET
DISPLAY RESEARCH PROPOSAL

YEAR 3 – (for months 25 thru 36)

Period of award
01/01/2026-12/31/2028

Period of award: 01/01/2028-12/31/2028

Contractor: The Regents of the University of California, ANR

Project Title/Description: Following the Trail: Can Mitigation Measures Reduce Rodenticide Exposure in Coyotes?_________________

Description	Hours	Rate	Total
PERONNEL SERVICES			
7. Staff Research Associate I	25% FTE	$63,490 *includes escalation each FY	$16,190
8. Classification			
9. Classification			
		Total Salaries	$16,190
		Total Benefits	$9,597 (59.28%)
		Total Personnel Services (A)	$25,787
SUBCONTRACTOR SERVICES			
7. USDA/NWRC			$12,715
8. Classification			
9. Classification			
		Total Subcontractor Services (B)	$12,715
OTHER SERVICES			
7. Classification			
8. Classification			
9. Classification			
		Total Other Services (C)	
OPERATING EXPENSES			
11. Supplies and Expense			
12. Travel In-State			
13. Travel Out-of-State			
14. Equipment			
15. Other Costs			
		Total Operating Expenses (D)	
Total Personnel and Operating (Add A through D)		$38,502	
Indirect Costs (detail) (25% MTDC)		$7,126	
TOTAL COSTS – Year 3 (for final 12 months)		$45,628	

ATTACHMENT 2, Cont.

COST PROPOSAL/BUDGET
DISPLAY RESEARCH PROPOSAL

COMBINED YEARS – (up to 3 years or 36 months)

Period of award
(i.e., 1/1/26-12/31/28)
Use separate sheet for each year

Period of award: 01/01/2026-12/31/2026

Contractor: The Regents of the University of California, ANR

Project Title/Description: Following the Trail: Can Mitigation Measures Reduce Rodenticide Exposure in Coyotes?________________

Description	Hours	Rate	Total
PERONNEL SERVICES			
10. Staff Research Associate I			$46,726
11. Classification			
12. Classification			
		Total Salaries	$46,726
		Total Benefits	$27,699
		Total Personnel Services (A)	$46,726
SUBCONTRACTOR SERVICES			
10. USDA/NWRC			$35,000
11. Classification			
12. Classification			
		Total Subcontractor Services (B)	$35,000
OTHER SERVICES			
10. Classification			
11. Classification			
12. Classification			
		Total Other Services (C)	
OPERATING EXPENSES			
16. Supplies and Expense			$138,650
17. Travel In-State			
18. Travel Out-of-State			
19. Equipment			
20. Other Costs (DNA detection)			$17,900
		Total Operating Expenses (D)	$156,550
Total Personnel and Operating (Add A through D)	$265,975		
Indirect Costs (detail) (25% MTDC)	$63,995		
TOTAL COSTS – GRAND TOTAL UP TO 3 YEARS (for UP TO 36 months)	$329,970		

ATTACHMENT 2-1 (Contractor Budget)

COST PROPOSAL/BUDGET
DISPLAY RESEARCH PROPOSAL

YEAR 1 – (for first 12 months)

Period of award
01/01/2026 – 12/31/2028

Period of award: 1/1/2026-12/31/2026

Contractor: United States Department of Agriculture

Project Title/Description: _Following the Trail: Can Mitigation Measures Reduce Rodenticide Exposure in Coyotes?

Description	Hours	Rate	Total
PERONNEL SERVICES			
1. Classification	113.59	66.25 / hr	$7526
2. Classification			
3. Classification			
		Total Salaries	$5438.42
		Total Benefits	$2088.58
		Total Personnel Services (A)	$7527
SUBCONTRACTOR SERVICES			
1. Classification			
2. Classification			
3. Classification			
		Total Subcontractor Services (B)	
OTHER SERVICES			
1. Classification			
2. Classification			
3. Classification			
		Total Other Services (C)	
OPERATING EXPENSES			
1. Supplies and Expense			
2. Travel In-State			
3. Travel Out-of-State			
4. Equipment			
5. Other Costs			
		Total Operating Expenses (D)	
Total Personnel and Operating (Add A through D)		$7527	
Indirect Costs (detail) 27.15%		$2043	
TOTAL COSTS – Year 1 (for the first 12 months)		$9570	

ATTACHMENT 2-1 (Contractor Budget), Cont.

COST PROPOSAL/BUDGET
DISPLAY RESEARCH PROPOSAL

YEAR 2 – (for months 13 thru 24)

Period of award
01/01/2026-12/31/2028

Period of award: 1/1/2027-12/31/2027

Contractor: United States Department of Agriculture

Project Title/Description: Following the Trail: Can Mitigation Measures Reduce Rodenticide Exposure in Coyotes?

Description	Hours	Rate	Total
PERONNEL SERVICES			
4. Classification	151	66.25 / hr	$10000
5. Classification			
6. Classification			
		Total Salaries	$7226.17
		Total Benefits	$2773.83
		Total Personnel Services (A)	$10000
SUBCONTRACTOR SERVICES			
4. Classification			
5. Classification			
6. Classification			
		Total Subcontractor Services (B)	
OTHER SERVICES			
4. Classification			
5. Classification			
6. Classification			
		Total Other Services (C)	
OPERATING EXPENSES			
6. Supplies and Expense			
7. Travel In-State			
8. Travel Out-of-State			
9. Equipment			
10. Other Costs			
		Total Operating Expenses (D)	

Total Personnel and Operating (Add A through D)	$10000
Indirect Costs (detail) (27.15%)	$2715
TOTAL COSTS – Year 2 (for 12 months)	$12,715.00

ATTACHMENT 2-1 (Contractor Budget), Cont.

COST PROPOSAL/BUDGET
DISPLAY RESEARCH PROPOSAL

YEAR 3 – (for months 25 thru 36)

Period of award
01/01/2026-12/31/2028

Period of award: 1/1/2028-12/31/2028

Contractor: United States Department of Agriculture

Project Title/Description: Following the Trail: Can Mitigation Measures Reduce Rodenticide Exposure in Coyotes?

Description	Hours	Rate	Total
PERONNEL SERVICES			
7. Classification	151	66.25 / hr	$10000
8. Classification			
9. Classification			
		Total Salaries	$7226.17
		Total Benefits	$2,773.83
		Total Personnel Services (A)	$10,000
SUBCONTRACTOR SERVICES			
7. Classification			
8. Classification			
9. Classification			
		Total Subcontractor Services (B)	
OTHER SERVICES			
7. Classification			
8. Classification			
9. Classification			
		Total Other Services (C)	
OPERATING EXPENSES			
11. Supplies and Expense			
12. Travel In-State			
13. Travel Out-of-State			
14. Equipment			
15. Other Costs			
		Total Operating Expenses (D)	
Total Personnel and Operating (Add A through D)		$10000	
Indirect Costs (detail) (27.15%)		27.15% IDC: $2715	
TOTAL COSTS – Year 3 (for final 12 months)		$12715.00	

ATTACHMENT 2-1 (Contractor Budget), Cont.

COST PROPOSAL/BUDGET
DISPLAY RESEARCH PROPOSAL

COMBINED YEARS – (up to 3 years or 36 months)

Period of award
1/1/26-12/31/28)
Use separate sheet for each year

Period of award: 1/1/2026-12/31/2028

Contractor: United States Department of Agriculture

Project Title/Description: Following the Trail: Can Mitigation Measures Reduce Rodenticide Exposure in Coyotes?

Description	Hours	Rate	Total
PERONNEL SERVICES			
10. Classification	415.5	66.25 / hr	$27,527
11. Classification			
12. Classification			
		Total Salaries	$19,892
		Total Benefits	$7,635
		Total Personnel Services (A)	$27,527
SUBCONTRACTOR SERVICES			
10. Classification			
11. Classification			
12. Classification			
		Total Subcontractor Services (B)	
OTHER SERVICES			
10. Classification			
11. Classification			
12. Classification			
		Total Other Services (C)	
OPERATING EXPENSES			
16. Supplies and Expense			
17. Travel In-State			
18. Travel Out-of-State			
19. Equipment			
20. Other Costs			
		Total Operating Expenses (D)	

Total Personnel and Operating (Add A through D)	$27,527
Indirect Costs (detail)	$7,473
TOTAL COSTS – GRAND TOTAL UP TO 3 YEARS (for UP TO 36 months)	$35,000

ATTACHMENT 3,

BUDGET NARRATIVE FORM AND EXPLANATION OF COSTS:

Explain the need for individual staff, budgeted travel, equipment, subcontracts and consultants:

Staff are essential for coyote capture and collaring, deployment and retrieval of tracking tunnels to assess rodent populations, and collection of coyote feces for isotopically-labelled anticoagulant rodenticide (iLAR) detection. These activities generate the data needed to meet key project deliverables, including population indices, GPS-collar movement data, and repeated scat sampling for exposure analysis. The USDA National Wildlife Research Center (NWRC), the only laboratory equipped to detect iLAR residues in hair, feces, blood, and liver, is a critical subcontractor to ensure valid and defensible residue testing.

The isotopically-labelled bait active ingredient must be custom synthesized by a specialized chemical manufacturer and integrated into bait for field use, enabling precise tracing of rodenticide exposure pathways. DNA genotyping services (UC Davis Mammalian Ecology and Conservation Unit) are required to identify individual coyotes, allowing exposure patterns to be tracked across the population and through time. Specialized equipment (including GPS collars, tracking tunnels, and field supplies) directly support these field operations, ensuring that the study can generate the replicable, high-resolution data necessary for SPCB reporting, interim presentations, and the final project report.

Please explain how the costs were arrived at:

Personnel costs include $46,726 for a Staff Research Associate I, with benefits ($27,699) calculated at 59.8% in accordance with UCANR's federally negotiated benefit rate agreement. Materials and supplies reflect current vendor pricing and prior project expenditures, including $20,000 for GPS/GSM collars and data (10 collars at $17,500; Quinn already owns 10 additional collars; $2,500 for a data package enabling 15-minute location fixes per day) and $118,650 for 7g of iLAR technical material, which must be custom synthesized by a chemical supplier.

Subaward costs include $35,000 to the USDA National Wildlife Research Center, the only facility capable of testing fecal, hair, and tissue samples for iLAR compounds. Additional direct costs include $17,900 for species typing and individual/sex genotyping services from the UC Davis Mammalian Ecology and Conservation Unit to identify individual coyotes and track exposure across the population.

Indirect costs total $63,995, calculated using the State of California's 25% Modified Total Direct Costs (MTDC) off-campus rate, as specified in Exhibit B of the solicitation. All costs reflect federally negotiated rates, published service fees, vendor quotes, or documented market prices, ensuring the budget is transparent, justified, and appropriate for the scope of work.

Please explain why the rates are considered reasonable and/or appropriate in your opinion:

The proposed rates are reasonable and appropriate for several reasons. All personnel salaries and fringe benefits are based on UC Agriculture and Natural Resources' federally negotiated rates and reflect actual, current pay scales for the listed classifications (e.g., Principal Investigator, Co-Investigators, and Staff Research Associate I). These rates are consistent with UC systemwide compensation policies and with prior projects of similar scope funded by state agencies, including SPCB and DPR.

Fringe benefit rates (59.8% for staff, as noted in the budget) are derived from the UCANR federally negotiated benefit rate agreement and applied uniformly. Indirect costs are calculated using the State of California off-campus negotiated rate of 25% Modified Total Direct Costs (MTDC), which is the standard for state-funded research agreements.

Subcontract and testing costs, such as the $35,000 to USDA National Wildlife Research Center for iLAR fecal testing and $17,900 to UC Davis Mammalian Ecology and Conservation Unit for species typing and genotyping, reflect established service rates charged to external clients and are directly tied to the specialized analyses needed for the project.

Materials such as GPS/GSM coyote collars and associated data packages are priced at competitive vendor rates, with bulk purchasing leveraged where possible. All other expenses, including supplies, laboratory services, and iLAR, are benchmarked against current market pricing and vendor quotes to ensure cost efficiency.

As a whole, these rates are in line with industry and academic standards, have been validated through prior state and federally funded projects, and ensure the project can meet its objectives without inflating costs.

Are costs based on industry standard or other basis of measurement? Please explain:

Yes. Salaries and fringe benefits follow the UCANR federally negotiated rates, which are reviewed annually. Indirect costs use the State of California’s standard 25% MTDC off-campus rate. Subcontract and testing fees (e.g., USDA NWRC and UC Davis) reflect each institution’s published service rates. Field equipment, collars, lab supplies, and iLAR are priced using current vendor quotes and market rates, consistent with prior state-funded projects.

ATTACHMENT 4

PROPOSER REFERENCES

1. Please attach three letters of reference on company letterhead.
2. List below three references of similar types of services performed, as described in the description of services, within the last five years. If three references cannot be provided, please explain why on an attached sheet of paper.

REFERENCE 1	
Name of Firm	National Pest Management Association
Address	10460 North Street, Fairfax, VA 22030
Contact Person	Michael Bentley, PhD, BCE, Vice President of Training and Technical Services
Telephone Number	(571) 224-0372
Dates of Service	2022-2023
Value or Cost of Service	$ 14,170.00

Brief Description of Service Provided:

This project, delivered on schedule, investigated the behavior of roof rats (*Rattus rattus*) around rodenticide bait stations and evaluated tracking tunnels as a monitoring tool to improve structural pest management practices. Field studies were conducted at 36 residential properties in Orange County, California, to address two primary goals: (1) determine how bait station design, baiting approaches (including supplemental bait), and the use of scent lures influenced station discovery, entry, and bait consumption by roof rats, and (2) assess whether tracking tunnel indices correlated reliably with other measures of rat activity and abundance, including camera detections and trapping.

Three sequential field trials were performed using digital game cameras, tamper-resistant bait stations, and tracking tunnels. Roof rats discovered roughly 60–75% of bait stations but entered only 30–35% of those stations under typical conditions. Supplemental bait significantly increased both station entry and bait consumption, while bait station design and scent lures had minimal influence on rat behavior. Tracking tunnel indices were strongly correlated with camera and live-trap-based activity estimates, validating the use of tracking tunnels as a reliable, non-lethal method for estimating rat presence and relative abundance before and during management efforts.

The tracking index developed in this research will be directly instrumental for the success of the proposed *"Following the Trail: Can Mitigation Measures Reduce Rodenticide in Coyotes?"* study. In that project, the index will serve as the standardized method to quantify rodent activity across treatment sites, ensuring that rodent populations are accurately monitored alongside iLAR deployments. This will allow us to evaluate the effectiveness of different mitigation strategies while controlling for rodent population dynamics, thereby improving the rigor and interpretability of wildlife exposure assessments.

The outcomes of this completed research addressed key knowledge gaps regarding roof rat behavior and provided structural pest management professionals with evidence-based recommendations to improve bait station performance and better align rodent management strategies with California's regulatory framework and integrated pest management principles.

REFERENCE 2	
Name of Firm	Rodenticide Task Force
Address	437 Delano Road, Marion, MA 02738
Contact Person	Katie Swift, Rodenticide Task Force Chair
Telephone Number	(808) 284-8322
Dates of Service	2021-2024
Value or Cost of Service	$99,005

Brief Description of Service Provided:

This on-time completed research developed and validated a novel, non-lethal, longitudinal monitoring framework for assessing anticoagulant rodenticide (AR) exposure in free-ranging coyotes (*Canis latrans*). Unlike traditional carcass-based monitoring, which provides only static, single-point residue data, this study integrated repeated fecal sampling, hair collection, DNA genotyping, and GPS collar tracking to track exposure events over time and space across Los Angeles and Orange counties. Over 12 months, scat and hair samples from 186 individually identified coyotes, including 12 collared animals, were analyzed for residues of 12 AR compounds, alongside movement data and landscape variables. These methods revealed that 59% of coyotes carried residues of at least one AR compound, often over multiple weeks, despite the statewide bans and restrictions implemented under AB 1788 and AB 1322. The approach also identified illegal or unregistered rodenticides, provided evidence of episodic and spatially heterogeneous exposure within home ranges, and highlighted that legislation alone has not eliminated non-target contamination.

The non-invasive monitoring framework developed here is essential for the success of the proposed *"Following the Trail: Can Mitigation Measures Reduce Rodenticide in Coyotes?"* study. By combining this validated scat- and hair-based residue testing protocol with iiLARs and GPS telemetry, the proposed research will directly build on this methodology to trace exposure pathways with unprecedented precision. These methods will allow us to quantify how mitigation measures, such as pulsed baiting a, affect both rodent populations and wildlife exposure risk in real time. The ability to repeatedly track individual animals and link exposure events to specific locations and management actions is the cornerstone for testing whether regulatory and operational changes can truly reduce contamination without compromising rodent control efficacy.

By advancing these tools, this program will provide DPR, SPCB, and other regulatory agencies with a scalable, data-driven monitoring system for evaluating pesticide mitigation outcomes, applicable not only to coyotes but also to other sentinel species such as raptors and mesopredators. The framework establishes the foundation for long-term, statewide AR surveillance and for the first-ever field validation of mitigation measures using isotope-traced rodenticides.

REFERENCE 3	
Name of Firm	UC Davis
Address	1 Shields Ave, Davis, CA 95616
Contact Person	Roger Baldwin, Professor of Cooperative Extension
Telephone Number	(530) 752-4551
Dates of Service	2019-2022
Value or Cost of Service	$ 499,609.00

Brief Description of Service Provided:

The *Best Management Practices (BMP)* study evaluated the effectiveness of commonly used rodent control strategies—including trapping, and baiting, across commercial, industrial, residential, and institutional sites in Southern California. Implemented over a year, the project partnered with licensed pest management professionals (PMPs) who selected and applied management strategies based on site needs. Rodent activity was monitored using tracking tunnels and game cameras before and after interventions.

Results showed that trapping provided more success that all treatments that included the use of rodenticide. However, these methods were considered the most expensive and labor intensive. Tracking tunnels proved to be a reliable, scalable monitoring tool, while game cameras were less effective due to variability in placement and labor demands.

This research offers a valuable foundation for the proposed project, *“Following the Trail: Can Mitigation Measures Reduce Rodenticide Exposure in Coyotes?”* The BMP study’s real-world implementation model and documentation of how pest control is practiced on the ground, particularly the reliance on rodenticides, provides essential operational context. It underscores the urgency of developing feasible, science-based alternatives and mitigation strategies.

The proposed project builds directly on these findings by testing the outcomes of different rodenticide application methods (e.g., pulsed vs. continuous) using iLARs to track non-target exposure. Insights from the BMP study, particularly around baiting frequency, device interaction, and site variability, help inform realistic treatment design and interpretation of exposure pathways. Together, these efforts bridge a critical gap between rodent management efficacy and environmental protection, directly supporting the goals of the SPCB-25-01 solicitation.

UCDAVIS
Wildlife, Fish and Conservation Biology

Date: July 30, 2025

Structural Pest Control Board
Department of Consumer Affairs
2005 Evergreen Street, Suite 1500
Sacramento, CA 95815

Subject: **Reference Letter in Support of Proposal SPCB-25-01 – Dr. Niamh Quinn**

Dear Members of the Research Advisory Panel,

I am pleased to provide this letter of support for Dr. Niamh Quinn's proposal, "Following the Trail: Can Mitigation Measures Reduce Rodenticide Exposure in Coyotes?" submitted under SPCB Solicitation No. SPCB-25-01.

I collaborated with Dr. Quinn on the recently completed project evaluating Best Management Practices (BMPs) for rodenticide deployment in urban-wildland interface environments. This project was completed on time and successfully met all objectives outlined in the original scope of work. The findings offer valuable insights into how structural pest management practices—including bait station placement, environmental conditions, and surrounding landscape features—affect rodent activity and potential risk to non-target species. We are currently drafting a peer-reviewed manuscript based on these results to further disseminate the study's implications.

The proposed project builds directly on this work. While the BMP project focused on rodent behavior and bait station use, Dr. Quinn's new research will extend this framework to evaluate how mitigation strategies translate to reduced exposure in wildlife, with an emphasis on field-based validation of DPR's proposed measures. The project design is a logical progression that addresses urgent regulatory needs, and it is clear that Dr. Quinn has the field expertise, regulatory knowledge, and professional credibility to lead such an effort effectively.

I fully endorse this proposal and am confident in Dr. Quinn's ability to produce rigorous, policy-relevant outcomes that will benefit both the structural pest control industry and wildlife protection efforts. Please feel free to contact me with any questions.

Sincerely,

Dr. Roger Baldwin
Professor of Cooperative Extension
Department of Wildlife, Fish, and Conservation Biology
University of California, Davis

NPMA
National Pest Management Association
Our Mission is Your Protection

Date: July 30, 2025

Structural Pest Control Board
Department of Consumer Affairs
2005 Evergreen St., Suite 1500
Sacramento, CA 95815

Subject: **Reference Letter in Support of Dr. Niamh Quinn**

To the Structural Pest Control Board Research Advisory Panel,

As Vice President of Training and Technical Services for the National Pest Management Association (NPMA), I am writing to strongly support Dr. Niamh Quinn's research proposal, *"Following the Trail: Can Mitigation Measures Reduce Rodenticide Exposure in Coyotes?"* (SPCB Solicitation No. SPCB-25-01). NPMA and I directly oversaw the foundational research underpinning this proposal, including the work completed in **the Pest Management Foundation funded research project "**Behavior and Activity of Commensal Roof Rats Around Bait Stations and Tracking Tunnels in Southern California: Insights to Improve Management", which established key methodologies now integrated into this proposed research.

The study, supported by NPMA and the Pest Management Foundation, advanced our understanding of commensal roof rat behavior, bait station usage, and the reliability of **tracking tunnels as population indices**. These findings, coupled with Dr. Quinn's validated **isotopically-labelled anticoagulant rodenticide (iLAR)** detection methods and GPS-collar wildlife tracking, form the basis of a research framework that directly meets the **SPCB's priorities** for science-based evaluation of Integrated Pest Management (IPM) tools in the structural pest control context.

This proposal demonstrates:

- **Clear research objectives (Scoring Criterion 1):** It seeks to empirically test whether proposed DPR mitigation measures, including pulsed baiting, reduce non-target wildlife exposure without compromising rodent control efficacy.
- **A robust and field-ready work plan (Scoring Criterion 2):** The integration of real-world service sites, validated rodent indices, iLAR tracing, and GPS-collared coyotes ensures the study captures exposure dynamics across space and time with unprecedented precision.
- **Exceptional qualifications (Scoring Criterion 3):** Dr. Quinn and her collaborators have successfully delivered multiple SPCB, DPR, and industry-funded studies on rodent management and wildlife exposure, all completed on schedule and with deliverables that have informed California regulatory discussions.

10460 North Street, Fairfax, VA 22030 www.npmapestworld.org t 703.352.6762 f 703.352.3031

- **Alignment with IPM and industry needs:** By generating **replicable monitoring tools and evidence-based recommendations**, this project will support both regulatory agencies and pest management professionals in implementing practices that are effective, environmentally responsible, and scalable to other species and contexts.

Given my direct oversight of the prior research and my extensive collaboration with Dr. Quinn, I can attest to the **team's capability to deliver all proposed deliverables (six-month progress reports, interim presentations, and a comprehensive final report)** and to produce findings that will withstand scientific and regulatory scrutiny. I strongly recommend funding this proposal to advance California's science-based regulatory framework for structural pest control.

Please feel free to contact me at 703-352-6762 or mbentley@pestworld.org for additional details regarding the research team's prior work and qualifications.

Sincerely,

Michael Bentley, PhD, BCE
Vice President of Training and Technical Services
National Pest Management Association (NPMA)
Executive Director, Pest Management Foundation

Rodenticide
TASK FORCE

July 23, 2025

Structural Pest Control Board
Department of Consumer Affairs
2005 Evergreen Street, Suite 1500
Sacramento, CA 95815

Re: Support for the grant proposal 'Following the Trail: Can Mitigation Measures Reduce Rodenticide Exposure in Coyotes?' submitted by Dr. Niamh Quinn and co-investigators

Dear Members of the Structural Pest Control Board and the Scientific Advisory Panel:

As Chair of the Rodenticide Task Force, I am writing to express our strongest endorsement of Dr. Niamh Quinn's proposal, "Following the Trail: Can Mitigation Measures Reduce Rodenticide Exposure in Coyotes?" submitted under SPCB Solicitation No. SPCB-25-01.

Having worked closely with Dr. Quinn on the DPR-funded longitudinal study of rodenticide exposure in coyotes and the DCA-supported assessment of urban wildlife exposure, I can state unequivocally that no other researcher in California is as uniquely equipped to lead this project. Dr. Quinn possesses a rare and essential combination of:

- Proven methodologies – She developed and validated the non-lethal, longitudinal monitoring framework using scat, hair, and GPS collaring, which is now the benchmark for tracking exposure across live wildlife populations.
- Dual trust and credibility – She is one of the few scientists whose work is simultaneously respected by regulators, relied upon by pest management professionals, and cited in policy discussions at the state level.
- Capacity for complex, real-world implementation – Her team is the only one with the infrastructure, permits, and field expertise to integrate isotopically-labelled anticoagulant rodenticides (iLARs) with landscape-level exposure data and service-site rodent activity metrics.

For these reasons, Dr. Quinn is the only investigator capable of delivering a study that regulators can trust for decision-making and that pest management professionals can use to adapt practices without jeopardizing control efficacy**.** Without her leadership, California would lack the credible, field-validated evidence necessary to evaluate and refine mitigation measures before they become regulation.

The Rodenticide Task Force fully endorses this proposal and urges the SPCB to fund it. Dr. Quinn's leadership ensures that this research will not only meet all deliverables but will also produce results that can withstand scientific and regulatory scrutiny while providing practical solutions for the pest control industry.

Please feel free to contact me at swiftk@Liphatech.com if you need further information on our collaboration with Dr. Quinn or our support for this critical project.

Sincerely,

Katie Swift

Katie Swift
Chair, Rodenticide Task Force

Comprised of 12 rodenticide registrants, the Rodenticide Task Force is committed to providing educational information about the appropriate and effective use of rodenticides as part of Integrated Pest Management programs that protect public health, food safety, and property, while also protecting the environment, endangered species, and other non-target animals.

Research Article

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Use of rodenticide bait stations by commensal rodents at the urban–wildland interface: Insights for management to reduce nontarget exposure

Christopher B Burke,[a] Niamh M Quinn[b] and Paul Stapp[a*]

Abstract

BACKGROUND: Pest management professionals use anticoagulant rodenticides, usually placed in tamper-resistant bait stations, to control commensal rodents, but significant concerns remain about exposure of nontarget species, especially at the urban–wildland interface. We deployed digital cameras to monitor use of bait stations placed in 90 residential yards across Orange County, California, USA. Two bait stations, supplied with nontoxic bait, were monitored in each yard for approximately 30 consecutive days during two camera-trapping sessions between December 2017 and March 2019. One station was placed on the ground, while the other was elevated 1–1.5 m to determine if elevating stations could reduce nontarget exposure.

RESULTS: Black rats (*Rattus rattus* L.) were present at 80% of sites, with mean activity ranging from 0 to 9.6 h each night. There were no significant differences between elevated and ground stations in the time to discovery, time to bait station entry, or nightly activity of rats. Rats discovered bait stations more quickly, and mean nightly activity was greater, in yards where rats were detected more frequently. Although native rodents visited and entered bait stations occasionally, they were relatively rare among our sites (13.3%), and were detected five times less often at elevated stations compared to those on the ground. Yards visited by these rodents were significantly nearer to areas of green open space and natural vegetation, and tended to have no significant barriers to entry, e.g. solid fences or walls.

CONCLUSIONS: By elevating bait stations and avoiding placing rodenticides in yards that are likely to be visited by wildlife, pest management professionals may be able to reduce the risk of nontarget exposure, including secondary poisoning of predators and scavengers, while still providing effective control of commensal pests.

Keywords: California; commensal rodents; nontarget wildlife species; *Rattus*; rodenticide bait stations

1 INTRODUCTION

Commensal rodents such as rats and mice pose significant risks to human health and cause considerable damage to property and infrastructure.[1,2] Globally, these species consume billions of dollars' worth of human foods annually,[3] making them one of the most costly introduced species in the world.[4] Moreover, rats and mice are carriers of diseases such as plague, salmonella, and tularemia that are harmful to humans, as well as diseases of native wildlife species.[5–8]

A variety of methods have been used to control commensal rodent populations, ranging from habitat modification to trapping to rodenticides.[9] The abundance of food in urban environments, combined with the innate tendency of some rats for neophobia,[10] can make it difficult to attract animals to traps.[2,11] In urban and suburban areas, rodenticides, particularly second-generation anticoagulant rodenticides, have been widely used because of their relatively high efficacy and low cost.[7] Rodenticides are usually placed in tamper-resistant bait stations to prevent children, pets, and nontarget animals from accessing the bait. The use of bait stations can be particularly important in residential and mixed-use settings at the urban–wildland interface, where nontarget poisoning of wildlife is a significant conservation concern.[12–14] Mammalian carnivores and raptors can also be exposed secondarily by consuming rodents that have ingested rodenticide bait and died away from cover,[15–17] especially mobile species such as coyotes (*Canis latrans* Say), which can themselves live in urban and suburban environments.[18]

Despite the effectiveness of rodenticides in urban settings, relatively little is known of the behavioral response of commensal rodents to bait applications, presumably because of the challenges of field work in urban areas.[19] Recent studies have tended to focus on agricultural or conservation applications,[20–25] which

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may not be applicable to situations requiring the use of rodenticides in urban areas or at the urban–wildland interface.[26] A better understanding of factors such as bait station neophobia and the effects of placement and rat abundance on bait station use could help pest management professionals effectively control commensal rodents while minimizing exposure of nontarget wildlife.

To determine how commensal rodents respond to rodenticide bait stations in a suburban setting, we quantified the rate of discovery, activity, and entry of black rats (*Rattus rattus* L.) in commercial bait stations in residential yards in Orange County, California, USA. We also compared visitation of bait stations placed on the ground to that of bait stations elevated 1–1.5 m off the ground. Because black rats are excellent climbers,[27] elevating bait stations may reduce exposure of wildlife species to rodenticides, as has been examined for *R. rattus* elsewhere.[28–31] Lastly, we examined characteristics of yards that were visited by rats and wild rodents to determine if the use of anticoagulant rodenticides should be avoided in certain types of yards to reduce opportunities for nontarget exposure.

2 MATERIALS AND METHODS

Reconyx PC800 digital cameras were deployed at 90 residential yards across Orange County from December 2017 to August 2018 (Session 1; Fig. 1). A subset of 64 of these yards were surveyed again from September 2018 to March 2019 (Session 2) to see if the patterns that emerged from Session 1 held. Yards were

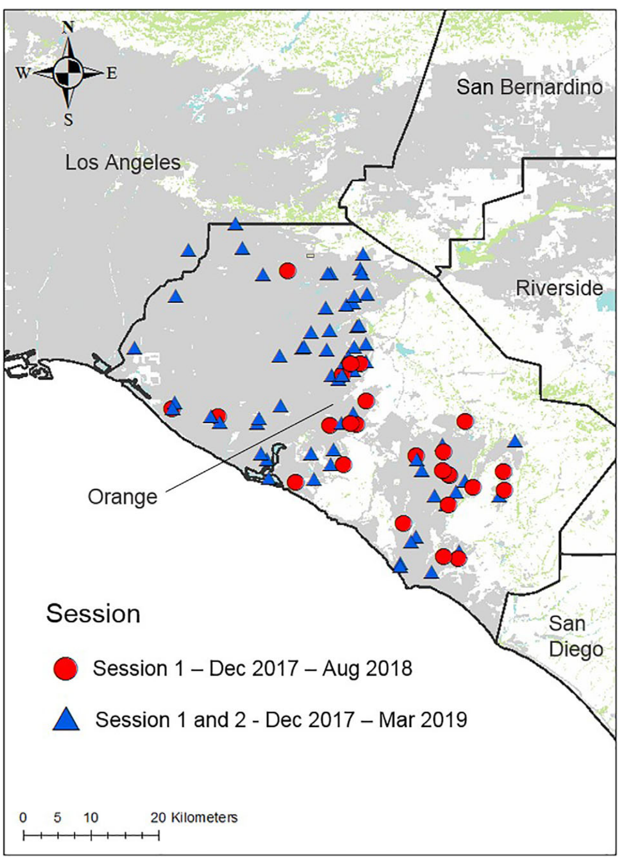

Figure 1. Map of camera-trapping sites in Orange County, California, USA. Circles represent sites sampled in Session 1 (December 2017–August 2018), whereas triangles represent sites sampled in both sessions (December 2017–March 2019). Map generated in ArcGIS (version 10.6.1).[33]

the residences of volunteers in the University of California Cooperative Extension Master Gardeners of Orange County program. Most were single-family homes with yards that ranged in size from 19 to 2675 m^2 (median = 248 m^2); 88% (78) were $\geq$100 m^2 in area. Mean housing density in the area was 73.1 km^{-2} (range 11.5–100.0 km^{-2}). Yards were, on average, 1.6 km from the nearest neighboring yard sampled (range = 0.1–50.2 km), which is many times the diameter of a rat home range (25–40 m, assuming a circular home range of 0.2–5 ha[32]), so yards were assumed to be independent.

Land use in Orange County ranges from intensive urban development to suburban subdivisions with developed open spaces such as sports fields, schoolyards, and golf courses. There are several large parks, and public lands with natural coastal sage scrub, grassland, and riparian woodland vegetation, especially in the eastern and southern parts of the county (Fig. 1). Native rodents in the surrounding natural vegetation include several species of deer mouse (*Peromyscus maniculatus* Wagner, *P. fraterculus* Miller, *P. boylii* Baird, *P. californicus* Gambel), woodrats (*Neotoma macrotis* Thomas, *N. lepida* Thomas), western harvest mice (*Reithrodontomys megalotis* Baird), southern grasshopper mice (*Onychomys torridus* Coues), California voles (*Microtus californicus* Peale), Dulzura kangaroo rats (*Dipodomys simulans* Merriam), pocket mice (*Chaetodipus californicus* Merriam, *Perognathus longimembris* Coues), Botta's pocket gophers (*Thomomys bottae* Eydoux and Gervais), western gray squirrels (*Sciurus griseus* Ord), and California ground squirrels (*Otospermophilus beecheyi* Richardson). The fox squirrel (*S. niger* L.), a naturalized non-native species, is very common in suburban neighborhoods and parks, as are desert cottontails (*Sylvilagus audubonii* Baird). Urban-adapted mesopredators such as Virginia opossums (*Didelphis virginiana* Kerr), raccoons (*Procyon lotor* L.), and striped skunks (*Mephitis mephitis* Schreber) also visit yards and are potentially at risk from both primary and secondary exposure to rodenticides, whereas coyotes and bocats (*Lynx rufus* Schreber) are the most common mammalian predators. Several species of raptors, owls, and corvids are potential scavengers of carcasses.

Two cameras were placed in each yard, with each one 1–2 m away from a Bell PROTECTA EVO Ambush bait station. Bait stations (approximately 26 × 22 × 11 cm) were constructed of heavy-duty, injection-molded black plastic, with two semi-elliptical openings measuring 5.0 × 5.4 cm each. One camera was focused on a ground-level bait station placed along the base of a fence or structure, whereas the other camera was focused on a bait station elevated 1–1.5 m off the ground and anchored on a small wooden platform to a fence, wall, or tree branch. Elevated and ground stations were typically at least 13 m apart, except in the smallest yards, where we placed them as far apart as possible. Bait stations were baited with two nontoxic blocks (Bell Detex Blox, labeled with Lumitrack fluorescent marker) and two nontoxic soft attractants (Liphatech Rat and Mouse Attractant); these matrices were the same as those commonly used in commercial rodenticide applications except that they lacked the active rodenticide ingredients. Cameras ran continuously and were triggered by motion across detection zones by an object with a temperature different from ambient temperature. They were set to take three images per trigger, one per second, with a 1-s delay between triggering events, to increase the chance of detecting instances of entering the bait stations. Camera settings were checked and confirmed before each deployment. Residents checked bait stations approximately every 7 days and replaced baits if they were missing; however, they did not consistently check for fluorescent rodent

Table 1. Mean (+ 1 SD) time to discovery, time to entry, activity time, and number of entry events for black rats detected at ground and elevated bait stations in Orange County, California, USA

Session station placement	Time to discovery (days)	Time to entry (days)	Activity per night (h)	Entry events per night
Session 1 (72 yards)				
Ground	7.6 ± 8.7 (59)	9.7 ± 8.9 (35)	1.4 ± 1.9 (59)	5.6 ± 3.0 (26)
Elevated	8.3 ± 7.2 (56)	9.9 ± 8.6 (36)	1.2 ± 1.4 (56)	4.8 ± 2.6 (28)
Session 2 (47 yards)				
Ground	9.3 ± 8.7 (40)	11.9 ± 8.8 (25)	1.4 ± 1.8 (40)	6.3 ± 3.7 (15)
Elevated	8.3 ± 7.6 (37)	11.1 ± 7.6 (26)	1.1 ± 1.2 (37)	5.7 ± 2.9 (18)

Cell values in parentheses denote the number of yards. A total of 72 (80%) of the 90 yards were visited by rats in Session 1, whereas rats were recorded in 47 (73%) of 64 yards trapped in Session 2. The mean number of entry events refers only to entries during the first 2 weeks that the stations were operational, and only includes yards where one or both stations were entered within the first 2 weeks.

droppings during these checks. Stations were checked for the presence of droppings at the end of the session, although these were not quantified. Each yard was camera-trapped for approximately 30 consecutive days in each trapping session [31.3 ± 2.2 days (standard deviation, SD), range = 26–38 days, n = 154]. Fifteen yards were usually sampled concurrently.

To discretize the continuous stream of camera images, we classified 1 day of camera-trapping as the 24-h period starting and ending at 1500 h Pacific Standard Time. Because rats were often very common, we estimated mean nightly activity at a given bait station by summing the number of hours during each night in which at least one rat was detected at, though not necessarily entering, a station (visitation), summing across all nights, and then dividing by the total number of nights in the session. Because multiple individuals were sometimes present at a bait station at a time, we also tallied the maximum number of rats seen in a single image during a given hour as a measure of relative abundance. We defined time to discovery as the number of hours elapsed until the first image of a rat was recorded at a given bait station, i.e. first detection, and time to entry as the number of hours elapsed until a rat was first photographed actually entering or exiting the opening of a bait station. Unless otherwise noted, means are presented ±1 SD. The lead author (CBB) did all of the image processing.

To examine differences among yards in the patterns of rat activity over the camera-trapping period, we categorized yards with rats based on the mean amount of activity per night. Sites were assigned high activity (>4 h of activity/night), intermediate activity (1–4 h activity/night), or low activity (<1 h of activity/night). To determine if there were any yard characteristics that influenced the level of rat activity, we documented the presence of fruits or vegetables, anthropogenic food (pet food or bird seed), qualitatively characterized the density of vegetation in the yard (high, medium, low), and surveyed residents at the start of Session 1 about current use or past use, i.e. during the previous year, of rodent control methods.

In addition, we examined the effect of yard barrier permeability on visitation to bait stations by both commensal and native small mammals. Yards with no exterior barrier or only a chain-link or wrought-iron fence were categorized as having a permeable outer barrier (from the perspective of nonarboreal, nonvolant wildlife), whereas those with brick, stone, or solid wood-slatted fences were categorized as impermeable. Similarly, to determine if yards close to green open space (e.g. natural areas, parks, cemeteries, golf courses) tended to have higher rates of visitation by native rodents, we estimated the distance from each yard to the nearest patch of natural or park vegetation ≥2 ha in area using ArcGIS (version 10.6.1).[33] ArcGIS was also used to estimate the area of each yard.

3 RESULTS

Camera-trapping efforts yielded more than 500 000 images. Of the non-native commensal species potentially present in southern California, we detected only black rats, i.e. no Norway rats (*R. norvegicus* Berkenhout) or house mice (*M. musculus* L.) were seen. Rats were detected at 80% (72) of the 90 yards in Session 1, and in 73% (47) of the 64 yards trapped in Session 2. We did not detect rats in Session 2 in nine of the yards where rats had been detected in Session 1. Likewise, in Session 2, rats were detected in four yards where they had not been seen in Session 1. Rats were never detected in eight of the 64 yards trapped in both sessions. Across both camera-trapping sessions, a total of 23 133 unique images contained at least one rat. Even where rats were common, however, it was unusual for an image to contain multiple individuals: 97.8% of all images with rats had only one rat, 2.1% had two rats, and 0.01% had three rats. Although the sex of rats could not be consistently determined from the images, adult and juvenile rats were detected at both ground and elevated stations.

In Session 1, rats were detected at both ground and elevated stations in 43 yards, only ground stations in 16 yards, and only elevated stations in 13 yards. A similar pattern was observed in Session 2 (10 yards ground only, seven yards elevated only, 30 yards with detections at both). In yards where rats were detected, ground-level bait stations were first discovered by rats at 7.6 ± 8.7 days (n = 59, range = 1–31, median = 4, mode = 2) and first entered at 9.7 ± 8.9 days (n = 35, range = 1–35, median = 7, mode = 2). By comparison, elevated stations were first discovered at 8.6 ± 7.3 days (n = 56, range = 1–31, median = 6, mode = 2) and first entered at 9.9 ± 8.6 days (n = 36, range = 1, median = 8, mode = 4). There was no significant difference between either time to discovery (t = 0.61, df = 112, P = 0.27) or entry (t = −0.09, df = 69, P = 0.92) between elevated and ground stations in Session 1 or Session 2 (discovery: t = −0.57, df = 75, P = 0.28; entry: t = −0.32, df = 44, P = 0.37; Table 1). Rats were detected entering 59% (35/59 ground) and 64% (36/56 elevated) of the stations visited in Session 1, and 63% (25/40 ground) and 70% (26/37 elevated) of the stations visited in Session 2 (Table 1). Focusing on only the first 2 weeks that a station was operational during Session 1 (when we could be reasonably confident that bait remained in the station or that a volunteer had replaced it), rats were detected entering ground stations, on average, 5.6 times per night, compared to 4.6 times per night at elevated stations, a difference that was not statistically significant (t = 1.07, df = 51, P = 0.14). A similar result was seen in Session 2 (Table 1; t = 0.58, df = 31, P = 0.28).

In yards where rats were detected, they were recorded on an average of 1.8 ± 2.7 h per night during Session 1 (n = 72) and 1.4 ± 2.1 h during Session 2 (n = 47). During Session 1, rats were active at ground stations, on average, for 1.4 ± 1.9 h per night (n = 59), compared to 1.2 ± 1.4 h at elevated stations (paired t-test, t = −0.56, df = 110, P = 0.29; Table 1). Activity was similar in Session 2, with rats at ground and elevated stations active for 1.4 ± 1.8 h (n = 40) and 1.1 ± 1.2 h (n = 37), respectively. In both sessions, slightly more than half of the total activity at a site occurred at ground stations (Session 1: 55.7 ± 38.5%; Session 2: 56.5 ± 37.6%), but there was no significant difference in the proportion of activity in ground *vs* elevated stations in either session (paired t-tests, $P \geq 0.16$). Pooling activity across elevated and ground stations, in the 56 yards where rats were detected in at least one session, there was no significant difference between sessions in the number of hours of activity per night (paired t-test, t = 0.79, df = 55, P = 0.43) or in the time to discovery for the 43 yards where rats were detected in both sessions (t = 0.21, df = 42, P = 0.84).

During Session 1, yards where rats were detected at bait stations regularly had the highest mean levels of nightly activity, particularly at ground stations (Fig. 2(A)). Some yards were obviously infested: rats were detected on more than 24 of the 30 nights, and there was more than 4 h of activity each night. Moreover, in yards where rats were seen at stations very regularly (>50% of nights), rats discovered both elevated and ground stations quickly (Fig. 2(B)). For all but a handful of yards, time to discovery of ground stations was relatively short (<10 days) and largely independent of the frequency with which rats were photographed at ground stations during the 30-day trapping period. By comparison, it took slightly longer for rats to discover elevated stations, even in yards where rats were common (Fig. 2(B)). However, there was no significant difference between ground and elevated stations in the relationship between frequency of visitation and mean nightly activity (analysis of covariance, ln-transformed response: frequency $P < 0.0001$, placement P = 0.75, interaction P = 0.99), nor between frequency of visitation and time to discovery (frequency $P < 0.0001$, placement P = 0.21, interaction P = 0.89). We saw similar patterns in Session 2 (results not shown).

The pattern of nightly rat activity varied from no activity to an average of 9.6 h of activity at a given station per night. Combining ground and elevated stations, in Session 1 most of the 72 yards with rats had low levels of activity (34 yards), followed by intermediate (25) and high activity (13). In Session 2, 23 yards were characterized as having low activity, 14 yards had intermediate activity, and 10 yards had high activity. Levels of activity were generally consistent between sessions for the 64 yards that were sampled twice: eight of 10 yards with high levels of activity in Session 1 had high or intermediate activity in Session 2, and only three yards of the 10 with high activity in Session 2 had low or no activity in Session 1.

The temporal pattern of detection of rats varied with levels of rat activity. In yards with high activity, the presence of rats often cycled with bait replenishment (about every 7 days), with a spike on the day of replenishment, followed by nights of prolonged

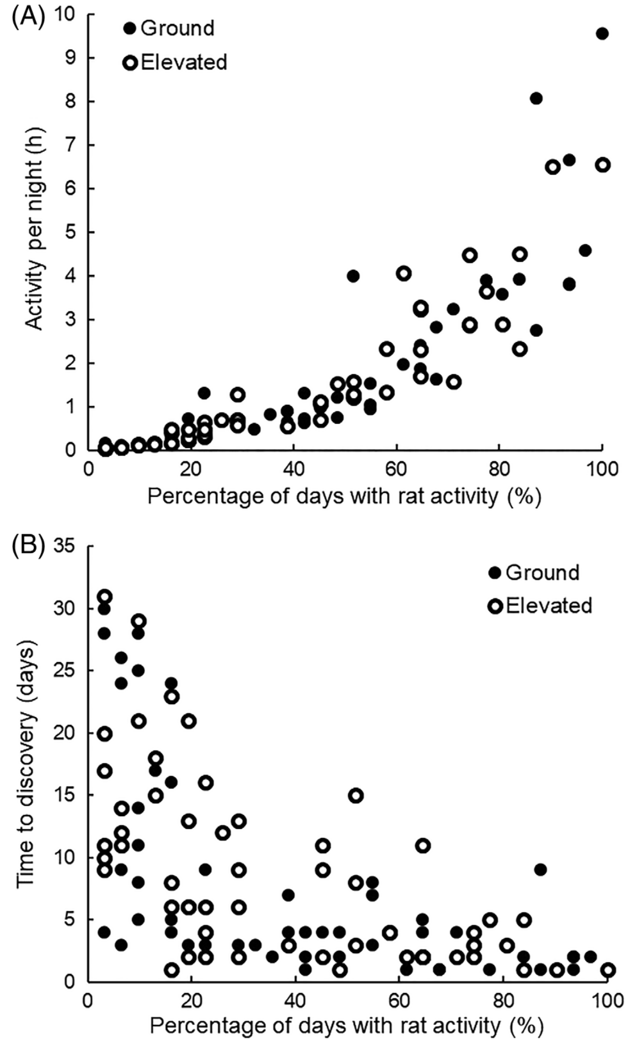

Figure 2. Relationships between the frequency of rat detections in a given yard and (A) mean levels of nightly black rat activity and (B) time to discovery of ground-level and elevated bait stations. Data are from Session 1, in which camera traps were set in 90 yards in Orange County, California, USA, between December 2017 and August 2018. Trapping periods lasted approximately 30 days. Rats were detected at ground stations in 59 yards and elevated stations in 56 yards.

activity and then precipitous declines (Fig. 3). Yards with intermediate levels of activity tended to be visited regularly across multiple nights. In yards with low activity, i.e. less than ~30 total hours, most activity bouts tended to be very short, 1 or 2 h or less, and across multiple nights, rather than multiple hours across a few nights (Fig. 3).

Nearly all yards had some level of fruit or vegetable production, and most had sources of water, but these factors were not consistently related to rat activity (Table 2). Approximately one-third of yards with rats had anthropogenic foods, regardless of activity level, whereas yards with no rats tended to also lack anthropogenic foods. Rat activity seemed to vary with the amount of vegetation in the yard (Table 2). Yards with high rat activity were categorized as having high or medium vegetation density, whereas most yards with no rats or low nightly activity had comparatively little vegetation. Nearly 85% of the 13 yards with high rat activity were surrounded by solid walls or fencing, compared to approximately one-third of those with no rats or low to

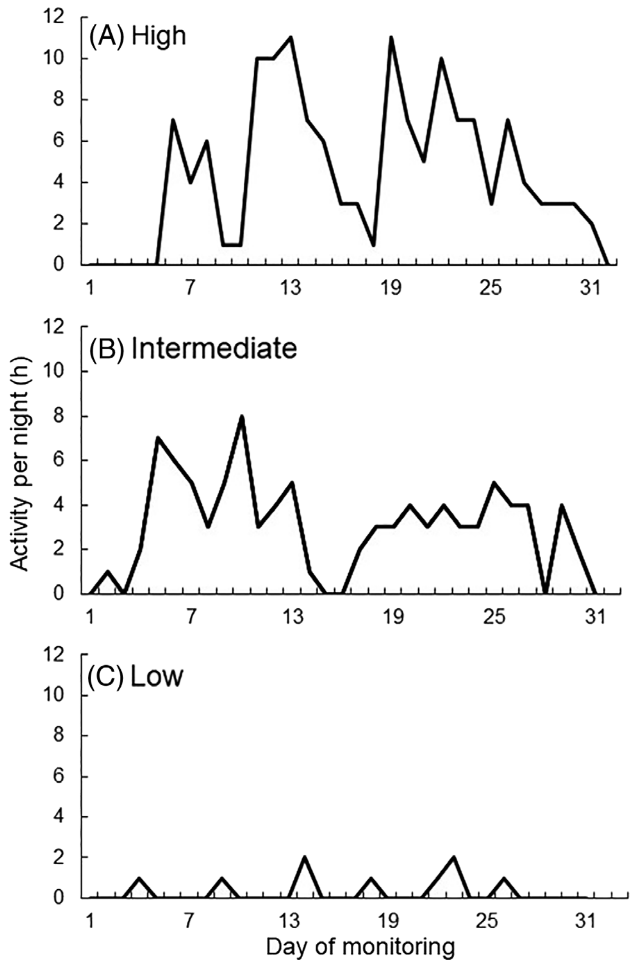

Figure 3. Representative plots of nightly black rat activity categorized in three activity groups (high activity, >4 h of activity/night, $n = 15$; intermediate activity, 1–4 h/night, $n = 23$; low activity, <1 h/night, $n = 34$) from 90 yards in Orange County, California, USA, between December 2017 and August 2018 (Session 1). There was no rat activity in 18 yards.

intermediate levels of activity (Table 2), although level of rat activity was not significantly related to barrier permeability (2 × 4 contingency table, $X^2 = 1.85$, df = 3, $P = 0.18$).

Residents were taking measures to control rat numbers in 35 yards (38.9%) at the time of our sampling in Session 1 (15.6% rodenticide, 23.3% trapping), whereas 57.8% (52) had done so in the past year (28.9% rodenticide, 28.9% trapping). In total, 61.1% (55) of residents had used or were using some form of rodent control (26 rodenticide, 34 trapping; current and past use differed for 28 yards). Most residents were not currently using any type of rodent control, including in yards with high levels of rat activity (Table 2) and especially in yards with no rats. Trapping was the most common method of current and past control in yards with high and intermediate activity, whereas rodenticides tended to be used in yards with little or no rat activity (Table 2). Of the 14 yards where residents were using rodenticides at the start of Session 1, all had used rodenticides in the past, and rat activity was low or absent in 10 of these yards. In 10 of the 13 yards where residents had trapped in the past and were currently trapping, rat activity was intermediate or high.

We detected four types of native rodents, deer mice, woodrats, kangaroo rats, and California ground squirrels in yards, although the species of deer mouse and woodrat could not always be reliably identified from camera images. Native rodents visited relatively few yards (n = 12, 13.3%), and these yards usually had permeable outer barriers ($X^2 = 12.44$, df = 1, $P = 0.0004$) and were closer to areas of green open space (range = 0–164 m, t-test, $t = 3.01$, df = 88, $P = 0.0035$; Table 3). Considering only areas with natural vegetation, yards with native rodents were significantly closer than those with no native rodents (native rodents 850.4 ± 1339.6 m; no native rodents 1640.5 ± 1168.6 m; t = 2.21, df = 88, $P = 0.04$). Rodenticides had been applied in only two of the yards with native rodents, and most of the yards (9/12) with native rodents had low levels of rat activity (only one yard had high rat activity). However, native rodents were also absent from the 13 yards where rats were never detected.

Most visits by native rodents were at ground rather than elevated stations (234/279 h of activity, 83.9%). Ground squirrels were

Table 2. Black rat activity in Session 1 (December 2017–August 2018) across Orange County, California, USA, yards with different characteristics ($n = 90$)

	Yard characteristics (% of yards)									
					Vegetation density			Rodent control measures used		
Level of rat activity (n)	Permeable barriers	Water	Fruits or vegetables	Anthropogenic foods	High	Medium	Low	Trapping	Rodenticide	No control
High (13)	15.4	61.5	84.6	38.5	30.8	46.2	23.1	23.1 (53.8)	7.7 (15.4)	69.2 (30.8)
Intermediate (25)	36.0	56.0	96.0	36.0	20.0	36.0	44.0	40.0 (32.0)	12.0 (24.0)	48.0 (44.0)
Low (34)	32.4	50.0	97.1	32.4	23.5	23.5	52.9	20.6 (23.5)	26.5 (41.2)	52.9 (35.3)
None (18)	33.3	61.1	88.9	22.2	16.7	27.8	55.6	5.6 (16.7)	5.6 (22.2)	88.9 (61.1)

High activity, >4 h of activity/night; intermediate activity, 1–4 h/night; low activity, <1 h/night. Note that percentages do not sum to 100% within rows because yards may have more than one of these characteristics. For rodent control measures, the top value refers to rodent control used at the time of our study, and the lower value (in parentheses) refers to rodent control practices used during the 6 months prior to sampling.

Table 3. Characteristics of yards where native rodents visited bait stations in suburban southern California, USA

Presence of native rodents	Type of yard barrier		Yard size (m^2)	Distance to nearest green open space (m)
	Permeable	Impermeable		
Native rodents detected (12)	9	3	397.9 ± 594.4	45.4 ± 62.2
No native rodents detected (78)	19	59	383.5 ± 436.1	200.2 ± 176.0

Native rodents were detected more often in yards with permeable barriers (as described in the Methods section) than in those with impermeable barriers and in yards closer to green open space. Values for yard size and distance to green space are means + 1 SD.

detected by cameras in a total of 10 yards, but at elevated stations in just three (hours of activity at ground:elevated = 166:13). Deer mice were detected in five yards, but at elevated stations in only three (51:13). Woodrats were detected in three yards (16:19), although they used elevated stations in only one yard. We detected a kangaroo rat in a single image, at a ground bait station in a very small yard (43.9 m^2) with no fence and immediately bordering a grassy natural area. Also, it is worth noting that non-native fox squirrels were detected in a total of 46 yards and, although adults are too large to enter the bait station opening, they were able to access the bait in four yards by chewing through the plastic box (all were elevated stations). Combining across both sessions, fox squirrels were detected more often at elevated than ground bait stations (431/725 h of activity, 59.5%), although there was no significant difference in the hours of fox squirrel activity between placement locations (paired t-test, t = 1.68, df = 45, $P = 0.99$), and squirrels usually visited both stations in a given yard (26 of 46 yards; only elevated stations visited in 14 yards).

4 DISCUSSION

Black rats are considered one of the most harmful commensal rodents worldwide, particularly when they have been introduced to islands and other environmentally sensitive areas,[24] but their ecological effects at the urban–wildland interface have not been as intensively studied.[34] In southern California, black rats are largely restricted to peridomestic or highly modified or disturbed areas, e.g. orchards, and can be a major household and garden pest. Efforts to control commensal rat populations using rodenticides pose a threat to wildlife when wild species have access to rodenticide baits or scavenge carcasses of poisoned rats, either near homes or, in some cases, far from where they were poisoned.[35] Recent experimental and comparative studies of nontarget exposure[22,25,26,36–39] have focused on farms, where the surrounding landscape, fauna, and management concerns and options are very different from those in an urban environment. The aim of our study was to determine the potential for primary exposure of commensal and native rodents to rodenticides in a suburban residential setting by monitoring visitation of and entry into commercial bait stations using camera-traps. This also allowed us to investigate local factors that affect the relative activity of rats and wild rodents, as well as test whether elevating bait stations can reduce nontarget exposure while still being readily accessible to commensal rodents.

Black rats were very common in the residential yards we sampled, although activity varied greatly among yards, both in terms of the number of nights rats were detected and the number of hours of nightly activity. Bait stations were discovered quickly in yards where rats had high levels of activity, especially at ground-level stations, where rats were recorded in nearly 90% of yards within 10 days of placement. Time to discovery did not differ significantly between ground and elevated stations, with mean times ranging from 7 to 10 days across both sampling sessions. Mean time to enter the bait station also did not differ between elevated and ground stations, varying from 10 days in Session 1 and 11–12 days in Session 2, although rats apparently entered only 59–70% of the bait stations they visited, suggesting some degree of neophobia toward new objects in their environment.[40] Although time to discovery appeared to be slightly more sensitive to the amount of rat activity at elevated stations (Fig. 2(B)), overall, our results support the conclusions of previous studies[17–20] that elevated bait stations would be as effective as ground stations as a way of delivering rodenticide to black rats.

The presence of fruits and vegetables in a given yard was a poor predictor of rat activity, presumably because nearly all yards (87–100%) of these master gardeners had some form of produce. These yards typically also had compost bins or piles, which are known to attract rats,[41] although we did not consistently record their presence. Similarly, for yards with rats, the level of rat activity was independent of the proportion of yards with water and anthropogenic foods, though more of the rat-free yards also lacked anthropogenic foods, suggesting such resources might serve as an attractant. In contrast, vegetation density did seem to influence rat activity: yards with high levels of rat activity tended to have high or medium vegetation density, and yards with little vegetation also had few or no rats. Black rats are known to preferentially use complex, three-dimensional habitats, including in suburban southern California.[32] Barrier permeability did not significantly affect levels of rat activity, although most yards with high rat activity had solid walls or fences, suggesting that these structures could serve as a barrier that contributes to high rat densities.

Most homeowners (61.1%) were not using any active method of rodent control at the time of our sampling in Session 1, although most (57.8%) had done so in the past. Except for yards where no rats were detected, where control measures were not usually used, the use and type of control did not appear to be strongly related to rat activity levels. It is worth noting that our estimates of rat activity may have been affected by current or past control efforts. Residents of yards where rodenticides were applied at the time of Session 1 had also used rodenticides in the past, suggesting a persistent rat problem. Most (71%) of these yards had low or no rat activity, implying that rodenticides were perceived to be effective. In contrast, in yards where residents chose to use trapping for both current and past control, 77% had intermediate or high rat activity, underscoring the difficulty of controlling a large rat infestation by trapping alone. The use of rodenticides is considered the easiest and least expensive method of knocking down a rat infestation, but neither rodenticide nor trapping target

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the source of the infestation, which is why pest management professionals recommend environmental modification, i.e. removing food sources and harborage and sealing buildings, for the long-term control of commensal rodents.[41,42] However, implementing such an integrated approach on a large scale in a mild climate such as California, where residents grow citrus, avocadoes, and vegetables in well-vegetated yards inter-connected by utility lines and neighborhood trees, remains a daunting challenge.[42]

The proportion of residents who used some type of rodent control (61.1%) in our study was similar to that reported by respondents in surveys of rodent control methods used elsewhere in southern California (65–75%[43], 59%[44]). Orange County residents tended to use rodenticides over physical methods more often than those in suburban Los Angeles/Ventura County[44] (ratio of physical:chemical methods = 2.06 for Los Angeles/Ventura County *versus* 1.30 for our study), as well as in heavily agricultural Kern County (1.84). One possible explanation for the preference for physical methods by residents in Los Angeles/Ventura County may be the close proximity of the Santa Monica Mountains National Recreation Area, where the effects of rodenticides on wildlife have been highly publicized; 80% of these respondents were very or somewhat concerned about this issue, and only 10% of respondents reported using anticoagulants. A similar survey of Orange County residents about rodenticide use and attitudes towards rodents and wildlife would be worthwhile.

Yard characteristics influenced the likelihood that a given yard would be visited by nontarget wildlife species. Although native rodents were only detected at 13.3% of yards, these yards tended to have permeable outer barriers and to be in close proximity to patches of green open space or natural vegetation, where populations of these rodents likely persist. If our bait stations had contained anticoagulant rodenticides, native or commensal rodents that consumed bait in these yards and then subsequently died in a nearby open space might have been eaten there by native scavengers and predators, exposing them to anticoagulant rodenticides secondarily. Of course, such yards, especially those without significant barriers, might also be visited by the carnivores themselves, where they might encounter rodenticide-laden carcasses of rats.[45] This underscores the need to monitor and remove rat carcasses regularly after applying rodenticides,[39,46] particularly in yards that are close to natural areas and relatively accessible. As has been shown in other studies,[28–31] the risk of primary exposure to native rodents could also be reduced significantly by simply elevating bait stations off the ground, with no apparent loss of rodenticide availability to target pest species such as black rats. Rats actually entered elevated stations at a higher rate (64–70%) than ground stations (59–63%).

5 CONCLUSIONS

Our results have important implications for the control of black rats and other rodent pests in residential areas of southern California. We make the following recommendations for pest management professionals.

First, the high levels of rat activity in some yards may result in rapid depletion of bait and, potentially, loss of effectiveness. Rats apparently responded behaviorally to bait depletion and replenishment, so it may be useful to monitor bait consumption frequently during the first week of bait application and adjust levels accordingly. Failure to maintain sufficient bait levels may allow a target population to recover and thus result in a longer period of active control and more rodenticide-exposed animals in the environment than is necessary. We emphasize, however, that the stations in our study had commercial bait but lacked rodenticides, so we do not know how the presence of toxicant or the deaths of other rats might alter their behavioral responses.

On the other hand, the fact that we photographed rats actually entering only 59–70% of the bait stations suggests either that cameras missed some of these entry events or that they were reluctant to enter bait stations, even when no rodenticide was present. Even in yards where rats eventually entered stations, it took a median of 7–8 days for them to first directly encounter the bait. Because the first mortalities from anticoagulant rodenticide might not occur for several more days, pest management professionals should be prepared to communicate these possible delays to their customers to prevent them from becoming impatient and taking more drastic (and potentially illegal) measures if results are not immediate.

Lastly, given the mobility of many predators and scavengers that live at the urban–wildland interface in southern California, if rodenticides are the preferred option for effective pest control, special efforts should be made to search for and remove carcasses quickly, especially in yards that might be accessible to native wildlife or adjacent to areas where wild populations exist. In such yards, integrated pest control approaches other than rodenticides, e.g. habitat and harborage reduction,[32,47] should be attempted first to minimize risk to nontarget wildlife species. Other possible options would be to place rodenticides indoors (garages, outbuildings) where only rats are likely to find them,[25] although this will not prevent rats from dying outside and away from buildings,[43] or for homeowners bordering natural areas to consider enclosing their yards with solid walls or fencing to restrict access to wildlife. It should be noted that some homeowners also probably consider wild rodents such as fox squirrels, ground squirrels, and deer mice to be pests and thus might support such an approach. However, because most native rodents are not listed as potential targets on the labels of anticoagulant rodenticides for residential use, these species should not be illegally targeted and baits should not be placed in locations where there is significant risk of unintentional primary exposure. Care should be taken when deploying even nonchemical tactics for rodent management such as snap traps or glue traps, etc., that can also kill nontarget species. If rodenticides must be used and semiarboreal black rats are the target species, bait stations should be elevated to try to prevent native rodents from gaining access to baits. This may have the additional benefit of reducing exposure to small children and other nontarget animals, such as pets.

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CONFLICT OF INTEREST

The authors claim no conflicts of interest.

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Behavior and activity of commensal roof rats around rodenticide bait stations in southern California, USA

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A B S T R A C T

The roof rat (*Rattus rattus*) is a highly invasive rat that poses a threat to humans and native species. In urban settings they are typically managed with bait stations containing chemical rodenticides, however, their behavior around bait stations is not well understood. We conducted field studies in 36 residential yards in Orange County, California, to determine whether different bait station designs or baiting approaches influence roof rat behavior around stations. Specifically, we tested whether the bait station's design, the presence of supplemental bait, and the addition of a scent lure in the station influenced rat behavior over three separate trials. Using digital game cameras, we monitored stations containing non-toxic bait for three weeks during each trial to estimate the time to discovery, entry, bait consumption, and nightly activity of rats around stations. We also determined whether landscape characteristics associated with each yard (presence of rodent management, pets/livestock, or fruits/vegetables) influenced rat behavior. Rats were detected in most yards (75 – 91 % of yards), and they discovered stations in most of these yards (59 – 89 % stations discovered). However, they did not enter many stations (24 – 63 % stations entered). Neither the station's design nor the addition of a scent lure in the station affected any of the measured response variables. Supplemental bait around stations decreased the time to entry and increased the nightly activity of rats at two types of stations, and increased bait consumption in all station designs. The presence of fruits and vegetables in the yard decreased the time to discovery of stations, but did not affect any other response variables. Rats in yards that were currently or recently (within last six months) managed for rodents were just as active as in unmanaged yards but were less likely to consume bait, indicating that neophobia is not the only factor contributing to bait avoidance – previous exposure to management may also lead to bait avoidance by commensal rats. This underscores that new approaches may be needed to effectively control commensal rats with the tools currently available.

1. Introduction

Commensal rats and mice (genus *Rattus*, *Mus*) are globally distributed and harm natural and human-dominated ecosystems (Pimentel et al., 2000; Lapuz et al., 2008; Meerburg et al., 2009). Almost half of the world's islands harboring a threatened or endangered species also contain one invasive *Rattus* species (Spatz et al., 2017). Roof rats (*R. rattus*; also called ship rats and black rats) are commensal and maintain close contact with humans, allowing them to be significant vectors for diseases, such as leptospirosis and typhus (Lapuz et al., 2008; Meerburg et al., 2009; Spatz et al., 2017). They pollute billions of dollars of food annually in the United States alone (Pimentel et al., 2000), and roughly 5–10 % of grain produced annually in Southeast Asian countries is lost to rodents, contributing to the undernourishment of millions of people (Singleton, 2003). Despite these impacts, relatively little is known about the behavior and ecology of commensal rats, and these knowledge gaps must be filled if we hope to improve our ability to manage these species (Parsons et al., 2017).

Bait stations containing chemical (anticoagulant and acute) rodenticides are among the most common tools used to manage rodent infestations in the United States (Morzillo and Mertig, 2011). Because rodenticides can pose serious risks to children, livestock, pets, and non-target wildlife (Ruiz-Suárez et al., 2014; Nakayama et al., 2019), the United States' Environmental Protection Agency (EPA) requires structural pest management professionals (PMPs) to place rodenticides in tamper-resistant bait stations (Jacobs, 1990). However, rats seemingly

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do not enter many of the bait stations they encounter, with roof rats estimated to visit roughly 30–70 % of the bait stations they encounter in residential Orange County, California (Burke et al., 2021). This is also an issue with Norway rats. On farms in Hampshire, England, Quy et al. (1992) found that Norway rats often avoided both rodenticide and non-toxic baits placed in plastic bait stations over multiple-week management periods. If rats do not consume much of the rodenticide bait applied by PMPs, management will be ineffective, and resources will be wasted.

Roof and Norway rats (*R. norvegicus*) thrive in urban habitats where food and harborage are abundant (Feng and Himsworth, 2014), and rat infestations tend to be associated with increasing urbanization (e.g., Blasdell et al., 2022). In California, recent legislative changes, such as Assembly Bills 1788 and 2552 (Bloom et al., 2020; Friedman, 2024), aim to reduce non-target exposure by restricting which rodenticides can be applied, however, they limit the "toolbox" of rodent control options available to PMPs. These rodenticide restrictions, in concert with increasing urbanization and global human populations, underscore the need to improve invasive rodent management with the tools that are available, as emerging conditions outpace current control strategies (Capizzi et al., 2014; Quinn et al., 2019). Therefore, it is critical to improve our understanding of rat behavior around bait stations and identify the potential shortcomings of these devices to improve our ability to manage commensal rodents.

We conducted three field evaluations to better understand the behavior of free-roaming roof rats around bait stations in suburban, backyard settings in southern California, where roof rats are the most common commensal rodent. Specifically, we assessed whether behavior differs around bait stations depending on the (1) station design, (2) baiting protocol, and (3) the addition of a scent lure within the station. We quantified whether these modifications affected the risk of station discovery or entry by roof rats over a 21-day period, and determined whether site-level characteristics, such as the presence of recent or current rodent management and production of fruits or vegetables, influenced station visitation by rats.

2. Methods

We conducted three trials to evaluate the effectiveness of different bait stations and baiting approaches. In the first trial (Trial I: Station Design), we tested whether free-roaming roof rats responded differently to three commercially available bait stations. In the second trial (Trial II: Supplemental Baiting), we evaluated whether the presence of non-toxic supplemental bait scattered around each station affected rat behavior at the three different bait stations. In the third trial (Trial III: Scent Lure), we investigated whether a scent lure placed inside the feeding area of a bait station affected visitation and bait consumption compared to a non-scented control.

2.1. Study Locations

We conducted each trial in 36 suburban yards in residential Orange County, California, United States, in sequence, with a minimum of 28 days between consecutive trials at a given site. Access to yards was provided by volunteers associated with University of California's Cooperative Extension Master Gardeners of Orange County program, and ranged in size from < 100 m^2 to > 4000 m^2. In 32 yards, residents grew fruits and vegetables for personal consumption. Common crops in yards included citrus (oranges, lemons, limes), avocados, and berries (raspberries, blackberries, currants, etc.). We recorded the characteristics of each yard, including the presence of livestock (e.g., chickens, goats, and llamas; five yards), pets (29 yards), fruits and vegetables (32 yards), and whether the owner currently or recently (within last 6 months) controlled for rats with rodenticides or traps (18 yards). In yards where homeowners managed for rodents, management did not cease during the study period.

2.2. Trial I: Station Design

We conducted Trial I from February to March 2023. In each yard (site), we placed three different commercially available bait stations ("EZ" - EZ-Secured® Bait Station, VM Products, Bedford, Texas, USA; "Rock" - Rodent Rock® 2 G Plastic Bait Station, J. T. Eaton & Co., Inc., Twinsburg, Ohio, USA; "Snap-E" - Big Snap-E® Cover Station, Kness Pest Defense, Albia, Iowa, USA) along perimeter walls or structures, which is a standard placement practice among structural PMPs. The stations were all composed of stiff plastic and similar in size (EZ $=$ 31.75 $\times$12.14 $\times$22.23 cm; Rock $=$ 26.04 $\times$10.16 $\times$26.67 cm; Snap-E $=$ 57.15 $\times$10.69 $\times$11.43 cm), but the EZ station was the largest and weighted with a cement block attached to the bottom of the station. We chose the EZ station to represent the 'conventional' bait station because it is widely used for structural pest control in the United States. We tested the Rock station because it is designed to mimic the appearance of a large rock and be less conspicuous than other common bait stations, which we assumed might influence rat behavior. We tested the Snap-E station because it fundamentally differs from the other two station designs, with a long, tunnel-like shape. Additionally, bait placed inside the Snap-E station is visible from the outside when looking through the station entrance.

We placed four non-toxic soft bait packs (NoTox™ Soft Bait Attractant, Liphatech, Milwaukee, Wisconsin, USA) in each station and monitored stations with a digital game camera (HF2X Hyperfire 2™ Covert IR Camera, RECONYX, Holmen, Wisconsin, USA), placed roughly 1 m from each station, and set to take three images in sequence (1 s interval between images) upon motion detection. Prior to setting stations and cameras, we identified areas with visible rat activity in each yard (droppings, gnaw/rub marks, discarded food items, etc.). If there were three different areas with visible rat activity, we placed each station within 1 m of these locations, otherwise we placed stations haphazardly along bordering walls or physical structures near fruits or vegetables, potential harborage, movement corridors, and locations that resembled places used by rats in other yards. Distances between stations varied depending on the yard's size, but they were a minimum of 10 m apart, which is roughly the standard distance between bait stations placed by structural PMPs. We monitored the stations for three consecutive weeks (21 nights) and visited each location every seven days to estimate bait consumption and replenish bait

2.3. . Trial II: Supplemental Baiting

Trial I served as a baseline for Trial II, which evaluated the effectiveness of supplemental bait provisioned around the three types of bait stations and was conducted during April and May 2023. We randomized the positions of each station (EZ, Rock, Snap-E) without replacement from their locations in Trial I. During Trial II, we provided supplemental bait around each station, which was five non-toxic soft bait packs (NoTox™ Soft Bait Attractant) spread within a 1-m radius of each of the three stations. We monitored the stations for 21 nights using digital game cameras and visited every seven days to estimate bait consumption and replace supplemental bait and bait in the stations.

2.4. Trial III: Scent Lure

We conducted Trial III in June and July 2023 to evaluate the effectiveness of a scent lure placed inside the bait station. We deployed two EZ stations per yard, each containing four non-toxic bait packs and monitored with a digital game camera. We placed each station in a new location using the same placement criteria as the previous two trials. In one station, we added an Airzonix™ scent lure (VM Products; peanut butter and chocolate scent), which was wrapped in steel wool and 0.6-cm wire mesh and fastened inside the feeding chamber with steel zip ties. We chose the Airzonix™ lure because it mimics the scent of peanut butter, which is a common food bait used for trapping rodents. It is also a relatively new lure on the market, and there are very few commercially available scent lures that do not contain food. The other EZ station contained only bait and served as a control.

As in previous trials, we monitored stations for 21 consecutive nights with digital game cameras and visited each yard once every seven days to estimate bait consumption and replenish bait.

2.5. Response Variables

We used time-stamped camera images to determine the time of the first discovery and entry events by roof rats at each station, as well as estimate the relative nightly activity of rats around each of the stations. We categorized and sorted images using PhotoMechanic (version 5.0, CameraBits, Portland, Oregon, United States). The time of the first discovery event was the number of elapsed hours between sunset on the first night and the time of the first image that captured a roof rat showing 'interest' in the station. 'Interest' was defined as the rat placing a forelimb on the station with their hindlimbs on the ground as they investigated the station over consecutive images per camera trigger or inserting their head into the station entrance. Rats would often run across the top of the bait station or use the station as an elevated point to move vertically or scan their surroundings, which we did not consider evidence of 'interest' in the station. We recorded the entry event as the number of elapsed hours between sunset on the first night and the first image of a rat entering or exiting the bait station, which was identified when more than half of the rat's body was in the station or the rat's head or body protruding from the station. We only used exit events to determine the time of the first entry if we had not observed an earlier apparent entry. Additionally, we recorded the frequency of entrances into each station by roof rats. Because the cameras captured three images in sequence, with 1 s between images, we often captured multiple images of the same entrance event. We only recorded the last captured image as the 'entrance' event, with preceding images categorized as 'interest' events. This was useful in situations where there was no latency between the first observed 'interest' and 'entrance' events.

We calculated relative nightly rat activity at each station as the proportion of hours of each night (out of 12 h) that contained an image of a roof rat at each station in each yard. We then calculated the mean proportion of hours of rat activity across all 21 nights for each station in each yard to develop an estimate of relative activity.

We estimated bait consumption visually as the percentage of bait consumed per week. We placed four ~9-g bait packs in each station, so that one bait pack represented 25 % of the total bait, and divided each individual bait pack roughly into quarters, which each represented 6.25 % of all the bait in the station. If less than one quarter of a bait pack was consumed, we estimated consumption as 5 %. We then calculated the mean percentage of weekly bait consumption for each station at each site, which was scored on an ordinal, whole-number scale from 0 to 3 (0 = 0–5.0 % bait consumed, 1 = 5.1–33.0 %, 2 = 33.1–66.0 %, 3 = 66.1–100 %). We only measured bait consumption by rodents, which was identifiable by gnaw marks left in the bait, but it was not possible to differentiate between rodent species (e.g., woodrats, *Neotoma* sp., or *R. rattus*). Consumption from invertebrates (mollusks and arthropods) could be easily identified and therefore was not included in bait consumption estimates.

2.6. Data Analysis

All data analyses and visualizations were conducted in R (version 4.3.2; R Core Team, 2023), and we omitted any yards where we did not detect rats in any camera images. To compare differences in the risk of discovery or entry among different station designs or control and scented stations, we created mixed-effects Cox models ('coxme' package; Therneau, 2024) for each trial with time to discovery or entry as the response variable, and the station design or scent treatment, presence of fruits or vegetables, presence of pets or livestock, and management status included as fixed effects, and yard included as a random effect (Station + Management + Fruits or Vegetables + Pets or Livestock + (1|Yard)). To analyze the effect of supplemental baiting, we created a model that included the interaction between supplemental baiting and station type and any landscape characteristics that were determined significant ($p < 0.05$) for each individual trial analysis (Station*Supplemental Bait + Station + Supplemental Bait + (1|Yard)). Survival curves for these analyses were created with the 'survminer' package (Kassambara et al., 2021).

Because bait consumption was recorded as an ordinal response variable, we used a cumulative-link mixed models from the 'ordinal' package (Christensen, 2023) for each trial, with station design or scent treatment, presence of fruits or vegetables, presence of pets or livestock, and management status as fixed effects, and yard as a random effect (Station + Management + Fruits or Vegetables + Pets or Livestock + (1|Yard)). To determine the effect of supplemental baiting on bait consumption, we created a model with station type, supplemental baiting, their interaction, and any landscape characteristics determined to be significant in the previous analysis as fixed effects, and yard as a random effect (Station*Supplemental Bait + Station + Supplemental Bait + (1|Yard)).

To compare whether relative nightly rat activity differed between station designs and control or scented stations, we used linear mixed models from the package 'lme4' (Bates et al., 2015) with station design or scent treatment, management status, presence of fruits or vegetables, and the presence of pets or livestock as fixed effects, and yard as a random effect (Station + Management + Fruits or Vegetables + Pets or Livestock + (1|Yard)). To analyze the effect of supplemental baiting on nightly activity, we included the interaction between supplemental bait and station type and any landscape characteristics that were significant in the individual trial analysis as fixed effects, and yard as a random effect.

In yards where we observed roof rats enter at least one bait station during each trial, we calculated the number of entries into each station per yard and compared the frequency of entries into stations using several paired t-tests.

3. Results

We captured a total of 852,270 images across all three trials, with 401,691 (47.1 %) images containing animals detected around bait stations and roof rats detected in a total of 203,060 images (23.8 %). We observed other mammals enter stations, including juvenile opossums (*Didelphis virginiana*), house mice (*Mus musculus*), deer mice (*Peromyscus maniculatus*), big-eared woodrats (*Neotoma macrotis*), pocket gophers (*Thomomys bottae*), and one Pacific kangaroo rat (*Dipodomys agilis*). We occasionally saw lizards (*Elgaria multicarinata*, *Sceloporus occidentalis, Uta stansburiana*) enter stations as well (Table 1). At four sites, juvenile opossums entered stations and removed bait throughout the study period. At another location, a coyote (*Canis latrans*) carried the Rock station off-site and dropped it in a nearby park, roughly 30–40 m away from its placement site. We also observed roof rats regularly remove bait from stations in three yards, despite being anchored inside the stations. This bait appeared to be hoarded: the residents at one site found multiple weeks' worth of bait stored by roof rats under patio furniture. Mollusks (snails, slugs) consumed bait at all locations, and evidence of their feeding was ubiquitous across yards and station types.

3.1. Trial I: Station Design

We captured 442,031 total images during this trial, with 52,164 images (11.8 %) containing roof rats. We detected roof rats in camera images in 33 of 36 yards during Trial I, and rats discovered roughly 65 % of the stations in these yards (EZ = 60.0 %, Rock = 76.7 %, Snap = 60.0 %). However, rats entered only 31 % of the stations (EZ = 23.3 %, Rock = 36.7 %, Snap = 33.3 %) by the end of the trial (Fig. 1). The mean

Table 1
Number of entries detected by target/nonnative species and non-target/native species across the three bait station trials (Station Design, Supplemental Baiting, and Scent Lure) conducted in residential yards in Orange County, California, USA, from February to July 2023. Values in parentheses show the percentage of entries by a particular species out of the total number of entries per station in each trial.

		Number of entrances (% of total entries into station)							
		Station Design (Trial I)			Supplemental Bait (Trial II)			Scent Lure (EZ; Trial III)	
Target species		EZ	Rock	Snap-E	EZ	Rock	Snap-E	Control	Scent
	Rattus rattus	265 (80.5)	499 (93.1)	302 (79.7)	949 (80.8)	507 (84.3)	440 (92.8)	458 (81.9)	842 (98.1)
	Mus musculus	1 (0.3)	5 (0.9)	17 (4.5)	10 (0.9)	8 (1.3)	0 (0.0)	30 (5.4)	4 (0.5)
Non-target/native species									
Mammals	*Didelphis virginiana*	0 (0.0)	0 (0.0)	0 (0.0)	49 (4.2)	9 (1.5)	18 (3.8)	0 (0.0)	0 (0.0)
	Neotoma macrotis	60 (18.2)	18 (3.4)	40 (10.6)	148 (12.6)	58 (9.7)	13 (2.7)	70 (12.5)	8 (0.9)
	Peromyscus maniculatus	3 (0.9)	10 (1.9)	20 (5.3)	18 (1.5)	6 (1.0)	1 (0.2)	0 (0.0)	2 (0.2)
	Thomomys bottae	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	2 (0.3)	0 (0.0)	0 (0.0)	0 (0.0)
	Dipodomys agilis	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (0.2)	0 (0.0)
Reptiles	*Elgaria multicarinata*	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	6 (1.0)	0 (0.0)	0 (0.0)	1 (0.1)
	Sceloporus occidentalis	0 (0.0)	3 (0.6)	0 (0.0)	0 (0.0)	5 (0.8)	2 (0.4)	0 (0.0)	1 (0.1)
	Uta stansburiana	0 (0.0)	1 (0.2)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)

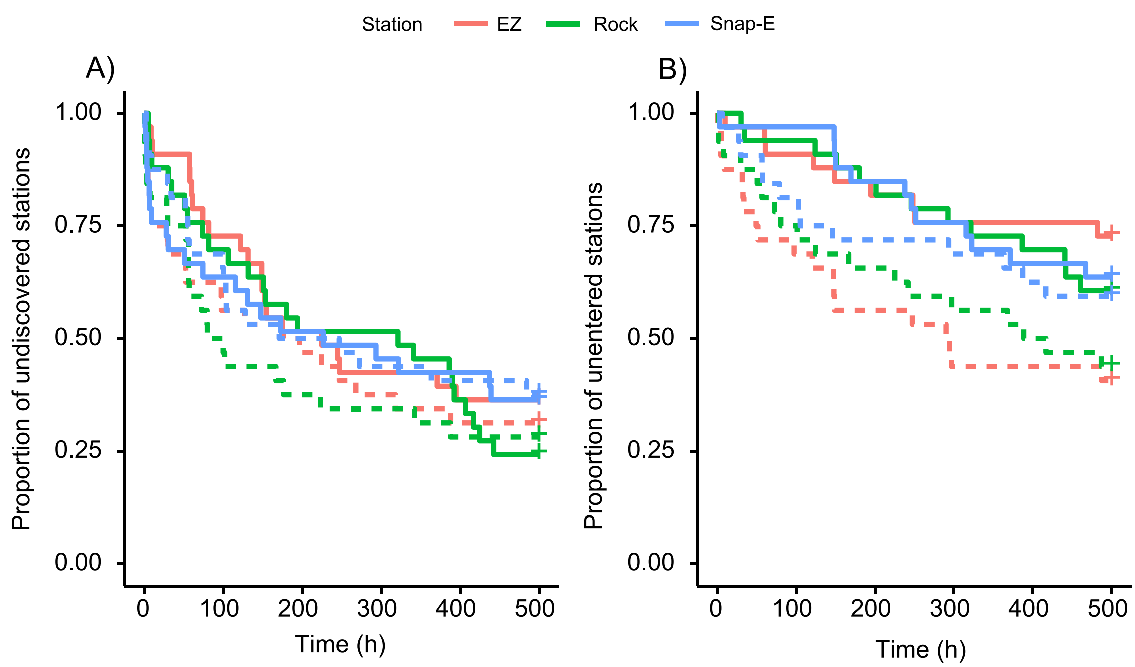

Fig. 1. Survival curves displaying discovery (left) and entry (right) of the EZ (Red), Rock (green), and Snap-E (blue) bait stations by roof rats over the three-week observation periods during Trials I (Station Design; solid lines) and II (Supplemental Baiting; dotted lines) in residential yards in Orange County, California, USA, where rats were detected. * ***Use color for** Fig. 1* *.

time to discovery was lowest at Snap-E stations, whereas mean time to entry was lowest in the EZ station (Table 2).Seven stations were discovered within a few hours after dusk on the first night (0.7–8.4 h; Fig. 1), but three stations were not discovered until the end of the trial, after 17 – 18 nights (408 – 439 h). They entered at least one station in 19 yards but did not enter one station type more often than another

Table 2
Percentage of bait stations that were discovered and entered by roof rats, along with the mean time of discovery and time of entry (± *SE*) for each station type, during trials between February and July 2023 in residential yards across Orange County, California, USA, where rats were detected.

Trial	Station	% Discovered	Mean time of discovery (h) ± SE (Range)	% Entered	Mean time of entry (h) ± SE (Range)
Station Design	EZ	60.6 (20/33)	139.4 ± 23.8 (2.0–394.9)	24.2 (8/33)	175.1 ± 47.5 (9.9–481.8)
	Rock	75.7 (25/33)	191.6 ± 32.6 (4.8–442.6)	36.4 (12/33)	254.6 ± 41.6 (30.2–460.5)
	Snap-E	60.6 (20/33)	119.1 ± 31.6 (0.7–439.2)	33.3 (11/33)	235.8 ± 35.6 (2.9–466.8)
Supplemental Bait	EZ	65.6 (21/32)	106.4 ± 25.4 (0.7–388.1)	56.3 (18/32)	131.3 ± 31.0 (0.7–487.0)
	Rock	68.8 (22/32)	90.3 ± 22.0 (0–387.7)	53.1 (17/32)	173.2 ± 37.3 (1.3–486.7)
	Snap-E	59.4 (19/32)	118.7 ± 29.1 (2.7–484.4)	37.5 (12/32)	159.3 ± 41.5 (6.5–416.4)
Scent Lure (EZ)	Control	81.5 (22/27)	145.3 ± 33.0 (1.5–485.9)	48.1 (13/27)	165.5 ± 41.5 (2.0–386.9)
	Scented	88.9 (24/27)	178.0 ± 29.6 (0–482.1)	63.0 (17/27)	199.8 ± 34.9 (0–483.4)

($t_{Rock} = 1.57$, $d.f. = 18$, $p_{Rock} = 0.133$; $t_{Snap\text{-}E} = 0.20$, $d.f. = 18$, $p_{Snap\text{-}E} = 0.840$; Table 1).

The risk of station discovery did not differ among station types during Trial I (Fig. 1; Supplementary Data Table A1). Neither management nor pets and livestock had any significant effect on station discovery, but rats were more likely to discover stations in yards containing fruits and vegetables ($HR = 2.04$ [1.03, 4.07], $p = 0.042$; Supplementary Data Table A1).

The risk of entry into stations did not differ among station types during Trial I (Fig. 1; Supplementary Data Table A2). The presence of management, pets or livestock, and fruits or vegetables did not affect station entry by rats (Supplementary Data Table A2).

The likelihood of bait consumption did not differ between stations during Trial I (Fig. 2; Supplementary Data Table A3). Neither the presence of pets or livestock, nor the presence of fruits or vegetables, had any effect on the likelihood of bait consumption during Trial I (Supplementary Data Table A3). The presence of rodent management in yards tended to reduce the likelihood of bait consumption, but the difference was not significant (Supplementary Data Table A3).

We observed similar levels of rodent activity each night at all station types (Fig. 3; Supplementary Data Table A4), and none of the evaluated landscape characteristics had any significant effect on nightly activity of rats during Trial I (Supplementary Data Table A4).

3.2. Trial II: Supplemental Baiting

We captured 331,762 images during this trial, with 108,508 images (32.7 %) containing roof rats. We detected roof rats in 32 of 35 yards during Trial II (one homeowner dropped out of supplemental bait trial). Most yards which contained rats during Trial I also had rats during Trial II. Roof rats discovered each station type at similar rates, and they discovered most stations by the end of the trial in yards where they were detected (Table 2; EZ = 65.6 %, Rock = 68.8 %, Snap-E = 59.4 %). Compared to Trial I, entry rates increased for all station types when surrounded by supplemental bait (Table 2; EZ = 56.3 %, Rock = 53.1 %, Snap-E = 37.5 %), although the increase for Snap-E stations was very small (only one additional station was visited). Supplemental bait decreased the mean times to discovery and entry for the EZ and Rock stations, but not the Snap-E station (Fig. 1; Table 2). Roof rats entered at least one station in 24 yards, but did not enter one station type significantly more often than another (Table 1; $t_{Rock} = -1.50$, $d.f. = 23$, $p = 0.147$; $t_{Snap\text{-}E} = -1.60$, $d.f. = 23$, $p_{Snap\text{-}E} = 0.124$).

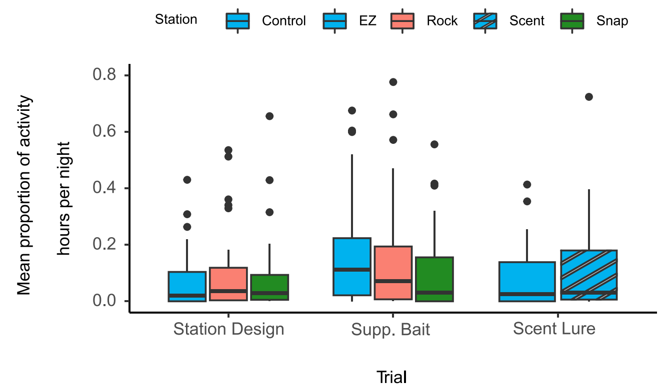

Fig. 3. Boxplot of the median and upper and lower quartiles of the mean proportion of nightly activity hours of roof rats per night residential yards where they were detected during each bait station trial in Orange County, California, USA. Vertical black line separates Station Design and Supplemental Baiting Trials (Trials I-II) from the Scent Lure Trial (Trial III). * ***Use color for** Fig. 3* *.

The presence of supplemental bait did not increase the chance of station discovery relative to Trial I (Fig. 1; Supplementary Data Table A5), and there was no difference in the risk of discovery between station types during Trial II (Fig. 1; Supplementary Data Table A6). The presence of rodent management did not affect the risk of station discovery, nor did the presence of pets or livestock. However, the presence of fruits and vegetables in the yard tended to increase the risk of station discovery by roof rats (Supplementary Data Table A6).

The presence of supplemental bait increased the risk of station entry, with rats significantly more likely to enter stations surrounded by supplemental bait (Fig. 1; $HR = 6.17$ [2.61, 14.6], $p < 0.001$; Supplementary Data Table A7). However, rats were less likely to enter the Snap-E station compared to the EZ station when surrounded by supplemental bait (Fig. 1; Supplementary Data Table A8). None of the landscape characteristics influenced station entry during Trial II (Supplementary

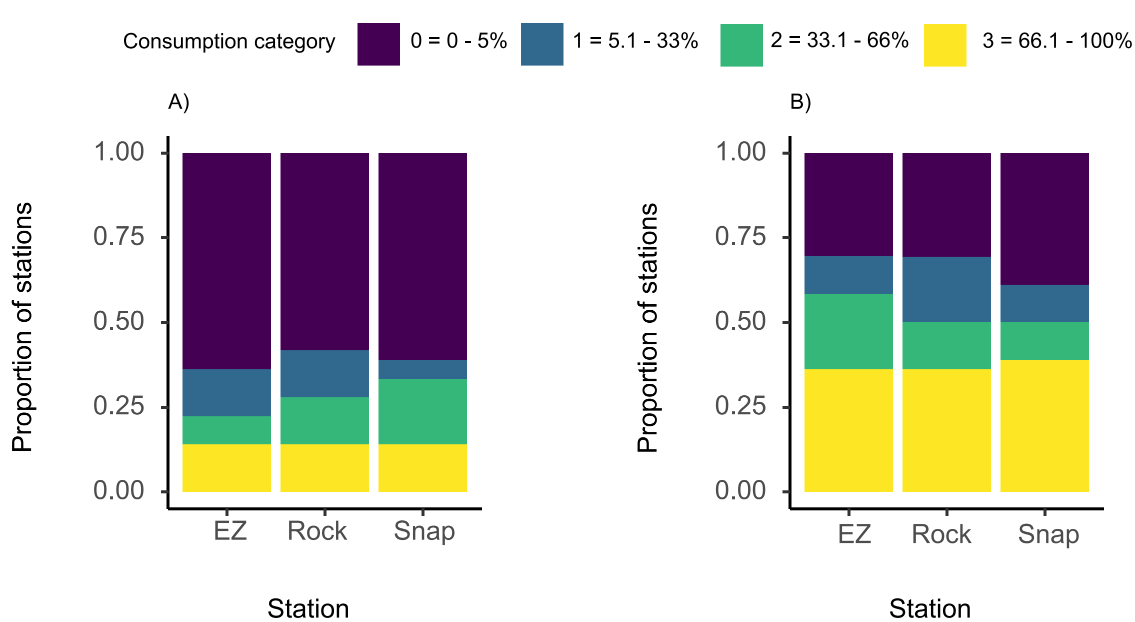

Fig. 2. Mean bait consumption category (0 = 0 – 5.0 % consumed, 1 = 5.1 – 33.0 % consumed, 2 = 33.1 – 66.0 % consumed, 3 = 66.1 – 100 % consumed) of each station over the three-week observation periods during Trials I (Station Design; a) and II (Supplemental Baiting; b) in residential yards in Orange County, California, USA, where rats were detected. * ***Use color for** Fig. 2* *.

Data Table A8).

Supplemental baiting significantly increased the likelihood of bait consumption relative to Trial I (Supplementary Data Table A9), but the likelihood of bait consumption did not differ among different station types during Trial II (Fig. 2; Supplementary Data Table A10). The presence of fruits or vegetables and pets or livestock did not affect the likelihood of bait consumption (Supplementary Data Table A10). Rodent management reduced the likelihood of bait consumption, with rats in managed yards significantly less likely to consume bait than those in yards that had no rodent management (OR = 0.04 [1.66e-3, 0.83], $p = 0.038$; Supplementary Data Table A10).

Rats were significantly more active around bait stations surrounded by supplemental bait (Fig. 3; Supplementary Data Table A11), although nightly activity around the Snap-E station was significantly lower than the EZ station during Trial II (Fig. 3; Supplementary Data Table A12). There was no difference in activity between the Rock and EZ stations, and none of the evaluated landscape characteristics had any effect on the mean nightly activity of roof rats during Trial II (Supplementary Data Table A12).

3.3. *Trial III: Scent Lure*

We captured 78,477 images during Trial III, with 42,388 images (54.0 %) containing roof rats. We detected roof rats in 27 yards during Trial III (when two EZ stations were placed in each yard), and they discovered 85 % of the stations (Control = 81.5 %, Scent = 88.9 %). The entry rate in scent-treated stations (63.0 %) was higher than in the control (48.1 %), although many stations still were not entered over 21 nights, despite rats discovering and being active around these stations. Roof rats did not enter scented stations more often than control stations ($t = 1.15$, $d.f. = 17$, $p = 0.264$).

The scent lure did not have any significant effect on the risk of station discovery or entry (Fig. 4; Supplementary Data Tables A13, A14). None of the yard characteristics had any significant effect on the risk of station discovery or entry by roof rats (Supplementary Data Tables A13, A14).

The scent lure did not affect the likelihood of bait consumption relative to the control stations (Fig. 5; Supplementary Data Table A15). None of the yard characteristics had any significant effects on bait consumption during Trial III (Supplementary Data Table A15). The nightly activity of rats was not affected by either the scent lure or yard characteristics (Fig. 3; Supplementary Data Table A16).

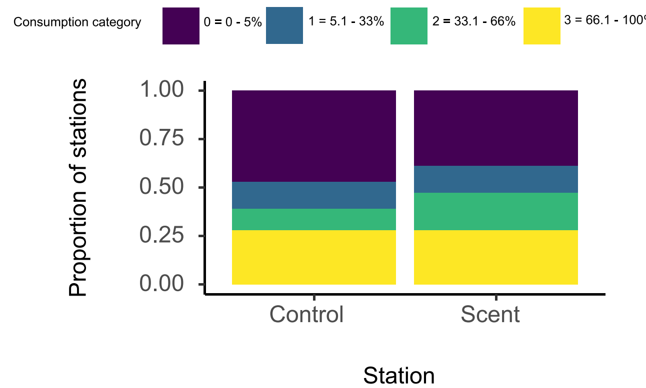

Fig. 5. Mean bait consumption category (0 = 0 – 5.0 % consumed, 1 = 5.1 – 33.0 % consumed, 2 = 33.1 – 66.0 % consumed, 3 = 66.1 – 100 % consumed) of each EZ station over the three-week observation period during Trial III (Scent Lure) in 27 residential yards in Orange County, California, USA, where rats were detected. * * **Use color for** Fig. 5* *.

4. Discussion

Although we did not detect any differences between station designs, there are conflicting conclusions regarding the responses of commensal rodents to different bait stations. In captivity, the behavior of wild commensal Norway and roof rats differs around different kinds of bait stations, with rats entering homemade wooden bait stations ("rat motels") quicker than plastic Philproof stations (Philproof Pest Control Products, Hamilton, New Zealand) (Spurr et al., 2006, 2007). These rats also consumed more bait and spent more time in the "rat motel" stations (Spurr et al., 2006, 2007). Shahwar et al. (2016) found that rats on poultry farms in Pakistan removed more bait from homemade wooden "rat motel" stations compared to PVC pipes and cardboard box stations. Each station we tested was composed of similar plastic material, which may explain why rats did not prefer one station over another, and

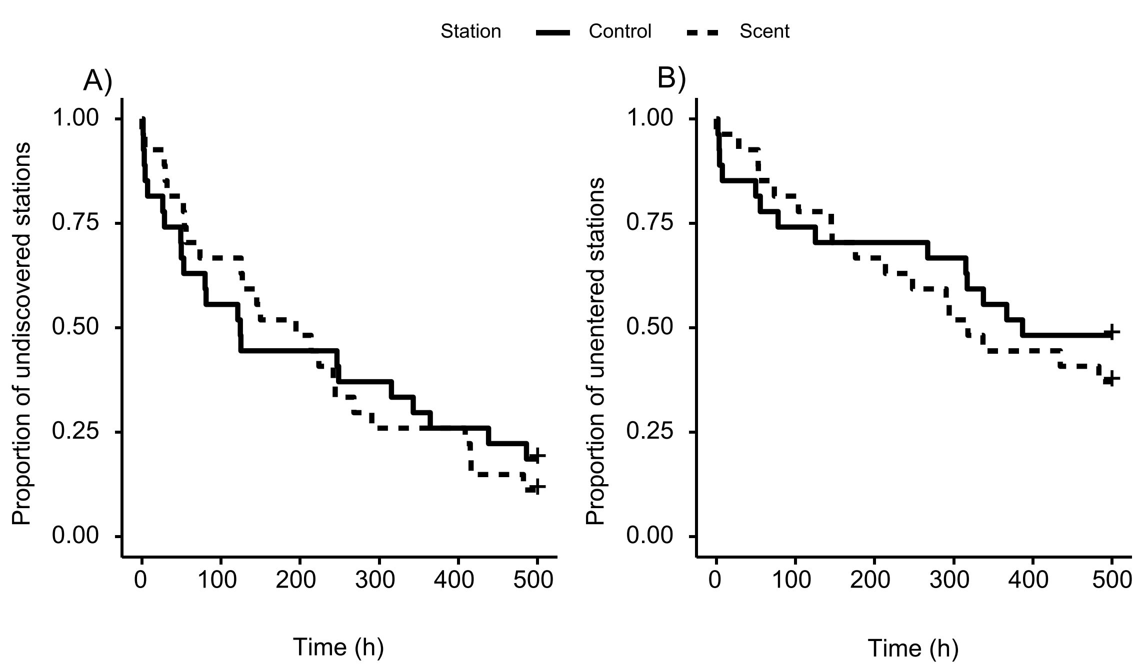

Fig. 4. Survival curve displaying discovery (left) and entry (right) of the control (solid line) and scent-treated (dotted line) bait stations by roof rats over the three-week observation period throughout Trial III in 27 residential yards in Orange County, California, USA, where rats were detected.

behavioral differences may emerge if we compared stations made of different materials.

Our most noteworthy result was that supplemental bait placed around stations may improve the effectiveness of rodent bait stations. Although supplemental baiting is not a common practice, it may be comparable to pre-baiting, which involves making bait freely available prior to arming traps and other devices to reduce neophobia (Chitty and Kempson, 1949; Matschke et al., 1982; Himsworth et al., 2015). Pre-baiting is often used when trapping rodents, but it does not always result in higher capture success (Gurnell, 1980; Edalgo and Anderson, 2007). Bytheway et al. (2021) proposed three mechanisms to explain why pre-baiting may attract target species: (1) it reduces neophobia, (2) it increases opportunities for rats to interact with devices, or (3) it relays information to conspecifics about the 'safety' of the device. Their results suggest that pre-baiting likely increases device interactions by rats because they have more time to interact with the device prior to the management period (Bytheway et al., 2021). Although this may be the mechanism to increase device interaction over relatively short time periods, we monitored stations for 21 nights and assumed rats had ample time to interact with stations. Rats also had the same amount of time to interact with stations during Trials I and II. Therefore, supplemental baiting seems to increase device visitation by habituating rats to feeding around the station. This should be investigated further using rodenticide bait in stations because a different bait formulation inside the station may induce bait avoidance.

Some researchers have suggested that the optimal station design should have a large entrance that allows rats to see the bait from outside of the station (Monro and Dennis, 1988), yet the Snap-E station, which had these features, was not better at attracting rats than the EZ and Rock stations. The large entrance and exterior holes in the Snap-E station may in fact explain why supplemental bait did not increase visitations to those stations by roof rats in our study. Schmolz et al. (2008) evaluated the behavior of captive Norway rats around a black, opaque bait station, where the bait was not visible from outside the station, in comparison to a station with transparent parts around the bait that provided an exterior view into the station. Norway rats consumed more bait from the black, opaque bait stations compared to translucent ones, presumably because the solid-walled station reduced visibility to predators (Schmolz et al., 2008). The exterior holes in the Snap-E station may have deterred entry by roof rats during Trial II, but this does not explain why the Snap-E station performed similarly to the other stations during Trial I and had similar bait removal rates to other stations during Trial II. It is unclear why the Snap-E station did not perform as well as the other stations during the supplemental baiting trial.

Although the higher rate of station visitation during Trial II may be due to a learned familiarity with the general locations of the stations over consecutive trials, the presence of supplemental bait did not increase visitations to the Snap-E station, suggesting the increased visitations to stations during Trial II was due to the supplemental bait treatment. It is also possible that rat abundance changed throughout our study period, leading to behavioral differences across trials. However, most of the yards we monitored produced a variety of fruits and vegetables that were in-season throughout the study period. Therefore, we assumed that rats had sufficient access to resources during our study, which presumably limited changes in seasonal abundance, although without trapping data we cannot confirm this was the case. There is conflicting evidence regarding the effect of season on rat abundance (Himsworth et al., 2014), but some research suggests that in commensal settings, where rats have access to food and water year-round, season does not seem to affect rat abundance (Villafañe et al., 2013; Panti-May et al., 2016; Himsworth et al., 2014).

Another potential way to reduce the avoidance to management devices involves using scent lures, but there is conflicting evidence regarding their effectiveness. Captive Norway rats exhibit preferences for certain food scents, but the addition of those scents to traps does not consistently increase trapping success (Witmer et al., 2008). Moreover, if preferred food sources are abundant, rats may not be attracted to scent lures or bait (Linklater et al., 2013). This could explain why, in our study, the scent lure did not increase visitations to bait stations, as many yards contained fruits and vegetables during the study period, although the presence of these food sources did not affect station visitations or rat activity. Additionally, the scent of the Airzonix™ lure may have been too strong and acted as a deterrent to entry, as previous research has shown that the attractiveness of a scent lure to rats may be inversely related to its concentration (Jackson et al., 2018).

Lures mimicking food odors might not be as effective as other scents. The presence of caged laboratory rats adjacent to live traps can increase the capture success of wild Norway rats in the field (Shapira et al., 2013). Food and rodenticide baits treated with male pheromones have also been shown to increase the capture success and bait uptake for female Norway (Takács et al., 2016a) and roof rats (Selvaraj and Archunan, 2006), and the addition of soiled bedding, food lures, and playbacks of ultrasonic vocalizations of rat pups to traps can increase capture success of Norway rats (Takács et al., 2016b). Parsons et al. (2015) used urine, feces, and sebum from rats to successfully attract wild Norway rats to passive monitoring devices. Taken together, it seems that conspecific odors and cues may be more effective than food-scent lures at attracting rats. The use of urine, droppings, or pheromones from roof rats should be investigated as a potential attractant to rodenticide bait stations.

We detected clear evidence of station avoidance throughout our study, and our estimated entry rates were consistent with previous research in our study area, which suggested that roof rats enter only 30 – 70 % of the stations they encounter (Burke et al., 2021). However, our results suggest that neophobia (Cowan, 1977; Inglis et al., 1996) is not the only factor contributing to bait station avoidance. In our study, rats were just as active in managed yards as they were in unmanaged yards, and regularly displayed interest in the stations, but took less bait from stations in yards that were managed for rodents. This suggests that previous exposure to rodenticide bait stations and traps enhanced bait avoidance, which indicates that it may be more difficult to control rats in locations that have been recently managed for rodents.

5. Conclusions

Our recommendations for PMPs are that the type of bait station used in a management context does not seem to affect the efficacy of a control program, but the provisioning of non-toxic supplemental bait around stations can increase entry into bait stations and bait consumption. The supplemental bait provided should contain the same non-toxic matrix as the rodenticide bait in the station because rats may not readily accept an unfamiliar bait matrix. Provisioning supplemental bait may increase the materials cost associated with rodent management, but it may reduce the time necessary to attract rats to stations and would therefore be less expensive than prolonging ineffective management efforts. The addition of a scent lure to bait stations also did not seem to affect station visitation, although other types of scents, such as conspecific lures, may have better success. Prior to management in an area, PMPs should also consider whether the site has been recently managed for rats, as rats may avoid consuming rodenticide baits; modified approaches may be necessary. Improving our understanding of rat behavior around management devices remains necessary to develop new solutions to the problems presented by commensal rats.

CRediT authorship contribution statement

Miles Abram Bosarge: Conceptualization, Formal analysis, Investigation, Methodology, Data curation, Visualization, Writing – original draft, Writing – review & editing. **Paul Stapp:** Conceptualization, Methodology, Validation, Formal analysis, Data curation, Writing – review & editing, Supervision, Project administration, Funding acquisition. **Niamh Quinn:** Conceptualization, Methodology, Validation, Resources, Writing – review & editing, Supervision, Project administration, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.applanim.2025.106653.

Data availability

The data supporting the results in this manuscript are available on Zenodo at http://doi.org/10.5281/zenodo.14708325.

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Environmental Health and Societal Wealth Predict Movement Patterns of an Urban Carnivore

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ABSTRACT

How societal, ecological and infrastructural attributes interact to influence wildlife movement is uncertain. We explored whether neighbourhood socioeconomic status and environmental quality were associated with coyote (*Canis latrans*) movement patterns in Los Angeles, California and assessed the performance of integrated social–ecological movement models. We found that coyotes living in more anthropogenically burdened regions (i.e. higher pollution, denser development, etc.) had larger home ranges and showed greater daily displacement and mean step length than coyotes in less burdened regions. Coyotes experiencing differing levels of anthropogenic burdens demonstrated divergent selection for vegetation, pollution, road densities and other habitat conditions. Further, movement models that included societal covariates performed better than models that only assessed ecological features and linear infrastructure. This study provides a unique social–ecological lens examining the anthropogenic drivers of urban wildlife movement, which should be applicable to urban planners and conservationists when building more equitable, healthy and wildlife-friendly cities.

1 | Introduction

Globally, urbanisation is bringing people and wildlife into increasingly closer contact with one another (Jenerette and Potere 2010; Schell et al. 2021; Soulsbury and White 2015). This closer contact can lead to deleterious effects, such as human–wildlife conflicts (Gilleland 2010; Murray, Cembrowski, et al. 2015), biodiversity loss (McDonald et al. 2013) and increased stress and disease susceptibility for wildlife (Murray et al. 2019). These effects are likely to worsen with climate change (Abrahms et al. 2023). Yet some species can exhibit resilience or even thrive in urban landscapes (Rodewald and Gehrt 2014). Within cities, animal movements can help researchers and managers to understand what constitutes usable habitat and connectivity (Beaujean et al. 2021; Braaker et al. 2017; Kirk et al. 2023; LaPoint et al. 2015), and which anthropogenic barriers and threats may inhibit dispersal, foraging, reproduction and other key behaviours (Byers et al. 2019; Grubbs and Krausman 2009; Kobryn et al. 2022; Voigt et al. 2020). Movement analysis is thus an important tool for approximating the unique needs and survival tactics of urban wildlife (Ryan and Partan 2014). With accelerating global urbanisation, it is critical to examine how wildlife move through cities across scales, and in turn determine how humans and wildlife can successfully coexist in these tightly coupled human–natural ecosystems.

Most urban wildlife behaviour studies focus on urban–rural comparisons, with the relative proportion of green space to grey space (i.e., the built environment) as the main environmental covariate explaining behavioural divergence in urban taxa (Ditchkoff et al. 2006; Swanwick et al. 2003). These studies have emphasised habitat-driven connectivity between urban green spaces (Coulson et al. 2014; Ignatieva et al. 2011). Additional studies have shown that anthropogenic disturbances—such as linear infrastructure and human activity—can disrupt (Doherty et al. 2021; Poessel et al. 2014) or facilitate (Hill et al. 2020; Maclagan et al. 2019; Niesner et al. 2021) animal movements, with additional emerging research into the impacts of human mobility on wildlife activity (Ellis-Soto et al. 2023). However, there have been recent calls to examine how human societal factors may work in tandem with ecology to dictate animal movement and connectivity (Williamson et al. 2023; Wilkinson et al. 2024).

Societal factors that are relevant to urban wildlife extend beyond linear infrastructure and human activity and can include socioeconomics, values, perceptions, political preferences, and anthropogenic pollutants (Dickman 2010; Ditmer, Niemiec, et al. 2022; Murray et al. 2019). Previous research has explored how socioeconomic factors, such as 'luxury effects' (i.e., wealth; Hope et al. 2003) and 'legacy effects' (i.e., redlining; Wilson 2023) influence urban wildlife occupancy and biodiversity due to habitat heterogeneity linked to these effects (Leong et al. 2018; Magle et al. 2021; Schell et al. 2020). Wealth is a dominant predictor of urban black-tailed deer habitat selection due to preferences for landscape features linked to affluence (e.g., house size, green space access; Fisher et al. 2024). Chemical pollution, meanwhile, can alter wildlife movement and social behaviours (Bertram et al. 2022; Saaristo et al. 2018). Evidence also suggests that human perceptions and political leaning dictate wildlife landscape permeability, especially for controversial species (Ditmer, Wittemyer, et al. 2022; Sage et al. 2022; Wilkinson et al. 2024). Despite their importance, we have yet to determine whether integrating societally driven landscape features into animal movement models may yield a better understanding of wildlife decision-making than ecological models alone.

Incorporating societal factors, linear infrastructure and ecological factors together in animal movement models may yield a myriad of benefits. Such integrations may help us to better determine where human–wildlife interactions will most likely occur (Gonzalez-Crespo et al. 2023; Lischka et al. 2018) and to mitigate conflicts accordingly through improved urban design (Hwang and Jain 2021; Kay et al. 2022) and community engagement (Ceausu et al. 2018; Puri et al. 2024; Wilkinson, Caspi, et al. 2023). Recent work has noted that wildlife connectivity planning should consider societal, economic and institutional factors to develop the most effective and long-lasting wildlife connectivity practices (Williamson et al. 2023). Importantly, connectivity is key to fostering biodiversity even within urban areas (LaPoint et al. 2015), and sociocultural factors dictate whether cities may fulfil their potential contributions to biodiversity conservation (Aronson et al. 2017). Building societal factors into urban wildlife movement models can thus advance the transdisciplinary approaches needed to assure biodiverse, wildlife-inclusive cities (Kay et al. 2022; Lambert and Schell 2023).

The coyote (*Canis latrans*) is a behaviourally flexible carnivore that has expanded its range across North America over the last century (Hody and Kays 2018) and has been the subject of considerable publicity and debate (Draheim et al. 2019; Niesner et al. 2024). Coyotes may serve as bioindicators of urban ecological health, since their residence in highly developed areas and reliance on anthropogenic food correlate with stress and disease (Murray, Edwards, et al. 2015; Raymond et al. 2024; Robertson et al. 2023). Urban coyote movement also differs from their rural and wildland counterparts (Chamberlain et al. 2021; Chamberlain et al. 2000; Holzman et al. 1992; Way et al. 2004), with urban individuals occasionally demonstrating smaller home ranges and shorter travel distances. Further, urban coyotes show greater exploration and boldness relative to rural conspecifics (Breck et al. 2019). Their behavioural flexibility and ability to persist across development gradients (Grinder and Krausman 2001) make this species an ideal candidate for testing the efficacy of integrating societal, linear infrastructure and ecological factors to predict urban wildlife movement.

Here, we addressed the gap in social–ecological wildlife movement analysis using coyotes in Los Angeles County, California. Los Angeles encompasses dramatic gradients of wealth, green space availability and linear infrastructure density, providing an ideal location to test hypotheses oriented around social–ecological systems. We used a coyote movement data set to answer the following questions: (1) How are coyote home ranges structured along heterogeneous social-ecological gradients? (2) Which factors best predict coyote movement patterns? and (3) How does coyote movement differ across varying levels of environmental health and vulnerability? We hypothesised that integrating societal (pollution burden, median income, population density, noise pollution, building density, development intensity), linear infrastructure (i.e., features known to serve as distinct barriers and/or conduits for wildlife: road density, distance to flood channels, distance to railways) and ecological factors (vegetation greenness, distance to freshwater, distance to green spaces) would better predict coyote space use and movement than ecological factors alone (Figure 1), with our detailed hypotheses listed in Table 1.

2 | Methods

2.1 | Study Site

We conducted this study in Los Angeles County (> 95% of the study area) and San Bernardino County, California (34.106357, −118.279013). Los Angeles County has a human population density of 952.5 people/km^2 (United States Census Bureau 2023). Natural spaces within the county are interspersed with intense urbanisation, major freeways and agricultural regions. Los Angeles County has a Mediterranean climate with the driest, hottest periods comprising May–October (i.e., 'drier season') and the coldest, wettest periods comprising November–April (i.e., 'wetter season'). Coyotes

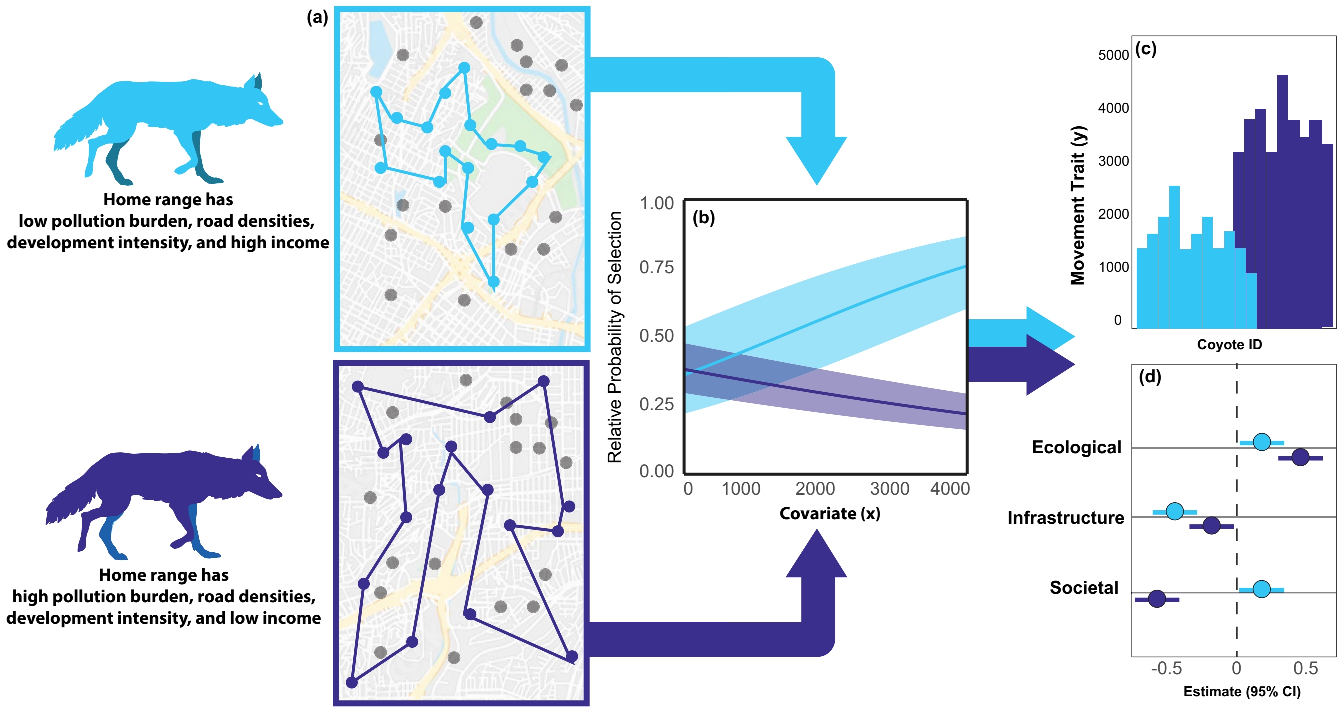

FIGURE 1 | Conceptual figure describing the hypothesised integrated effects of societal, linear infrastructure and ecological factors on urban coyote movement characteristics and habitat selection across differing levels of anthropogenic burden. Coyotes in more anthropogenically burdened regions (i.e., higher pollution burden, road densities, development intensity and lower income) are hypothesised to have larger home ranges (a) with increased movement metrics like daily displacement or step length (c). Individuals across anthropogenic burden gradients may also show divergent selection patterns (b) and strength (d) in response to environmental covariates, whereby more burdened individuals exhibit stronger selection for ecological variables and selection against societal covariates, relative to lower burdened conspecifics.

occur throughout most of the study area, though their county-level populations have not been empirically estimated.

2.2 | Data Collection

2.2.1 | GPS Collars

In October 2019, for a separate study that was later cancelled, we outfitted 20 coyotes (6 females and 14 males) with GPS collars (Ecotone, solar powered, GPS/GSM/UHF), which remained active between 1 and 23 months. All captured coyotes were collared with the intention of achieving an equal sex ratio over time; however, this was not possible. Fix rates varied across coyotes and ranged between 15 min and 2 h to extend collar battery life.

2.2.2 | GIS Data

Geospatial covariates for coyote movement models comprised ecological, linear infrastructure and human socioeconomic and environmental health (hereafter 'societal') variables. All geospatial covariates (see detailed sources in Table S1) were rasterised to 30 m^2 spatial resolution using ArcGIS Pro v 3.1.1 (ESRI 2023). For the ecological covariates, we considered (1) normalised difference vegetation index (NDVI) from spring 2021 (Landsat 8), (2) distance to rivers and streams (California Department of Fish and Wildlife 2020), (3) distance to lakes (California State Geoportal 2021) and (4) distance to green spaces, including (a) county parks (County of Los Angeles 2022), (b) golf courses and (c) cemeteries (City of Los Angeles 2023). Importantly, in arid regions, green spaces will not always have a notable vegetation greenness signature.

For the linear infrastructure covariates, we considered (1) road density, (2) distance to storm and flood channels and drains (County of Los Angeles, 2023) and (3) distance to railways (California Rail Network 2022).

Finally, we considered the following societal covariates: (1) human population density (United States Census Bureau 2023), (2) building density (Dao 2020), (3) development intensity (National Land Cover Database (NLCD) 2019), (4) median income (County of Los Angeles, 2023), (5) noise pollution and (6) pollution burden percentile (Cal Enviro Screen 4.0). Population density and building density can describe different aspects of a city's population (i.e., population density is important in residential areas, while building density is relevant across zones). Development intensity was reclassified as 0 = no data, 1 = undeveloped land cover classes, 2 = developed: open space, 3 = developed: low intensity, 4 = developed: medium intensity and 5 = developed: high intensity. Cal Enviro Screen provides a pollution burden index that is calculated from 13 metrics related to drinking water characteristics, groundwater quality, air quality, soil pollutants and hazardous waste.

TABLE 1 | Hypotheses regarding social–ecological predictors of landscape use and movement of urban coyotes (*Canis latrans*) in Los Angeles, California.

Question	Hypothesis	Justification
How are coyote home ranges structured along heterogeneous social–ecological gradients?	Coyotes in more densely urbanized parts of the city have larger home ranges than those in less densely urbanized locations	Anthropogenic development can deplete prey or access to prey, leading to urban and peri-urban carnivores needing to range further to hunt and forage (Bateman and Fleming 2012; Leighton et al. 2021; Smith et al. 2016)
	Coyotes whose ranges are adjacent to major highways have smaller home ranges than coyotes whose ranges are farther from major highways	Highways can pose major barriers to both urban and rural wildlife, preventing movement through wildlife fear and through wildlife deaths due to vehicles (Doherty et al. 2021; Murray and St. Clair 2015; Poessel et al. 2014)
	Coyotes that have more flood channels and storm drains within their home ranges have relatively larger home ranges	Flood channels, storm drains and easements for other linear infrastructure can serve as corridors for urban wildlife, increasing connectivity within urban spaces with these features (Fletcher 2009; Maclagan et al. 2019; Niesner et al. 2021)
	Coyotes living in more polluted areas have smaller home ranges than coyotes living in less polluted areas	1. Urban pollutants contribute to wildlife stress and disease, which can potentially affect their mobility (Murray et al. 2019; Saaristo et al. 2018) 2. More polluted, underserved regions may provide coyotes with more access to unsecured refuse and associated synanthropic prey animals such as rats (*Rattus* spp.) (Childs et al. 1991; Dyer et al. 2023; Murray et al. 2024; Promkerd et al. 2008; Traweger et al. 2006) 3. Chemical pollution has been linked to alterations in wildlife behaviours and movement (Bertram et al. 2022; Saaristo et al. 2018)
Which factors—societal, linear infrastructure, ecological or a combination of these—are the best predictors of coyote movement patterns?	Urban coyote movement is best predicted by a combination of societal, linear infrastructure, and ecological variables.	1. Human societal factors, such as wealth, perceptions, population density and development intensity, can have cascading impacts on ecology and wildlife landscape use (Aznarez et al. 2023; Ditmer, Niemiec, et al. 2022, Ditmer, Wittemyer, et al. 2022; Ghoddousi et al. 2021; Leong et al. 2018; Magle et al. 2021; Markovchick-Nicholls et al. 2007) 2. Anthropogenic pollutants, such as environmental pollution and noise pollution, can impact wildlife behaviour, stress, illness and survival (Berkhout et al. 2023; Ditchkoff et al. 2006; Shannon et al. 2015) 3. Linear infrastructure, such as roads, fences, railway easements and flood channels, can serve as barriers or habitats to wildlife or can facilitate movement (Barrientos et al. 2019; Doherty et al. 2021; Fletcher 2009; Hill et al. 2020; Maclagan et al. 2019; Murray and St. Clair 2015; Niesner et al. 2021; Poessel et al. 2014; Popp and Hamr 2018) 4. Despite relatively less 'natural' coyote habitat available in cities versus rural areas, coyotes have been known to den in and generally favour urban green spaces such as parks, cemeteries and golf courses and also seek out urban water sources as a primary need (Baker and Timm 1998; Grubbs and Krausman 2009; Wurth et al. 2020)
	Coyotes on the urban-wildland interface are more likely to select for neighborhoods with higher annual median income	There are preferable ecological resources, such as increased tree cover and more access to green spaces, associated with urban high-income locations; these influence biodiversity and animal movement (Chamberlain et al. 2020; Fisher et al. 2024; Leong et al. 2018; Schell et al. 2020)

(Continues)

TABLE 1 | (Continued)

Question	Hypothesis	Justification
	Coyotes in densely populated urban areas are less likely to select for neighborhoods with higher annual median income	1. Lower-income areas are more likely than high-income areas to experience a lack of access to quality municipal services (i.e., Feigenbaum and Hall 2015), meaning unsecured refuse may be more common (Sprague et al. 2022) 2. Lower-income urban areas are more likely than high-income areas to have higher densities of synanthropic wildlife that constitute coyote prey, such as rats (*Rattus* spp.) and raccoons (*Procyon* spp.) due to access to waste (Bozek et al. 2007; Childs et al. 1991; Dyer et al. 2023; Murray et al. 2024)
	Within their home ranges, coyotes select for regions with lower population density	1. Both urban and rural coyotes tend to spatiotemporally avoid people (Gehrt et al. 2009; Wang et al. 2015) 2. Urbanisation is correlated with lower quantity and quality of wildlife habitat (Liu et al. 2016)
	Within their home ranges, coyotes select for flood channels and railways	Linear infrastructure can serve to facilitate wildlife movement through human-dominated landscapes (Clarke et al. 2006; Fletcher 2009; Maclagan et al. 2019; Niesner et al. 2021; Popp and Hamr 2018)
	Within their home ranges, coyotes use areas with lower levels of environmental pollutants	Anthropogenic pollutants affect wildlife stress, behaviour and health (Berkhout et al. 2023; Ditchkoff et al. 2006; Shannon et al. 2015) and are linked to lower habitat quality and resource availability (Scanes 2018)

2.3 | Analyses

2.3.1 | Home Ranges and Movement Characteristics

Relevant spatial covariates were summarised at the home range level for each coyote using ArcGIS Pro v.3.1.1 (ESRI 2023), and statistical analyses were conducted in R v.4.3.2 (R Core Team 2023). Using the 'adehabitatHR' package, we determined the 50% (core range) and 95% kernel utilisation distribution (KUD) for each coyote and calculated their home range sizes per level. We calculated mean NDVI, pollution burden, median income, road density, development intensity and human population density for each home range and used linear regressions and Mann–Whitney *U* tests to determine relationships between home range size and social–ecological landscape characteristics, including comparing means across levels of anthropogenic burden (i.e., higher vs. lower NDVI, development intensity, median income, pollution burden, population density, development intensity and road density).

To understand the relationship between social–ecological landscape covariates and coyote movement characteristics, we used Wilcoxon rank-sum tests to compare means for two key movement metrics—mean daily displacement and step length—across sex, across season and across lower vs. higher anthropogenic burden.

2.3.2 | Resource Selection

To examine coyotes' landscape feature selection, we derived resource selection functions (RSFs) using the 'lme4' package. To reduce autocorrelation, we rarified data to 2-h fixes for a total of 93,670 fixes and generated random points within 95% KUD home ranges, with generated 'available' points equaling three times the number of GPS fixes within each coyote's home range. We tested for collinearity among the covariates using the *vif* function in the 'car' package (Fox et al. 2007). Using the 'raster' package and base R, we centred and scaled covariates (mean = 0, SD = 1) to facilitate interpretability and model convergence. We assessed resource selection using generalised linear mixed effects models with a logit link, with coyote identity as a random effect to control for individual variation in behaviours (Gillies et al. 2006). We tested the following models: (1) a global model, (2) a model containing only societal covariates, (3) a model containing only ecological covariates and (4) a model containing only linear infrastructure covariates. Data were analysed in aggregate and also subset into the following groups, as indicators of potential anthropogenic burden on coyotes: (1) coyotes with less polluted and more polluted (more burdened) home ranges (i.e., below or above the 50th percentile), (2) coyotes with home ranges consisting of lower or higher (more burdened) human populations than the average across all coyote home ranges and (3) coyotes with home ranges in wealthier or less wealthy (more burdened) regions than the average across all coyote home ranges. We used Akaike's Information Criterion (AIC) to determine the best-performing models (Burnham and Anderson 2002).

2.3.3 | Step-Level Selection

To understand how coyotes move in relation to landscape features at the step scale, we derived step selection functions

(SSFs) using the 'amt' (Signer et al. 2019) and 'survival' packages (Therneau 2015). After creating tracks from the data using the *mk_track* function, we thinned the data to 2-h fixes for a total of 33,378 steps (mean step length = 414.9 m) and filtered the data so bursts would have at least 3 points (Signer et al. 2019). We chose 2-h fixes since only a smaller subset of our sample individuals had finer fixes available. We generated five random steps per used step using the *random_steps* function, which uses a gamma distribution fitted to the entire dataset to derive step lengths and derives turn angles from a von Mises distribution (Thurfjell et al. 2014). Covariate scaling and model comparisons reflect our RSF analyses, though for SSFs, we only conducted a global model across all coyotes. To reduce autocorrelation, we used individual coyotes as a cluster term, following the 20 minimum clusters recommended by Prima et al. (2017) and reported on robust standard errors (Nisi et al. 2021; Prima et al. 2017; Roever et al. 2010; Suraci et al. 2020). We estimated coefficients by fitting conditional logistic regressions on covariates. We considered the log of step length (i.e., speed of movement) and cosine of the turning angle (i.e., directionality of movement) as interaction terms with linear infrastructure since linear infrastructure can influence carnivore behavioural states (Abrahms et al. 2016; Thorsen et al. 2022), and with NDVI since we expected coyotes to move more cautiously in places with less vegetative cover. We used the quasi-likelihood independence model criterion (QIC) to determine the best-supported models.

3 | Results

3.1 | Home Range and Movement Characteristics

The mean 95% KUD home range size (Figure 2) was 26.12 km^2 (95% CI = 13.04, 38.96) and the mean 50% KUD home range size was 4.56 km^2 (2.11, 6.65) (Table S2). Home ranges with higher pollution burden were larger than home ranges with lower pollution burden (Figure 3a, Table S4). Human population density was positively correlated with core (50%) home range size ($\beta = 0.173$, $p < 0.0001$, $R^2 = 0.94$). NDVI was marginally negatively correlated with core home range size ($\beta = -0.002$, $p = 0.001$, $R^2 = 0.14$). Road density, income and development intensity were not significantly correlated with home range size.

Home ranges with higher pollution burden had lower mean NDVI and income and higher mean road density, population density and development intensity (Table S2). Males' home ranges had higher mean pollution burden, road density, human population density, development intensity and parks access than did females' (Tables S2 and S3).

Movement characteristics demonstrated impacts of landscape vulnerability on coyote movement (Figure 3; Figure S1). Mean coyote step length was significantly higher during the drier season and for coyotes with home ranges in regions of lower NDVI, lower income, higher population density, higher road density and higher development intensity (Figure 3d, Table S5). There was no significant difference in step length across sex and pollution burden. Mean daily displacement was greater for females and for coyotes in regions of lower NDVI, lower income, higher road density, higher population density, higher pollution burden and higher development intensity.

3.2 | Resource Selection

When assessing multicollinearity among our spatial covariates (Table S6), we found that noise pollution and road density were highly correlated (> 0.7) and thus removed noise pollution from our models since roads are ecologically important as both

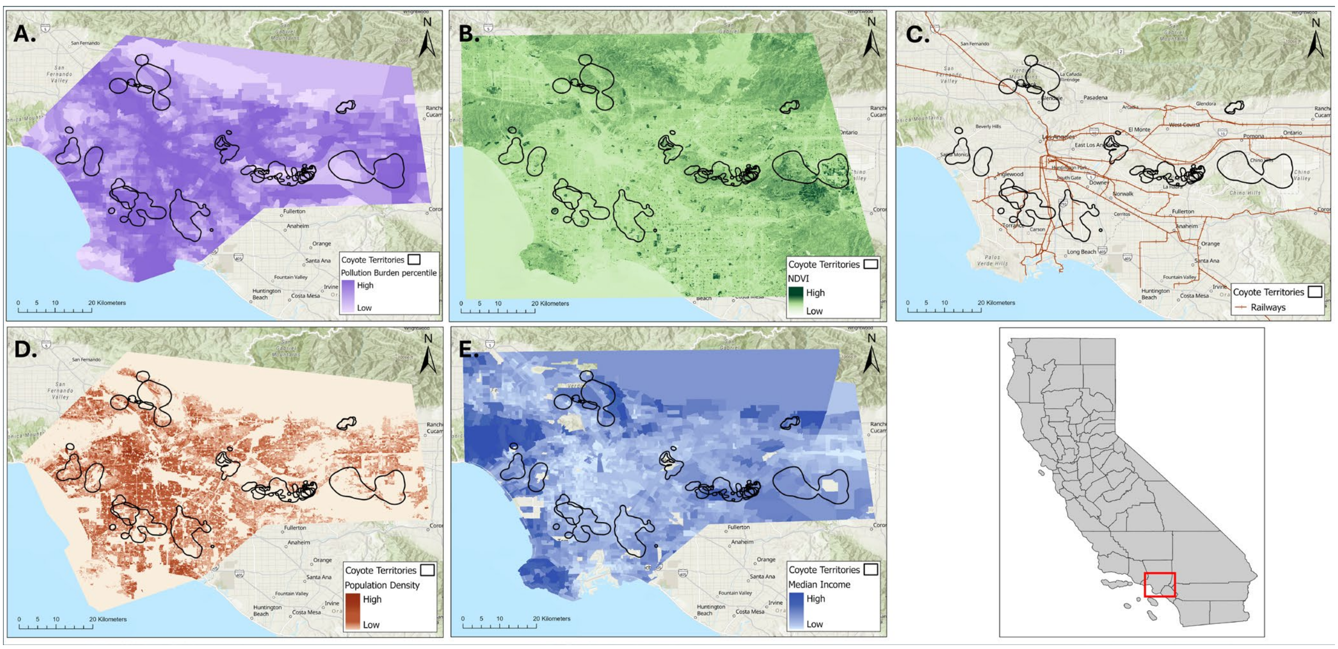

FIGURE 2 | Home ranges (derived from 95% KUD) for the 20 coyotes tracked for this study, overlaid on a subset of the societal, ecological and linear infrastructure covariates considered. The example covariates included here are (a) pollution burden, (b) normalised difference vegetation index (NDVI), (c) railways, (d) population density and (e) median income.

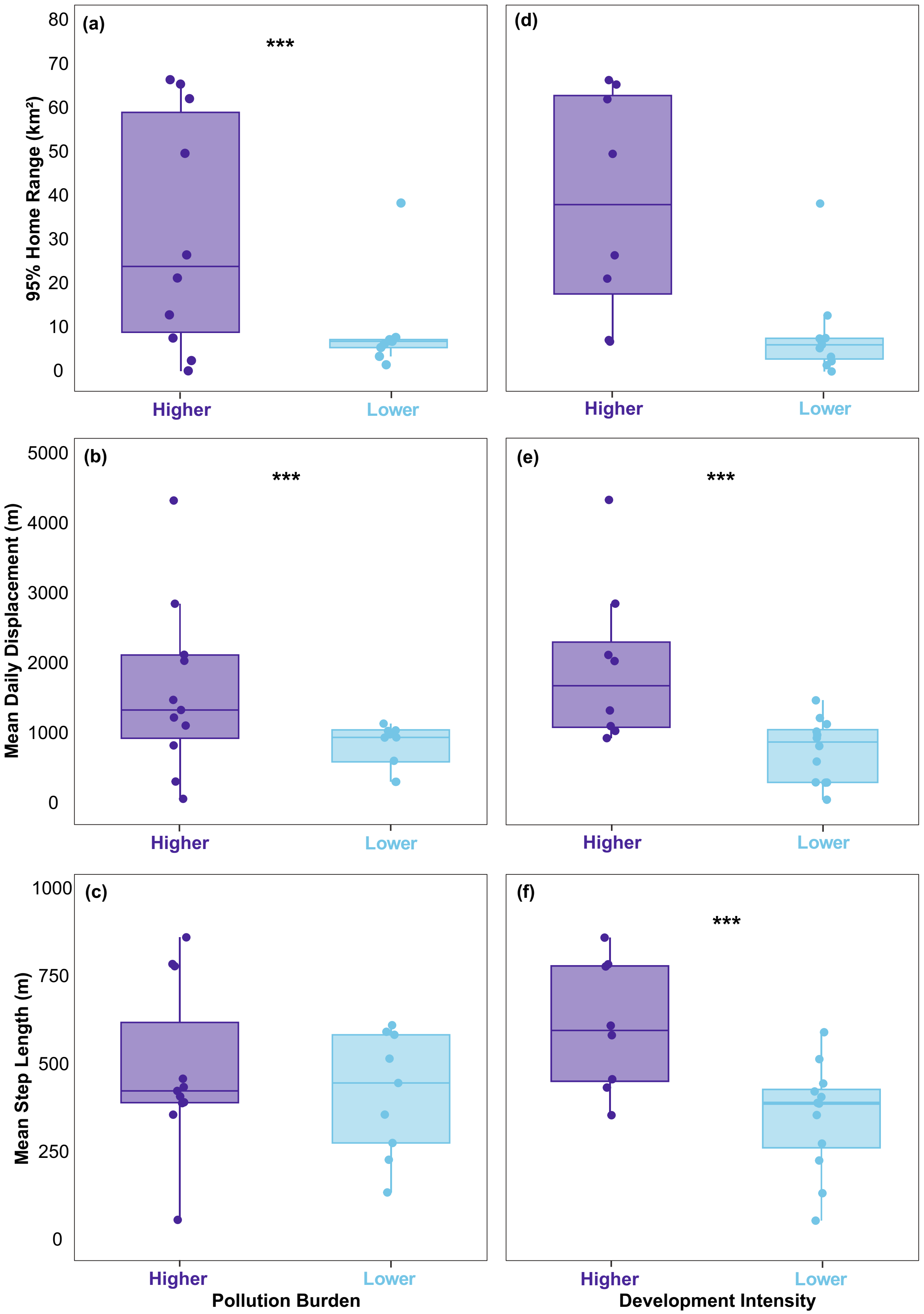

FIGURE 3 | Legend on next page.

FIGURE 3 | Box plots demonstrating coyote home range sizes, mean daily displacement and mean step lengths across levels of anthropogenic burden (higher and lower pollution burden and development intensity), for 20 coyotes tracked in Los Angeles and San Bernardino Counties from 2019 to 2021. Higher pollution burden is calculated as having a 95% kernel utilisation distribution (KUD) home range with a mean pollution burden above the 50th percentile. Higher population density is calculated as having a 95% KUD home range with a mean population density that is above the average for our sample.

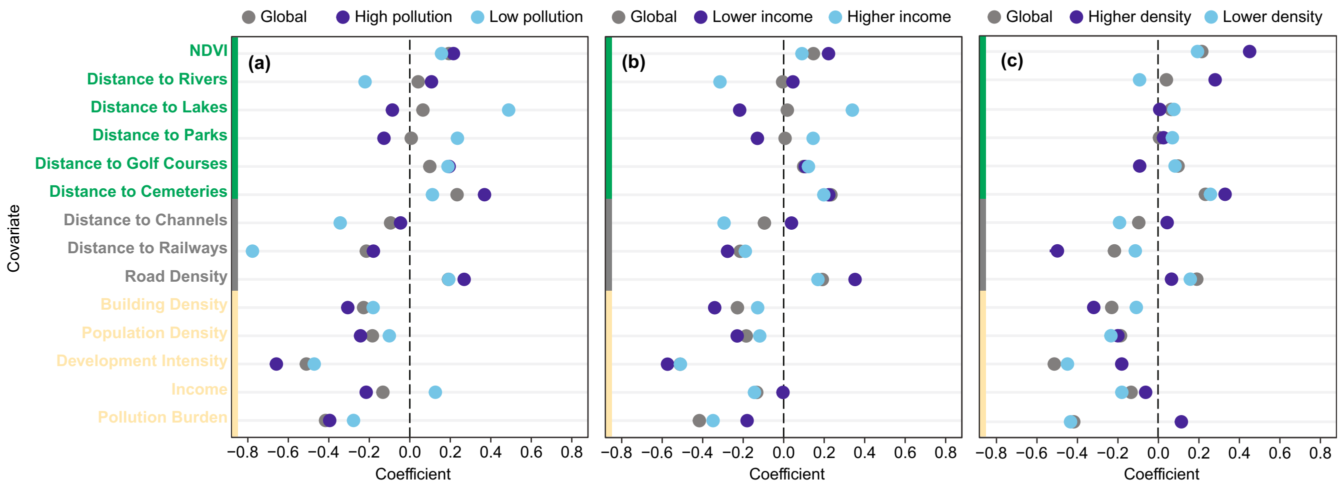

FIGURE 4 | Results from resource selection function random effects models including all covariates for (a) coyotes living in regions of higher or lower pollution burden, (b) coyotes living in regions of higher and lower median income and (c) coyotes living in regions of higher and lower human population densities compared to the estimates from the global model including all sampled coyotes. Ecological covariates are colour-coded green, linear infrastructure covariates are grey, and societal covariates are yellow. 95% confidence intervals were included yet smaller than the coefficient markers and are thus not visible.

barriers and attractants for mammalian carnivores (Poessel et al. 2014).

3.2.1 | Resource Selection for all Sampled Coyotes

The best-performing global models ($\Delta AIC \leq 2$) included (1) all covariates and (2) all covariates except distance to cemeteries (Table S7). In the random effects model, including all covariates (Figure 4), coyotes exhibited strong selection for NDVI, road density, rivers, flood channels and railways and against income, building density, population density, lakes, golf courses, cemeteries and development intensity. Of these, the most pronounced effects were selection for railways ($\beta = -0.212$, 95% CI $= -0.232$: -0.192, $p < 0.0001$) and road density ($\beta = 0.195$, 0.176:0.212, $p < 0.0001$) and against development intensity ($\beta = -0.504$, -0.517:-0.491, $p < 0.0001$) and pollution burden ($\beta = -0.412$, -0.428: -0.397, $p < 0.0001$).

3.2.2 | Resource Selection for Highly Burdened vs. Less Burdened Coyotes

Coyotes with home ranges in locations of higher pollution burden selected against higher income locations and rivers and selected for parks and lakes, while less-burdened coyotes showed the opposite patterns (Figures 4a, 5, Table S7). Selection against human population density, development intensity and pollution burden was stronger for more burdened coyotes, with weaker selection for flood channels and railways compared with less burdened coyotes. Coyotes with home ranges in locations of lower (i.e., more burdened) median income selected for parks and lakes and selected against rivers and channels, whereas less-burdened coyotes showed opposing patterns (Figures 4b, 5, Table S7). More burdened coyotes also demonstrated stronger selection for NDVI, railways and road density; stronger selection against building density and weaker selection against pollution burden relative to burdened coyotes.

Coyotes with home ranges in locations of higher (i.e., more burdened) human population density selected against rivers and flood channels and selected for golf courses and pollution burden, whereas less-burdened individuals showed the opposite patterns (Figures 4c, 5, Table S7). Selection for NDVI and railways and against building density was stronger for burdened coyotes, with weaker selection against development intensity and median income relative to less-burdened coyotes.

Across all data subsets (including the full data set), the societal model always performed the best among the partitioned ecological, societal and linear infrastructure models (Table S8).

3.3 | Step Selection

The best-performing SSF models included three interaction terms: median income: log(step length), NDVI:log(step length) and development intensity: cosine(turn angle), which we retained for the global model. The most influential covariates within the global model were development intensity (relative

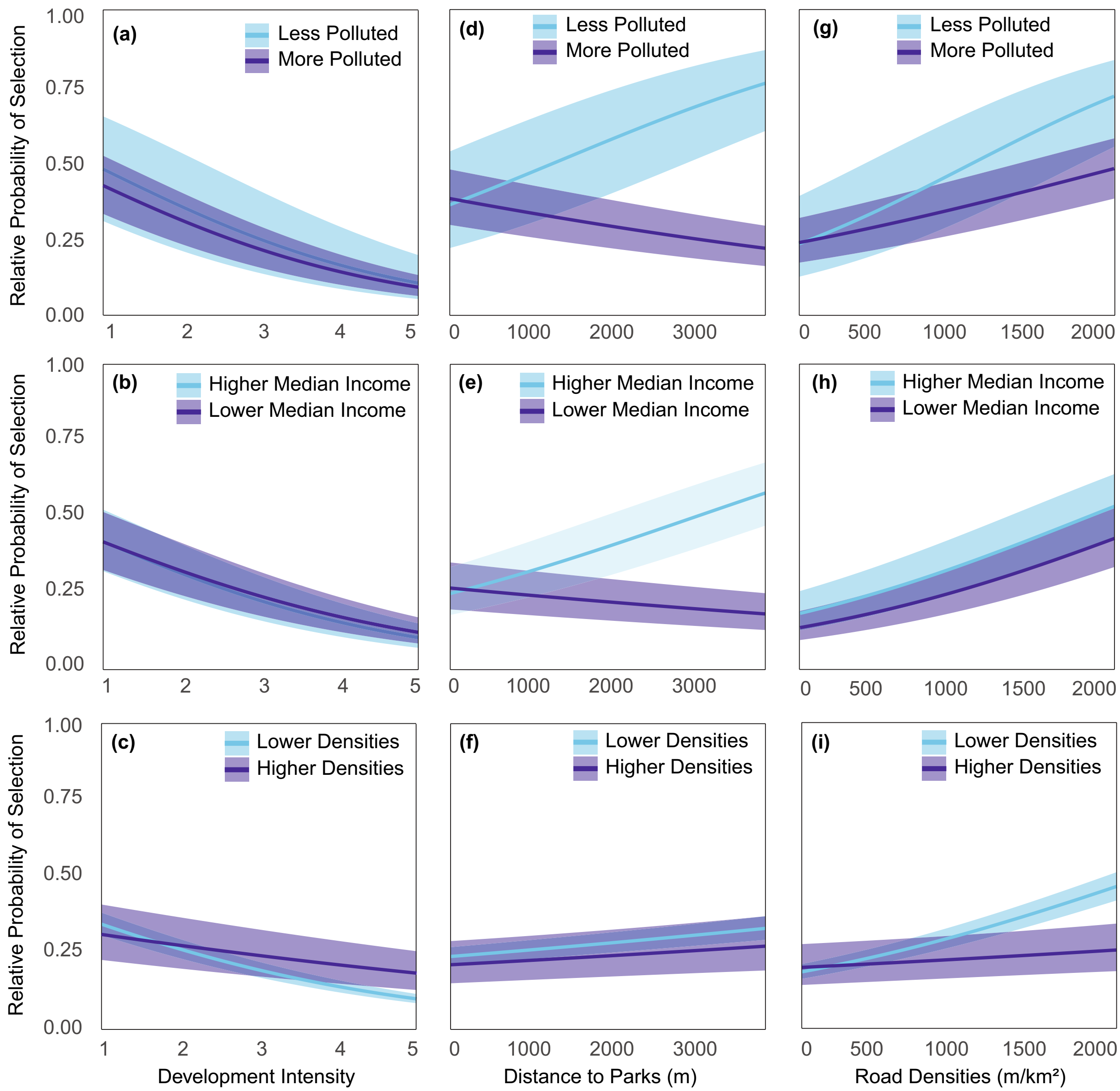

FIGURE 5 | Relative probability of selection for three variables: Development intensity (a–c), distance to parks (d–f), and road density (g–i) for coyotes with home ranges in locations of higher and lower pollution burden (a, d, g), median income (b, e, h) and population density (c, f, i), as derived from resource selection function models.

importance = 0.18), pollution burden (0.15) and distance to golf courses (0.09). The global model with interaction terms (Table S9) showed strong selection against pollution burden ($\beta = -0.357$, 95% CI = -0.692: -0.022, $p = 0.037$), building density ($\beta = -0.185$, -0.289: -0.081, $p = 0.0004$), population density ($\beta = -0.160$, -0.268: -0.052, $p = 0.004$) and development intensity ($\beta = -0.434$, -0.565: -0.303, $p < 0.0001$). Coyotes' steps were longer in areas with higher NDVI ($\beta = 0.032$, 0.007:0.057, $p = 0.012$) and shorter in areas with higher median income ($\beta = -0.022$, -0.04: -0.004, $p = 0.022$).

4 | Discussion

Our study demonstrated that movements and habitat selection by urban coyotes can best be described by a combination of societal and ecological factors. This runs contrary to prior movement studies that have solely examined ecological landscape features and aligns well with recent studies suggesting that we should consider societal elements when examining and planning for wildlife landscape permeability, connectivity and restoration (Ghoddousi et al. 2021; Williamson et al. 2023; Wilkinson et al. 2024).

4.1 | Home Range and Movement Characteristics

Our analysis of home range and movement characteristics confirmed the influence of anthropogenic burden on urban coyotes. Coyotes living in more polluted, densely populated areas had significantly larger home ranges. Of all measures of burden, human population density was the strongest predictor of coyote home range size. The latter aligns with previous findings that coyote occupancy and behaviour are influenced by human presence and activity (Gallo et al. 2022; Gehrt et al. 2009; Murray and St. Clair 2015; Nickel et al. 2020). Meanwhile, urban wildlife in more polluted areas may experience more dispersed resources and frequent disturbances (Murray et al. 2019; Soulsbury and White 2015). Daily displacement, a measure of exploration (e.g., Hertel et al. 2019), was significantly higher for coyotes in more burdened areas (i.e., regions of lower NDVI, lower income, and higher population density, pollution burden, development intensity and road density). Mean step length followed the same pattern, with the addition of significantly longer step lengths during the drier season, though the latter difference was small. However, coyotes travelling longer distances per step in the drier season support evidence demonstrating seasonal variation in coyote movement due to altered resource availability (Bateman and Fleming 2012; Poessel et al. 2017). Larger home ranges, displacement values and step lengths suggest higher energetic demands for coyotes in more burdened environments. Consuming more human subsidies may be a coping strategy to deal with increased energetic costs, though there may be trade-offs, such as ingesting foods with lower nutritional value or bringing individuals into conflict with people (Murray, Cembrowski, et al. 2015; Murray and St. Clair 2017). Future research quantifying the energetic costs of individuals across social–ecological gradients may provide insight into how divergent stable behavioural strategies can be locally adapted.

4.2 | The Relative Influence of Societal, Infrastructural and Ecological Covariates on Coyote Movement

Overall, models containing only societal covariates tended to perform better than models containing only ecological and linear infrastructure covariates. Urban features linked to societal characteristics, such as pollution, wealth and human population density, thus may be key predictors for urban wildlife movement. This finding builds upon existing evidence of the influences of these societally driven features on wildlife biodiversity, occupancy and survival (Leong et al. 2018; Magle et al. 2021; Saaristo et al. 2018). Additionally, across all data subsets, models that integrated societal, ecological and infrastructural characteristics performed better than siloed models. Together, these findings provide some of the first empirical evidence to support recent frameworks proposing the importance of considering social–ecological landscape suitability for wildlife connectivity (Ghoddousi et al. 2021; Williamson et al. 2023).

4.3 | Social–Ecological Predictors of Coyote Resource and Step Selection

4.3.1 | Selection by all Sampled Coyotes

Across all movement metrics and data subsets, development intensity was the most influential covariate for coyote habitat selection and movement. Overall, coyotes selected for vegetation greenness, road density, rivers, flood channels and railways. Coyotes selected against income, building density, population density, pollution burden, development intensity, lakes, golf courses and cemeteries. The latter two, along with relatively lower selection for parks in our model, run counter to studies that have shown coyotes and other urban wildlife select for large urban green spaces (Wurth et al. 2020), though this tendency may be reflected in our coyotes' selection for vegetation greenness and railways. In arid regions (e.g., southern California), not all parks are vegetatively green. Additionally, urban spaces can contain many small, ungazetted vegetated areas along with potential habitats alongside railways and rivers (Douglas 2020). However, within our step-selection models, golf courses emerged as an important covariate, indicating potential fine-scale movement preferences towards golf courses, even if coyotes in our study spend relatively little time within these spaces.

Paradoxically, selection for road density and against development intensity showed the strongest effects (Figure 4). While high development intensity is often correlated with more human presence and disturbance for wildlife (i.e., Lendrum et al. 2017), roads may have more nuanced impacts on wildlife by allowing them to move more easily through complex landscapes (Abrahms et al. 2016; Hill et al. 2020). Road-dense areas may also be associated with key resource opportunities, such as roadkill and roadside habitat patches that potentially harbour mammalian prey (e.g., Bellamy et al. 2001; Kent et al. 2021; Meunier et al. 1999).

Contrary to our hypotheses, coyotes select against wealthier areas and move more slowly in less wealthy areas. While wealthier urban areas may have preferable ecological resources like natural prey items and refugia (Leong et al. 2018; Schell et al. 2020), wealthier neighbourhoods also tend to harbour more unfavourable and separationist views on coyotes than others (Niesner et al. 2024; Wilkinson, Caspi, et al. 2023). Coyote encounters, human–coyote conflicts, hazing and support for lethal control of coyotes have all been found to be more likely in wealthier areas (Draheim et al. 2019; Wilkinson, Caspi, et al. 2023; Wine et al. 2015). Additionally, under California state law, residents can hire a trapper to remove coyotes from their communities, which is not uncommon in southern California. Combined with the wealth-linked tendency towards coyote intolerance, the high costs of hiring a trapper (N. Quinn, pers. comm.) may mean that coyotes are being more frequently trapped in wealthier areas, potentially influencing coyote habitat selection.

4.3.2 | Differences Between More Burdened and Less Burdened Home Ranges

The degree of anthropogenic burden altered habitat selection. Coyotes with more burdened home ranges demonstrated stronger selection against population density, building density, and development. Coyotes in more burdened regions may be more acutely affected by these societal factors, influencing the strength of selection against these features. Unexpectedly, coyotes living in locations of higher human population densities selected for higher pollution burden, and for those living in lower-income areas, selection against pollution burden was weaker than in higher-income areas. In lower-income areas, unsecured refuse may be more common due to reduced quality and quantity of municipal services (Sprague et al. 2022). Underserved regions that are subject to higher pollution burden may also have higher populations of synanthropic rodents and other prey (Childs et al. 1991; Murray et al. 2024). Additionally, in Los Angeles, higher population densities are correlated with increased trash generation (Liang et al. 2019). Human refuse, synanthropic rodents and outdoor cats are coyote attractants, especially in urban areas where native wild prey may be less accessible (Baker and Timm 1998; Bucklin et al. 2023; Poessel et al. 2017; Sugden et al. 2021).

All burdened coyotes exhibited stronger selection for more vegetated areas (i.e., higher NDVI) and for road densities than did less burdened coyotes. Coyotes in lower-income and more population-dense locations also selected more strongly for railways than did their less-burdened counterparts. Though roads may operate as dispersal and movement barriers for wildlife (Riley et al. 2003), roads, railways and other linear infrastructure may also provide habitat and connectivity for wildlife living in urban and peri-urban spaces (Barrientos et al. 2019; Fletcher 2009; Maclagan et al. 2019). Our study indicates that vegetated habitat, roads and railways may be particularly important for urban coyotes in places that are more anthropogenically burdened and provides further evidence regarding the diverse effects of societally driven risks and burdens on urban wildlife (e.g., Murray et al. 2019; Schell et al. 2020). These results also point to the potential disproportionate impact of linear infrastructure for improving wildlife landscape permeability in more burdened or complex contexts (Niesner et al. 2021; Popp and Hamr 2018).

Diverging from our global results, coyotes with more polluted home ranges and those with more highly populated home ranges selected for parks, unlike less-burdened coyotes. Because public parks often contain concentrated resources such as potential den sites and prey, urban coyotes are known to frequent public parks regardless of the human activities within (Gehrt et al. 2013; Wilkinson, Caspi, et al. 2023). Coupled with our broader results showing that coyotes typically selected against golf courses and cemeteries, it is possible that coyotes living in more burdened regions are more willing to spend time in parks despite the risks of human activity. Parks may differ from golf courses and cemeteries in two key ways. First, while parks vary in spatiotemporal patterns of human activity, golf courses and cemeteries have constant, predictable human activity due to visitors and staff. Golf courses and cemeteries are also consistently maintained, including landscaping choices that may thin any available bushy vegetation which coyotes can use for cover (i.e., Nooten et al. 2018). Finally, due to variations in management and use, parks are more likely to contain persistent potential anthropogenic resources (i.e., trash) that could be attractive to coyotes and their prey (Sugden et al. 2021). Anthropogenic food removal by urban wildlife in parks also positively correlates with vegetation cover (Morales-Vasquez et al. 2018), which coyotes strongly selected for across all models. Coyotes tend to spatiotemporally partition themselves from human activity (Murray and St. Clair 2015), so in Los Angeles they are likely avoiding exposure to people by also prioritising non-gazetted green spaces, as mentioned earlier.

4.3.3 | Urban Complexity and Coyote Movement

To contextualise our results, it is important to consider that some of the coyote movements we observed may reflect decision-making at a finer spatial scale than our analysis could capture. For example, societal covariates such as pollution burden and income were collected at the census tract level, and our movement data were also collected at an intermediate scale. Further, cities are highly complex landscapes, likely requiring urban coyotes—and other urban wildlife—to thread the needle by selectively navigating areas that minimise risk while capitalising on accessible resources, both anthropogenic and natural. Future research should focus on fine-scale wildlife movement in relation to the myriad localised attractants, deterrents and barriers present in cities to fully understand the nuanced decisions made by urban wildlife in these complex environments.

4.4 | Utility of These Approaches for Improved Urban Wildlife Ecology and Management

Most prior studies regarding the effects of within-city social–ecological heterogeneity on wildlife have focused on species distribution and biodiversity (Magle et al. 2016) and non-linear infrastructure (Haight et al. 2023), leaving a significant gap in our understanding of wildlife movements through these societally driven landscapes. Though behaviourally flexible species can successfully live alongside people, these resilient species may exhibit key across- and within-population divergences in their responses to anthropogenic risks and rewards on the landscape (Breck et al. 2019; Murray and St. Clair 2015; Wilkinson et al. 2024). Our study demonstrates that environmental health, wealth and linear infrastructure are key predictors of urban coyote movement and habitat selection. Further, the effects of these features on coyotes differ depending on variations in the city's social–ecological gradient.

Future studies should make it standard practice to assess the relative importance of societal covariates on wildlife landscape permeability, particularly for wildlife that are more likely to interact with or live alongside people. Social–ecological modelling should reflect species' unique interactions with human-altered environments. For instance, while urban-adapted coyotes in our study respond strongly to pollution and development intensity, other species, such as large carnivores in less urbanised settings, may require different societal predictors (e.g., hunting prevalence or political attitudes toward rewilding efforts). Such flexible approaches are especially pressing considering the global spatial overlap of people and wildlife is projected to significantly increase by 2070 due to the intensification of human population densities (Ma et al. 2024). Similarly, scientists and wildlife managers are also increasingly concerned about climate change exacerbating human–wildlife conflicts through societal and ecological pathways (Abrahms et al. 2023). Finally, our study has demonstrated the nuanced influence of linear infrastructure on urban coyotes, confirming previous anecdotal evidence that coyotes utilise linear features for traversing and surviving within urban landscapes (Fletcher 2009; Niesner et al. 2021). In the future, it will be key to reimagine conservation perspectives regarding the potentially positive roles of linear infrastructure for wildlife landscape permeability, especially in places of higher anthropogenic development (Douglas 2020; McInturff et al. 2020; Niesner et al. 2021; Wilkinson, Jones, et al. 2023). Overall, with increasing data availability and collaborative capacity, these integrated approaches will provide the nuanced information needed to design healthy, equitable shared landscapes in an urbanising world.

Author Contributions

C.E.W. conceived the ideas, designed methodology, led analyses and visualisations and led writing. N.Q. coordinated and provided resources for field research, which was aided substantially by C.E. C.J.S. aided in conceiving ideas, aided in creating visualisations and contributed to revisions. All authors discussed, edited and approved the final version.

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Data Availability Statement

Data, metadata and R Code necessary to reproduce model results, analyses and figures are available in the Dryad Digital Repository (https://doi.org/10.5061/dryad.15dv41p5j) and Zenodo (https://doi.org/10.5281/zenodo.14597737). See the 'Description of the data and file structure' section of the associated metadata for a full list of data sources.

Peer Review

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Supporting Information

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Patterns of exposure of coyotes to anticoagulant rodenticides in California, USA

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Abstract

Secondary exposure to anticoagulant rodenticides (ARs) causes the death of mammalian predators and scavengers directly and indirectly through sublethal effects that reduce fitness. Poisoning by ARs has been proposed to be a significant source of mortality for coyotes (*Canis latrans*), a medium-sized canid that thrives at the urban–wildland interface and may prey upon species targeted by pest control efforts. However, only 1 study, with a relatively small sample size, documented the prevalence of AR exposure in a free-roaming coyote population. We quantified AR exposure in carcasses of 365 urban and suburban coyotes in southern California, USA, and compared AR prevalence and hepatic residue concentrations to those of 120 rural coyotes collected elsewhere in the state. For urban coyotes, we also examined demographic (sex, age, body mass, cause of death) and environmental factors (season, degree of urbanization, diet) that could influence the number of AR compounds and residue concentrations. Nearly all urban coyotes (98.1%) were exposed to at least 1 AR, compared to 41.7% of rural coyotes, and most individuals had residues of both first-generation (FGAR) and the more potent second-generation (SGAR) compounds, often at concentrations exceeding thresholds considered lethal in other mammals. Anticoagulant rodenticide exposure of urban coyotes did not vary by sex or season, but the number of compounds detected increased with mass, and adults tended to have residues of more compounds and at higher concentrations than juveniles, suggesting repeated and chronic exposure. Livers of road-killed coyotes had higher SGAR concentrations than those euthanized as nuisance animals, which had lower SGAR concentrations in intensively urbanized areas. Concentrations of SGAR and FGAR residues were highest in suburban areas with natural open space and lower intensity development, and stable isotope values suggested that these coyotes were exposed to ARs by consuming commensal rodents and possibly mesocarnivores. In contrast, coyotes from urbanized areas had lower AR concentrations possibly because less AR is applied in these settings or because coyotes consumed foods with less AR, such as domestic cats and anthropogenic resources. Although some coyotes showed evidence of internal bleeding consistent with AR toxicosis and were in poorer body condition, there was no clear relationship between the extent of hemorrhaging and AR exposure. Despite statewide legislation to restrict their use and mitigate non-target impacts, AR exposure remains ubiquitous in southern California and represents another stressor of urban life to which coyotes have successfully adjusted, making them a potential sentinel of environmental contamination.

KEYWORDS

anticoagulant rodenticide, California, *Canis latrans*, exposure pathways, lethal nuisance control, roadkill, rural exposure, stable isotope analysis, sublethal effects, urbanization

Commensal and pest rodents cause hundreds of millions of dollars of economic damage annually and risk human health through the spread of diseases and allergens and poor sanitation (Meerburg et al. 2009, Ahluwalia et al. 2013, Diagne et al. 2023). These rodents are also invasive in many natural systems, especially islands, where they contribute to declines and extinction of native species (Howald et al. 2007). Chemical toxicants, particularly anticoagulant rodenticides (ARs), are commonly used to control rodent pests. Although appropriate baiting strategies can reduce broader contamination (Jacob and Buckle 2018), exposure and subsequent mortality of non-target species continue to be major environmental concerns. Wild granivorous and omnivorous species (e.g., rodents, songbirds) may consume poisoned baits directly (primary exposure), whereas predatory and scavenging mammals and birds are exposed secondarily by eating contaminated invertebrates or dead and moribund prey, resulting in accumulation of ARs in their tissues (Rattner et al. 2014).

Anticoagulant rodenticides act by binding to and inactivating vitamin K epoxide reductase (VKOR), impairing blood clotting, and resulting in fatal hemorrhaging and toxicosis (Rattner et al. 2014). These are typically classified as first-generation (FGARs) or second-generation (SGARs) compounds, which differ in their potency and persistence, both in the body and the environment (Erickson and Urban 2004). First-generation compounds include warfarin and coumatetralyl and are often grouped with intermediate-generation compounds such as diphacinone and chlorophacinone (Rattner and Mastrota 2018). Second-generation compounds, including brodifacoum, bromadiolone, difethialone, and difenacoum, were developed in response to decreasing effectiveness of FGARs, in part due to development of genetic resistance (Jacob and Buckle 2018). In general, FGARs are considered to be less toxic, requiring multiple feedings to deliver a lethal dose, whereas SGARs are more toxic, with lower LD_{50} values and longer half-lives in the liver, the organ where VKOR expression is greatest and that is usually tested for AR residues (Rattner and Harvey 2021). Although a single meal of SGAR-laden bait may be fatal, the time lag between consumption and toxicosis may cause an individual rodent to consume multiple meals, resulting in a super-lethal concentration of ARs in its body. Predatory and scavenging wildlife that consume these dead and dying prey or that consume many poisoned individuals may be exposed to large quantities of ARs (López-Perea and Mateo 2018), causing or contributing to mortality in raptors, owls, and mammalian carnivores (Rattner et al. 2014, Elliott et al. 2016). However, the extent to which ARs are metabolized and accumulate in tissues and cause systemic effects and mortality varies considerably within and among species that have been studied in captivity, and are unknown for most non-target species in the wild (Rattner and Harvey 2021).

In the United States, application of ARs has been restricted to reduce risk of non-target exposure, with FGARs used in rural and agricultural settings and urban and suburban areas, and SGARs largely restricted to control of commensal rodents in and near buildings and to protect infrastructure and public health and safety (Rattner et al. 2014), although both are used for invasive species eradication. California is one of the most restrictive states in terms of legal use of ARs, with recent legislation to ban most uses of SGARs in 2021 (California Assembly Bill [AB] 1788) and diphacinone (AB1322), effective in 2024. Recent restrictions have been spurred by evidence of AR exposure of raptorial birds and, especially, top predators such as mountain lions (*Puma concolor*) and bobcats (*Lynx rufus*) in southern California (Riley et al. 2007, Serieys et al. 2015), although population impacts are not known.

Coyotes (*Canis latrans*) are the most common, medium-sized carnivore throughout much of North America and as habitat and dietary generalists that are tolerant of human development, have successfully adjusted to urban and suburban environments (Gehrt and Riley 2010). Despite the great potential for coyotes to be exposed to ARs, only a single study has estimated the prevalence of AR exposure in a free-roaming coyote population, and the few other unpublished incident reports are scattered and based on small sample sizes. Summarizing research from the Santa Monica Mountains in southern California, Moriarty et al. (2012) reported that livers of 83% (20) of 24 coyotes tested between 1996 and 2004 contained residues of ≥1 AR. They attributed 14 fatalities to AR toxicosis (representing 30% of known-cause mortalities); all were exposed to SGARs and 4 were exposed to both SGARs and FGARs. Erickson and Urban (2004) reported liver residue concentrations in 22 coyotes that were exposed to ARs, including many of the coyotes tested for the Santa Monica Mountains study referenced above, 10 coyotes from northern California (also summarized in Hosea [2000]), and 1 from New York. Poessel et al. (2015) found SGAR residues in the livers of all 5 coyotes tested from outside Denver, Colorado, and attributed the deaths of at least 2 individuals to AR poisoning. Way et al. (2006) described an instance in which 3 coyotes were intentionally poisoned with brodifacoum (an SGAR) in Massachusetts, indicating primary exposure is also possible.

We marshaled data and evidence from a variety of sources to investigate patterns and pathways of AR exposure in 365 coyotes in southern California and 120 coyotes collected in rural and agricultural areas of the state. We predicted that because of the wide variety of AR compounds used in urban and suburban settings and the mix of professional and private rodent control efforts, urban coyotes would be exposed to more AR compounds and have higher liver SGAR residues than coyotes from rural areas. We also predicted that adult coyotes would be exposed to more AR compounds and have higher residue concentrations than juveniles because they have consumed more prey over their lives, including prey exposed to ARs. We also expected that AR exposure would be inversely related to the intensity of urban development, reflecting higher use of rodenticides in suburban areas with single-family homes and larger yards that are closer to open space (Morzillo and Schwartz 2011). Finally, we predicted that AR exposure would be higher in coyotes consuming prey that are the targets of rodenticide applications versus those dependent on natural or human-provisioned foods.

STUDY AREA

We opportunistically obtained carcasses of coyotes from urban and rural areas of California, USA. We collected urban carcasses from Los Angeles County and Orange County, in locations that were characterized as urban or suburban, although coyotes regularly moved between areas of human development and more natural areas, including private and government-owned parks, water conveyance infrastructure, and protected open space (Riley et al. 2003). The Los Angeles-Long Beach-Anaheim metropolitan statistical area (12,580 km^2) had a population of 13.2 million people (2020 Census; www.census.gov). The basin has a Mediterranean climate, with warm, dry summers and mild, wet winters (Cleland et al. 2016). Most of the 46 cm of average annual precipitation falls as rain between November and April, although there is much inter-annual variability. The natural vegetation is characterized as coastal sage scrub and chaparral mixed with riparian woodlands and grasslands, although most areas have been transformed by human development and landscaped with ornamental plants and turf.

We collected carcasses of coyotes from rural and agricultural areas of 19 other California counties. Climate and vegetation varied greatly across these counties, which spanned the length of the state and nearly 10° of latitude. Most coyotes were from agricultural counties in the Central Valley or the surrounding foothills, in areas dominated by irrigated cropland, non-native grasslands, or oak or mixed-conifer woodlands. Some were from desert scrubland areas in the southern part of the state. Coyotes were subjectively characterized as rural by the individuals who collected them (see below).

METHODS

Our sample of urban coyotes consisted of 501 coyotes killed by vehicles (roadkill) or by professional trappers and animal control agents (euthanized). We took liver samples from 365 of these coyotes (256 euthanized, 109 roadkill), killed between July 2015 and January 2020 (Figure 1). We also obtained liver samples from 120 coyotes euthanized between March 2019 and August 2021. Sample size differed among the 19 rural counties: we collected between 7–20 individuals from 8 counties (Madera [7], Amador [9], Sonoma [10], Fresno [10], Modoc [12], San Diego [13], El Dorado [14], Kern [20]) and between 1–5 individuals from 11 counties (San Luis, Riverside, Kings, Colusa, Butte, Placer, Humboldt, Solano, Imperial, Calaveras, Mendicino). We recorded sex, age class (adult and juvenile, including young-of-year), and evidence of conspicuous sarcoptic mange (*Sarcoptes scabiei*) infestation (hair loss, skin lesions). For urban coyotes, we also recorded body mass (in kg), cause of death (roadkill, euthanized), season of collection (wet: Nov–Apr; dry: May–Oct), and location (latitude, longitude). When precise location information was not available, we used the intersection of the nearest cross streets. We did not have specific location data for rural coyotes.

Sample processing

We sent livers to the Texas A&M Veterinary Medical Diagnostic Laboratory (College Station, Texas) to test for residues of 7 ARs using a dispersive solid-phase extraction procedure (QuEChERS method; Vudathala et al. 2010), with chemical analysis using liquid chromatography-mass spectrometry (LC-MS). The lab analyzed extractions for the residues of 3 FGARs (diphacinone, chlorophacinone, warfarin) and 4 SGARs (brodifacoum, bromadiolone, difethialone, difenacoum). Because liver samples were analyzed at different times, the limits of detection (LOD) and quantitation (LOQ) varied. Limit-of-quantitation values were 5 or 10 ng/g for all compounds except chlorophacinone, for which quantitation limits were 5, 10, or 20 ng/g. We assigned samples with concentrations between the LOD and LOQ a residue value of half the quantitation limit. Although this method of addressing left-censored data has been criticized and alternatives have been proposed (Helsel 2009, Zoffoli et al. 2013), we took this approach because relatively few detections were below the LOQ ($\bar{x}$ = 7.3%) and because of its simplicity. Moreover, Zoffoli et al. (2013) reported that this approach had low bias for datasets with high geometric standard deviations (GSD close to or >3.0), which was the case for our concentration values ($\bar{x}$ GSD = 3.4; range = 2.6–4.0).

We used 2 sets of variables to describe exposure to ARs: counts of the numbers of FGARs, SGARs, and total AR compounds detected in each coyote; and summed concentrations of FGAR and SGAR compounds (ΣFGAR, ΣSGAR)

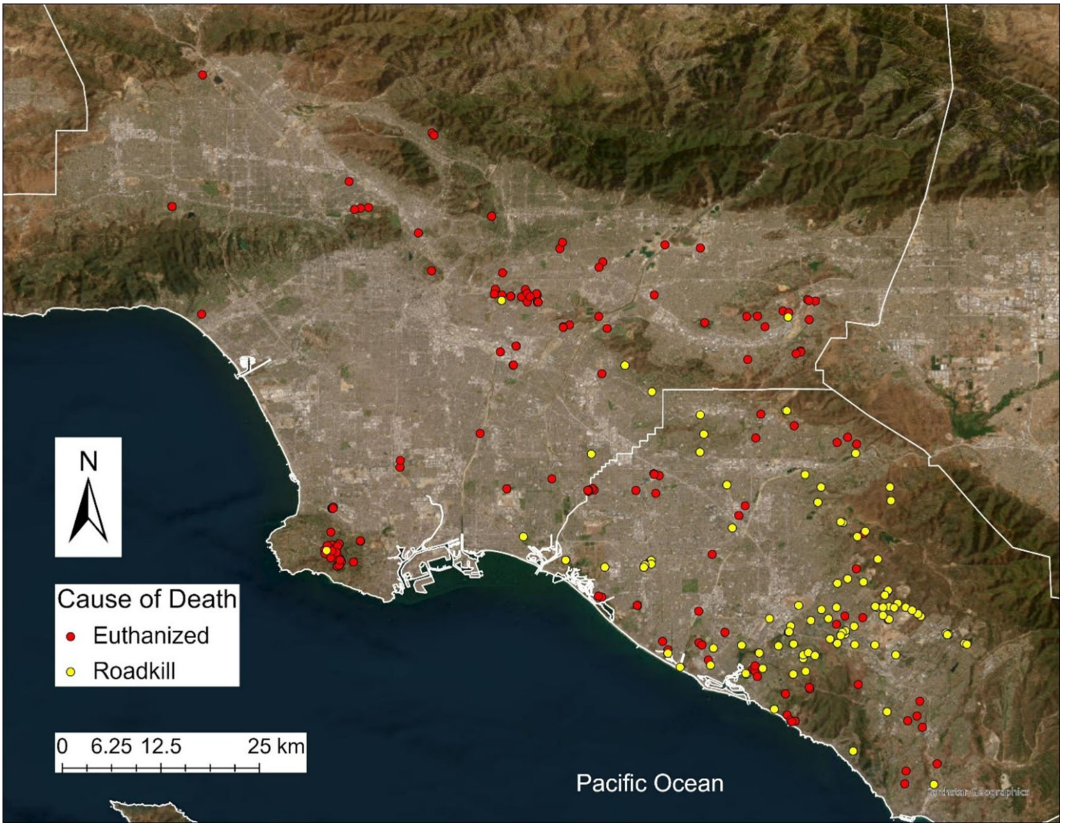

FIGURE 1 Locations of euthanized and road-killed coyotes tested for exposure to anticoagulant rodenticides in Los Angeles County and Orange County, California, USA, 2015–2020. Locations of 2 coyotes from the Antelope Valley, north of the San Gabriel Mountains at the top of the image, are not shown. White lines show the county borders. Map created in ArcGIS Pro (version 3.3; Esri).

for coyotes with measurable residues (≥LOQ). We included detections of warfarin (24 coyotes) and difenacoum (5 coyotes) in counts of the number of FGAR and SGAR compounds, respectively, and in the total number of ARs but did not include warfarin or difenacoum residues in ΣFGAR and ΣSGAR values because concentrations were consistently very low (20/24 warfarin and 4/5 difenacoum concentrations were below the LOQ). For both FGARs and SGARs, the individual compounds have similar molecular weights and roughly similar potency (Rattner and Harvey 2021), making summing them reasonable. In laboratory rodents, hepatic half-lives of the FGARs we included range from 3 days to 35.4 days, whereas those of SGARs vary from 28.5 days to 350 days (Horak et al. 2018); there are no comparable persistence data for dogs or other canids.

Ecological correlates of rodenticide exposure

Following Bucklin et al. (2023), to investigate landscape characteristics around urban coyote locations, we generated 1,500-m-radius buffers (7-km^2) around GPS coordinates using ArcGIS Pro (version 3.3; Esri, Redlands, California, USA). We used the 2016 National Land Cover Database to estimate percent cover of 6 land cover variables (high-, medium-, and low-intensity development, altered open space, shrub, grass) in buffers. We also estimated building density (buildings/km^2) using county building footprint data. We transformed all variables to a uniform mean and standard deviation (z-score) prior to analysis. We used principal components analysis (PCA) to reduce the number of variables and create composite variables that described the extent and type of urbanization in the landscape around coyote locations.

We collected muscle tissue of 149 coyotes from Los Angeles and Orange County, 130 of which were tested for ARs, to assess long-term, assimilated diet using stable carbon (C) and nitrogen (N) isotope analysis. In terrestrial systems, variation in the ratio of heavy and light C stable isotopes reflects relative dietary contributions of C_3 and C_4 or crassulacean acid metabolism (CAM) plants and the consumers that feed upon them (Ben-David and Fleharty 2012). Anthropogenic food sources derived from corn, a C_4 plant, also tend to have higher (enriched) C isotope ratios, making the C isotope ratio a potentially useful measure of consumption of human-associated foods in C_3 plant-dominated ecosystems (Newsome et al. 2015). In addition to providing dietary source information, the N isotope ratio typically increases with trophic level, with carnivores usually having more enriched N isotope ratios than omnivores and herbivores in the same system (Ben-David and Fleharty 2012).

We removed a sample of masseter (jaw) muscle from each carcass, placed it in a vial with 95% ethanol, and kept it in a conventional laboratory freezer (−20°C) until preparation. We dried, homogenized, and shipped samples to the University of California Davis (UCD) Stable Isotope Facility (Plant Sciences). The lab analyzed samples using a PDZ Europa ANCA-GSL elemental analyzer interfaced to a PDZ Europa 20-20 isotope-ratio mass spectrometer (Sercon, Cheshire, United Kingdom). They calculated stable isotope ratios, expressed using delta (δ) notation in parts per mille (‰) as:

$$\delta X = \left(\frac{R_{sample}}{R_{standard}} - 1\right) \times 1{,}000,$$

where X is ^{13}C or ^{15}N and R is the corresponding ratio of heavy ^{13}C to light ^{12}C or ^{15}N to ^{14}N. The $R_{standard}$ values are based on international standards for $\delta^{13}C$ (Vienna PeeDee Belemnite [VPDB]) and $\delta^{15}N$ (atmospheric N_2). The long-term standard deviation at the facility is 0.2‰ for ^{13}C and 0.3‰ for ^{15}N.

We compared $\delta^{13}C$ and $\delta^{15}N$ values of coyotes to those of potential food items collected from the region. We collected all prey samples opportunistically in suburban and urban areas in Los Angeles County and Orange County area between May 2017 and January 2024. We collected plant samples by hand. For domestic cats, clinics conducting spay and neuter programs donated ear tissue. We obtained commensal rodents through trapping and from pest control operators that donated carcasses. For all other mammals, we took muscle tissue from carcasses (usually masseter) of roadkills or those donated from pest control operators and agencies. We obtained 3°C_4 and CAM plant samples: seeds of unidentified cactus species, unidentified cholla species, and commercial silo millet. We collected 19°C_3 plants: fruits, berries, and seeds of ornamental plants including avocado, lime, orange, fig, palm, Japanese mock orange, unidentified ornamental shrubs, and sunflower seeds. We obtained 22 anthropogenic food samples: dry and wet cat and dog food (11 samples) and retail fast food, including beef hamburger, chicken, hot dog, french-fried potatoes, and corn tortilla (11 samples). We obtained 67 samples of commensal rodents: (roof rat [*Rattus rattus*] and house mouse [*Mus musculus*]), 14 samples of wild rodents (fox squirrel [*Sciurus niger*], California ground squirrel [*Otospermophilus beecheyi*], valley pocket gopher [*Thomomys bottae*], California vole [*Microtus californicus*], western harvest mouse [*Reithrodontomys megalotis*], woodrats [*Neotoma* spp.], deer mice [*Peromyscus* spp.]), 6 samples of desert cottontails (*Sylvilagus audubonii*), 6 samples of mesocarnivores (striped skunk [*Mephitis mephitis*], Virginia opossum [*Didelphis virginiana*], raccoon [*Procyon lotor*]), and 343 samples of domestic cats (*Felis catus*). We dried plant samples (seeds, fruits) and stored animal tissues (muscle) in 95% ethanol in a conventional freezer. We prepared prey samples as described above for coyote muscle samples and sent them for analysis at the UCD facility.

Necropsies and body condition

For a subset of 50 coyote carcasses collected in 2019, we conducted detailed necropsies to seek evidence of internal and subcutaneous hemorrhaging and poor body condition that might be indicative of coagulopathy related to AR exposure. We used 3 measures to assess body condition. First, to describe external condition visually, we assigned each coyote a whole-number rating on a 5-point body condition score (BCS) developed for domestic dogs (American Animal Hospital Association, Lakewood, CO, USA, https://www.aaha.org/wp-content/uploads/globalassets/02-guidelines/weight-management/weightmgmt_bodyconditionscoring.pdf), with each rating point associated with key, palpable changes in fat stores and prominence of bony structures. Second, we calculated the kidney fat index (KFI), an index of total body fat, by removing the right kidney and the surrounding (perirenal) fat and then dividing the mass of the perirenal fat by the mass of the fat-free kidney, expressed as a percentage (Finger et al. 1981). Lastly, we counted the number of helminths in the digestive tract, under the premise that animals in poorer health might have high parasite loads. We removed the intestinal tract and stored it at −80°C for at least 72 hours to kill any infectious eggs and then stored it at −20°C. We then thawed and dissected the intestines and suspended their contents in warm water (40°C) for 30 minutes. After a series of sedimentation and clearing steps to remove excess debris, we washed the final sediment in a 106-µm sieve and removed all helminths. We fixed helminths in alcohol-formalin-acetic acid for 3 days, then placed them in a mixture of 70% ethanol and 5% glycerine for storage. We categorized helminths into major groups using a dissection microscope. For consistency, one author (AM) conducted all necropsies, which were completed prior to AR residue testing.

Because 16 of these coyotes were killed by vehicles and thus suffered injuries that likely caused or contributed to internal bleeding, we restricted our analyses of relationships between evidence of hemorrhaging and AR exposure to the 34 euthanized coyotes. In consultation with a wildlife veterinarian, we developed a 6-point, whole-number qualitative rating to describe the intensity of subcutaneous and internal (pulmonary, thoracic, coelomic) hemorrhaging observed during necropsy that could not be attributed to injury.

Data analysis

We used contingency table analyses and non-parametric tests for univariate and bivariate comparisons. We used generalized linear multiple regression to investigate relationships between measures of AR exposure and demographic and environmental variables. We conducted analyses in R (version 4.2.2; R Core Team 2022) implemented through RStudio (version 2024.4.2.764; RStudio Team 2024) and GraphPad Prism (version 10.2.3; GraphPad Software, Boston, Massachusetts, USA). *A priori*, we constructed a base model consisting of additive main effects of sex, season, cause of death, body mass (in kg; a continuous proxy for age), and the first 2 landscape principal components (PC1, PC2). We used a negative binomial distribution to model counts of the number of AR compounds and quantile regression to identify significant predictors of ΣFGAR and ΣSGAR concentrations. We $\log_{10}$-transformed ΣFGAR prior to analysis and square-root-transformed ΣSGAR and mass. After initial runs of the base model, we removed variables with weak or no evidence of an effect ($P > 0.05$) and re-ran models using only the remaining variables. We investigated interactions between continuous and categorical variables in these subsequent runs to identify evidence of an effect. Because stable isotope data were only available for 36% of coyotes tested for AR exposure, we explored the potential contributions of $\delta^{13}C$ and $\delta^{15}N$ by examining Spearman rank correlations with other factors and by including $\delta^{13}C$ and $\delta^{15}N$ as additive main effects in the final median models for ΣFGAR and ΣSGAR concentrations.

RESULTS

Patterns of exposure

All but 7 of the 365 urban coyotes (98.1%) had detectable liver residues of at least 1 AR (Table 1): 97.3% were exposed to SGARs, 67.4% were exposed to FGARs, and 66.6% were exposed to both AR classes. Diphacinone was

TABLE 1 Frequency of detection (%) and summed concentrations of anticoagulant rodenticide (AR) residues in livers (ng/g) of 365 coyotes from urban Los Angeles County and Orange County compared to 120 coyotes from rural areas of California, USA, 2015–2021.

AR compound type	Urban (*n* = 365)	Rural (*n* = 120)
First-generation (FGAR)		
Diphacinone (%)	65.5	22.5
Chlorophacinone (%)	6.6	7.5
Warfarin (%)	6.6	0.8
All FGAR frequency (%)	67.4	25.8
Median Σ concentration (ng/g)	45.8	41.0
Maximum Σ concentration (ng/g)	1,752.3	1,527.6
Second-generation (SGAR)		
Brodifacoum (%)	95.1	12.5
Bromadiolone (%)	83.3	24.2
Difethialone (%)	72.9	5.0
Difenacoum (%)	1.4	2.5
All SGAR frequency (%)	97.3	30.0
Median Σ concentration (ng/g)	803.2	60.0
Maximum Σ concentration (ng/g)	3,276.2	1,355.3
Both FGAR and SGAR compounds (%)	66.6	13.3
All AR frequency (%)	98.1	41.7

the only commonly detected FGAR (65.5%), whereas 3 SGARs (brodifacoum, bromadiolone, difethialone) were present in most urban coyotes. In contrast, fewer rural coyotes (41.7%) were exposed to ARs (χ^2_1 = 215.2, $P < 0.001$), with FGAR and SGAR compounds detected in similar frequencies (25.8%, 30.0%, respectively; Table 1). Only 13.3% of rural coyotes were exposed to both AR classes. Diphacinone (22.5%) was the most common FGAR in rural coyotes, whereas bromadiolone (24.2%) was the only SGAR detected regularly. Exposure to the number of FGAR compounds, the number of SGAR compounds, and both types of compounds were higher for urban coyotes than for rural ones (chi-square tests, $P < 0.001$). In the 8 counties with ≥7 individuals sampled, prevalence of SGARs ranged from 10.0–70.0% ($\bar{x}$ = 32.8%) and FGARs ranged from 0 to 71.4% ($\bar{x}$ = 25.5%), with the highest combined AR prevalence in 2 Central Valley agricultural counties, Madera (85.7%) and Fresno (70.0%; average AR prevalence in the other 6 rural counties was 33.3%). Coyotes from Modoc (41.7%) and San Diego (38.5%) counties also had relatively high SGAR exposure among rural counties sampled.

Urban coyotes were exposed to many more AR compounds than their rural counterparts. Whereas most rural coyotes (58.3%) were exposed to no ARs and only 19% had residues of 2 or more compounds, livers of urban coyotes usually contained residues of 3 or 4 ARs (71.2%), and 8.8% contained 5 or 6 compounds (Figure 2). Most urban coyotes had residues of 1 (57.6%) or no FGAR compounds (32.6%), whereas 88.8% were exposed to 2 or more SGARs. Combining the lowest (0-1) and highest counts (4-6) to ensure sufficient cell frequencies for analyses, the distribution of total AR compounds across the 4 bins differed between urban and rural coyotes (χ^2_3 = 261.7, $P < 0.001$). We observed similar results for FGAR and SGAR compounds examined separately. Liver ΣFGAR concentrations were similar between urban and rural coyotes (Mann-Whitney U = 4,261, P = 0.834), but ΣSGAR

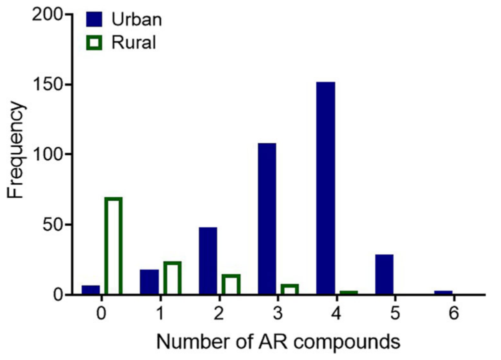

FIGURE 2 Frequency distribution of counts of the number of urban and rural coyotes in California, USA, exposed to different numbers of anticoagulant rodenticide (AR) compounds (first-generation and second-generation ARs combined) in 2015–2021.

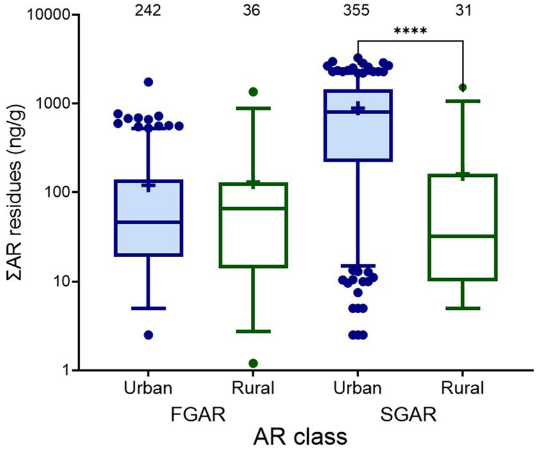

FIGURE 3 Summed residue concentrations (ng/g) of 2 first-generation (FGAR) and 3 second-generation (SGAR) anticoagulant rodenticide (AR) compounds in livers of urban and rural coyotes in California, USA, 2015–2021. Box shows median and 25% and 75% quartiles, whiskers show 5% and 95% confidence limits, and + indicates the mean. Numbers above whiskers are sample sizes. **** denotes a difference between urban and rural coyotes in a Mann-Whitney test, with $P < 0.001$. Only coyotes exposed to FGAR or SGAR are included.

concentrations were much higher in urban coyotes ($U = 1687$, $P < 0.001$; Figure 3). Of the 355 urban coyotes exposed to SGARs, 76.3% had ΣSGAR concentrations >200 ng/g, and 40.8% (145) had ΣSGAR concentrations >1,000 ng/g (Figure S1, available in Supporting Information), compared to 13.9% (5) and 2.8% (1), respectively, of the 36 exposed rural coyotes.

Pooling urban coyotes with low (0-1) and very high (4-6) numbers of ARs, we found no evidence for differences in the number of ARs between males and females ($\chi^2_3 = 4.99$, $P = 0.173$), between wet and dry seasons ($\chi^2_3 = 1.75$, $P = 0.627$), or between euthanized and roadkill coyotes ($\chi^2_3 = 5.03$, $P = 0.170$; Figure 4). Juveniles tended to be overrepresented among urban coyotes with few ARs and underrepresented among those most heavily exposed (Figure 4), and we found only weak evidence for a difference in the number of ARs between juveniles and adults ($\chi^2_3 = 7.30$, $P = 0.063$). We did not find evidence that the number of AR compounds in rural coyotes differed between sexes ($\chi^2_2 = 0.38$, $P = 0.829$; bins of 0, 1, ≥2 ARs) or seasons ($\chi^2_2 = 0.71$, $P = 0.703$). There were too few juvenile rural coyotes (12) to compare ages.

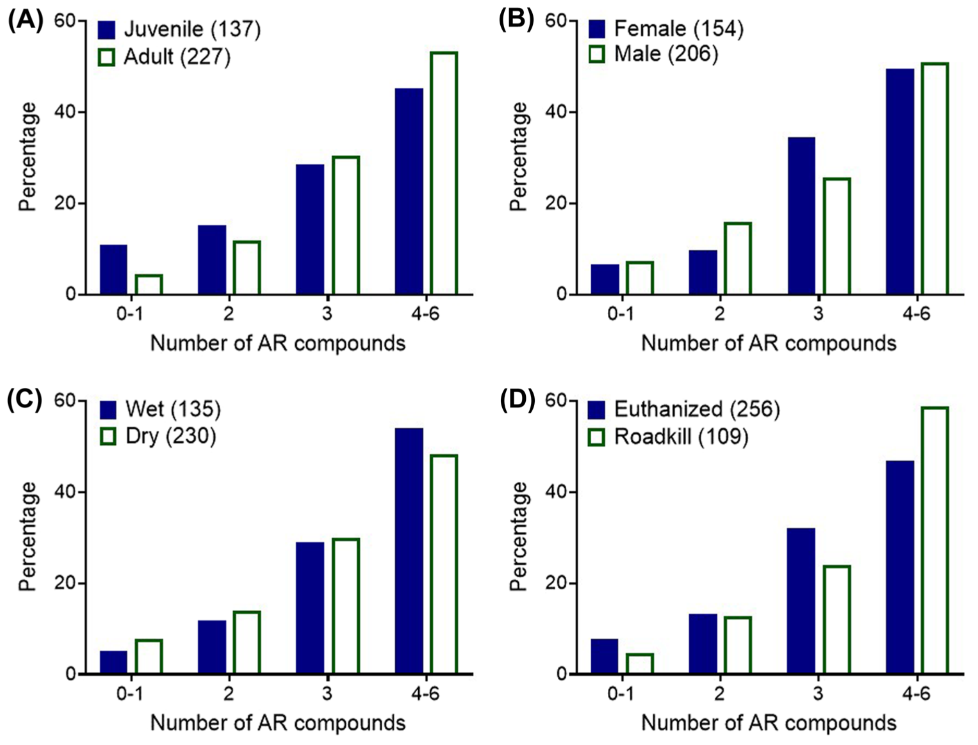

FIGURE 4 Differences in frequency distributions (%) of the number of anticoagulant rodenticide (AR) compounds detected in urban coyotes in southern California, USA, 2015–2020, between A) ages, B) sexes, C) seasons of collection, and D) cause of death. Values in parentheses are sample sizes.

Univariate tests of differences in summed residue concentrations (ΣFGAR, ΣSGAR) between sexes and seasons yielded similar results for urban and rural coyotes: no evidence for an effect (Mann-Whitney tests, $P > 0.117$). The ΣFGAR concentrations of urban coyotes also did not differ between age classes ($U = 6593$, $P = 0.682$) or cause of death ($U = 5710$, $P = 0.317$), but roadkill coyotes had higher ΣSGAR concentrations (median = 1,030.1 ng/g) than euthanized ones (median = 669.0 ng/g; $U = 9{,}476$, $P < 0.001$) and adults tended to have higher ΣSGAR concentrations (median = 749.2 ng/g) than juveniles (623.2 ng/g; $U = 1{,}2903$, $P = 0.058$).

Ecological correlates of rodenticide exposure

Principal components analysis reduced the 7 landscape variables to 2 composite axes with eigenvalues >1, which collectively explained 70.9% of the total variance (Figure 5). The first component (PC1) was positively correlated to percent cover of medium- and high-intensity development and building density ($r > 0.37$) and negatively correlated to cover of altered open space and shrub cover ($r < -0.39$). The second (PC2) was strongly and positively related to cover of grasses and shrubs and high-intensity development ($r > 0.30$), and negatively related to cover of low-intensity development, altered open space, and building density ($r < -0.32$). Thus, we interpreted PC1 to reflect a gradient from low- to moderate- and high-intensity development with high building densities, whereas PC2 distinguished between locations based on whether the surrounding open space was altered and dominated by low-intensity development versus natural open space adjacent to high-intensity development.

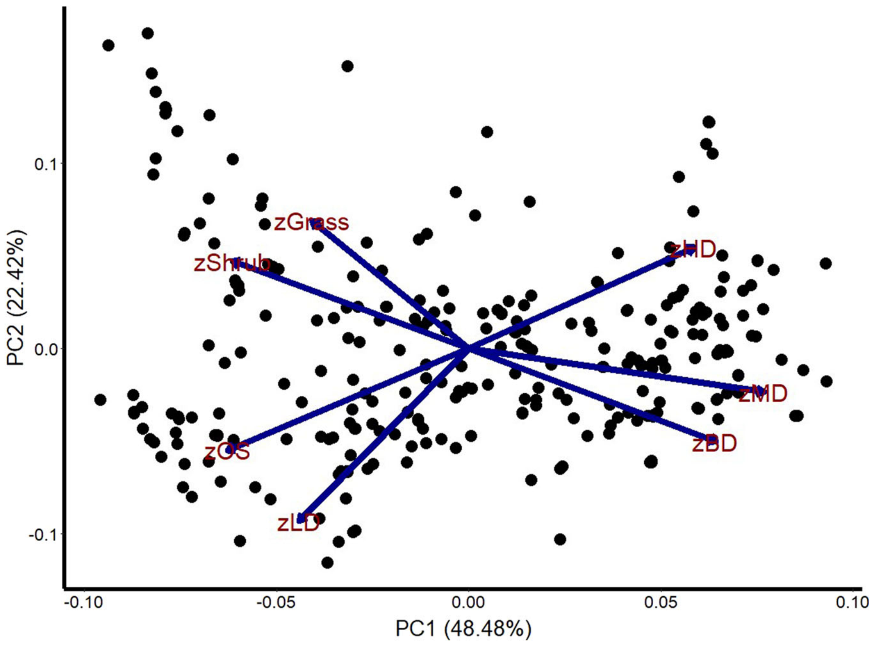

FIGURE 5 Results of principal components (PC) analysis of 7-km^2 buffers around collection locations of urban coyotes in southern California, USA, 2015–2020. Variables were building density (BD); percentage cover of high- (HD), medium- (MD), and low-intensity (LD) development; altered open space (OS); and grass and shrub cover types. We converted measurements to z-scores before analysis.

Of the 6 factors in the base negative binomial model, body mass was the only supported predictor of the number of AR compounds detected (intercept: $\beta_0 = 0.566$, SE = 0.202, $P = 0.005$; √mass: $\beta_1 = 0.194$, SE = 0.061, $P = 0.001$; $\chi^2_{358} = 151.7$, $P = 1.000$; pseudo-$R^2 = 0.07$), with larger coyotes exposed to more compounds (Figure S2, available in Supporting Information). Mean mass of coyotes with ≤2 AR compounds was 9.2 ± 4.0 kg, whereas coyotes with ≥5 AR compounds weighed, on average, 11.1 ± 3.2 kg. Body mass was also the only predictor with evidence for an effect in separate regression models of the number of FGAR and SGAR compounds (results not shown). However, ΣFGAR and ΣSGAR residue concentrations were not correlated with mass ($P \geq 0.542$; Figure S2).

Based on quantile regression, none of the 6 factors included in the initial model were supported predictors of low levels (quantiles 0.1 and 0.3) of ΣFGAR. At higher ΣFGAR concentrations (quantiles 0.5, 0.7, and 0.9), the only variable with strong evidence of an effect in the final models was PC2 (Table 2; Figure 6), which suggests that ΣFGAR concentrations increased with increasing cover of shrub and grass vegetation. At the lowest levels (quantiles 0.1 and 0.3), ΣSGAR concentrations increased with body mass (Table 2) and ΣSGAR was also lower during the wet season than the dry season at the lowest quantile (0.1). At higher quantiles, evidence did not indicate a relationship with mass, but ΣSGAR concentrations were consistently higher in roadkill coyotes than euthanized ones and, overall, decreased with the intensity of human development (PC1). Interactions between PC1 and cause of death, however, revealed a negative relationship between ΣSGAR and PC1 for euthanized coyotes but not for roadkill coyotes (Table 2; Figure 6).

Including all 130 coyotes with both AR residue and stable isotope values, ΣSGAR was negatively correlated with $\delta^{13}C$ (Spearman $r = -0.36$, $P < 0.001$) and positively correlated with $\delta^{15}N$ ($r = 0.23$, $P = 0.010$; Figure 7). Summed residues of first-generation compounds (ΣFGAR) were also positively correlated with $\delta^{15}N$ ($r = 0.33$, $P = 0.001$) but not $\delta^{13}C$ ($r = -0.02$, $P = 0.866$). Analysis revealed $\delta^{13}C$ was positively correlated with PC1 ($r = 0.54$, $P < 0.001$) and negatively correlated with PC2 ($r = -0.22$, $P = 0.009$), but $\delta^{15}N$ was not related to either landscape variable ($P \geq 0.340$). When we added $\delta^{13}C$ and $\delta^{15}N$ to the final median regression model of ΣSGAR, $\delta^{13}C$ was the

TABLE 2 Summary of quantile regression analyses to fit summed first-generation (ΣFGAR) and second-generation (ΣSGAR) anticoagulant rodenticide residue concentrations in livers of urban coyotes in southern California, USA, 2015–2020, as a function of demographic (sex, square-root (sqrt) of mass, cause) and environmental (season, principal components PC1 and PC2) factors. Results shown are the final models containing only variables with $P < 0.05$. Cause (RK) and season(wet) refer to coefficients for roadkill coyotes and wet season samples, which are compared to euthanized coyotes and dry season samples, the reference levels for these categorical variables. The quantile (τ) column shows the percentile of the response variable that was tested in a given model. The last row shows results of regression analysis of ΣSGAR that included the final median model (intercept, cause, PC1, PC1×cause) and stable isotope values ($\delta^{13}C$, $\delta^{15}N$) for 130 coyotes, with $\delta^{13}C$ the only factor remaining with $P < 0.05$. For ΣFGAR, there were no variables in models of quantiles 0.1 and 0.3 with $P < 0.05$ and neither $\delta^{13}C$ nor $\delta^{15}N$ were significant predictors of ΣFGAR when included in the final median regression (intercept, PC2).

Response	Quantile (τ)	GOF[a]	Residual df	Factors	Coefficient	[95%LCL, 95%UCL]	*P*
logΣFGAR	0.5	0.046	235	Intercept	1.69	[1.55, 1.74]	<0.001
				PC2	0.13	[0.025, 0.185]	0.003
	0.7	0.036	235	Intercept	1.99	[1.86, 2.13]	<0.001
				PC2	0.13	[0.035, 0.209]	0.019
	0.9	0.035	235	Intercept	2.54	[2.41, 2.61]	<0.001
				PC2	0.11	[0.020, 0.292]	0.014
sqrtΣSGAR	0.1	0.071	347	Intercept	−8.48	[−15.0, −5.84]	0.002
				Season(wet)	−4.79	[−8.11, −0.56]	0.002
				Sqrt(mass)	5.65	[4.46, 7.76]	<0.001
	0.3	0.077	347	Intercept	−6.70	[−12.60, 6.16]	0.316
				Cause(RK)	11.60	[7.03, 16.70]	<0.001
				Sqrt(mass)	6.28	[2.16, 8.13]	0.002
	0.5	0.082	345	Intercept	25.9	[22.5, 27.9]	<0.001
				Cause(RK)	7.12	[3.56, 11.20]	0.003
				PC1	−2.68	[−3.79, −1.33]	0.001
				PC1 × cause(RK)	4.05	[1.50, 6.32]	0.006
	0.7	0.072	345	Intercept	32.3	[31.1, 35.2]	<0.001
				Cause(RK)	8.21	[2.60, 10.9]	<0.001
				PC1	−1.90	[−2.77,−0.97]	0.001
				PC1 × cause(RK)	3.16	[0.65, 5.24]	0.015
	0.9	0.078	345	Intercept	41.4	[39.1, 43.6]	<0.001
				Cause(RK)	5.24	[3.30, 7.25]	0.001
				PC1	−2.13	[−3.27, −0.42]	0.002
				PC1 × cause(RK)	2.89	[1.75, 4.68]	0.001
sqrtΣSGAR	0.5	0.671	126	Intercept	−37.7	[−78.4, −0.4]	0.035
				$\delta^{13}C$	−3.29	[−5.16, −1.57]	<0.001

[a]The goodness-of-fit (GOF) measure (Koenker and Machado 1999) was estimated as 1 minus the ratio between the sum of absolute deviations in the fully parameterized models and the sum of absolute deviations in the null quantile model (intercept only). The GOF values are lower than coefficients of determination (R^2) from linear regression, which are based on the variance of squared deviations.

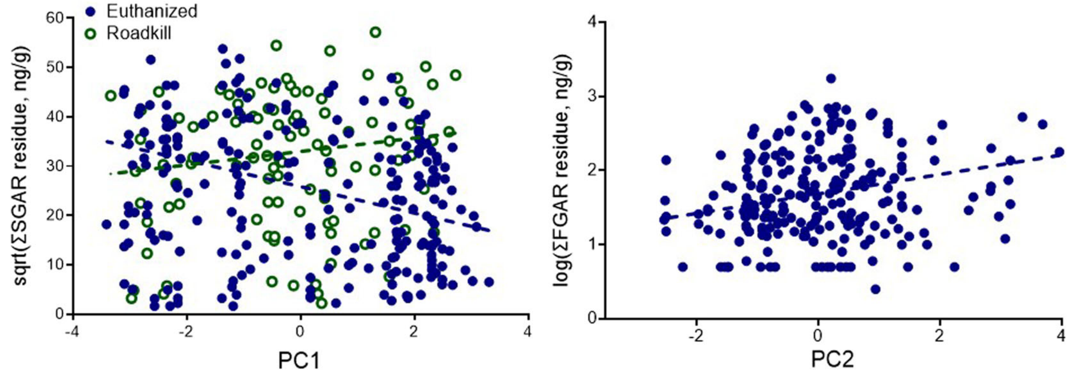

FIGURE 6 Scatterplots of the relationships between composite landscape variables (principal components PC1 and PC2) and the sum of second-generation (ΣSGAR) and first-generation anticoagulant rodenticide (ΣFGAR) concentrations in livers of coyotes from southern California, USA, 2015–2020. Dashed lines in the plot of ΣSGAR concentrations versus PC1 show predictive values of final median regressions for road-killed and euthanized coyotes separately, based on the PC1×cause interaction.

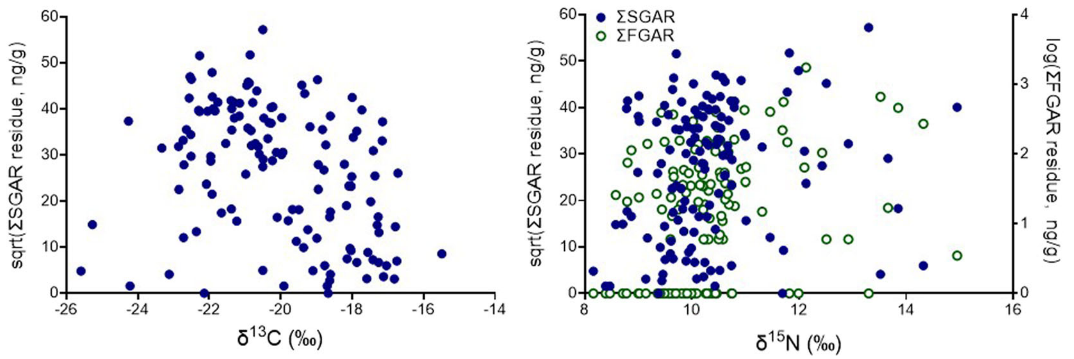

FIGURE 7 Scatterplots of liver second-generation (ΣSGAR) and first-generation anticoagulant rodenticide (ΣFGAR) residue concentrations (ng/g) and stable C and N isotope values of 129 urban coyotes from southern California, USA, 2015–2020.

only factor with evidence of an effect (Table 2). Neither $\delta^{13}C$ nor $\delta^{15}N$ had a relationship with median ΣFGAR concentration.

Domestic cats, mesocarnivores, and anthropogenic resources such as fast food and pet food tended to have more enriched $\delta^{13}C$ values compared to commensal and wild rodents and rabbits (Figure 8). Mesocarnivores, commensal rodents, and cats had higher mean $\delta^{15}N$ values than wild rodents, rabbits, and anthropogenic foods. Collectively, these results suggest that AR residue concentrations were highest for coyotes consuming primarily C_3-based prey (lower $\delta^{13}C$; e.g., rodents and rabbits) in areas with less-intensive development (lower PC1) and more natural open space (higher PC2) and increased as coyotes ate more prey from relatively higher trophic positions (higher $\delta^{15}N$), such as commensal rodents and mesocarnivores. Coyotes living in areas with more medium- and high-intensity development and higher building densities had enriched $\delta^{13}C$, suggesting that they consumed more cats and anthropogenic foods.

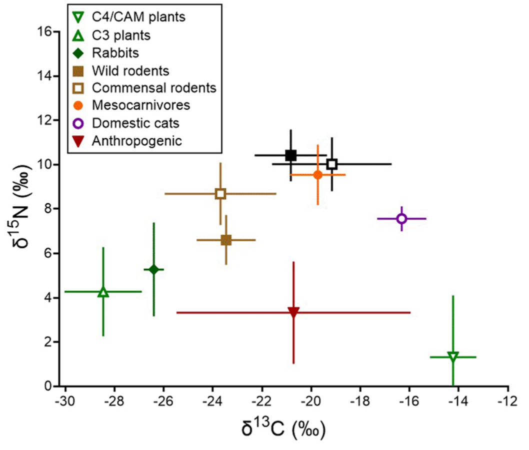

FIGURE 8 Mean (±1 SD) stable C and N isotope values of potential prey of urban coyotes in southern California, USA, 2017–2024. Samples sizes: C_4 and crassulacean acid metabolism (CAM) plants (3), mesocarnivores (6), domestic cats (343), anthropogenic foods (22), commensal rodents (67), wild rodents (14), rabbits (6), C_3 plants (19). For illustration purposes, mean isotope values of exposed coyotes are plotted as black squares, with the filled symbol showing concentrations in the upper 30% of second-generation anticoagulant rodenticide residue concentrations (ΣSGAR ≥ 1,262 ng/g, n = 43) and the open symbol showing concentrations in the lower 30% (ΣSGAR ≤ 279 ng/g, n = 38) of all ΣSGAR values. The δ^{13}C (U = 392, P < 0.001) and δ^{15}N (U = 585, P = 0.028) values differed between the 2 groups of ΣSGAR concentrations.

Necropsies and body condition

Three of 92 rural coyotes examined (3.3%) showed obvious signs of sarcoptic mange infection; 1 had a low liver diphacinone concentration (32 ng/g), whereas the other 2 had no detectable residues. Of the 501 carcasses of urban coyotes from Los Angeles County and Orange County examined, 6 (1.2%) had severe mange symptoms, 4 of which were tested for AR residues. Livers of these animals had 2 or 3 SGAR compounds, with a median ΣSGAR concentration of 364.6 ng/g (range = 99–2288 ng/g), and 1 FGAR, with a median ΣFGAR concentration of 26.1 ng/g (range = 24–368 ng/g). Overall, mange was uncommon (1.5%) in the 593 animals that we examined, and AR exposure of coyotes with mange was similar to or lower than that of the sample as a whole (Table 1).

For the 50 urban coyotes we necropsied, BCS was positively correlated with KFI (Spearman r = 0.31, P = 0.030) but we found no evidence it was related to helminth load (r = −0.23, P = 0.115; helminth prevalence = 88%, median intensity = 22.5 helminths/infested host). Summed residue of first-generation compounds (ΣFGAR) was inversely related to KFI (r = −0.28, P = 0.047) and positively correlated with helminth load (r = 0.29, P = 0.039) but did not vary with BCS (r = −0.07, P = 0.623). We did not find evidence of relationships between measures of body condition and ΣSGAR concentration (P ≥ 0.642) or the number of AR compounds detected (P ≥ 0.140). Of the 34 coyotes that had been euthanized, 8 had no evidence of gross internal and subcutaneous hemorrhaging (rating = 0), whereas 3 had very high levels (rating = 5). We combined euthanized coyotes with hemorrhage intensity ratings of 0 and 1 and ratings of 4 and 5 to create 4 bins of similar sample size (7–10) and permit statistical comparisons. Based on BCS values, coyotes with high levels of hemorrhaging were in visibly poorer condition than those with less hemorrhaging (Kruskal-Wallis: H = 11.90, k = 4 groups, P = 0.008; Table 3), but neither KFI values (H = 1.15, P = 0.764) nor helminth loads (H = 1.00, P = 0.801) differed across hemorrhage intensity groups. None of the euthanized coyotes were exposed to <2 AR compounds, and except for 1 animal with no FGAR residues, all were exposed to both FGARs and SGARs. However, the number of AR compounds detected did not vary with hemorrhage intensity (H = 0.367, P = 0.943), nor did ΣFGAR (H = 3.32, P = 0.345) or ΣSGAR (H = 1.96, P = 0.580) concentration (Table 3).

TABLE 3 Results of necropsies of 34 euthanized coyotes (29 adults, 5 juveniles) collected in 2019 from urban Los Angeles County and Orange County, California, USA. Hemorrhage intensity was rated from 1–6 based on the relative amount of subcutaneous and internal hemorrhaging. Total anticoagulant rodenticides (ARs) shows the number of coyotes having 2–3 and 4–6 AR compounds in their livers (no necropsied coyotes had fewer than 2 ARs). We also present a veterinary body condition score (BCS) taking whole-number values from 1–5, the kidney fat index (KFI), and helminth load, which is the number of helminths in the intestines, divided by body mass in kilograms to account for size variation. We also provide summed liver concentrations of first-generation (ΣFGAR) and second-generation (ΣSGAR) AR compounds (in ng/g). For BCS, KFI, helminth load, and residue concentrations, values reported are medians (ranges).

Hemorrhage intensity rating	*n*	BCS	KFI (%)	Helminth load (count/kg)	Total ARs 2–3	Total ARs 4–6	ΣFGAR (ng/g)	ΣSGAR (ng/g)
0–1	10	3 (2–4)	15.7 (15.9–18.8)	0.5 (0.3–9.6)	2	8	52.6 (13.5–199.2)	530.0 (15.0–1,348.0)
2	9	3 (2–3)	17.4 (7.9–43.6)	2.5 (0.2–5.9)	1	8	30.2 (24.2–165.6)	1,027.0 (15.0–2,001.0)
3	8	2 (2–4)	15.3 (11.5–20.7)	2.0 (0–14.8)	2	6	58.6 (0–566.3)	641.4 (303.8–1,749.0)
4–5	7	2 (2)	15.3 (4.0–22.3)	3.6 (0–6.5)	2	5	23.9 (15.9–64.0)	421.6 (5.0–1,648.0)

DISCUSSION

Nearly all (>98%) of the 365 urban coyotes in southern California we tested were exposed to anticoagulant rodenticides, with most coyotes exposed to both SGARs and FGARs and to multiple SGAR compounds. Prevalence was much higher than that reported in large-sample studies of other North American carnivores (bobcat: 89%, Serieys et al. 2015; kit fox [*Vulpes macrotis*]: 74%, Cypher et al. 2014; fisher [*Pekania pennanti*]: 58%, Gabriel et al. 2012; 79%, Silveira et al. 2024) and European canids (e.g., red fox [*Vulpes vulpes*]: 84%, Tosh et al. 2011; grey wolf [*Canis lupus*]: 62%, Musto et al. 2024) and similar to that reported for mustelids from Europe (e.g., stone marten [*Martes foina*]: 99%; European polecat [*Mustela putorius*]: 95%, 79%; stoat [*Mustela erminea*]: 97%; least weasel [*Mustela nivalis*]: 95%; Elmeros et al. 2011, 2018; Sainsbury et al. 2018). Our data indicated that AR exposure increased with body mass and, to some degree, age, suggesting that larger and older coyotes had consumed more AR-contaminated prey in their lifetimes and consequently accumulated AR residues in their livers. Because commercial baits used to control rodent populations contain a single active AR ingredient (U.S. Environmental Protection Agency 2008), these coyotes must have been exposed repeatedly.

This result was in stark contrast to the rural coyotes that we sampled, which were exposed at a much lower frequency overall (47.1%) and usually to 1 SGAR or FGAR compound. Aside from a report of a single coyote tested from Kern County, central California, that had no detectable residues (McMillin et al. 2008), coyotes tested for AR exposure have been from urban and suburban settings. Primary and secondary poisoning of non-target wildlife by SGARs is a pressing environmental concern in agricultural areas of Europe and Asia (Hindmarch and Elliott 2018). However, in California at the time of our sampling, legal applications of SGAR compounds, the most toxic and environmentally persistent types of ARs (Hindmarch and Elliott 2018), were restricted to locations close to buildings or to protect water conveyance and on-farm transportation and would have only been available for sale by licensed dealers to certified applicators (California Department of Pesticide Regulation 2014). First-generation compounds were the only AR products legally available to kill rodents that damage field crops and rangeland, many of which are native species (e.g., California ground squirrels, deer mice, voles [*Microtus* spp.], gophers [*Thomomys* spp.]) that usually die belowground (Quinn and Baldwin 2014, Baldwin et al. 2021). Given the cost of applying rodenticides at large scales in rural and agricultural settings and restrictions on the toxicants, baiting techniques, and timing of applications (Hueth et al. 1998, Sterner 2008), combined with the availability of alternative prey such as rabbits (*Sylvilagus* spp.), there may be relatively few AR-contaminated prey for coyotes on the rural landscape at any given time. This could explain why fewer rural coyotes were exposed to ARs and why fewer compounds were detected than in urban settings.

Liver residue concentrations of rural coyotes, notably SGARs, were also much lower than those of urban ones. Median ΣSGAR concentration of urban coyotes (802.3 ng/g) was more than 4 times the 200-ng/g potential toxicity threshold that has been used in other studies to describe lethal levels of SGAR exposure in mammals (Berny et al. 1997, Shore et al. 2003, Ruiz-Suárez et al. 2016, Elmeros et al. 2018, López-Perea et al. 2019), and is higher than SGAR concentrations of coyotes believed to have been killed by ARs. The 2 Colorado coyotes suspected by Poessel et al. (2015) of dying from AR intoxication had liver ΣSGAR concentrations of 176 and 1,205 ng/g, whereas 2 Massachusetts coyotes that were intentionally poisoned had liver brodifacoum residues of 542 and 733 ng/g (Way et al. 2006). Summarizing incident reports from across the United States (including those from Hosea [2000] and Riley et al. [2003]), Erickson and Urban (2004) described detectable ΣFGARs in 4 (median = 856 ng/g; range = 43–1,300 ng/g) and ΣSGARs in 18 (median = 280 ng/g; range = 30–930 ng/g) of 22 coyotes in California. Seven of the 34 euthanized coyotes (20.6%) we necropsied had high levels of hemorrhaging that arguably would have been fatal if the coyotes had not been killed, which is similar to the estimated fraction (23%) of coyote deaths attributed to toxicants reported by Moriarty et al. (2012). However, given the ubiquity of AR exposure in the large population of coyotes in southern California, and the high residue levels detected in animals that appeared asymptomatic and otherwise healthy, we believe it is premature to conclude that rodenticide poisoning is a significant source of mortality for coyotes compared to other causes such as vehicle strikes and targeted control, or that ARs have population-level effects.

Even if ARs are not the direct cause of many deaths, they could contribute to mortality through sublethal effects if they make coyotes susceptible to other factors (Rattner et al. 2014). For example, researchers have argued that exposure to ARs weakens the immune system of urban bobcats (Riley et al. 2007; Serieys et al. 2013, 2015, 2018), making them more vulnerable to death from notoedric mange (but see Kopanke et al. 2018). Sarcoptic mange was rare in the coyotes we sampled (1.5%), and coyotes with mange did not have unusually high levels of AR exposure. Urban coyotes with high ΣFGAR concentrations tended to be in poorer body condition, based on low kidney fat levels and high helminth loads, hinting at a possible sublethal effect of FGARs. Coyotes with the highest degree of hemorrhaging also consistently had the lowest body condition scores. Elmeros et al. (2011) similarly reported a negative correlation between body condition and liver SGAR concentrations in mustelids in Denmark. However, we found no clear connection between the intensity of hemorrhaging (as evidence of coagulopathy) and the number of ARs or liver residue concentrations in euthanized coyotes.

It has been suggested that sublethal exposure may also alter movements and behavior, making animals more susceptible to vehicle mortality (Shore et al. 2003, Sainsbury et al. 2018, Musto et al. 2021). Roadkill coyotes had higher ΣSGAR concentrations than euthanized ones, although we cannot assess whether AR exposure increased the likelihood of being struck. Necropsied roadkill coyotes had higher BCSs than euthanized ones ($U = 178.5$, $P = 0.039$) and did not differ in the other body condition measures ($P \geq 0.841$), suggesting that those killed by vehicles were not in poorer condition. Alternatively, AR exposure may simply be higher in places with a high risk of vehicle mortality, such as areas with large roads with high speed limits and traffic volumes that traverse or are adjacent to open space (Elliott 2008). We found that PC2, which reflected the type and amount of open space, was the best predictor of ΣFGAR concentration, with higher levels in locations with more grass and shrub cover. First-generation compounds such as diphacinone may be used to kill commensal and wild rodents (e.g., squirrels, mice, gophers) in larger and wilder yards farther away from structures, and in parks, golf courses, and cemeteries. The ΣSGAR concentrations of roadkill coyotes did not vary strongly with PC1, which increased with cover of medium- and high-intensity development and building density, but we also tended to have fewer roadkill coyotes in locations with high PC1 scores (Figure 6). Instead, for higher concentrations of ΣSGAR, ΣSGAR decreased with PC1 for euthanized coyotes, with those in the most heavily urbanized settings having lower ΣSGAR levels. We offer 2 possible explanations for these patterns, which are not mutually exclusive. First, coyotes living in these areas may have access to fewer AR-contaminated prey, either because AR use is lower or because coyotes select foods that are not exposed to ARs. Second, coyotes that are targeted for nuisance control may not persist in these areas long enough to accumulate high liver AR residue concentrations.

Surveys of residential landowners in southern California indicate that rodent control and use of ARs is higher in areas with single-family homes and in areas close to developed or natural open space (Morzillo and Schwartz 2011, Bartos et al. 2012). Based on reports of pests seen outdoors and damage to property or landscaping (Morzillo and Mertig 2011), rats and mice are the most common targets (Morzillo and Schwartz 2011). Landowners apply rodenticide themselves, obtain assistance from gardeners, or hire professional pest-control operators, all of whom differ in their understanding of how to use toxicants safely and diligently and of the risks of non-target exposure (Bartos et al. 2012). Although we do not have detailed information on demographic or spatial patterns of AR applications in our study area, we speculate that coyote locations with low-intensity development and altered open space (low PC1) and high cover of natural open space (high PC2) are in areas of relatively high AR use because these areas commonly have rat infestations (Burke et al. 2021). Bait stations are conspicuous and widespread in commercial, retail, and industrial settings, but we also lack specific data on AR use in these environments.

Coyotes living in more intensively urbanized areas may also be exposed to fewer ARs because they tend to consume large numbers of cats (Bucklin et al. 2023), a result that is consistent with our stable isotope analysis (Figure 8). Although stomach contents analysis may not necessarily reflect a predator's long-term diet, coyotes with cat remains in their stomachs (from Bucklin et al. 2023) had lower ΣSGAR residues and enriched $\delta^{13}C$ values compared to those with no cat remains in their stomachs (P. Stapp, California State University, Fullerton, unpublished data). Cats can be exposed to ARs (Mahjoub et al. 2022), but many cats in our study area live in small groups and colonies associated with trap-neuter-release programs and likely depend more upon provisioned pet food than potentially AR-contaminated prey. Moreover, attacking and killing pets is a major reason why these habituated coyotes are targeted for lethal control (Timm et al. 2004). More euthanized coyotes had cat remains in their stomachs than road-killed ones in a concurrent study (Bucklin et al. 2023). High population turnover and low residence times could help explain the lower ΣSGAR concentrations in euthanized coyotes from intensively urbanized settings, many of which were juveniles and exposed to fewer ARs.

Stable isotope analysis also helped elucidate pathways of secondary exposure of coyotes in less intensively developed, suburban areas. Based on their depleted $\delta^{13}C$ and enriched $\delta^{15}N$ values compared to possible food sources, these coyotes likely consumed commensal rodents and mesocarnivores. Non-native roof rats are the most widespread commensal rodent living outdoors in suburban Orange and Los Angeles County (Krueger et al. 2015). Although their diet has not been well-studied in commensal settings, these semi-arboreal rodents are known to eat fruits and seeds of native and cultivated plants, including avocados and citrus common in backyards, and small animals (Quinn 2024), which is reflected in their stable isotope signatures (Figure 8). Roof rats are a target of outdoor pest control applications in California, and although many likely die in concealed areas, carcasses are regularly seen in the open, where they may be scavenged by corvids, raptors, and mammals, including mesocarnivores and coyotes, often within 24 hours (Lotts and Stapp 2020). Virginia opossums, one of the most common mesocarnivores in urban southern California (Crooks 2002, Burke 2021), are capable of entering enclosed yards to consume rat carcasses, and juveniles enter AR bait stations and consume bait (Burke et al. 2021). Mesocarnivore remains were detected in 11% of the stomachs of coyotes from our study area (Shedden 2021), with opossums consumed most frequently (8%); however, because of their larger size, the importance of mesocarnivores may be under-represented based on stomach and scat contents studies compared to stable isotope analysis. Rodenticide residues were detected in livers of 2 euthanized raccoons from southern California, and multiple raccoons, opossums, and striped skunks from New York were exposed to SGARs (Erickson and Urban 2004), but there is remarkably little data on AR exposure of opossums and other mesocarnivores from California. Sainsbury et al. (2018) also reported that detection of SGAR compounds in European polecats in Great Britain increased with whisker $\delta^{15}N$, which they attributed to consumption of higher trophic level prey, such as rats, that were contaminated with ARs.

Compared to our study area, AR exposure appears to be lower for coyotes in the Chicago, Illinois, area (no deaths attributed to ARs; Gehrt and Riley 2010), where the ecology of urban coyotes has been especially well-studied (Gehrt et al. 2011), which may indicate regional differences in the use of ARs for urban pest control, both by professionals and the public. Alternatively, the hospitability of the California climate and abundance of native and ornamental plants may permit roof rats to become common outdoor pests year-round (Quinn 2024). Moreover, the presence of small fragments of natural habitat in the urban and suburban matrix brings wild rodents into proximity to human development (Crooks 2002, Burke et al. 2021), where they may also be targeted for control. Coyotes in southern California differ markedly from those in other North American cities in consuming domestic cats and commensal rodents regularly (Shedden 2021), in addition to wild rodents and rabbits.

Lastly, we note that most of our sampling took place prior to the implementation of AB1788 and AB1322, which severely restricted availability and uses of SGARs and diphacinone, respectively, in California. Baits containing these compounds will likely remain in stockpiles and will continue to be applied illegally, or they may be purchased elsewhere and brought to the state. There are also exceptions to bans for protecting water infrastructure, food production and storage facilities, and public health and for removing harmful invasives on islands. A network for monitoring ARs in coyotes will aid in the assessment of the effectiveness of these new laws and identify areas of non-compliance, especially by private landowners. Our results also highlight that the risk of non-target exposure is much greater in the urban and suburban environment in California compared to agricultural and rural settings, which may warrant different mitigation strategies. It remains to be seen if the removal of ARs as a tool for commensal rodent management will result in increased use of acute toxicants such as bromethalin and cholecalciferol or a renewed emphasis on integrated pest management (trapping, exclusion, and management of waste and harborage; Quinn et al. 2019) that focuses mitigation efforts on the impact of commensal rodents as the main source of food web contamination. An enforced ban on outdoor feeding of wildlife and other animals, such as domestic cats, would significantly reduce food resources that subsidize rat populations and attract predators like coyotes, and therefore reduce opportunities for human–wildlife conflict.

MANAGEMENT IMPLICATIONS

The near-universal exposure of coyotes in southern California to ARs reflects how widespread and acceptable it is to apply rodenticides to control rodents perceived as pests. The availability of toxicants, both in retail stores and through the internet, including from out-of-state and international vendors, and their effectiveness compared to other more labor-intensive, expensive, and unsightly approaches such as landscape management and trapping, has arguably made chemical control the standard practice (Quinn et al. 2019). The ecology of commensal urban rodents remains poorly understood, and census methods are inadequate for assessing when control applications will be effective and when continuing them is counterproductive, including possibly contributing to genetic rodenticide resistance. Despite environmental awareness campaigns, many people prioritize a fast and inexpensive solution to the presence of rats and other rodents outdoors over potential risks to unseen, non-target species, and it is common practice to apply ARs prophylactically to a permanent network of bait stations, which leads to over-use. Because of their omnivorous habits and tolerance for human development, coyotes can be useful sentinels of environmental contamination from ARs and other pollutants, even if direct links between AR residue concentrations and mortality and sublethal effects at the population scale are tenuous at best. The ability to test ARs and other contaminants in samples collected less invasively (e.g., hair; Leporati et al. 2016) or scats (Sage et al. 2010, Seljetun et al. 2019), will improve monitoring capabilities, although assigning biological and environmental significance to residue concentration values, especially across different tissues, will remain a major challenge.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

ETHICS STATEMENT

Mammal carcasses were obtained opportunistically (the authors had no involvement in decisions about the use and deposition of live animals) and were salvaged under valid Scientific Collecting Permits from the California Department of Fish and Wildlife. Some rodent tissue samples were collected as part of research approved under California State University Fullerton Institutional Animal Care and Use Committee protocol (#2022-1302) to P. Stapp, following ethical guidelines described by Sikes and Animal Care and Use Committee of the American Society of Mammalogists (2016). Ear tissue from domestic cats was donated by veterinarians who removed ear tips from anesthetized cats as part of trap-neuter-return sterilization programs.

DATA AVAILABILITY STATEMENT

Data available on request from the authors.

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Associate Editor: Benjamin Sacks.

SUPPORTING INFORMATION

Additional supporting material may be found in the online version of this article at the publisher's website.

How to cite this article: Stapp, P., A. McKenzie, D. M. Bucklin, R. A. Baldwin, and N. Quinn. 2025. Patterns of exposure of coyotes to anticoagulant rodenticides in California, USA. Journal of Wildlife Management 89:e22696. https://doi.org/10.1002/jwmg.22696

STATE OF CALIFORNIA

STANDARD AGREEMENT

STD 213 (Rev 02/20)

	AGREEMENT NUMBER
STATE CONTROLLER'S OFFICE IDENTIFIER	REGISTRATION NUMBER

1. This Agreement is entered into between the State Agency and the Contractor named below:

STATE AGENCY'S NAME

, hereinafter referred to as "State"

CONTRACTOR'S NAME

, hereinafter referred to as "University"

2. The term of this Agreement is: through

3. The maximum amount of this Agreement is: $

4. The Parties agree to comply with the terms and conditions of the following Exhibits, which by this reference are made a part of the Agreement.

Exhibit A – A7: A–Scope of Work; A1–Deliverables; A2–Key Personnel; A3–Authorized Representatives; A4–Use of Intellectual Property & Data; A5–Resumes/Biosketch; A6–Current & Pending Support; A7-Third Party Confidential Information (if applicable)	page(s)
Exhibit B – B–Budget; B1–Budget Justification; B2– Subawardee Budgets (if applicable); B3–Invoice Elements	page(s)
Exhibit C* – University Terms and Conditions	UTC-220

Check mark additional Exhibits below, and attach applicable Exhibits or provide internet link:

- ☐ **Exhibit D** – Additional Requirements Associated with Funding Sources — page(s)
- ☐ **Exhibit E** – Special Conditions for Security of Confidential Information — page(s)
- ☐ **Exhibit F** – Access to State Facilities or Computing Resources — page(s)
- ☐ **Exhibit G** – Negotiated Alternate UTC Terms — page(s)

Items shown with an Asterisk (*) are hereby incorporated by reference and made part of this agreement as if attached hereto. You can find these documents on the University of California, Office of the President and the California Department of General Services websites.

IN WITNESS WHEREOF, this Agreement has been executed by the Parties hereto.

CONTRACTOR		***California Department of General Services Use Only***
CONTRACTOR'S NAME *(if other than an individual, state whether a corporation, partnership, etc.)*		
BY *(Authorized Signature)*	DATE SIGNED *(Do not type)*	
PRINTED NAME AND TITLE OF PERSON SIGNING Kimberly Lamar, Interim Director		
ADDRESS UCANR Office of Contracts & Grants; 2801 Second Street, Davis, CA 95618		
STATE OF CALIFORNIA		
AGENCY NAME		
BY *(Authorized Signature)*	DATE SIGNED *(Do not type)*	
PRINTED NAME AND TITLE OF PERSON SIGNING		☐ Exempt per:
ADDRESS		

Exhibit A – Scope of Work

Project Summary & Scope of Work

☐ Contract ☒ Grant

Does this project include Research (as defined in the UTC)? ☒ Yes ☐ No

PI Name: Quinn, Niamh

Project Title: Following the Trail: Can Mitigation Measures Reduce Rodenticide Exposure in Coyotes?

Project Summary/Abstract

The long-term objective of this project is to develop and validate a science-based framework for evaluating and reducing non-target exposure of anticoagulant rodenticides (ARs) in urban wildlife, particularly coyotes (*Canis latrans*), within California's structural pest control context. By deploying isotopically labelled anticoagulant rodenticides (iLARs) at active management sites and integrating non-invasive fecal sampling, GPS-collar data, and rodent population indices, this study will generate robust, field-based data on how specific application strategies, such as pulsed baiting and reduced-frequency deployment, affect exposure across space and time.

Over the long term, these methods will provide regulatory agencies, including the California Department of Pesticide Regulation (DPR) and the Structural Pest Control Board (SPCB), with a replicable monitoring system for assessing mitigation measures, enabling ongoing evaluation beyond this project. The approach is designed to be scalable to other taxa (e.g., raptors, mesocarnivores) and adaptable to additional chemical or non-chemical pest management tools where non-target exposure is of concern. Ultimately, this work will support the development of integrated pest management (IPM) strategies that remain effective in controlling commensal rodent populations while minimizing ecological risks, helping agencies craft durable, evidence-based policies for urban pest control.

If Third-Party Confidential Information is to be provided by the State:

☐ Performance of the Scope of Work is anticipated to involve use of third-party Confidential Information and is subject to the terms of this Agreement; ***OR***

☐ A separate CNDA between the University and third-party is required by the third-party and is incorporated in this Agreement as Exhibit A7, Third Party Confidential Information.

Scope of Work

Describe the goals and specific objectives of the proposed project and summarize the expected outcomes. If applicable, describe the overall strategy, methodology, and analyses to be used. Include how the data will be collected, analyzed, and interpreted as well as any resource sharing plans as appropriate. Discuss potential problems, alternative strategies, and benchmarks for success anticipated to achieve the goals and objectives.

Background:

Anticoagulant rodenticides (ARs) have been a primary tool in structural pest management for decades due to their efficacy in controlling commensal rodent populations. However, their environmental persistence, bioaccumulation potential, and

toxicity to non-target species have raised significant ecological and regulatory concerns (Keating et al., 2024). Numerous studies have documented widespread residues of first-generation (FGARs) and second-generation (SGARs) anticoagulants in non-target wildlife, including predatory and scavenging species in urban and peri-urban environments (Poessel et al., 2015; Riley et al., 2007; Stapp et al., 2025). In California, where SGAR use has been substantially restricted after the implementation of Assembly Bill 1788 in January 2021, exposure continues to be detected at high frequencies in species such as coyotes (*Canis latrans*), suggesting that complex trophic pathways and legacy contamination may contribute to ongoing risk (Quinn et al., unpublished). Despite these concerns, regulatory mitigation measures are often based on theoretical modelling rather than empirical evidence from free-ranging wildlife, leaving critical knowledge gaps regarding the effectiveness of proposed strategies such as reduced-frequency baiting and pulsed applications.
Traditional monitoring approaches, which rely heavily on liver residue analysis of opportunistically collected carcasses, provide only static, end-point data and fail to capture the temporal and spatial dynamics of exposure in living populations (Quinn, 2019). These limitations hinder the ability to link exposure events to specific management practices or land-use features, making it difficult to assess whether mitigation measures achieve their intended outcomes. Furthermore, existing datasets lack the resolution needed to evaluate exposure risk across seasons and individual home ranges, particularly in highly mobile species such as coyotes, which frequently traverse residential and industrial landscapes. Addressing these limitations requires innovative, field-based methodologies that can trace ARs across trophic levels in real time.

The Quinn Lab has validated the use of isotopically labelled anticoagulant rodenticides (iLARs) to enable high-sensitivity detection of residues in non-invasive biological samples such as feces. These compounds are chemically identical to existing ARs but incorporate a stable isotope of the rodenticide active ingredient, allowing for their discrimination from background residues of nonlabelled products in biological matrices (Quinn unpublished). When coupled with GPS-collared wildlife, iLARs make it possible to directly link exposure to specific application strategies and landscapes, providing unprecedented insight into the pathways and timing of exposure events. These methodological innovations build on prior work by the Quinn Lab and collaborators, which validated fecal and hair sampling as reliable tools for detecting AR exposure in over 190 free-ranging coyotes across Southern California (SPCB, DPR-and Rodenticide Task Force-funded studies).

This project leverages these advances to rigorously evaluate the efficacy of proposed mitigation measures for structural AR applications, including pulsed deployment, compared to current industry practices. By deploying iLARs at managed structural sites and monitoring both rodent activity and coyote exposure across time and space, this study will provide empirical, field-based evidence to guide the California Department of Pesticide Regulation's (DPR) reevaluation process. In doing so, it will also establish a replicable framework for ongoing monitoring of non-target exposure, one that can be expanded to additional taxa (e.g., raptors, other mesopredators) and even other non-rodenticide pesticide-based control where nontarget exposure is of concern. The outcomes will help develop and evaluate pest management strategies that are both effective and ecologically responsible, aligning with the integrated pest management (IPM) principles prioritized by DPR and the Structural Pest Control Board (SPCB).

Project Goals

The overarching goal of this project is to evaluate the non-target exposure of anticoagulant rodenticides (ARs), with a particular focus on California's structural pest control context, using isotopically-labelled anticoagulant rodenticide (iLARs). Qualitative and quantitative evidence will be used to assess whether mitigation strategies currently anticipated to be implemented by the California Department of Pesticide Regulation (DPR) effectively reduce risk of exposure to non-target wildlife. These would be compared with other possible application strategies. This project is uniquely positioned to inform policy with empirical data derived from field-based application and wildlife exposure monitoring.

Hypothesis:

There will be no significant difference in isotopically labelled anticoagulant rodenticide exposure in coyotes or rodent control efficacy between pulsed baiting, increased-frequency applications and current standard practices.

Specific Objectives

- **Monitor the Exposure Pathways of Isotopically-Labelled Rodenticides**

  Deploy iLARs in controlled structural settings and trace their presence through wildlife up trophic levels.

- **Evaluate Wildlife Exposure Across Time and Space**

  Use GPS-collared coyotes and fecal sample collection across multiple regions to detect and track rodenticide exposure. This objective builds on the Quinn Lab's validated non-invasive approach to assess real-time AR exposure in live, free-ranging wildlife (developed with funding provided by DPR, SPCB and the Rodenticide Task Force).

- **Compare Current Application Methods With Potential Mitigation Measures**

  Assess the effectiveness of various application strategies in reducing detectable wildlife exposure while maintaining rodent control efficacy. Rodent populations will be monitored using indices validated by the Quinn lab.

Rodenticides will be applied in one of three treatments at different application sites:

1. **Status Quo (30-Day Application Cycle):**

   This reflects the current standard practice where AR baits are applied monthly.

2. **Pulsed Baiting (Two Pulses):**

   An iLAR is applied in two distinct pulses. Each pulse is a single application remaining in place for a maximum of 35 days. The time in between pulses will be 90 days. In between pulses, the iLAR will be replaced by a non-AR product.

3. **Complete Rodent Management (Weekly Service, Always Bait Present):**

   Continuous bait availability through weekly service visits to the application site, ensuring consistent and immediate response to rodent infestations.

Develop and Validate a Science-Based Framework for Evaluating Mitigation Measures

Evaluate mitigation measures in the structural environment using current professional application practices to determine whether DPR's anticipated Reevaluation mitigation measures result in significant measurable differences in exposure rates from those of current industry standard practices.

Methodology and Strategy

Study Sites:

This study will be limited to Los Angeles and Orange County due to the short response times need when responding to collared coyotes. Study sites will all need to be independent and not have any overlap in coyote homeranges.

Rodenticide Deployment:

We will apply iLARs at existing real-world sites currently being serviced by professional pest management companies, consistent with typical industry practices in the structural pest control environment. These iLARs enable high-sensitivity tracing in biological matrices such as feces. Treatments (3) will be assigned to research sites (9). ILARs will be applied for a maximum of 6 months and rodent populations will be monitored for an additional 3 months after the termination of the treatments. Treatments will be independent for both rodents and coyotes.

Wildlife Monitoring and Sample Collection:

We will monitor 20 radio-collared coyotes (*Canis latrans*) across multiple urban and suburban landscapes in Southern California. Coyotes will be trapped and radio-collared with GPS collars that will record locations every 15 minutes. Trapping of urban coyotes will take place for 9 months prior to the application of iLARs. Treatments will be assigned based on the homeranges of the coyotes. An ear biopsy will be taken on capture to provide DNA to match to fecal samples. Fecal samples will be collected at regular intervals and analyzed for iLAR residues to assess temporal and spatial exposure patterns. Fecal samples will also be tested for DNA to assign individual identity to coyotes. These methods had been tested by the Quinn Lab successfully with the detection of rodenticide exposure in all collared individuals and an additional 174 individual coyotes (work funded by DPR and Rodenticide Task Force). Fecal sampling will continue while treatments are applied and for 3 months subsequent to the cessation of treatment applications.

Rats will be monitored at treatment sites using tracking tunnels. Each tracking tunnel will contain a sheet of paper (Tracking Tunnel Card, traps.co.nz) with an inkpad (Tracking Ink 100mL, traps.co.nz) at the center of the paper. Each tunnel will be baited with one bait block (NoTox™ Monitoring Block, Liphatech, Inc.) on the center inkpad and left for three nights to determine a population index based on rat footprints recorded in each tunnel. This index has been validated in previous research (Bosarge, 2024).

Data Analysis:

All statistical analyses will be performed in R studio.

To calculate the population index, the percent cover of rat tracks on the tracking paper will be quantified using digital-image processing software, ImageJ (ver. 1.54g; Rasband, WS, ImageJ, U. S. National Institutes of Health, Bethesda, Maryland, USA, imagej.net, 1997-2018). The tracking paper will be scanned and the image converted to an 8-bit black-and-white image, with footprints displayed in black, and shadows, smears, and tracks of non-target species removed. The percent cover of the remaining black pixels will be divided by the number of nights each tunnel was operational each week, to calculate a tracking index (percent cover of tracks per night) for a weekly measure of rat activity.

In ArcGIS Pro, geospatial exposure maps will be developed for the collared coyotes. We will use normalized vegetation difference index, National Land Cover Database, Building footprint and census data to assess land use by collared coyotes. Coyote homeranges will be calculated using 95% kernel density estimates. Statistical modelling (Generalized Linear Mixed Models and spatial correlation models) will be employed to evaluate the relationship between application methods and exposure outcomes.

Benchmarking and Success Criteria:

Success will be defined as statistically significant differences in detected iLAR exposure rates in the feces of collared coyotes under different mitigation scenarios. Data will be used to determine which application method(s) result in the lowest rates of exposure, which will then be used to develop evidence-based recommendations to guide DPR policy and structural pest control best practices.

Potential Challenges and Alternative Strategies

Variability in coyote home range or site fidelity may obscure the exposure source among multiple application sites.

Alternative: Use GPS location overlap with bait application zones to assign probabilistic exposure risk.

Expected Outcomes

- A validated protocol for using iLARs in field-based mitigation research.
- New data on how specific AR application practices affect wildlife exposure rates from structural application sites
- Geospatial and statistical models to inform risk assessment and application strategy.
- Evidence to evaluate mitigation measures proposed by DPR based on real-world outcomes.
- A practical framework for ongoing evaluation of structural pest control practices using non-target monitoring.

Citations

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Exhibit A1 - Deliverables

SCHEDULE OF DELIVERABLES

List all items that will be delivered to the State under the proposed Scope of Work. Include all reports, including draft reports for State review, and any other Deliverables, if requested by the State and agreed to by the Parties.

If use of any Deliverable is restricted or is anticipated to contain preexisting Intellectual Property with any restricted use, it will be clearly identified in Exhibit A4, Use of Preexisting Intellectual Property & Data.

Unless otherwise directed by the State, the University Principal Investigator shall submit all Deliverables to the State Contract Project Manager, identified in Exhibit A3, Authorized Representatives.

Deliverable	Description	Due Date
1	Monitor the Exposure Pathways of Isotopically-Labelled Rodenticides	12/31/28
2	Evaluate Wildlife Exposure Across Time and Space	12/31/28
3	Compare Current Application Methods with Potential Mitigation Measures	12/31/28
4	Develop and Validate a Science-Based Framework for Evaluating Mitigation Measures	12/31/28
5	Final project report	6/30/29
The following Deliverables are subject to Section 19. Copyrights, paragraph B of Exhibit C		

Exhibit A2 – Key Personnel

KEY PERSONNEL

List Key Personnel as defined in the Agreement starting with the PI, by last name, first name followed by Co-PIs. Then list all other Key Personnel in alphabetical order by last name. For each individual listed include his/her name, institutional affiliation, and role on the proposed project. Use additional consecutively numbered pages as necessary.

Last Name, First Name	Institutional Affiliation	Role on Project
PI:		
Quinn, Niamh	*UCANR*	*Principal Investigator*
Co-PI(s) – if applicable:		
Stapp, Paul	*CSU, Fullerton*	*Co-PI*
Wilkinson, Christine	*UC Santa Cruz*	*Co-PI*
Other Key Personnel (if applicable):		
Last name, First name	*Institutional affiliation*	*Role on the project*
Last name, First name	*Institutional affiliation*	*Role on the project*

Exhibit A3 – Authorized Representatives

AUTHORIZED REPRESENTATIVES AND NOTICES

The following individuals are the authorized representatives for the State and the University under this Agreement. Any official Notices issued under the terms of this Agreement shall be addressed to the Authorized Official identified below, unless otherwise identified in the Agreement.

State Agency Contacts Agency Name: <Agency Name>	**University Contacts** University Name: UCANR
Contract Project Manager (Technical) Name: <Name> <Title> Address: <Department> <Address> <City,State,Zip> Telephone: <Telephone#> Fax: <Fax#, if available> Email: <EmailAddress>	***Principal Investigator*** Name: Niamh Quinn Human-Wildlife Interactions Advisor Address: UCCE Orange County 7601 Irvine Blvd. Irvine, CA 92618 Telephone: 949-301-9182 Fax: <Fax#, if available> Email: nmquinn@ucanr.edu Designees to certify invoices under Section 14 of Exhibit C on behalf of PI: 1. <Name>, <Title>, <EmailAddress> 2. <Name>, <Title>, <EmailAddress> 3. <Name>, <Title>, <EmailAddress>
Authorized Official (contract officer) Name: <Name> <Title> Address: <Department> <Address> <City,State,Zip> Telephone: <Telephone#> Fax: <Fax#, if available> Email: <EmailAddress> ***Send notices to (if different):*** Name: <Name> <Title> Address: <Department> <Address> <City,State,Zip> Telephone: <Telephone#> Email: <EmailAddress>	***Authorized Official*** Name: Kimberly Lamar Interim Director Address: UCANR Office of Contracts & Grants 2801 Second Street Davis, CA 95618 Telephone: 530-750-1305 Fax: <Fax#, if available> Email: kdlamar@ucanr.edu; ocg@ucanr.edu ***Send notices to (if different):*** Name: <Name> <Title> Address: <Department> <Address> <City,State,Zip> Telephone: <Telephone#> Email: <EmailAddress>

Administrative Contact Name: <Name> <Title> Address: <Department> <Address> <City,State,Zip> Telephone: <Telephone#> Fax: <Fax#, if available> Email: <EmailAddress>	***Administrative Contact*** Name: Heidi von Geldern Sr. Contracts & Grants Manager Address: UCANR Office of Contracts & Grants 2801 Second Street Davis, CA 95618 Telephone: 530-750-1304 Fax: <Fax#, if available> Email: hvongeldern@ucanr.edu
Financial Contact/Accounting Name: <Name> <Title> Address: <Department> <Address> <City,State,Zip> Telephone: <Telephone#> Fax: <Fax#, if available> Email: <EmailAddress>	***Authorized Financial Contact/Invoicing/Remittance*** Name: Nicole D. Tardiff Director Address: Office of Contracts & Grants Accounting 1441 Research Park Drive Davis, CA 95618 Telephone: 530-754-3692 Fax: <Fax#, if available> Email: ndtardiff@ucdavis.edu Designees for invoice certification in accordance with Section 14 of Exhibit C on behalf of the Financial Contact: 1. <Name>, <Title>, <EmailAddress> 2. <Name>, <Title>, <EmailAddress> 3. <Name>, <Title>, <EmailAddress>

Exhibit A4 – Use of Intellectual Property & Data

USE OF INTELLECTUAL PROPERTY & DATA

If either Party will be using any third-party or pre-existing intellectual property (including, but not limited to copyrighted works, known patents, trademarks, service marks and trade secrets) "IP" and/or Data with restrictions on use, then list all such IP/Data and the nature of the restriction below. If no third-party or pre-existing IP/Data will be used, check "none" in this section.

A. State: Preexisting IP/Data to be provided to the University from the State or a third party for use in the performance in the Scope of Work.

☒ None or ☐ List:

Owner (Name of State Agency or 3rd Party)	Description	Nature of restriction:

B. University: Restrictions in Preexisting IP/Data included in Deliverables identified in Exhibit A1, Deliverables.

☒ None or ☐ List:

Owner (Name of University or 3rd Party)	Description	Nature of restriction:

C. Anticipated restrictions on use of Project Data.
If the University PI anticipates that any of the Project Data generated during the performance of the Scope of Work will have a restriction on use (such as subject identifying information in a data set) then list all such anticipated restrictions below. If there are no restrictions anticipated in the Project Data, then check "None" in this section.

☒ None or ☐ List:

Owner (University or 3rd Party)	Description	Nature of Restriction:

Exhibit A5 - RÉSUMÉ/BIOSKETCH

RÉSUMÉ/BIOSKETCH

Attach 2-3 page Resume/Biosketch for the PI and other Key Personnel listed in Exhibit A2, Key Personnel

NIAMH QUINN

HUMAN-WILDLIFE INTERACTIONS ADVISOR

CONTACT ME AT

7601 Irvine Blvd.,
Irvine, CA 92618

nmquinn@ucanr.edu

www.UCscurri.com

cosmopolitancoyotes

linkedin.com/in/ratwhacker

EDUCATION

PhD Small Mammal Ecology
National University of Ireland, Galway 2010

BSc Zoology
National University of Ireland, Galway 2005

CURRENT APPOINMENT

I am a University of California Cooperative Extension Human-Wildlife Interactions Advisor, based at the South Coast Research and Extension Center in Irvine with a focus directed on the coordination of Cooperative Extension programming regarding human-wildlife conflicts

RESEARCH AND EXTENSION FUNDING

Extramural grants: Total funding $1,700,000
Selected titles

- Can rodenticide toxicosis be mitigated by changes in management practices? Examination of two different bait stations, their placement, visitations by small mammals and birds, and their interaction with mesocarnivores- Pest Management Foundation
- Development of best management practices to manage urban rats, protect public health, and reduce rodenticide use- Department of Pesticide Regulation
- Investigation of Rodenticide Pathways in an Urban System Through the Use of Isotopically Labelled Bait- Department of Consumer Affairs
- Ground squirrel best management practices website- expansion of passive extension capacities- Department of Food and Agriculture
- Monitoring rodenticide exposure in urban carnivores- Department of Pesticide Regulation
- Investigating roof rat resistance-Department of Food and Agriculture
- Improving commensal rodent management by improving the utility of bait stations and the consumption of bait- Pest Management Foundation
- Sanitation and light sabers; what is left for pest management professionals?-Pest Management Foundation

Industry/programmatic funding and in-kind support: Total funding $750,000

NIAMH QUINN

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EDUCATION

PhD Small Mammal Ecology
National University of Ireland, Galway 2010

BSc Zoology
National University of Ireland, Galway 2005

PUBLICATIONS

- Bosarge, M. A., Stapp, P., & Quinn, N. (2025). Behavior and activity of commensal roof rats around rodenticide bait stations in southern California, USA. Applied Animal Behaviour Science, 106653.
- Stapp, P., McZenzie, A., Bucklin, D., Baldwin, R. & Quinn, N. (2025) Patterns of exposure of coyotes to anticoagulant rodenticides in California, USA. Journal of Wildlife Management.
- Wilkinson, C. E., Quinn, N., Eng, C., & Schell, C. J. (2025). Environmental health and societal wealth predict movement patterns of an urban carnivore. Ecology Letters, 28(2), e70088.
- Bucklin, D. M., Shedden, J. M., Quinn, N. M., Cummings, R., & Stapp, P. (2023). Do trap-neuter-return (TNR) practices contribute to human–coyote conflicts in southern California?. Human–Wildlife Interactions, 17(1), 7.
- Shultz, L., López-Pérez, A.M., Jasuja, R., Helman, S., Prager, K., Tokuyama, A., Quinn, N., Bucklin, D., Rudd, J., Clifford, D. and Brown, J.. (2023). Vector-Borne Disease in Wild Mammals Impacted by Urban Expansion and Climate Change. EcoHealth, 20(3), 286-299.
- Javeed, N.N., Shultz, L., Barnum, S., Foley, J.E., Hodzic, E., Pascoe, E.L., Martínez-López, B., **Quinn, N.**, Bucklin, D. and Dear, J.D. (2022) Prevalence and geographic distribution of Babesia conradae and detection of Babesia vogeli in free-ranging California coyotes (Canis latrans)
- Burke, C. B., **Quinn, N. M.**, & Stapp, P. (2021). Use of rodenticide bait stations by commensal rodents at the urban–wildland interface: Insights for management to reduce nontarget exposure. Pest Management Science.
- Baldwin, R. A., Becchetti, T. A., Meinerz, R., & **Quinn, N.** (2021). Potential impact of diphacinone application strategies on secondary exposure risk in a common rodent pest: implications for management of California ground squirrels. Environmental Science and Pollution Research, 1-12.

NIAMH QUINN

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EDUCATION

PhD Small Mammal Ecology
National University of Ireland, Galway 2010

BSc Zoology
National University of Ireland, Galway 2005

PUBLICATIONS

- Baldwin, R. A., Becchetti, T. A., Quinn, N., & Meinerz, R. (2021). Utility of visual counts for determining efficacy of management tools for California ground squirrels. Human–Wildlife Interactions, 15(1), 19.
- Quinn, N. (2019). Assessing individual and population-level effects of anticoagulant rodenticides on wildlife. Human–Wildlife Interactions, 13(2), 7.
- Quinn, N., Kenmuir, S., & Krueger, L. (2019). A California without rodenticides: challenges for commensal rodent management in the future. Human–Wildlife Interactions, 13(2), 8.
- Baldwin, R. A., Chapman, A., Kofron, C. P., Meinerz, R., Orloff, S. B., & Quinn, N. (2015). Refinement of a trapping method increases its utility for pocket gopher management. Crop Protection, 77, 176-180.
- Quinn, N., and R. A. Baldwin. 2014.Managing roof rats and deer mice in nut and fruit orchards. Division of Agriculture and Natural Resources, Publication 8513.
- Baldwin, R. A., Quinn, N., Davis, D. H., & Engeman, R. M. (2014). Effectiveness of rodenticides for managing invasive roof rats and native deer mice in orchards. Environmental Science and Pollution Research, 21(9), 5795-5802.

Paul Stapp
Department of Biological Science — Telephone: (657) 278-2849
California State University Fullerton (**CSUF**) — Email: pstapp@fullerton.edu
Fullerton, CA 92831 — ORCID ID: 0000-0003-1320-1461

<u>Professional Preparation</u>:

University of California Davis	Environmental Science/Policy	Postdoc, 1998-2002
University of Wyoming	Zoology and Physiology	Postdoc, 1998
Colorado State University (**CSU**)	Zoology/Ecological Studies	Ph.D., 1996
University of New Hampshire	Wildlife Ecology	M.S., 1990
University of California Davis	Zoology	B.S., 1986

<u>Professional Appointments</u>:

2024 – *present* Faculty Director, California Desert Studies Consortium
2012 – *present* Professor, Biological Sciences, CSUF
2007 – 2012 Associate Professor, Biological Science, CSUF
2002 – 2007 Assistant Professor, Biological Science, CSUF
2000 Lecturer (Tenure-track), Biology, University of York, York, UK
1996 – 2002 Adjunct Lecturer, Harvey Mudd College; University of California Davis; University of Northern Colorado; Colorado State University

Five Relevant Peer-Reviewed Publications:

Bosarge, M.A., **P. Stapp**, & N. Quinn. 2025. Behavior and activity of commensal roof rats around rodenticide bait stations in southern California, USA. Applied Animal Behaviour Science 287:106653.

Stapp, P., A. McKenzie, D.M. Bucklin, R.A. Baldwin, & N. Quinn. 2024. Patterns of exposure of coyotes to anticoagulant rodenticides in California, USA. Journal of Wildlife Management 2024: e22696. doi.org/10.1002/jwmg.22696

Bucklin, D.M., J.M. Shedden, N.M. Quinn, R. Cummings, & **P. Stapp**. 2023. Do trap-neuter-return (TNR) practices contribute to human-coyote conflicts in southern California? Human-Wildlife Interactions 17:46-60. doi.org/10.26077/b86e-600f

Burke, C.B., N.M. Quinn, & **P. Stapp**. 2021. Use of rodenticide bait stations by commensal rodents at the urban-wildland interface: Insights for management to reduce non-target exposure. Pest Management Science 77:3126-3134. doi.org/10.1002/ps.6345

Stapp, P., & D.J. Salkeld. 2009. Inferring host-parasite feeding relationships using stable isotopes: implications for disease transmission and host specificity. Ecology 90:3268-3273.

Five Other Significant Publications:

Salkeld, D.J., **P. Stapp**, D.W. Tripp, K.L. Gage, J. Lowell, C.T. Webb, R.J. Brinkerhoff, & M.F. Antolin. 2016. Ecological traits driving the outbreak and emergence of zoonotic pathogens. Bioscience 66:118-129.

Salkeld, D.J., M. Salathé, **P. Stapp** & J.H. Jones. 2010. Plague outbreaks in prairie dog populations: percolation thresholds of alternate host abundance explain epizootics. Proceedings of the National Academy of Sciences 107:14247-14250.

Franklin, H.A., **P. Stapp** & A. Cohen. 2010. Polymerase chain reaction (PCR) identification of rodent blood meals confirms host sharing by flea vectors of plague. Journal of Vector Ecology 35:363-371.

Stapp, P. 2002. Stable isotopes reveal evidence of predation by ship rats on seabirds on the Shiant Islands, Scotland. Journal of Applied Ecology 39:831-840.

Stapp, P., G.A. Polis, & F. Sánchez Piñero. 1999. Stable isotopes reveal strong marine and El Niño effects on island food webs. Nature 401:467-469.

Five Synergistic & Service Activities:

Supervised independent research projects and theses of 32 graduate and 29 undergraduate research students, 49 of whom were women and/or underrepresented minorities. Sixteen undergraduates were supported by NSF-UMEB/URM or REU funds.

Chair, CSUF Institutional Animal Care and Use Committee (2017-*present*).

California State University representative, Vertebrate Pest Control Research Advisory Committee, California Department of Food and Agriculture (2009-*present*).

Biology Graduate Program Adviser, Department of Biological Science, CSUF (2006-2024).

Publications Director, American Society of Mammalogists (ASM) (2016-2023).

CHRISTINE **WILKINSON, PH.D.**

Postdoctoral Researcher, UC Santa Cruz
Research Associate, California Academy of Sciences
Principal Investigator, Humans and Hyaenas Alliance
Emeryville, CA, USA & Elmenteita, Kenya

About Me

I am a conservation scientist and postdoctoral researcher whose work integrates ecology, participatory research, and environmental justice to address human-wildlife coexistence and carnivore conservation. My research spans urban and rural landscapes globally, focusing on how social and ecological factors influence carnivore movement, conflict, and coexistence. I have conducted extensive fieldwork in East Africa, urban California, and beyond, and I am an award-winning science communicator and mentor, recognized with the Schmidt Science Fellowship and Cell Press Rising Black Scientists Award. I also serves as lead for BayAreaCoyote.org, co-founder of Black Mammalogists Week, and a member of the IUCN SSC Hyaena Specialist Group.

Contact

christine.wilkinson@ucsc.edu
www.bayareacoyote.org

Positions and Education

Education

Ph.D., Environmental Science, Policy & Management, University of California, Berkeley (2015–2021)

B.S., Natural Resources, Applied Ecology (cum laude), Cornell University (2007–2011)

Positions and Appointments

2024–Present: Postdoctoral Researcher, Zavaleta & Wilmers Labs, UC Santa Cruz

2023–Present: Principal Investigator, Humans and Hyaenas Alliance (National Geographic Society)

2022–Present: Research Associate, California Academy of Sciences

2021–2024: Postdoctoral Researcher, Schell Lab, UC Berkeley

2012–2015: Digital Learning Coordinator, California Academy of Sciences

2011–2012: Field Manager, Kasokwa Forest Project, Uganda

CHRISTINE **WILKINSON, PH.D.**

Postdoctoral Researcher, UC Santa Cruz
Research Associate, California Academy of Sciences
Principal Investigator, Humans and Hyaenas Alliance
Emeryville, CA, USA & Elmenteita, Kenya

Honors and Awards

- Schmidt Science Fellowship ($202,500), 2022–2024
- Rising Black Scientists Award, Cell Press ($11,400), 2023
- The Wildlife Society Best Student Paper, 2021
- National Geographic Society Level II Grant ($99,884), 2023
- Switzer Fellowship ($15,000), 2019

Contact

christine.wilkinson@ucsc.edu
www.bayareacoyote.org

Selected Publications

- Wilkinson, C.E., Quinn, N., Eng, C., Schell, C.J. (2025). Environmental health and societal wealth predict movement patterns of an urban carnivore. Ecology Letters, 28(2).
- Murray, M.H., Larson, K.L., Morzillo, A.T., Young, J.K., Magle, S., Riley, S.P.D., Sikich, J.A., Schell, C.J., Wilkinson, C.E., et al. (2025). One Health and human-wildlife interactions: Drivers, feedbacks, and implications for health equity. BioScience.
- Sherman, W., Schell, C.J., Wilkinson, C.E. (2025). Socioeconomics and race predict social media carnivore reports. Science of the Total Environment, 977:179227.
- Wilkinson, C.E., Xu, W., Solli, A.L., Brashares, J.S., Chepkisich, C., Osuka, G., Kelly, M. (2024). Social-ecological predictors of hyena navigation in shared landscapes. Ecology and Evolution, 14(4):e11293.
- Estien, C.O., Fidino, M., Wilkinson, C.E., Morello-Frosch, R., Schell, C.J. (2024). Historical redlining and disparities in biodiversity in California cities. PNAS.

Contributions to Science

Human-Wildlife Coexistence and Environmental Justice – Pioneered research integrating social equity and ecological data to identify drivers of human-carnivore interactions in urban landscapes (Wilkinson et al. 2025, Sherman et al. 2025).

Carnivore Movement Ecology – Advanced understanding of how carnivores (coyotes, hyenas) navigate fragmented landscapes using telemetry and participatory methods (Wilkinson et al. 2024, 2021).

Conservation Fencing and Conflict Mitigation – Co-developed frameworks for evaluating ecological effects of fencing and coexistence interventions (McInturff et al. 2020, Wilkinson et al. 2021).

Science Communication and Mentorship – Co-founder of Black Mammalogists Week; frequent media contributor (National Geographic, Radiolab, PBS); mentor to 20+ students in the U.S. and Kenya.

CHRISTINE **WILKINSON, PH.D.**

Postdoctoral Researcher, UC Santa Cruz
Research Associate, California Academy of Sciences
Principal Investigator, Humans and Hyaenas Alliance
Emeryville, CA, USA & Elmenteita, Kenya

Selected Publications (continued)

- Wilkinson, C.E., Dheer, A., Torrents-Ticó, M., Dloniak, S., Yarnell, R., Ziv, E.B., et al. (2023). Global review of Hyaenidae literature and implications for conservation. Mammal Review, 54(2):193–212.

- Caspi, T., Stanton, L., Campbell, D., Schell, C.J., Wilkinson, C.E. (2023). Coexistence across space and time: A decade of human-coyote interactions in San Francisco. People and Nature, 5(6):2158–2177.

- Wilkinson, C.E., McInturff, A., Kelly, M., Brashares, J.S. (2021). Quantifying wildlife responses to conservation fencing in East Africa. Biological Conservation, 256:109071.

- McInturff, A., Xu, W., Wilkinson, C.E., Dejid, N., Brashares, J.S. (2020). Fence ecology: Frameworks for understanding the ecological effects of fences. BioScience, 70(11):971–985.

- Wilkinson, C.E., McInturff, A., Gaynor, K.M., Martin, J.V., Parker-Shames, P., Van Scoyoc, A., Brashares, J.S. (2020). An ecological framework for contextualizing carnivore-livestock conflict. Conservation Biology, 34(4):854–867.

Exhibit A6 – Current & Pending Support

CURRENT & PENDING SUPPORT

University will provide current & pending support information for Key Personnel identified in Exhibit A2 at time of proposal and upon request from State agency. The "Proposed Project" is this application that is submitted to the State. Add pages as needed.

PI: Niamh Quinn

Status (currently active or pending approval)	Award # (if available)	Source (name of the sponsor)	Project Title	Start Date	End Date
Proposed Project	N/a	Department of Consumer Affairs	Following the Trail: Can Mitigation Measures Reduce Rodenticide Exposure in Coyotes?	01/01/2026	06/30/2029
Current	22-1311-000-SA	Department of Food and Agriculture	Investigating Roof Rat Resistance	07/1/2022	6/30/2026
Pending	N/a	Department of Pesticide Regulation	Bridging the gap in IPM training for low-income housing	09/01/2025	06/30/2028

Co-PI: Paul Stapp

Status	Award #	Source	Project Title	Start Date	End Date
Proposed Project	N/a	Department of Consumer Affairs	Following the Trail: Can Mitigation Measures Reduce Rodenticide Exposure in Coyotes?	01/01/2026	06/30/2029
Current	2434735	National Science Foundation	Supporting Data-driven Field Studies at a Desert Studies Center	01/02/2025	31/01/2027
Current	L22AC00440-03	BLM California Plant Conservation and Restoration Management	CA CESU Building regional capacity for botanical research and outreach in the Mojave Desert	01/10/2022	09/30/2027
Pending	N/a	Department of Fish and Wildlife	CSU Biodiversity Sentinel Site Network	01/10/2025	12/30/2028

Co-PI: Christine Wilkinson

Status	Award #	Source	Project Title	Start Date	End Date
Proposed Project	N/a	Department of Consumer Affairs	Following the Trail: Can Mitigation Measures Reduce Rodenticide Exposure in Coyotes?	01/01/2026	06/30/2029
Current	NGS-99740R-23	National Geographic Society	Using interdisciplinary approaches to quantify hyena and scavenging bird benefits to people	01/08/2025	08/31/2027

Exhibit A7

Third Party Confidential Information

Confidential Nondisclosure Agreement

(Identified in Exhibit A, Scope of Work – will be incorporated, if applicable)

If the Scope of Work requires the provision of third party confidential information to either the State or the Universities, then any requirement of the third party in the use and disposition of the confidential information will be listed below. The third party may require a separate Confidential Nondisclosure Agreement (CNDA) as a requirement to use the confidential information. Any CNDA will be identified in this Exhibit A7.

N/A

Exhibit B - Budget

Budget for Project Period

Principal Investigator (Last, First): Quinn, Niamh **Exhibit B**

COMPOSITE BUDGET FOR ENTIRE PROPOSED PROJECT PERIOD
01/01/2026 to 06/30/2028

From: / To:	1/1/2026 12/31/2026	1/1/2027 12/31/2027	1/1/2028 12/31/2028	
BUDGET CATEGORY	**Year 1**	**Year 2**	**Year 3**	**TOTAL**
PERSONNEL: *Salary and fringe benefits.*	$23,843	$24,795	$25,787	$74,425
TRAVEL	$0	$0	$0	$0
MATERIALS & SUPPLIES	$138,650	$0	$0	$138,650
EQUIPMENT	$0	$0	$0	$0
CONSULTANT	$0	$0	$0	$0
SUBRECIPIENT	$9570	$12,715	$12,715	$35,000
OTHER DIRECT COSTS (ODC) ***Subject to IDC Calc***				
DNA detection ***Y***	$0	$17,900	$0	$0
ODC #2 ***Y***	$0	$0	$0	$0
ODC #3 ***Y***	$0	$0	$0	$0
ODC #4 ***Y***	$0	$0	$0	$0
ODC #5 ***Y***	$0	$0	$0	$0
ODC #6 ***Y***	$0	$0	$0	$0
TOTAL DIRECT COSTS	**$172,063**	**$55,410**	**$38,502**	**$265,974**
Indirect (F&A) Costs **F&A Base** *Rate* *MTDC ** **25**	$172,063 *$43,016*	$55,410 *$13,853*	$28,503 *$7,126*	$255,975 *$63,995*
TOTAL COSTS PER YEAR	**$215,079**	**$69,263**	**$45,628**	
TOTAL COSTS FOR PROPOSED PROJECT PERIOD				**$329,970**

* MTDC = Modified Total Direct Cost

JUSTIFICATION. *See Exhibit B1 - Follow the budget justification instructions.*

Funds Reversion Dates: Unless otherwise specified as following, fund reversion dates are three years from fiscal year end of year funded

Annual Budget Flexibility (lesser of % or Amount)

Prior approval required for budget changes between approved budget categories above the thresholds identified.

%	**10.00%**
	Or
Amount	*$10,000*

Principal Investigator (Last, First): Quinn, Niamh

Anticipated Program Income

(applicable only when the funded portion of the project generates income)

07/01/2026 to 06/30/2028

From:	**1/1/2026**	**1/1/2027**	**1/1/2028**	
To:	**12/31/2026**	**12/31/2027**	**12/31/2028**	
	Year 1	**Year 2**	**Year 3**	**TOTAL**
ANTICIPATED PROGRAM INCOME	**$0**	**$0**	**$0**	**$0**

Anticipated Program Income is an estimate of gross income earned by the University that is directly generated by a supported activity and earned only as a result of the State funded project, and this fact is known by the University at time of proposal. Anticipated Program Income is an estimate of potential income and not a guarantee of income to support the project.

Page 2 of Exhibit B will only be incorporated in the Agreement when Program Income is anticipated and proposed.

Program Income is subject to Section 14.D of Exhibit C of this Agreement.

If known, provide source(s) of Program Income:

Source	**Estimated Amount**

Exhibit B1

Budget Justification

The Budget Justification will include the following items in this format.

Personnel

Function	*Name*	*Effort*	*Roll on project*
PI	*Niamh Quinn*	*15%*	Coordinate coyote capture and feces acquisition and sampling across Southern California, managed partnerships with local agencies and pest control operators, and oversee laboratory testing for rodenticide residues and DNA. Contribute to study design, facilitate data interpretation within the regulatory and management context Co-author the resulting publication *(in-kind support)*
Co-PI	*Paul Stapp*	*5%*	Contribute to study design, facilitate data interpretation Co-author the resulting publication *(in-kind support)*
Co-PI	*Christine Wilkinson*	*5%*	Lead the spatial analysis and movement modeling components of the study, using GPS collar data to delineate coyote home ranges, identify habitat use patterns, and link movement behavior to potential rodenticide exposure hotspots. Support integration of movement data with isotopically labeled rodenticide (iLAR) detections to evaluate landscape-level mitigation outcomes. Co-author the resulting publication *(in-kind support)*
Staff Research Associate *(breakdown below)*	*TBD*	*75%*	Support field operations by assisting with the safe capture, handling, and collaring of coyotes, as well as collecting biological samples (e.g., feces, hair) for isotopically labeled rodenticide (iLAR) and bait application. Aid in maintaining field equipment, coordinating with landowners and agencies, and ensuring data and sample integrity for laboratory processing.

Personnel

SRA-TBD-75% FTE – Total salary $46,726

Fringe Benefits.

In accordance with University policy, explain the costs included in the budgeted fringe benefit percentages used, which could include tuition/fee remission for qualifying personnel to the extent that such costs are provided for by University policy, to estimate the fringe benefit expenses on Exhibit B.

$27,699

Staff Research Associate I benefits calculated at 59.8% in accordance with UCANR’s federally-negotiated benefit rate agreement.

Travel

Itemize all travel requests separately by trip and justify in Exhibit B1, in accordance with University travel guidelines. Provide the purpose, destination, travelers (name or position/role), and duration of each trip. Include detail on airfare, lodging and mileage expenses, if applicable. Should the application include a request for travel outside of the state of California, justify the need for those out-of-state trips separately and completely.

None

Materials and Supplies

Itemize materials supplies in separate categories. Include a complete justification of the project's need for these items. Theft sensitive equipment (under $5,000) must be justified and tracked separately in accordance with State Contracting Manual Section 7.29.

Collars and data-$20,000:

$17500-10 GPS GSM Coyote collars (Quinn already has 10 collars)

$2500- Data package for GPS GSM collars to allow for 15 min fixes per day.

$118,650- 7g of iLAR Rodenticide Technical

Equipment

List each item of equipment (greater than or equal to $5,000 with a useful life of more than one year) with amount requested separately and justify each.

None

Consultant Costs

Consultants are individuals/organizations who provide expert advisory or other services for brief or limited periods and do not provide a percentage of effort to the project or program. Consultants are not involved in the scientific or technical direction of the project as a whole. Provide the names and organizational affiliations of all consultants. Describe the services to be performed, and include the number of days of anticipated consultation, the expected rate of compensation, travel, per diem, and other related costs.

None

Subawardee (Consortium/Subrecipient) Costs

Each participating consortium organization must submit a separate detailed budget for every year in the project period in Exhibit B2 Subcontracts. Include a complete justification for the need for any subawardee listed in the application.

$35,000-USDA National Wildlife Research Center to test feces for iLAR compound.

Other Direct Costs

Itemize any other expenses by category and cost. Specifically justify costs that may typically be treated as indirect costs. For example, if insurance, telecommunication, or IT costs are charged as a direct expense, explain reason and methodology.

$17900- For services for species typing and individual/sex genotyping from UC Davis Mammalian Ecology and Conservation Unit.

Rent

If the Scope of Work will be performed in an off-campus facility rented from a third party for a specific project or projects, then rent may be charged as a direct expense to the award.

None

Indirect (F&A) Costs

Indirect costs are calculated in accordance with the budgeted indirect cost rate in Exhibit B.

Indirect costs are calculated in accordance with the budgeted indirect cost rate in Exhibit B. 25% MTDC – State of California off-campus rate.

Exhibit B2 – Subawardee Budgets

Budget Pertaining to Subawardee(s) (when applicable)

Exhibit B2

Subawardee Name: United States Department of Agriculture
Principal Investigator (Last, First): Volker, Steven

COMPOSITE SUBAWARDEE BUDGET FOR ENTIRE PROPOSED PROJECT PERIOD
01/01/2026 to 12/31/2028

BUDGET CATEGORY	From: / To:	1/1/2026 12/31/2026 Year 1	1/1/2027 12/31/2027 Year 2	1/1/2028 12/31/2028 Year 3	TOTAL
PERSONNEL: *Salary and fringe benefits.*		$7527	$10000	$10000	$27526
TRAVEL		$0	$0	$0	$0
MATERIALS & SUPPLIES		$0	$0	$0	$0
EQUIPMENT		$0	$0	$0	$0
CONSULTANT		$0	$0	$0	$0
SUBRECIPIENT		$0	$0	$0	$0
OTHER DIRECT COSTS (ODC)	***Subject to IDC Calc***				
ODC #1	***Y***	$0	$0	$0	$0
ODC #2	***Y***	$0	$0	$0	$0
ODC #3	***Y***	$0	$0	$0	$0
ODC #4	***Y***	$0	$0	$0	$0
ODC #5	***Y***	$0	$0	$0	$0
ODC #6	***Y***	$0	$0	$0	$0
TOTAL DIRECT COSTS		**$7,527**	**$10,000**	**$10,000**	**$27,527**
Indirect (F&A) Costs *Rate 27.15*	**F&A Base** *MTDC *: $27,526*	*$2,043*	*$2,715*	*$2,715*	*$7,473*
TOTAL COSTS PER YEAR		**$9,570**	**$12,715**	**$12,715**	
TOTAL COSTS FOR PROPOSED PROJECT PERIOD					**$35,000**

* MTDC = Modified Total Direct Cost

JUSTIFICATION. *See Exhibit B1 - Follow the budget justification instructions.*

Annual Budget Flexibility (lesser of % or Amount)

Prior approval required for budget changes between approved budget categories above the thresholds identified.

%	**10.00%**
	or
Amount	*$10,000*

Exhibit B3 – Invoice Elements

Invoice and Detailed Transaction Ledger Elements

In accordance with Section 14 of Exhibit C – Payment and Invoicing, the invoice, summary report and/or transaction/payroll ledger shall be certified by the University's Financial Contact and the PI (or their respective designees).

Invoicing frequency

☐ Quarterly ☐ Monthly

Invoicing signature format

☐ Ink ☐ Facsimile/Electronic Approval

Summary Invoice – includes either on the invoice or in a separate summary document – by approved budget category (Exhibit B) – expenditures for the invoice period, approved budget, cumulative expenditures and budget balance available[1]

- Personnel
- Equipment
- Travel
- Subawardee – Consultants
- Subawardee – Subcontract/Subrecipients
- Materials & Supplies
- Other Direct Costs
    - TOTAL DIRECT COSTS (if available from system)
- Indirect Costs
    - TOTAL

Detailed transaction ledger and/or payroll ledger for the invoice period [2]

- University Fund OR Agency Award # (to connect to invoice summary)
- Invoice/Report Period (matching invoice summary)
- GL Account/Object Code
- Doc Type (or subledger reference)
- Transaction Reference#
- Transaction Description, Vendor and/or Employee Name
- Transaction Posting Date
- Time Worked
- Transaction Amount

[1] If this information is not on the invoice or summary attachment, it may be included in a detailed transaction ledger.

[2] For salaries and wages, these elements are anticipated to be included in the detailed transaction ledger. If all elements are not contained in the transaction ledger, then a separate payroll ledger may be provided with the required elements.

Exhibit C – University Terms and Conditions

CMA (AB20) State/University Model Agreement Terms & Conditions UTC-220

Exhibit D- Additional Requirements Associated with Funding Sources

(if applicable)

If the Agreement is subject to any additional requirements imposed on the funding State agency by applicable law (including, but not limited to, bond, proposition and federal funding), then these additional requirements will be set forth in Exhibit D. If the University is a subrecipient, as defined in 2 CFR 200 (Uniform Guidance on Administrative Requirements, Audit Requirements and Cost Principles for Federal Financial Assistance), and the external funding entity is the federal government, the below table must be completed by the State agency. (Please see sections 10.A and 10.B of the Exhibit C.)

State Agency to Complete (Required for Federal Funding Source):

Federal Agency	
Federal Award Identification Number	
Federal Award Date	
Catalog of Federal Domestic Assistance (CFDA) Number and Name	
Amount Awarded to State Agency	
Effective Dates for State Agency	
Federal Award to State Agency is Research & Development (Yes/No)	

University to Complete:

Research and Development (R&D) means all research activities, both basic and applied, and all development activities that are performed by non-Federal entities. The term research also includes activities involving the training of individuals in research techniques where such activities utilize the same facilities as other R&D activities and where such activities are not included in the instruction function.

This award ☐ does ☐ does not support Research & Development.

Exhibit E – Special Conditions for Security of Confidential Information

(if applicable)

If the Scope of Work or project results in additional legal and regulatory requirements regarding security of Confidential Information, those requirements regarding the use and disposition of the information, will be provided by the funding State agency in Exhibit E. (Please see section 8.E of Exhibit C.)

Exhibit F – Access to State Facilities or Computing Resources

(if applicable)

If the Scope of Work or project requires that the Universities have access to State agency facilities or computing systems and a separate agreement between the individual accessing the facility or system and the State agency is necessary, then the requirement for the agreement and the agreement itself will be listed in Exhibit F. (Please see section 21 of Exhibit C.)

Exhibit G – Negotiated Alternate UTC Terms (if applicable)

An alternate provision in Exhibit G must clearly identify whether it is replacing, deleting or modifying a provision of Exhibit C. The Order of Precedence incorporated in Exhibit C clearly identifies that the provisions on Exhibit G take precedence over those in Exhibit C.

> *While every effort has been made to keep the UTC as universal in its application as possible, there may be unique projects where a given term in the UTC may be inappropriate or inadequate, or additional terms may be necessary. California Education Code §67327(b) allows for terms to be changed or added, but only through the mutual agreement and negotiation of the State agency and the University campus. If a given term in the UTC is to be changed, the change should **not** be noted in Exhibit C, but rather noted separately in Exhibit G.*

NIAMH QUINN

HUMAN-WILDLIFE INTERACTIONS ADVISOR

CONTACT ME AT

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Irvine, CA 92618

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cosmopolitancoyotes

linkedin.com/in/ratwhacker

EDUCATION

PhD Small Mammal Ecology
National University of Ireland, Galway 2010

BSc Zoology
National University of Ireland, Galway 2005

CURRENT APPOINMENT

I am a University of California Cooperative Extension Human-Wildlife Interactions Advisor, based at the South Coast Research and Extension Center in Irvine with a focus directed on the coordination of Cooperative Extension programming regarding human-wildlife conflicts

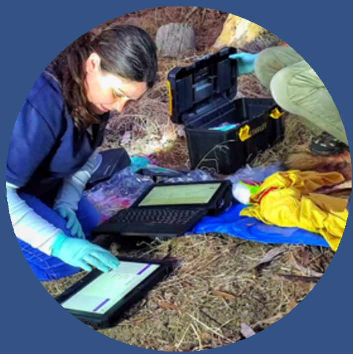
RESEARCH AND EXTENSION FUNDING

Extramural grants: Total funding $1,700,000

Selected titles

- Can rodenticide toxicosis be mitigated by changes in management practices? Examination of two different bait stations, their placement, visitations by small mammals and birds, and their interaction with mesocarnivores- Pest Management Foundation
- Development of best management practices to manage urban rats, protect public health, and reduce rodenticide use- Department of Pesticide Regulation
- Investigation of Rodenticide Pathways in an Urban System Through the Use of Isotopically Labelled Bait- Department of Consumer Affairs
- Ground squirrel best management practices website- expansion of passive extension capacities- Department of Food and Agriculture
- Monitoring rodenticide exposure in urban carnivores- Department of Pesticide Regulation
- Investigating roof rat resistance-Department of Food and Agriculture
- Improving commensal rodent management by improving the utility of bait stations and the consumption of bait- Pest Management Foundation
- Sanitation and light sabers; what is left for pest management professionals?-Pest Management Foundation

Industry/programmatic funding and in-kind support: Total funding $750,000



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EDUCATION

PhD Small Mammal Ecology
National University of Ireland, Galway 2010

BSc Zoology
National University of Ireland, Galway 2005

PUBLICATIONS

- Bosarge, M. A., Stapp, P., & Quinn, N. (2025). Behavior and activity of commensal roof rats around rodenticide bait stations in southern California, USA. Applied Animal Behaviour Science, 106653.
- Stapp, P., McZenzie, A., Bucklin, D., Baldwin, R. & Quinn, N. (2025) Patterns of exposure of coyotes to anticoagulant rodenticides in California, USA. Journal of Wildlife Management.
- Wilkinson, C. E., Quinn, N., Eng, C., & Schell, C. J. (2025). Environmental health and societal wealth predict movement patterns of an urban carnivore. Ecology Letters, 28(2), e70088.
- Bucklin, D. M., Shedden, J. M., Quinn, N. M., Cummings, R., & Stapp, P. (2023). Do trap-neuter-return (TNR) practices contribute to human–coyote conflicts in southern California?. Human–Wildlife Interactions, 17(1), 7.
- Shultz, L., López-Pérez, A.M., Jasuja, R., Helman, S., Prager, K., Tokuyama, A., Quinn, N., Bucklin, D., Rudd, J., Clifford, D. and Brown, J.. (2023). Vector-Borne Disease in Wild Mammals Impacted by Urban Expansion and Climate Change. EcoHealth, 20(3), 286-299.
- Javeed, N.N., Shultz, L., Barnum, S., Foley, J.E., Hodzic, E., Pascoe, E.L., Martínez-López, B., **Quinn, N.**, Bucklin, D. and Dear, J.D. (2022) Prevalence and geographic distribution of Babesia conradae and detection of Babesia vogeli in free-ranging California coyotes (Canis latrans)
- Burke, C. B., **Quinn, N. M.**, & Stapp, P. (2021). Use of rodenticide bait stations by commensal rodents at the urban–wildland interface: Insights for management to reduce nontarget exposure. Pest Management Science.
- Baldwin, R. A., Becchetti, T. A., Meinerz, R., & **Quinn, N.** (2021). Potential impact of diphacinone application strategies on secondary exposure risk in a common rodent pest: implications for management of California ground squirrels. Environmental Science and Pollution Research, 1-12.

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EDUCATION

PhD Small Mammal Ecology
National University of Ireland,
Galway 2010

BSc Zoology
National University of Ireland,
Galway 2005

PUBLICATIONS

- Baldwin, R. A., Becchetti, T. A., Quinn, N., & Meinerz, R. (2021). Utility of visual counts for determining efficacy of management tools for California ground squirrels. Human–Wildlife Interactions, 15(1), 19.
- Quinn, N. (2019). Assessing individual and population-level effects of anticoagulant rodenticides on wildlife. Human–Wildlife Interactions, 13(2), 7.
- Quinn, N., Kenmuir, S., & Krueger, L. (2019). A California without rodenticides: challenges for commensal rodent management in the future. Human–Wildlife Interactions, 13(2), 8.
- Baldwin, R. A., Chapman, A., Kofron, C. P., Meinerz, R., Orloff, S. B., & Quinn, N. (2015). Refinement of a trapping method increases its utility for pocket gopher management. Crop Protection, 77, 176-180.
- Quinn, N., and R. A. Baldwin. 2014.Managing roof rats and deer mice in nut and fruit orchards. Division of Agriculture and Natural Resources, Publication 8513.
- Baldwin, R. A., Quinn, N., Davis, D. H., & Engeman, R. M. (2014). Effectiveness of rodenticides for managing invasive roof rats and native deer mice in orchards. Environmental Science and Pollution Research, 21(9), 5795-5802.

Paul Stapp
Department of Biological Science
California State University Fullerton (**CSUF**)
Fullerton, CA 92831
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Email: pstapp@fullerton.edu
ORCID ID: 0000-0003-1320-1461

Professional Preparation:

University of California Davis	Environmental Science/Policy	Postdoc, 1998-2002
University of Wyoming	Zoology and Physiology	Postdoc, 1998
Colorado State University (**CSU**)	Zoology/Ecological Studies	Ph.D., 1996
University of New Hampshire	Wildlife Ecology	M.S., 1990
University of California Davis	Zoology	B.S., 1986

Professional Appointments:

2024 – *present*	Faculty Director, California Desert Studies Consortium
2012 – *present*	Professor, Biological Sciences, CSUF
2007 – 2012	Associate Professor, Biological Science, CSUF
2002 – 2007	Assistant Professor, Biological Science, CSUF
2000	Lecturer (Tenure-track), Biology, University of York, York, UK
1996 – 2002	Adjunct Lecturer, Harvey Mudd College; University of California Davis; University of Northern Colorado; Colorado State University

Five Relevant Peer-Reviewed Publications:

Bosarge, M.A., **P. Stapp**, & N. Quinn. 2025. Behavior and activity of commensal roof rats around rodenticide bait stations in southern California, USA. Applied Animal Behaviour Science 287:106653.

Stapp, P., A. McKenzie, D.M. Bucklin, R.A. Baldwin, & N. Quinn. 2024. Patterns of exposure of coyotes to anticoagulant rodenticides in California, USA. Journal of Wildlife Management 2024: e22696. doi.org/10.1002/jwmg.22696

Bucklin, D.M., J.M. Shedden, N.M. Quinn, R. Cummings, & **P. Stapp**. 2023. Do trap-neuter-return (TNR) practices contribute to human-coyote conflicts in southern California? Human-Wildlife Interactions 17:46-60. doi.org/10.26077/b86e-600f

Burke, C.B., N.M. Quinn, & **P. Stapp**. 2021. Use of rodenticide bait stations by commensal rodents at the urban-wildland interface: Insights for management to reduce non-target exposure. Pest Management Science 77:3126-3134. doi.org/10.1002/ps.6345

Stapp, P., & D.J. Salkeld. 2009. Inferring host-parasite feeding relationships using stable isotopes: implications for disease transmission and host specificity. Ecology 90:3268-3273.

Five Other Significant Publications:

Salkeld, D.J., **P. Stapp**, D.W. Tripp, K.L. Gage, J. Lowell, C.T. Webb, R.J. Brinkerhoff, & M.F. Antolin. 2016. Ecological traits driving the outbreak and emergence of zoonotic pathogens. Bioscience 66:118-129.

Salkeld, D.J., M. Salathé, **P. Stapp** & J.H. Jones. 2010. Plague outbreaks in prairie dog populations: percolation thresholds of alternate host abundance explain epizootics. Proceedings of the National Academy of Sciences 107:14247-14250.

Franklin, H.A., **P. Stapp** & A. Cohen. 2010. Polymerase chain reaction (PCR) identification of rodent blood meals confirms host sharing by flea vectors of plague. Journal of Vector Ecology 35:363-371.

Stapp, P. 2002. Stable isotopes reveal evidence of predation by ship rats on seabirds on the Shiant Islands, Scotland. Journal of Applied Ecology 39:831-840.

Stapp, P., G.A. Polis, & F. Sánchez Piñero. 1999. Stable isotopes reveal strong marine and El Niño effects on island food webs. Nature 401:467-469.

Five Synergistic & Service Activities:

Supervised independent research projects and theses of 32 graduate and 29 undergraduate research students, 49 of whom were women and/or underrepresented minorities. Sixteen undergraduates were supported by NSF-UMEB/URM or REU funds.

Chair, CSUF Institutional Animal Care and Use Committee (2017-*present*).

California State University representative, Vertebrate Pest Control Research Advisory Committee, California Department of Food and Agriculture (2009-*present*).

Biology Graduate Program Adviser, Department of Biological Science, CSUF (2006-2024).

Publications Director, American Society of Mammalogists (ASM) (2016-2023).

CHRISTINE **WILKINSON, PH.D.**

Postdoctoral Researcher, UC Santa Cruz
Research Associate, California Academy of Sciences
Principal Investigator, Humans and Hyaenas Alliance
Emeryville, CA, USA & Elmenteita, Kenya

About Me

I am a conservation scientist and postdoctoral researcher whose work integrates ecology, participatory research, and environmental justice to address human-wildlife coexistence and carnivore conservation. My research spans urban and rural landscapes globally, focusing on how social and ecological factors influence carnivore movement, conflict, and coexistence. I have conducted extensive fieldwork in East Africa, urban California, and beyond, and I am an award-winning science communicator and mentor, recognized with the Schmidt Science Fellowship and Cell Press Rising Black Scientists Award. I also serves as lead for BayAreaCoyote.org, co-founder of Black Mammalogists Week, and a member of the IUCN SSC Hyaena Specialist Group.

Contact

christine.wilkinson@ucsc.edu
www.bayareacoyote.org

Positions and Education

Education

Ph.D., Environmental Science, Policy & Management, University of California, Berkeley (2015–2021)

B.S., Natural Resources, Applied Ecology (cum laude), Cornell University (2007–2011)

Positions and Appointments

2024–Present: Postdoctoral Researcher, Zavaleta & Wilmers Labs, UC Santa Cruz

2023–Present: Principal Investigator, Humans and Hyaenas Alliance (National Geographic Society)

2022–Present: Research Associate, California Academy of Sciences

2021–2024: Postdoctoral Researcher, Schell Lab, UC Berkeley

2012–2015: Digital Learning Coordinator, California Academy of Sciences

2011–2012: Field Manager, Kasokwa Forest Project, Uganda

CHRISTINE **WILKINSON, PH.D.**

Postdoctoral Researcher, UC Santa Cruz
Research Associate, California Academy of Sciences
Principal Investigator, Humans and Hyaenas Alliance
Emeryville, CA, USA & Elmenteita, Kenya

Honors and Awards

- Schmidt Science Fellowship ($202,500), 2022–2024
- Rising Black Scientists Award, Cell Press ($11,400), 2023
- The Wildlife Society Best Student Paper, 2021
- National Geographic Society Level II Grant ($99,884), 2023
- Switzer Fellowship ($15,000), 2019

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christine.wilkinson@ucsc.edu
www.bayareacoyote.org

Selected Publications

- Wilkinson, C.E., Quinn, N., Eng, C., Schell, C.J. (2025). Environmental health and societal wealth predict movement patterns of an urban carnivore. Ecology Letters, 28(2).

- Murray, M.H., Larson, K.L., Morzillo, A.T., Young, J.K., Magle, S., Riley, S.P.D., Sikich, J.A., Schell, C.J., Wilkinson, C.E., et al. (2025). One Health and human-wildlife interactions: Drivers, feedbacks, and implications for health equity. BioScience.

- Sherman, W., Schell, C.J., Wilkinson, C.E. (2025). Socioeconomics and race predict social media carnivore reports. Science of the Total Environment, 977:179227.

- Wilkinson, C.E., Xu, W., Solli, A.L., Brashares, J.S., Chepkisich, C., Osuka, G., Kelly, M. (2024). Social-ecological predictors of hyena navigation in shared landscapes. Ecology and Evolution, 14(4):e11293.

- Estien, C.O., Fidino, M., Wilkinson, C.E., Morello-Frosch, R., Schell, C.J. (2024). Historical redlining and disparities in biodiversity in California cities. PNAS.

Contributions to Science

Human-Wildlife Coexistence and Environmental Justice – Pioneered research integrating social equity and ecological data to identify drivers of human-carnivore interactions in urban landscapes (Wilkinson et al. 2025, Sherman et al. 2025).

Carnivore Movement Ecology – Advanced understanding of how carnivores (coyotes, hyenas) navigate fragmented landscapes using telemetry and participatory methods (Wilkinson et al. 2024, 2021).

Conservation Fencing and Conflict Mitigation – Co-developed frameworks for evaluating ecological effects of fencing and coexistence interventions (McInturff et al. 2020, Wilkinson et al. 2021).

Science Communication and Mentorship – Co-founder of Black Mammalogists Week; frequent media contributor (National Geographic, Radiolab, PBS); mentor to 20+ students in the U.S. and Kenya.

CHRISTINE **WILKINSON, PH.D.**

Postdoctoral Researcher, UC Santa Cruz
Research Associate, California Academy of Sciences
Principal Investigator, Humans and Hyaenas Alliance
Emeryville, CA, USA & Elmenteita, Kenya

Selected Publications (continued)

- Wilkinson, C.E., Dheer, A., Torrents-Ticó, M., Dloniak, S., Yarnell, R., Ziv, E.B., et al. (2023). Global review of Hyaenidae literature and implications for conservation. Mammal Review, 54(2):193–212.
- Caspi, T., Stanton, L., Campbell, D., Schell, C.J., Wilkinson, C.E. (2023). Coexistence across space and time: A decade of human-coyote interactions in San Francisco. People and Nature, 5(6):2158–2177.
- Wilkinson, C.E., McInturff, A., Kelly, M., Brashares, J.S. (2021). Quantifying wildlife responses to conservation fencing in East Africa. Biological Conservation, 256:109071.
- McInturff, A., Xu, W., Wilkinson, C.E., Dejid, N., Brashares, J.S. (2020). Fence ecology: Frameworks for understanding the ecological effects of fences. BioScience, 70(11):971–985.
- Wilkinson, C.E., McInturff, A., Gaynor, K.M., Martin, J.V., Parker-Shames, P., Van Scoyoc, A., Brashares, J.S. (2020). An ecological framework for contextualizing carnivore-livestock conflict. Conservation Biology, 34(4):854–867.

STEVEN F. VOLKER – BIOSKETCH

Current Position

Chemist (GS-11), USDA, Animal & Plant Health Inspection Service, National Wildlife Research Center, Fort Collins, CO (2009–present)
Analytical chemist developing and validating instrumental methods for diverse residues including rodenticides, avicides, and biomarkers in various matrices (e.g., tissue, blood, soil, water).

Education

B.A. in Chemistry (ACS Certified), Minor in Earth Science, University of Northern Colorado, Greeley, CO – 1995
Major GPA: 3.89 / Overall GPA: 3.80

Areas of Expertise

• Analytical method development and validation (HPLC, GC, LC-MS/MS, GC-MS/MS, IC)
• Exposure studies for wildlife toxicology and pharmacokinetics
• Residue analysis of anticoagulant rodenticides, biomarkers, avicides
• Good Laboratory Practice (GLP) compliance
• Supervision and mentoring of laboratory personnel

Selected Publications (Recent)

- Witmer, G.W., Volker, S.F. (2024). Anticoagulant rodenticides and salamanders. Human-Wildlife Interactions.
- Buechley, E.R., et al., Volker, S. (2023). Rodenticide exposure in American Kestrels. Journal of Raptor Research.
- Horak, K.E., Campton, C.M., Volker, S.F. (2020). Metabolism of diphacinone/chlorophacinone in squirrels. Crop Protection.
- Rattner, B.A., Volker, S.F., et al. (2020). Brodifacoum toxicity in kestrels. Environmental Toxicology and Chemistry.
- Kimball, B.A., Volker, S.F., et al. (2019). Volatile metabolomic signatures post-rabies immunization. PLOS NTDs.

Selected Presentations

• Volker, S.F. (2022). LC-MS/MS Method for Rodenticides in Kestrel Tissues. Vertebrate Pest Conference, Reno, NV.
• Volker, S.F. (2023). Iophenoxic Acids in Mongoose Serum – Method Update. JoVE Live Presentation.

Relevant Technical Skills

• LC-MS/MS, GC-MS/MS, HPLC, IC, DSC, SEM
• Agilent ChemStation, MassHunter, Dionex Chromeleon
• Microsoft Excel/Word, data interpretation, QA/QC reporting

Professional Highlights

• Over 15 peer-reviewed publications and technical reports on pesticide residues and wildlife toxicology
• Extensive field and lab experience with rodenticide exposure studies in birds, reptiles, and mammals
• Contributor to PBPK model development for rodenticides in collaboration with USGS and NWRC
• Longstanding role in training staff, ensuring laboratory safety, and optimizing analytical workflows

Attachment 7

Narrative of Research Objectives, as described in Rating/Scoring Criteria

Importance of the Research Objectives and Potential to Advance Knowledge in Structural Pest Management

The goal of this research is to test whether pulsed baiting and other alternative applications of anticoagulant rodenticides (ARs) reduce non-target exposure in coyotes (*Canis latrans*) while maintaining effective rodent control. The study integrates a novel field-deployable technology, isotopically labelled anticoagulant rodenticides (iLARs**)**, with validated rat activity indices and non-invasive coyote monitoring (scat, hair, and GPS collar data). This approach has the potential to transform structural pest management by enabling real-time evaluation of AR mitigation strategies and by offering a science-based framework to guide regulatory decisions. If successful, this project will establish the first field-validated methodology for assessing how specific operational changes to AR deployment influence exposure in non-target wildlife, bridging a critical gap in rodenticide risk mitigation policy.

A. Research Objectives and Hypotheses

This research will:

1. Determine whether pulsed or increased-frequency AR applications lead to a lower frequency and intensity of rodenticide exposure in coyotes compared to standard monthly baiting practices.
2. Evaluate whether these mitigation strategies maintain effective commensal rodent control, as measured by a standardized roof rat activity index.

The central hypothesis is:

Modified application strategies will significantly reduce the frequency and intensity of iLAR detection in coyotes without compromising rodent control efficacy.

B. Background and Knowledge Gaps

California has enacted regulatory measures such as AB 1788 and AB 1322 to limit AR exposure in non-target wildlife. However, recent studies (e.g., Stapp et al. 2024) show that urban coyotes continue to experience near-ubiquitous exposure to both FGARs and SGARs. This suggests that current restrictions alone may be insufficient to reduce real-world risks.

Until now, there has been no method to precisely trace rodenticide exposure back to its point of origin in space and time. Carcass-based testing provides only static residue snapshots, while enforcement and compliance data do not capture ecological outcomes. The Quinn Lab has developed a novel tool, iLARs combined with non-lethal monitoring and movement ecology, to directly link baiting events to exposure events in the field. This proposal applies that tool to a real-world structural pest control context for the first time.

There is also a lack of validated field data on whether mitigation measures, such as pulsed baiting, are effective in reducing exposure without undermining rodent control performance. This study fills that critical gap.

C. Alignment with Solicitation Priorities

This project directly responds to the SPCB-25-01 priority to s*upport* new studies and technology methods within the framework of integrated pest management.

It will generate actionable data on how mitigation techniques affect rodent control success and wildlife safety. By using iLARs under field conditions and measuring outcomes in both rodents and coyotes, the project provides the Board and the Department of Pesticide Regulation (DPR) with a decision-making tool to evaluate the effectiveness, feasibility, and ecological consequences of structural AR mitigation strategies.

Attachment 8

Narrative of Project Direction (Work Plan and Work Schedule)

This project is structured as a three-year field trial to evaluate whether anticipated and alternative mitigation strategies, specifically pulsed baiting and increased-frequency rodenticide applications, can reduce non-target wildlife exposure to anticoagulant rodenticides (ARs) while maintaining effective rodent control. The research integrates isotopically labeled ARs (iLARs), validated rodent activity monitoring tools, non-invasive sampling, and GPS-collaring of coyotes to generate actionable, field-based data. The project is divided into 5 separate tasks.

A. Research Design and Tentative Timeline

The project will proceed in the following phases:

- Project Initiation (Months 1–3): Permits (Scientific Collection Permit, Institutional Animal Care and Use Committee), approvals, and staff training will be completed in the first 3 months.
- Coyote Trapping (Months 4–12): Site selection and field trapping efforts will occur over 9 months starting in Month 4.
- iLAR Treatments (Months 1–18): iLAR manufacture (Months 1–3), site selection (Months 7–9), and applications (Months 10–15). Rodent monitoring will continue through Month 18.

- Fecal Management (Months 10–27): Fecal collection and analysis will be conducted over 18 months.
- Data Management (Months 1–36): Data collection and analysis will occur throughout the project and conclude before Month 36.

B. Specific Objectives, Activities, and Timeline

Objective	Activities	Timeline
Project Initiation	Permits, approvals, staff training	Months 1–3
Coyote Trapping	Site selection, field trapping	Months 4–12
iLAR Treatments	iLAR manufacture, site selection, applications, monitoring	Months 1–18
Fecal Management	Sample collection and laboratory analysis	Months 10–27
Data Management	Data entry, cleaning, and analysis	Months 1–36

C. Data Collection, Analysis, and Interpretation

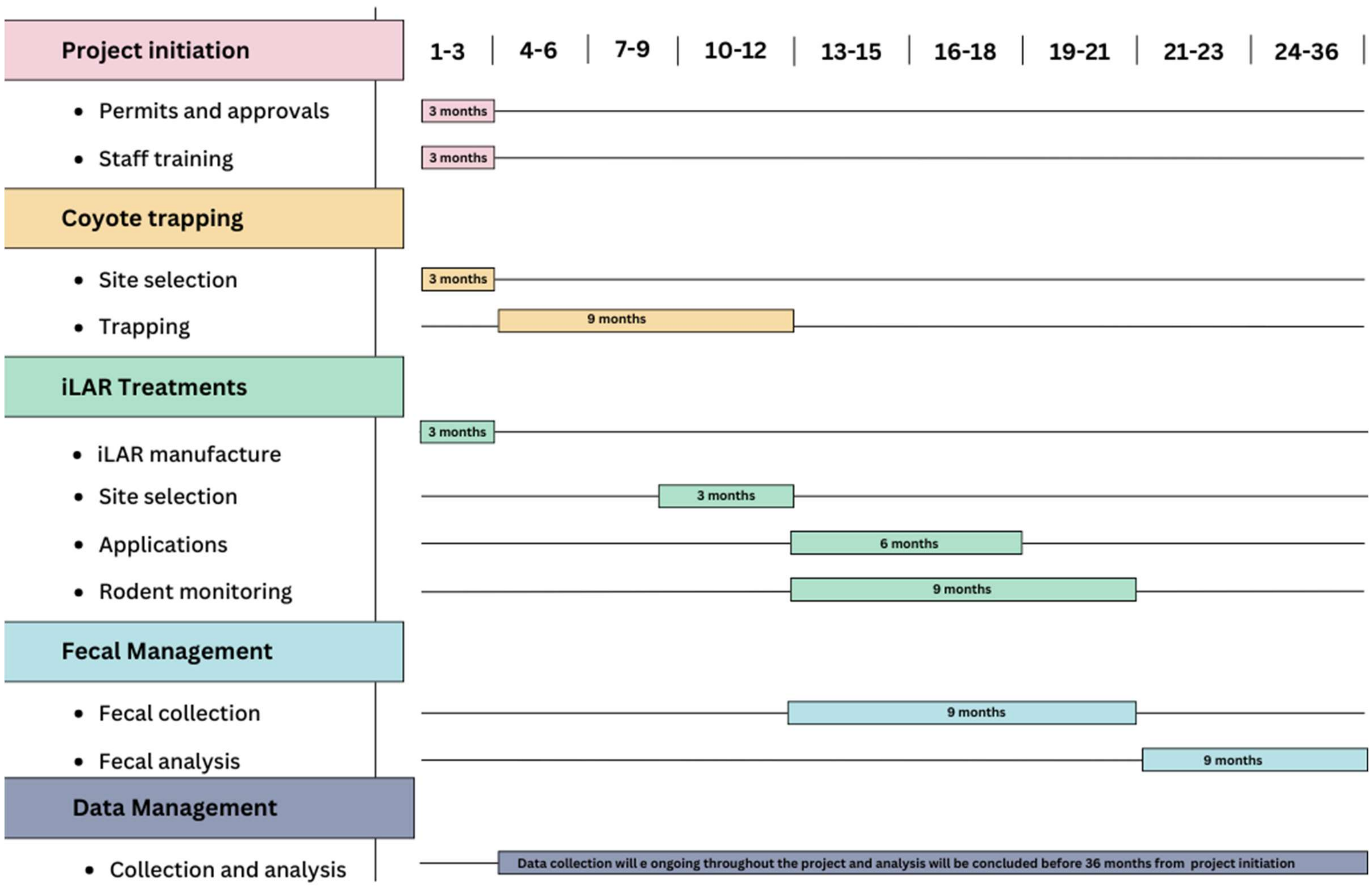
Rodent activity will be measured using tracking tunnels and camera traps, producing a standardized index. Coyote exposure will be assessed using feces and hair analyzed via LC-MS for iLAR compounds. DNA genotyping will ensure individual-level tracking. GPS collar data will be analyzed with spatial tools (e.g., kernel density estimation, step selection functions) to correlate exposure patterns with treatment types and habitat use. Data will be analyzed using GLMs and mixed-effects models.

D. Time Allocation and Monitoring System

- Dr. Niamh Quinn (PI): 15% FTE – project direction, iLAR deployment, coordination.
- Dr. Paul Stapp (Co-I): 5% FTE – study design, toxicology oversight, interpretation.
- Dr. Christine Wilkinson (Co-PI): 5% FTE – telemetry analysis, spatial modeling.
- Staff Research Associate: 75% FTE – trapping, sample collection, field coordination.
- Lab Partners (subaward): 10% FTE – iLAR analysis, genotyping.

Monitoring will occur via biweekly internal meetings, monthly updates from field teams, and quarterly performance check-ins to ensure progress, compliance, and data integrity. Deliverables will follow the planned schedule with flexibility for adaptive management.

Project Timeline



Attachment 9

Narrative of Qualifications - Key Personnel

Dr. Niamh Quinn – Principal Investigator

Dr. Niamh Quinn is the University of California Cooperative Extension (UCCE) Human-Wildlife Interactions Advisor, based at the South Coast Research and Extension Center in Irvine, California. She specializes in commensal rodent management, urban coyote ecology, and the impacts of anticoagulant rodenticides (ARs) on non-target wildlife. Dr. Quinn has led multiple field- and laboratory-based projects on AR exposure, including the development of iLARs for tracking exposure across trophic levels, and the first non-lethal, longitudinal monitoring program for coyotes using scat, hair, and GPS collar data (DPR Project). Her work has been instrumental in identifying exposure pathways, detecting illegal rodenticide use, and providing science-based recommendations to inform California Department of Pesticide Regulation (DPR) and Structural Pest Control Board (SPCB) policies. She will oversee project coordination, field operations, and integration of iLAR methods into the proposed study.

Dr. Paul Stapp – Co-Investigator

Dr. Paul Stapp is a Professor of Biology at California State University, Fullerton, with more than two decades of experience in wildlife ecology, trophic interactions, and contaminant exposure in mammalian carnivores. Dr. Stapp has co-authored studies on AR exposure in Southern California carnivores, including a statewide assessment of exposure in 485 coyotes (Stapp et al., *Journal of Wildlife Management*, 2024). He has extensive expertise in study design, data interpretation, and the integration of toxicological results with landscape and dietary analyses. Dr. Stapp will advise on study design, data synthesis, and ensure scientific rigor in exposure assessments and interpretation for management and policy applications.

Dr. Christine Wilkinson – Co-Investigator (Movement Ecology Lead)

Dr. Christine Wilkinson is a wildlife ecologist and Postdoctoral Researcher at the University of California, Berkeley, specializing in carnivore spatial ecology, movement modelling, and human–wildlife conflict. She has applied advanced spatial modelling tools, including kernel density estimation and step selection analyses, to quantify predator habitat use and risk in human-dominated landscapes. Dr. Wilkinson will lead the analysis of GPS collar data for collared coyotes, delineating home ranges, habitat use, and identifying potential exposure hotspots. Her work will be critical for linking movement patterns to iLAR detections, enabling the evaluation of how mitigation measures alter exposure across landscapes.

Together, this interdisciplinary team has developed the foundational methods that will ensure the success of the *"Following the Trail"* project.

- validated rodent activity indices (Bosarge, 2024)
- camera-based wildlife monitoring frameworks (Burke, 2018)
- non-invasive AR exposure tracking (DPR Project)
- isotopically labelled rodenticide technology

Their combined expertise in wildlife toxicology, spatial ecology, and applied rodent management ensures that the study will generate robust, field-validated data to inform DPR and SPCB decision-making on rodenticide mitigation strategies.

Research Facilities, Equipment, and Capacity to Execute Project Activities

This project will be supported by a network of established research facilities and service providers with proven capacity and a history of successful collaboration on rodenticide-related studies. All facilities listed below have been utilized in prior projects by the Principal Investigator and collaborators and have demonstrated their ability to deliver high-quality, timely outputs.

South Coast Research and Extension Center (SCREC) – Located in Irvine, California, SCREC is a University of California Agriculture and Natural Resources (UC ANR) field station that provides essential infrastructure for field-based research, including, administrative support, and access to diverse urban-edge landscapes ideal for wildlife research. SCREC has served as the operational base for prior coyote trapping and telemetry studies led by the PI.

USDA National Wildlife Research Center (NWRC) – Chemistry Services Laboratory – The NWRC's Chemistry Services Laboratory in Fort Collins, Colorado, is internationally recognized for its expertise in wildlife toxicology and rodenticide residue analysis. The lab routinely conducts high-sensitivity LC-MS/MS screening for anticoagulant rodenticides in biological samples. NWRC previously analyzed samples for the DPR- and SPCB-funded iLAR validation studies and has the infrastructure and personnel capacity to process fecal and hair samples for this project.

UC Davis – Ben Sacks Mammalian Ecology and Conservation Unit (MECU) – MECU will provide services for individual genotyping, species confirmation, and sex identification from fecal samples. The lab uses well-established PCR and SNP panels to identify individual coyotes with high accuracy. MECU has supported prior large-scale wildlife genetics projects and offers high-throughput processing with rigorous quality control.

Richmond Chemical – Richmond Chemical, specializes in the synthesis of custom compounds and has successfully produced iLARs for prior SPCB-funded research. The company follows rigorous quality assurance protocols to ensure compound identity, purity, and stability. Their ability to manufacture and deliver iLARs has been demonstrated through successful research collaborations.

Together, these facilities provide the infrastructure, technical expertise, and proven performance record necessary to execute all aspects of this project, from field implementation to lab analysis and data interpretation, ensuring scientific rigor and timely completion of milestones.

Attachment 10

State of California
Secretary of State

CERTIFICATE OF STATUS

ENTITY NAME:

THE REGENTS OF THE UNIVERSITY OF CALIFORNIA

FILE NUMBER:	0008116
FORMATION DATE:	06/18/1868
TYPE:	STATUTORY CORPORATION
JURISDICTION:	CALIFORNIA
STATUS:	ACTIVE (GOOD STANDING)

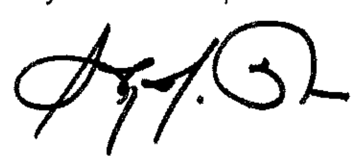
I, SHIRLEY N. WEBER, PH.D, Secretary of State of the State of California, hereby certify:

That on the 18th Day of June, 1868, THE REGENTS OF THE UNIVERSITY OF CALIFORNIA, (File Number C0008116), became incorporated with the filing of a Certificate of Incorporation under the General Laws of the State of California as provided by an Act of the California Legislature entitled "An Act to Create and Organize the University of California;"

That the statutory corporation is governed by the provisions of Article IX, Section 9, of the California Constitution and by the California Education Code, commencing at Section 92000; and

That no record exists in this office of a legislative act to dissolve or terminate said statutory corporation and no record exists in this office of a merger, consolidation or other type of reorganization that would terminate its existence.

IN WITNESS WHEREOF, I execute this certificate and affix the Great Seal of the State of California this day of March 14, 2024.



Shirley N. Weber, Ph.D.
Secretary of State

NP-25 (REV 01/2021)

Go to www.bizfileonline.sos.ca.gov for information about ordering a copy of a filed document.

NLH
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UNIVERSITY OF CALIFORNIA
Agriculture and Natural Resources

Statewide Integrated Pest Management Program

July 20, 2025

To the Members of the Structural Pest Control Board and Research Advisory Panel:

As the Associate Director for Urban & Community IPM with the University of California Statewide IPM Program, and Area Urban IPM Advisor for Sacramento, Yolo, and Solano Counties, I am uniquely positioned to understand the growing challenges urban communities face in balancing effective rodent management with protection of non-target wildlife. I am writing to strongly support the proposal *"Following the Trail: Can Mitigation Measures Reduce Rodenticide Exposure in Coyotes?"* submitted under Solicitation SPCB-25-01.

Rodents are a persistent and significant issue for California's urban and suburban areas, impacting public health, housing, food safety, and overall quality of life. Structural pest control professionals rely on anticoagulant rodenticides (ARs) as one of the most effective tools to protect communities, but their use has also raised legitimate concerns about impacts to predators like coyotes. With the California Department of Pesticide Regulation (DPR) poised to impose new mitigation measures through the reevaluation of SGARs and diphacinone, we face an urgent need for data-driven solutions that ensure decisions are based on sound science, not assumptions or bias.

This project addresses that need by combining:

- Cutting-edge, isotopically-labelled anticoagulant rodenticides (iLARs), which allow unprecedented tracking of rodenticide movement through food webs.
- GPS-collared coyotes and fecal DNA analysis, providing a powerful, non-invasive approach to measure exposure across time and space.
- A comparative evaluation of current practices versus potential mitigation strategies, giving regulators, the pest management industry, and communities the evidence needed to make informed decisions.

The data generated will directly inform policy, best practices, and IPM programs, ensuring that urban areas remain protected from rodent threats while wildlife impacts are minimized. This is exactly the type of science-based approach that urban IPM programs—and the communities we serve—depend on.

I fully endorse this proposal and urge the Structural Pest Control Board to fund it. The findings will benefit regulators, pest management professionals, and California's residents, ensuring that any future rodenticide policies are practical, defensible, and environmentally responsible.

Sincerely,

Karey Windbiel-Rojas

Karey Windbiel-Rojas
Associate Director, Urban & Community IPM
Area Urban IPM Advisor – Sacramento, Yolo, Solano Counties
University of California Statewide IPM Program
Email: Kwindbiel@ucanr.edu
Phone (916) 291-7791

2801 Second Street, Davis, CA 95618

Rodenticide
TASK FORCE

Structural Pest Control Board
Department of Consumer Affairs
2005 Evergreen Street, Suite 1500
Sacramento, CA 95815

July 23, 2025

Re: Support for the grant proposal 'Following the Trail: Can Mitigation Measures Reduce Rodenticide Exposure in Coyotes?' submitted by Dr. Niamh Quinn and co-investigators

Dear Members of the Structural Pest Control Board and the Scientific Advisory Panel:

The Rodenticide Task Force (RTF), comprised of registrants of rodenticides, strongly supports this proposal. Our products include most of those currently available in California for structural rodent control. Effective and practical mitigation measures for rodenticides applied in bait stations around the exteriors of structures for rat control are urgently needed. Most of the anticoagulant rodenticides are currently undergoing Reevaluation by the California Department of Pesticide Regulation. At the federal level, the U.S. EPA is nearing completion of their Registration Review process for all the rodenticides. A critically important phase of both regulatory processes is the identification of mitigation measures that minimize the risks of exposure to wildlife. None of the mitigation measures currently under agency consideration for rodent control around structures have been tested to determine whether they are practical to implement and whether they are effective at reducing wildlife exposure when compared to current practices for commercially applied structural rat control.

Therefore, within this context, we think that Dr. Quinn's proposed study is essential to ensuring that professional anticoagulant rodenticide products continue to be available to Pest Management Professionals (PMPs), both in California and nationally. No one else in the U.S. has her unique and successful track record of research on issues related to structural rat control, and no one else is going to conduct the challenging work proposed here. Dr. Quinn's demonstrated success in her previous projects of working collaboratively with the rodenticide industry, pest control companies, and residents of the areas being treated (single family structures, multi-family and Homeowners Associations) in large scale research projects in real world commercial pest control situations gives us high confidence that she will succeed with conducting this complex study. Her previous projects have substantially increased the state of knowledge regarding wildlife exposure, and the proposed study integrates results and conclusions from her multiple studies into a practical framework that addresses this urgent need.

The RTF recognizes the need to reduce wildlife exposure and is committed to assisting her efforts in whatever capacity we can. If the Board provides the requested funding, we will contribute substantially to the project, including financial support, by providing additional custom-made rodenticide baits, other resources as needed, and technical assistance.

If the study concludes that one or more of the tested application practices reduce wildlife exposure, we will support their adoption within California's and EPA's rodenticide regulations. It is important to the RTF that PMPs use our products safely and effectively, so we will also assist with the education and outreach necessary to ensure that PMPs implement them as new standard industry practices.

We appreciate your consideration of our comments on this proposal.

Sincerely,

Katie Swift

Katie Swift
Chair, Rodenticide Task Force

Comprised of 12 rodenticide registrants, the Rodenticide Task Force is committed to providing educational information about the appropriate and effective use of rodenticides as part of Integrated Pest Management programs that protect public health, food safety, and property, while also protecting the environment, endangered species, and other non-target animals.

PESTEC
3450 3rd St, 3F, San Francisco, CA 94124
Phone: 415-671-0300, Fax: 415-671-0305
www.pestec.com

July 29th, 2025

RE: Support for "Following the Trail Can Mitigation Measures Reduce Rodenticide Exposure in Coyotes"

The medical principle of "First, do no harm" and the environmental "precautionary principle" emphasize minimizing risks. While pesticide restrictions, particularly for rodenticides, stem from data showing environmental harm, they often overlook the critical role of pest management in safeguarding public health, infrastructure, and economic vitality.

Decades of public health science and training have validated rodenticide use to control rodent populations. Recent research, such as "Increasing rat numbers in cities are linked to climate warming, urbanization, and human population," connects rising urbanization and climate change to increasing rodent populations in the U.S. Rodent-linked diseases are also increasing in Southern California and nearby states. Factors like growing human populations and waste, deteriorating infrastructure, homeless encampments, and unusually warm winters are exacerbating rodent problems, posing elevated risks to Californians.

Further rodenticide restrictions without first assessing the risks and potential efficacy of proposed practices could worsen public health, social, and economic costs for the state. Dr. Niahm Quinn's proposal, "Following the Trail Can Mitigation Measures Reduce Rodenticide Exposure in Coyotes," aims to evaluate potential risk mitigation measures that regulators may prescribe. This project offers a crucial opportunity to assess both the efficacy of these practices and their impact on non-target organisms. This proactive approach aligns with the precautionary principle by prioritizing public health and quality of life for Californians.

I strongly support this proposal and urge the selection committee to consider it an excellent opportunity to **balance the scales of data for better policy and decision-making**. Dr. Quinn and her lab possess the scientific rigor, intellectual integrity, and the moral support of this industry and the policymakers she advises. Regardless of the findings, the data she collects will help bridge knowledge gaps that often lead to ineffective and risky pest management programs. I am proud to be part of an industry that protects people, property, and our shared economic resiliency. This project is a step in the right direction, and I thank you for your consideration.

Sincerely,

Luis Agurto Jr.
CEO
Pestec

July 27, 2025

Department of Consumer Affairs
Structural Pest Control Board
2005 Evergreen St., Suite 1500
Sacramento, CA 95815

Re: **Letter of Support for Proposal Submission – "Following the Trail: Can Mitigation Measures Reduce Rodenticide Exposure in Coyotes?"**

Dear Members of the Research Advisory Panel and the Structural Pest Control Board,

The Urban Pest Management Technical Committee is writing to express **our strongest support** for the proposal *"Following the Trail: Can Mitigation Measures Reduce Rodenticide Exposure in Coyotes?"* submitted under Solicitation SPCB-25-01.

This research arrives at a critical regulatory juncture. With the California Department of Pesticide Regulation (DPR) reevaluating second-generation anticoagulant rodenticides (SGARs) and diphacinone, the structural pest control industry faces looming restrictions and mitigation mandates that could significantly alter rodent control practices across the state. Yet, few mitigation measures under consideration are backed by empirical, field-based data on their efficacy for both rodent control and reduction of non-target exposure. Without such data, policy decisions risk being implemented without a sound scientific foundation, jeopardizing both public health protection and wildlife conservation.

This proposal directly addresses that gap by:

- Utilizing isotopically labelled anticoagulant rodenticides (LARs), a technology pioneered with prior SPCB funding, to trace rodenticide movement through the environment and across trophic levels with unparalleled sensitivity.
- Pairing LARs with GPS-collared coyotes, fecal analysis, and geospatial exposure modelling to generate real-time, field-validated data on how different application strategies (pulse, monthly, and weekly baiting) affect wildlife exposure.
- Producing the first science-based framework to assess the real-world effectiveness of DPR's anticipated mitigation measures for the structural pest control sector.

This work is not just timely, it is essential for ensuring that future regulations are effective, feasible, and protective of both public health and California's urban ecosystems**.** The data will provide the SPCB with the evidence needed to support or refine proposed policies, equip pest control operators with defensible best practices, and demonstrate the industry's commitment to sustainable, science-based IPM solutions.

Dr. Niamh Quinn and her team bring unparalleled expertise in rodent ecology, toxicant monitoring, and applied urban wildlife research. Their track record of delivering high-quality, policy-relevant science positions this project for success and immediate impact.

We strongly urge the SPCB to fund this project. Its outcomes will directly inform regulatory decision-making, protect industry viability, and set a precedent for evidence-driven rodenticide management in California.

Sincerely,

Signed by:
CHRISTIAN WILCOX
B481F7B4D9A2401...

CHRISTIAN WILCOX

President,Urban Pest Management Technical Committee

christianw@callmccauley.com

July 25, 2025

Department of Consumer Affairs
Structural Pest Control Board
2005 Evergreen St., Suite 1500
Sacramento, CA 95815

Re: Letter of Support for Proposal Submission from Dr. Quinn

Dear Members of the Research Advisory Panel and the Structural Pest Control Board,

On behalf of Clark Pest Control, I am writing to express strong support for the proposal *"Following the Trail: Can Mitigation Measures Reduce Rodenticide Exposure in Coyotes?"*.

Rodenticides remain a critical tool for the structural pest control industry**.** They protect public health by reducing the risks of disease transmission, property damage, and food contamination caused by rodents in homes and businesses across California. While our industry fully supports efforts to minimize impacts on non-target wildlife, we believe that regulatory decisions affecting rodenticide use must be based on sound scientific evidence, not assumptions or untested mitigation strategies.

The pending reevaluation of second-generation anticoagulant rodenticides (SGARs) and diphacinone by the California Department of Pesticide Regulation (DPR) makes this project particularly urgent. Without empirical, field-based data, new restrictions could unintentionally compromise our ability to manage rodents effectively, leading to increased risks for consumers, businesses, and public health**.**

This proposal will address these challenges by using isotopically labelled rodenticides (LARs)**,** a ground-breaking technology developed with SPCB support, to trace the movement of rodenticides in the environment and measure true exposure risks to wildlife This project will also provide evidence to help DPR and SPCB craft balanced, data-driven policies that protect public health while advancing California's goals for wildlife conservation and sustainable IPM practices.

As one of California's largest structural pest control providers, Clark Pest Control depends on tools like rodenticides to protect the health and safety of our clients. It is essential that any regulatory changes be informed by research that reflects real-world conditions and operational realities, as this project will provide.

For these reasons, I strongly encourage the SPCB to fund this research. Its outcomes will help ensure that future rodenticide regulations are both scientifically defensible and practical for the pest control industry**,** preserving our ability to safeguard the public while minimizing environmental impacts.

Sincerely,

Blair Smith,

Director of Technical & Quality Assurance

Clark Pest Control