BUSINESS, CONSUMER SERVICES AND HOUSING AGENCY • GAVIN NEWSOM, GOVERNOR
DEPARTMENT OF CONSUMER AFFAIRS • STRUCTURAL PEST CONTROL BOARD
2005 Evergreen St., Suite 1500, Sacramento, CA 95815
P (916) 561-8704 | F (916) 263-2469 | www.pestboard.ca.gov

PEST CONTROL INDUSTRY – WE NEED YOUR HELP!

The Structural Pest Control Board (SPCB) and the Office of Professional Examination Services (OPES) are recruiting licensed Applicators to assist with the development of the Applicators examination. The SPCB is updating the Occupational Analysis (OA) which describes and defines the nature of the work you do on a daily basis. OAs are necessary to maintain current and valid licensing examinations. Your participation is extremely valuable to help ensure that our licensing examination tests what Applicators actually do on the job.

We are seeking Applicators to serve as subject matter experts (SMEs) for a one-day remote workshop conducted by OPES. We need Applicators with various levels of experience and from diverse practice settings.

Examination Development		
Workshop	**Dates**	**Description**
Occupational Analysis Workshop (Remote)	July 27, 2022 **OR** July 29, 2022	During this workshop SMEs will identify the important tasks that are currently performed by those practicing as an Applicator and the knowledge required to perform those tasks.

Participant Requirements

The SPCB is currently seeking licensees which:

- Hold a current California Applicators license and be in good standing with SPCB.
- SMEs must have access to a computer with microphone and camera as well as an internet connection that can be used to join and participate for the entire workshop.
- Be able to commit to attend for the entire duration of the workshop starting at 8:30 a.m. and ending at 4:30 p.m. Two fifteen-minute breaks and a one-hour lunch break will be provided.
- Have a quiet, private room to work in without interruptions during the workshop.
- Not be a continuing education instructor. Due to potential conflict of interest, undue influence, and security considerations, instructors shall not serve as SMEs for, nor participate in, any aspect of licensure examination development or administration, pursuant to DCA Policy OPES 20-01.

Please direct questions regarding participant requirements to:
SPCBWorkshops@dca.ca.gov

Compensation and Benefits

- Licensees receive $200 per diem.
- Participants are awarded 8 hours of continuing education units (2 hours Rules & Regulations and 6 hours PAU).

If you are interested in participating, please respond to this email at your earliest convenience and indicate which workshop you would like to participate in.

Final selection of SMEs for workshops will be based on many factors. It is important to ensure representation of the profession in terms of experience, practice setting, geographical location, and years licensed.

<u>SME Notification</u>

If you are selected to participate in this OA, you will receive an email notification.

The email notification will confirm which workshop you have been selected to participate in or selected to be an alternate for.

SMEs not selected for this OA will not receive notification.

We greatly appreciate your interest in being a participant in the examination development process and look forward to working with you in the future.

SUBJECT MATTER EXPERT INTEREST FORM

LICENSEE CONTACT INFORMATION				
Last Name	First Name	RA License No.		
Company Name				
Home Address	City	State CA	Zip Code	
Phone Number	Email Address			
1. Are you actively working in the industry?	☐ YES	☐ NO		
2. Are you an approved continuing education instructor?	☐ YES	☐ NO		
3. Are you a trainer/instructor for a pest control company?	☐ **YES***	☐ NO		
*If you answered **yes** to question 3, please explain the type of training you provide:				

Please select which day you are interested:

By checking a box, you acknowledge this does NOT guarantee participation

☐ July 27, 2022	☐ July 29, 2022	☐ Available either day

Please choose one of the following methods to return your interest form to the SPCB:

Email
SPCBWorkshops@dca.ca.gov

Mail
2005 Evergreen Street, Suite 1500
Sacramento, CA 95815

You may also call the SPCB directly at (916) 561-8700 should you have any questions regarding these workshops.

SPCB RESEARCH TRACKING		
RESEARCHER	**TRACKING**	**CONTRACT BALANCE**
Dr. Niamh Quinn University of California, Agriculture and Natural Resources Agreement Number: 26727 “Investigation of Rodenticide Pathways in an Urban System Through the Use of Isotopically Labelled Bait” Original Term Dates: 10/16/18 – 12/31/20 Amendment #1 Term: 10/16/18 – 6/30/22 Amendment #2 Term: 10/16/18 – 6/30/23 **Total Contract: $329,749.00**	10/16/18 – UCANR notified of contract approval effective 10/16/18. 4/30/19 – Received April 2019 Progress Report 1/27/20 – received invoice #56318501 for $11,947.50 7/28/20 – received invoice 76c59-02 for $0.00 9/15/20 – received progress report 11/20/20 – received invoice #59174298 for $27,877.50 1/27/21 – No-cost extension approved to change term date from 12/31/20 to 06/30/22. 6/2/21 – No-cost extension requested to change term from 6/30/22 to 6/30/23 1/25/22 – Received fully executed amendment #2 2/2/22 – Received invoice #63702836 for $20,660.79 **Total Expenditures: $60,485.79**	**$269,264.21**
Neil Tsutsui University of California, Berkeley Agreement Number: 26735 “Diet and Colony Structure of Two Emerging Invasive Pest Ants” Original Term Dates: 10/18/18 - 08/31/21 Amendment #1: Change in personnel Amendment #2 Term: 10/18/18 – 8/31/22	10/18/18 – UC Berkeley notified of contract approval effective 10/18/18. 1/3/19 – received invoice #GM00159910 for $6,079.05 1/29/19 – received invoice #GM00162310 for $7,011.98 2/25/19 – received invoice #GM00166580 for $2,000.00 4/7/19 – received April 2019 Progress Report 5/29/19 – received invoice #GM00175634 for $681.23 7/2/19 – received invoice #GM00178838 for $1,220.99 8/9/19 – received invoice #GM00184114 for $22,099.22 8/19/19 - received invoice #GM00186274 for $764.23 9/19/19 – received invoice #GM00188490 for $10,290.87 10/19/19 – received invoice #GM00190757 for $517.02 11/19/19 – received invoice #GM00193312 for $827.24 12/19/19 – received invoice #GM00196412 for $2,849.02 1/20/20 – received invoice #GM00197182 for $1,259.45 2/19/20 – received invoice #GM00200261 for $174.19 3/19/20 – received invoice #GM00204264 for $239.20 4/20/20 – received invoice #GM00208324 for $2,696.44 5/19/20 – received invoice #GM00212124 for $7,394.14 6/19/20 – received invoice #GM00215027 for $16,451.16 8/6/20 – received invoice #GM00218961 for $6,644.52 8/19/20 – received invoice #GM00221330 for $6,499.04	

Total Contract: $146,325.00	10/12/20 – received October 2020 Progress Report 10/29/20 – received invoice #GM00228610 for $11,816.46 5/4/20 – received invoice #GM00248340 for $665.71 5/28/21 – received invoice #GM00251772 for $1,158.01 6/4/21 – Pending no-cost extension to change term date to 6/30/22 and change personnel. Pending at BSO for processing. 7/2/21 – received invoice #GM00254509 for $1,035.23 8/19/21 – received invoice #GM00262008 for $3,776.59 9/20/21 – received invoice #GM00265799 for $1,949.57 10/19/21 – received invoice #GM00269199 for $3,990.90 11/19/21 – received invoice #GM00272585 for $5,510.81 12/20/21 – received invoice #GM00276627 for $9,949.86 1/20/22 – received invoice #GM00279831 for $3,949.83 2/19/22 – received invoice #GM00283223 for $4,137.42 4/20/22 – received invoice #GM002906247 for $1,023.22 **Total Expenditures: $144,662.59**	**$1,662.41**
Dr. Andrew Sutherland University of California, Agriculture and Natural Resources Agreement Number: 26730 "Evaluation of bait station system efficacy for reduced-risk subterranean termite management in California" Original Term Dates: 10/10/18-08/31/21 Amended Term Date: 10/18/18 – 8/31/22	10/10/18 – UCANR notified of contract approval effective 10/10/18. 12/11/18 – received invoice #51140867 for $270.67 12/19/18 – received invoice #51464298 for $1,075.53 3/4/14 – received invoice #52326394 for $3, 671.22 4/2/19 – received invoice #52526107 for $2,617.68 4/26/19 – received April 2019 Progress Report 5/1/19 – received invoice #52892570 for $4,179.03 5/30/19 – received invoice #5330024 for $3,220.42 7/26/19 – received invoice #54113894 for $4,040.68 10/3/19 – received invoice #54886547 for $272.95 11/13/19 – no cost extension approved by BSO to extend contract term from August 31, 2021 to August 31, 2022. 1/21/20 – received invoice #56314886 for $1,475.42 3/26/20 – received invoice #57095974 for $12,702.80 5/4/20 – received invoice #57413857 for $6,097.63 5/14/20 – received invoice #57647938 for $2,383.03 6/19/20 – received invoice #57984215 for $22,324.44 7/23/20 – received invoice #58296943 for $4,581.79 9/5/20 – requested progress report 9/14/20 – received September progress report 10/21/20 – received invoice #59172744 for $6,091.16 11/30/20 – received invoice #59515731 for $6,893.52	

Total Contract: $190,425.00	2/4/21 – received invoice #59990730 for $17,611.97 2/25/21 – received invoice #60260692 for $1,881.22 3/23/21 – received invoice #60542078 for $3,141.40 5/28/21 – received invoice #61217379 for $5,277.38 6/17/21 – received invoice #61535348 for $5,148.25 7/23/21 – received invoice #61886116 for $2,382.03 8/19/21 – received invoice #62226637 for $2,777.03 9/28/21 – received invoice #62526387 for $7,371.99 11/5/21 – received invoice #62841155 for $2,821.88 12/7/21 – received invoice #63174937 for $3,754.81 12/16/21 – received invoice #63453845 for $2,640.82 1/28/22 – received invoice #63701704 for $1,866.86 3/8/22 – received invoice #64020822 for $2,583.05 3/24/22 – received invoice #64338202 for $4,254.77 4/18/22 – received invoice # 64682525 for $4,089.78 5/25/22 – received invoice #65033520 for $6,243.83 6/20/22 – received progress report **Total Expenditures: $155,745.04**	**$34,679.96**
Dr. Dong-Hwan Choe University of California, Riverside Agreement No. 26710 "Improving Urban Pest Ants Management by Low-Impact IPM Strategies" Original Term Dates: 10/22/18 - 12/31/19 Amended Term Dates: 10/22/18 – 8/31/20 **Total Contract: $77,309.00**	10/23/18 – UC Riverside notified of contract approval effective 10/22/18. 1/28/19 – received invoice #80105-001 for $689.61 4/30/19 – Received April 2019 Progress Report 5/11/19 – received invoice #80105-002 for $2,645.77 7/17/19 – received invoice #80105-003 for $3,468.85 10/17/19 – received invoice #80105-004 for $29,042.96 1/24/20 – received invoice #80105-005 for $17,532.01 **Pending no cost extension. Extends current contract from December 31, 2019 to August 31, 2020. 4/3/20 – Contract amended to reflect new extension date 4/28/20 – received invoice #80105-006R for $16,748.06 7/17/20 – received invoice #80105-007 for $6,713.11 9/4/20 – emailed Dr. Choe requesting final report due beginning of December 2020. Asked Dr. Choe to prepare a presentation for March 2021 board meeting. 10/21/20 – received final report 11/4/20 – received invoice #80105-008 for $468.63 March 2020 – Presented final report to Board Members at the March 2020 Board Meeting. **Total Expenditures: $77,309.00**	**$0.00**

Dr. Michael Rust University of California, Riverside Agreement No. 26732 "Development and Evaluation of Baiting Strategies for Control of Pest Yellowjackets in California" Original Term Dates: 10/23/18 - 12/31/20 Amended Term: 10/23/18 – 12/31/21 **Total Contract: $280,017.00**	10/23/18 – UC Riverside notified of contract approval effective 10/23/18. 1/11/19 – received invoice #80108-001 for $141.99 4/18/19 – received April 2019 Progress Report 5/11/19 – received invoice #80108-002 for $6,093.28 7/17/19 – received invoice #80108-003 for $21,870.43 10/16/19 -received invoice #80108-004 for $12,361.04 1/14/20 – received invoice #80108-005 for $18,431.65 4/6/20 – received invoice #80108-006 for $20,484.70 7/17/2 – received invoice #801808-007 for $16,767.87 9/5/20 – requested progress report, progress report extended to 10/4/20 to allow a more informative report. 10/14/20 – received progress report 11/5/20 – received invoice #80108-008 for $28,328.52 11/20/20 - *Pending no cost extension from December 31, 2020 to December 31, 2021. 2/4/21 – received invoice #80108-009 for $32,369.60 2/25/21 – No-Cost extension approved by BSO. Term extended to 12/31/21 4/29/21 – Received invoice #80108-011 for $12,107.51 7/16/21 – Received invoice #80108-012 for $67,365.25 10/19/21 – Received invoice #80108-013 for $13,363.49 1/31/22 – received Final Report March 2020 – Presented final report to Board Members at the March 2022 Board Meeting 3/29/22 – received invoice #80108-15 for $30,328.67 **Total Expenditures: $280,017.00**	**$0.00**

6/28/2022

June 2022

Project Update: July, 2022
PI: Niamh Quinn
Project: Investigation of Rodenticide Pathways in an Urban System Through the Use of Isotopically Labelled Bait

Dear Structural Pest Control Board,

The isotopically-labelled bait has been developed and tested. It has been administered to rats in Milwaukee at two different feeding regimes, lethal and sublethal. The methods for detection of rodenticide in hair is in progress. ARs can be detected in hair and we are working on trying to quantify the level of exposure. The method development for hair and feces is ongoing.

Travel to National Wildlife Research Center in Utah is required by PI and is scheduled for July 23. Isotopically labelled rats need to be processed as coyotes will not consume in their whole form. PI Quinn and assistants will travel to Utah to make rat meatballs to be fed to captive coyotes.

Ethical approval for the use of marked bait in bait stations is underway and currently in review at UC Merced (IACUC). Permission to apply labelled bait is also required by DPR and that is also under review. Application of labelled bait in pilot study will begin once permission from DPR and IACUC approval is received.

Sincerely,

Niamh Quinn

Human Wildlife Interactions Advisor

Diet and Colony Structure of Two Emerging Invasive Pest Ants

Interim Progress Report

Overall, we are nearing the end of this project. Our data collection is essentially complete for the rover ant, *Brachymyrmex patagonicus*, as we have described in previous reports. We have found that this species is widespread, often locally abundant, and displays strong behavioral attraction to food baits in the lab. *Brachymyrmex patagonicus* displays all the characteristics typical of invasive ants, and will likely grow in importance as a structural (and perhaps agricultural) pest in California.

Work on the sneaking ant, *Cardiocondyla mauritanica*, has proven to be more challenging, due to the relative rarity of the species, the furtive behavior that workers exhibit, and their limited responsiveness in laboratory behavioral assays. Nevertheless, we have found a significant preference of foraging workers for protein over sugar baits, and a weak preference for 10% and 20% sugar water concentrations versus water control. As we note below, we have been able to collect useful data on *Cardiocondyla* colonies in the field and feeding preferences in the lab, but our assessment is that this introduced ant is unlikely to become a damaging invasive species and, if it does, baiting is unlikely to be an effective approach to control.

1. Experiment 1A. <u>Overall goal:</u> *Census subpopulations within 20 colonies: eggs, larvae, pupae, workers, males, mated and unmated queens.*

No new updates for *B. patagonicus* - we have completed the data collection for this species. As previously reported, we have found that the mean number of workers per queen is approximately 325:1 and the worker:brood ratio was 8:1. An important caveat is that mated queens were only found at three of the sites, and we never found more than one queen, suggesting a monogyne colony structure. Interestingly, winged males were found at half of the sites, and sometimes in relatively large numbers (range = 0-41 males). When males were present, the average worker:male ratio was approximately 20:1. Winged (unmated) queens were also found in nearly half of sites (43%) and, when present, the worker:virgin queen ratio was 77:1.

The colony composition of *Cardiocondyla mauritanica* appears to be quite different from B. patagonicus. Queens were found at 85.7% of sites and the worker:queen ratio across these sites was 22:1. The number of queens varied from 0 to 20, so this species can clearly be quite polygyne. The worker:brood ratio was 11:1. Unlike B. patagonicus, winged males were not found at any of the sites. Unmated, winged queens (gynes) were found at 8 of 14 sites, and the worker:gyne ratio was 29:1.

2. Experiment 1B. <u>Overall goal</u>: *Determine the spatial extent of colonies in the field using behavioral assays*.

We have completed data collection for *B. patagonicus* and, as previously reported, we have found an interesting and unusual behavioral pattern. Nearly all other introduced pest ant species form large "supercolonies" that lack territorial aggression across large spatial areas. It is well known that the formation of supercolonies is one of the factors that underlies population growth, and hence the success, of nearly all invasive ants. In addition, the absence of behavioral boundaries has important implications for pest control, as insecticides can be distributed across a larger effective area as workers move freely from one site to the next. Our data for *B. patagonicus*, however, shows a strikingly different social organization. Ants from nearly all sites, even those quite spatially close together (<100m) do not belong to the same colony, and aggressively reject each other. This behavioral pattern matches up with the apparent monogyne (single-queen) colony structure noted above, as these traits typically co-occur in ants. From a control perspective, this colony structure may pose a challenge for the distribution of toxicants, as workers likely do not disperse far after consuming food (or baits).

In contrast, we have found that *Cardiocondyla muaritanica* displays a colony structure much more reminiscent of a typical invasive ant, forming large “supercolonies” across tens or hundreds of kilometers. However, unlike other invasive supercolonial ants, like the Argentine ant, population densities are always quite low and the ecological impact of *C. mauritanica* appears to be quite limited. In addition, the supercolonial colony structure is not absolute, as we have observed occasional intraspecific aggression among populations, revealing that at least several different supercolonies exist within California.

3. Experiment 2A. Overall goal: *Perform dietary preference experiments in the laboratory*.

As noted in previous reports, our dietary experiments with *B. patagonicus* show a clear preference for sugar over protein. This was true when protein was present in both a complex formulation (moist cat food) as well as just pure amino acids. In 16 trials, each one hour in duration with recruitment measured every five minutes, *Brachymyrmex* workers showed rapid recruitment to the sugar water bait and consistently preferred it by a 2-5X margin over protein. Tests comparing preference for difference concentrations of sugar water revealed that 15% w/v (weight to volume) was the preferred concentration when tested against both higher and lower concentrations.

The dietary data collection for *C. mauritanica* has produced very different results. First, *Cardiocondyla* shows the opposite preference compared to *Brachymyrmex*. *Cardiocondyla* consistently prefers protein baits to sugar water by about a 2X margin. Dietary preference trials comparing different concentrations of sugar water showed that workers prefer 10% and 20% w/v about equally, and chose these more often than the sugar water control. However, a serious caveat is that the number of *Cardiocondyla* worker that recruited to sugar water baits in the lab experiments was very low, often only one or two workers during the one-hour test period. This appears to largely be a consequence of the overall low worker activity typical of this species. Thus, food baits are unlikely to be an effective method for controlling *Cardiocondyla mauritanica* and, as noted above, such approaches are unlikely to be necessary anyway due to the low population densities that characterize introduced populations. This species does not appear to be on the pathway to becoming a serious pest in California.

4. Experiment 2B. Overall goal: *Quantify nitrogen (N) and carbon (C) stable isotope ratios to determine trophic position*.

As previously reported, we have found that, at some sites, *Cardiocondyla* exhibits a higher level of nitrogen ($_{14}$N) enrichment compared to other ants at the same site. This suggests that *Cardiocondyla* occupy a more predatory position in the food web, consistent with their apparent preference for protein in our laboratory dietary preference assays. In contrast, *Brachymyrmex* appears to occupy a trophic position that is similar to other ants in their habitat, suggesting a mixed foraging strategy that includes predation, scavenging, and perhaps feeding on exudates from homopterans such as aphids and scale insects.

Evaluation of bait station system efficacy

for reduced-risk subterranean termite management in CA

Progress Report

Period Covered: October 1, 2020 – June 30, 2022

Project Team: Andrew Sutherland, Siavash Taravati, University of California Cooperative Extension (UCCE) staff members, collaborating pest control operators (PCOs), collaborating property owners, collaborating laboratories

This project aims to evaluate the efficacy of three CA-registered termite bait systems against subterranean termites, in collaboration with PCOs and property owners, at 15 single-family homes in the San Francisco Bay Area and the Los Angeles Basin. This project also aims to increase our knowledge about seasonal and spatial effects on subterranean termite incidence within bait stations in CA. Progress towards these objectives, as well as towards regular administration of this project, is reported below, following the objectives, tasks, and deliverables identified in the Scope of Work included in the successful proposal for funding.

Objective 1. Conduct collaborative field research at participating single-family homes to evaluate bait system efficacy:

We are nearing completion of this objective, with our final inspection scheduled for mid-August 2022. Our findings suggest that all three bait systems being evaluated have successfully eliminated mature termite colonies at our participating single-family home research sites.

Task 1.1: Identify 15 participating homes, assemble necessary supplies and equipment, evaluate monitoring options, decide on specific monitoring protocols, and negotiate project subcontracts.

Task Complete. See below for a summary of sites and participating collaborators:

1. Hayward, Alameda County. Participating pest control operator: Omega Termite and Pest Control. Bait station system evaluated: Advance Termite Bait System / Trelona (BASF). Study period: March 2019 – March 2021
2. Oakland, Alameda County. Omega Termite and Pest Control. ATBS / Trelona. Study period: August 2020 – August 2022.

3. Berkeley, Alameda County. Participating PCO: Western Exterminator. Bait system evaluated: Sentricon Always Active / Recruit HD (Corteva). Study period: March 2020 – March 2022.
4. San Jose, Santa Clara County. Participating PCO: Thrasher Termite & Pest Control. Bait system evaluated: Exterra / Isopthor (Ensystex). Study period: February 2020 – February 2022.
5. San Jose, Santa Clara County. Thrasher Termite & Pest Control. Exterra / Isopthor (Ensystex). Study period: February 2020 – February 2022.
6. San Leandro, Alameda County. Western Exterminator. Sentricon Always Active / Recruit HD. Study period: January 2020 – January 2022.
7. Martinez, Contra Costa County. Western Exterminator. Sentricon Always Active / Recruit HD. Study period: January 2020 – January 2022.
8. Alameda, Alameda County. Omega Termite and Pest Control. ATBS / Trelona. Study period: January 2020 – January 2022.
9. San Jose, Santa Clara County. Thrasher Termite & Pest Control. Exterra / Isopthor (Ensystex). Study period: February 2020 – February 2022.
10. Huntington Beach, Orange County. Western Exterminator. Sentricon Always Active / Recruit HD. Study period: August 2019 – August 2021.
11. Monrovia, Los Angeles County. Participating PCO: Excellence Pest Control. Bait system evaluated: ATBS / Trelona. Study period: August 2019 – August 2021.
12. Pasadena, Los Angeles County. Excellence Pest Control. ATBS / Trelona. September 2019 – September 2021.
13. Pasadena, Los Angeles County. Participating PCO: Homeshield Pest Control. Bait system evaluated: Exterra / Isopthor. Study period: November 2019 – November 2021.
14. Pasadena, Los Angeles County. Participating PCO: Homeshield Pest Control. Bait system evaluated: Exterra / Isopthor. Study period: November 2019 – November 2021.
15. Glendale, Los Angeles County. Western Exterminator. Sentricon Always Active / Recruit HD. Study period: February 2020 – February 2022.

Task 1.2: Install bait stations at all participating homes.

Task Complete. Installations have been completed at all 15 homes.

Task 1.3: Visit each participating home every three months, collecting data, servicing stations, and monitoring as detailed above. Perform laboratory work, as detailed above, to determine colony presence and identity during study.

Task nearing completion: as of this report draft, 119 quarterly inspections of monitoring stations have been conducted. Additionally, 59 bait station inspections, with participating PCOs, have been conducted, adhering to six-month intervals. Foraging termites have been recovered during initial inspections, from wood blocks during quarterly inspections, and from bait matrices during bi-annual inspections with PCOs. In some cases, termites have been observed and collected from bait stations only six months after installation.

Figure 1. Sentricon Always Active bait tube damaged by termites (left) and associated bait station containing termites (right) approximately six months after installation at Berkeley site.

To date, 132 separate collections of *Reticulitermes* foragers have been curated and sent to a collaborating laboratory. We plan to send one more batch of samples after our final site inspection during August 2022. We expect a complete data set soon.

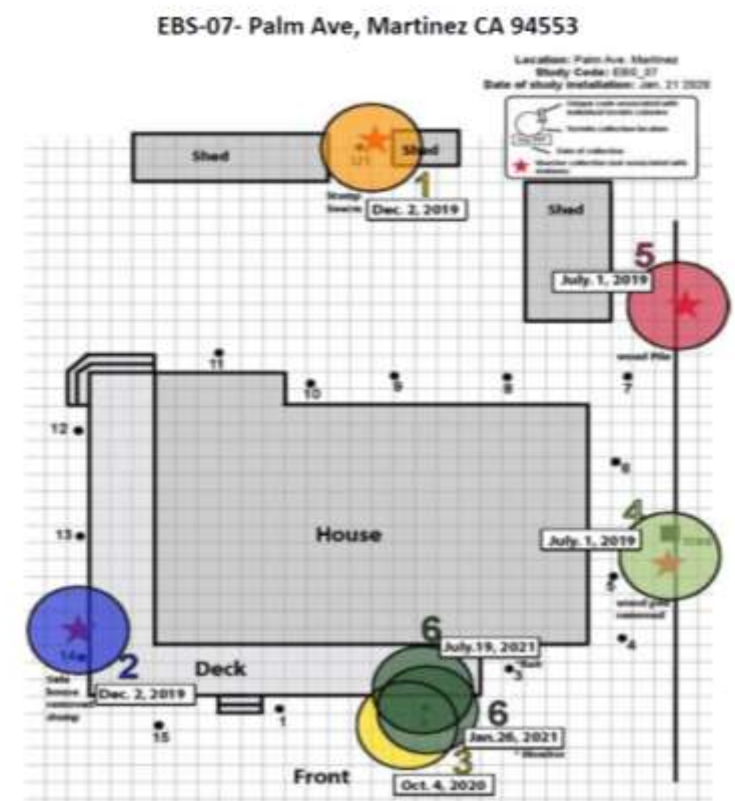
Figure 2. Vials containing *Reticulitermes hesperus* termites collected from research sites, preserved in 100% ethanol, and curated for later DNA analysis to determine colony fidelity.

Task 1.4: Analyze and summarize data, publish all reports and articles, perform all outreach and extension activities.

Task nearing completion: This task will be completed this autumn when all data are available.

Preliminary data suggest that all three bait systems have been effective at eliminating western subterranean termites in California. No termite colony recovered from bait stations has ever been detected again at study sites, according to colony fidelity as per DNA analysis.

To aid in data visualization, we have created maps for each site, indicating exactly when and where termites have been observed, collected, and assigned a colony identification number (according to DNA analysis). Below, we share the map for our Martinez site. Other maps are available upon request. Some maps cannot be completed until the DNA data set is complete.



Colony ID	Date of Collection	Location
1	Dec 2, 2019	Stump in back of property between sheds
2	Dec 2, 2019	Left side of house, old stump next to deck
3	Oct 4, 2020	Monitoring station #2
4	July 1, 2019	Wood pile by poplar tree
5	July 1, 2019	Wood pile by right side fence
6	Jan 26, 2021 July 19, 2021	First collected from Monitoring station #2, then from Bait station #2.

We have initiated surveys for participating pest control operators and property owners to learn about attitudes and intentions associated with subterranean termite bait services. For PCOs, we are most interested in whether they increased knowledge as part of this project, whether they will continue to provide bait services in the future, and the reasons behind these decisions. For property owners, we are most interested in measuring their satisfaction with the services provided and whether they will continue to hire PCOs for bait services in the future. These surveys can be found at the following links:

https://docs.google.com/forms/d/e/1FAIpQLSfTGhVKGTP4k3AUUjMrY_yrPwxBNjkSyjngIWVXJ0REWwlGqg/viewform

https://docs.google.com/forms/d/e/1FAIpQLSfMfEnvXvdUw3zSC26hiiKhuretc53xqDSwaAUdYCKKSDOpsA/viewform

We have plans to publish one peer-reviewed journal article, one trade magazine article, and one UC IPM newsletter article reporting on findings from this field research. Outreach has already begun, at UC Riverside's Urban Pest Management Conferences, PCOC's *Termite Academy*, the Entomological Society of America, and at local PCOC District meetings.

Objective 2. Conduct observational and manipulative research at UC field station(s) to describe colony attributes, seasonal phenology in CA, and determine time-to-attack for registered bait systems:

We have completed this objective. The main findings were that bait interception time (aka *time-to-attack*: time required for foraging termites to find and begin consuming baits after installation) can be significantly reduced when stations are installed at the beginning of the wet season as compared to at the beginning of the dry season.

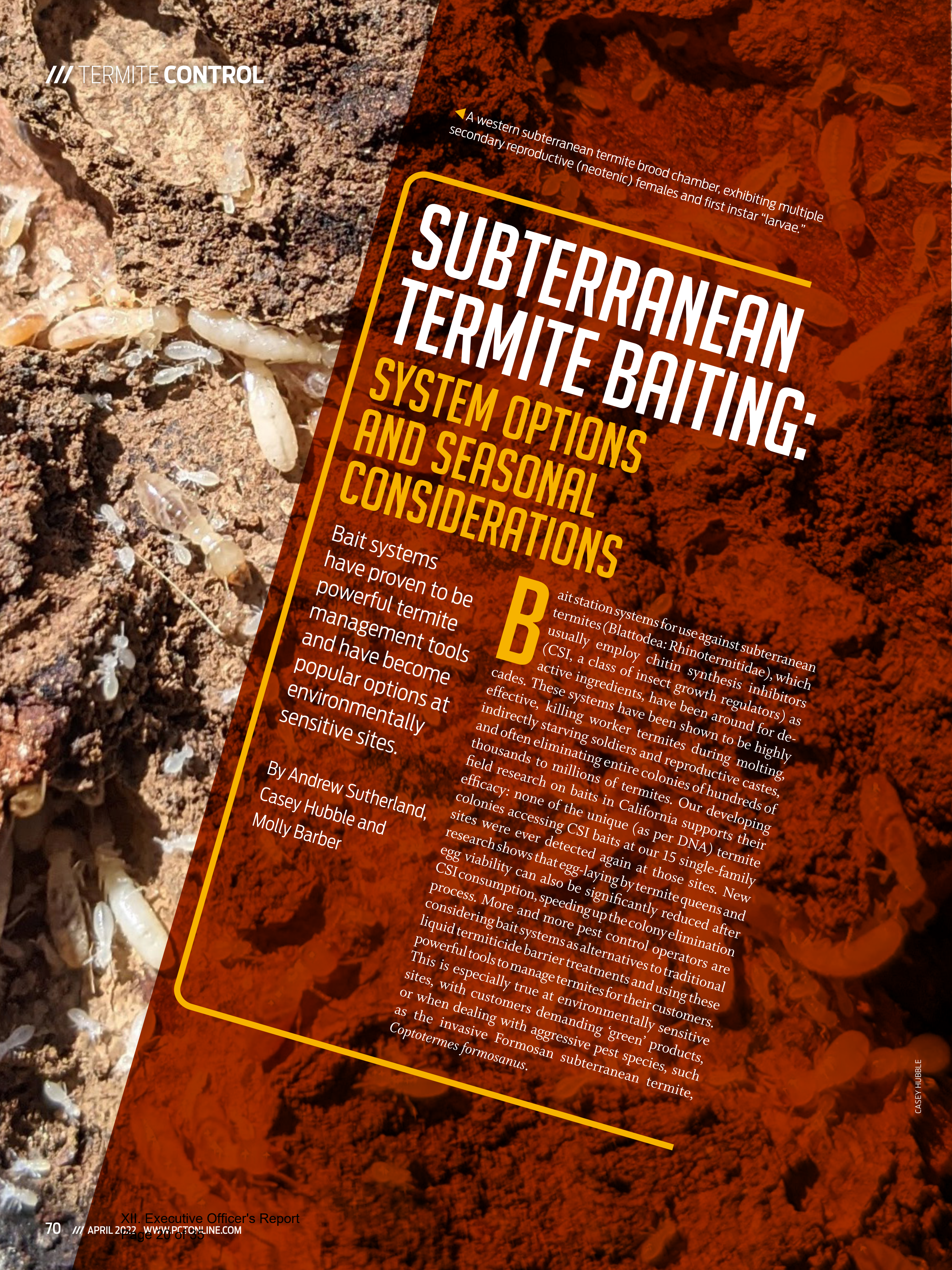
Several publications reporting on this work have already been produced. These are appended to this report. They can also be found at the following links:

https://www.pctonline.com/article/subterranean-termite-baiting-system-options-and-seasonal-considerations/

https://www.mdpi.com/2075-4450/13/5/445/htm

Objective 3. Grant Administration: Conduct general grant administration: meetings, progress reports, invoices, presentations, and final report as required.

We have completed all tasks and met all deadlines associated with this objective. This report serves as the fourth progress report for the project. Project team members will report at a future Board meeting upon direction by Board staff.



A western subterranean termite brood chamber, exhibiting multiple secondary reproductive (neotenic) females and first instar "larvae."

CASEY HUBBLE

SUBTERRANEAN TERMITE BAITING:

SYSTEM OPTIONS AND SEASONAL CONSIDERATIONS

Bait systems have proven to be powerful termite management tools and have become popular options at environmentally sensitive sites.

By Andrew Sutherland, Casey Hubble and Molly Barber

Bait station systems for use against subterranean termites (Blattodea: Rhinotermitidae), which usually employ chitin synthesis inhibitors (CSI, a class of insect growth regulators) as active ingredients, have been around for decades. These systems have been shown to be highly effective, killing worker termites during molting, indirectly starving soldiers and reproductive castes, and often eliminating entire colonies of hundreds of thousands to millions of termites. Our developing field research on baits in California supports their efficacy: none of the unique (as per DNA) termite colonies accessing CSI baits at our 15 single-family sites were ever detected again at those sites. New research shows that egg-laying by termite queens and egg viability can also be significantly reduced after CSI consumption, speeding up the colony elimination process. More and more pest control operators are considering bait systems as alternatives to traditional liquid termiticide barrier treatments and using these powerful tools to manage termites for their customers. This is especially true at environmentally sensitive sites, with customers demanding 'green' products, or when dealing with aggressive pest species, such as the invasive Formosan subterranean termite, *Coptotermes formosanus*.

Some regions may lag behind in bait station system adoption, however. This is true for California, where operators cite prohibitive licensing requirements, disturbance-related avoidance by termites, and excessive time required for control as major barriers to adoption. To the first point, some (older) bait systems include monitoring phases, which require pest identification and therefore a mid-tier Field Representative license in California, before CSI bait can be added to stations. To the second point, some termites, especially certain *Reticulitermes* species, have been considered "skittish," sometimes disappearing for months or longer due to disturbances such as bait station inspections. Finally, customers with infested structures often expect immediate results when hiring termite companies, and many months may pass before termites find and attack new bait stations. Similar concerns may exist in other regions. Newer bait systems and new product labels may have removed some of these barriers, however. Three systems registered for use in California (Sentricon Always Active by Corteva, Advance Termite Bait System by BASF, and Exterra by Ensystex; see Table 1) now allow for CSI bait on day 1, bypassing the monitoring phases (provided activity by the target species has been documented at the property) and allowing for installation and replenishment service by entry-level Applicator licensees. Furthermore, product labels now allow for longer service intervals (up to six months for Exterra and up to 12 months for Sentricon and ATBS), minimiz-

Three different bait systems were evaluated as part of this "time-to-attack" research project: (from left to right) Sentricon Always Active; Advance Termite Bait System; and Exterra.
Note: bait matrices were provided by manufacturers and did not contain active ingredients.

CASEY HUBBLE

ing disturbances that may repel foraging termites. The third bait system concern, that it simply takes too long to control infestations, is seemingly more difficult to alleviate.

A 'TIME-TO-ATTACK' THEORY. One explanation for "time-to-attack" problems in California has to do with the state's unique Mediterranean climate (hot summers with little to no rain, cool winters that typically produce the entire annual precipitation amount) and prevailing soil textures (high proportions of clay). Termite foraging at or near the soil surface may be limited or even nonexistent during summer months, especially when areas are not irrigated. Some research supports this idea: *Reticulitermes hesperus*, the western subterranean termite, has been observed to forage near the surface mostly during winter months in its native habitat in southern California. This suggests that bait stations installed in summer may sit uninvestigated for six months or more. To test this hypothesis, and to observe whether time-to-attack could be reduced by targeting specific seasons for installation, we established five research plots during 2019 at the UC Berkeley Richmond Field Station directly on top of known termite colonies. Naturally occurring subterranean termites (*Reticulitermes* spp.) had been observed, as foraging workers or brood chamber aggregations, and collected at the center of each plot.

Around these five areas of "documented

Two workers and a soldier of the western subterranean termite, *Reticulitermes* spp.

UC ANR staff research associate Casey Hubble uses a ratcheting hand auger to excavate a hole for bait station installation during March 2019 in Richmond, Calif.

SUSAN HARE, USED WITH PERMISSION; ANDREW SUTHERLAND termite activity," we established three concentric rings of bait stations at three distances from the center, installing one station from each of three registered systems along each of the rings at the beginning of each season over one year, for a total of 36 bait stations per plot. We didn't want to kill the termites in these plots because that would significantly confound our data, so we used cellulose bait matrices from manufacturers that did not contain the CSI active ingredients. We also installed a monitoring device (Isopthor EZE station housing containing wooden monitoring blocks) at the center of each plot and along each of the three distance rings. By the end of the year, we had installed 200 stations for this investigation, all by use of a ratcheting hand auger! We then checked each station every two months (about every 60 days) after its installation for two years, opening and inspecting up to 100 stations per month. We concluded this ambitious project in December 2021.

FINDINGS. So…what did we find? To begin with, our experiences and observations with all three bait systems over these past two years allows us to compare their potential advantages and disadvantages. We believe all three systems will be effective against

Table 1. Product information for bait systems evaluated as part of this "time-to-attack" research project (from 2019 product labels, as registered for use in California). Note: bait matrices were provided by manufacturers and did not contain active ingredients.

Bait System, Manufacturer	Bait Information	Installation Specifications	Service Specifications
Sentricon Always Active, Corteva Agriscience	Recruit HD Termite Bait (EPA# 62719-608): cellulose tube, 0.5% noviflumuron	In-ground, ≤ 20 feet intervals; buildings, fences, decking, utility poles, trees	Inspections at least once annually, replace bait if damaged or ≥ 1/3 consumed
Advance Termite Bait System (ATBS), BASF	Trelona Compressed Termite Bait (EPA# 499-557): cellulose wafers in plastic housing, 0.5% novaluron	In-ground, ≤ 20 feet intervals; buildings, trees, wood piles, landscape elements, railroads	Inspections every 60 – 120 d, up to 6 mo allowed, replace bait if damaged or ≥ ½ consumed
Exterra Termite Baiting System, Ensystex	Isopthor Termite Bait (EPA# 68850-2): cellulose wafers within burlap sachet, 0.25% diflubenzuron	In-ground, ≤ 20 feet intervals; buildings and other structures	Inspections every 45 – 120 d, up to 6 mo allowed, replace bait "after sufficient consumption"

subterranean termites and can be used to eliminate entire colonies, but some may be easier to install, easier to inspect, or more durable in the field. Economic barriers to adoption, such as cost, technical assistance from product representatives, or licensing agreements required, may also differ. Our objective in this work was not to highlight differences among these bait systems, however, but rather to find generalized trends common to all three, especially considering the effect of installation season on time-to-attack. As expected, air temperature and soil moisture varied widely from season to season. Summers were hot and dry, as expected, and rainfall occurred exclusively during cooler months. First significant rains were recorded during late November in 2019 and 2020 and during late October in 2021. Most of our termite foraging activity in stations was observed in winter and spring, with a marked activity plateau during the February – June period. Smaller activity peaks were observed during the summer, especially in September, which is immediately prior to the majority of *Reticulitermes* swarming observed in the San Francisco Bay Area. Generally, however, activity declined throughout the year, tapering to almost nothing during November and December (*see Figure 1*). Of the 180 bait stations and 20 monitoring stations installed, 78 bait stations and 9 monitoring stations had been hit by the end of the two-year project period, representing an overall hit rate of 44%. Three stations were attacked within 60 days after installation, and ten stations were attacked within 120 days. Overall, however, the average

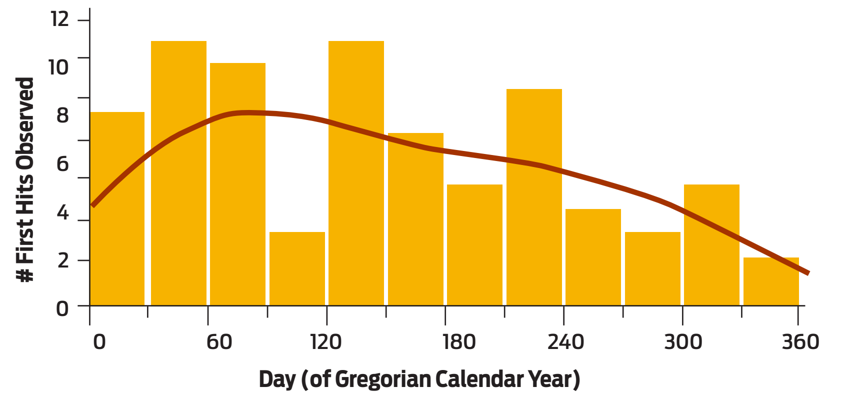


Figure 1: Observed western subterranean termite activity in field research plots by calendar date (1 - 365) during May 2019 - December 2021. Vertical bars show actual observation counts during each 30-day increment. Red line shows a statistical model output that fits the data.

time-to-attack (the amount of time between installation and the first observation of bait consumption by the target species) was 367 days, a full year after installation! This result supports the general claims of California's pest control operators that baiting may take too long for most remedial termite control jobs. There were no significant differences between the three bait systems, with average time-to-attack for all three between 327 and 383 days. We did not detect any significant differences in time-to-attack among the three distance rings. Proximity to adjacent stations and type of adjacent stations were considered as potential factors influencing time-to-attack, but there were no measurable effects detected.

There were statistically significant differences detected among the five different sites, which included differences in soil type and irrigation regimes. Average time-to-attack at Site 5, which was in unirrigated sandy soil near a wood building, was 292 days, significantly less than average time-to-attack at Site 4 (462 days), which was in clay loam soil within an irrigated landscape bed dominated by coast redwood trees. The other three sites, which were along a sporadically-irrigated linear grove of pine and oak trees, were intermediate in terms of time-to-attack and did not differ statistically from sites 4 or 5. Our experiment was not designed to determine the site factors that may influence time-to-attack, but one hypothetical explanation for the site differences observed is that there may have been much more cellulose debris (dead wood and decomposing mulch) in the landscape bed under the redwood trees than in the sandy and mostly unvegetated area adjacent to the old building, providing ample food for foraging termites and making the bait matrices comparatively less attractive.

Our study's main question was whether installation season significantly impacts time-to-attack due to seasonal differences in termite foraging in California. To answer this, we pooled data from all five sites and all three bait systems and then considered just the first year of observations. The result was striking: time-to-attack for stations installed at the beginning of winter was more than 100 days less than for stations installed at the beginning of summer (194 days vs. 296 days). This result was statistically significant. Installations at the beginning of spring and beginning of autumn were intermediate (282 and 268, respectively) and statistically inseparable from the other two seasons (*see Figure 2, page 82*). This effect was strongest at sites 1-3, along the pine and oak grove. In fact, none of the stations installed at Site 3 at the beginning of summer were hit during the first year of our observations. These data show that the lengthy time-to-attack many California operators have experienced may be reduced by targeting installations for the beginning of the wet season, usually during November – December. Also, this time of the year is usually the easiest time to dig in the region, with clay soils soft and muddy as compared with hard and dusty during the dry season.

FINAL THOUGHTS. Overall, these findings may help pest control operators to optimize their use of bait station systems as subterranean termite control tactics by targeting specific installation seasons, especially in areas with pronounced wet — dry or hot — cold periods. One way to extrapolate these results would be to consider the season known to be associated with the highest termite activity in your area and then to install bait stations immediately prior to (but not during) this season. For some, this may seem like a common-sense best practice. For others, especially those new to termite baiting, targeting the right season for new installations may facilitate early success. **PCT**

Sutherland is an urban pest management researcher and educator at UC Division of Agriculture and Natural Resources (UC ANR). Hubble is a staff research associate and Barber is a lab assistant in Sutherland's UC ANR program.

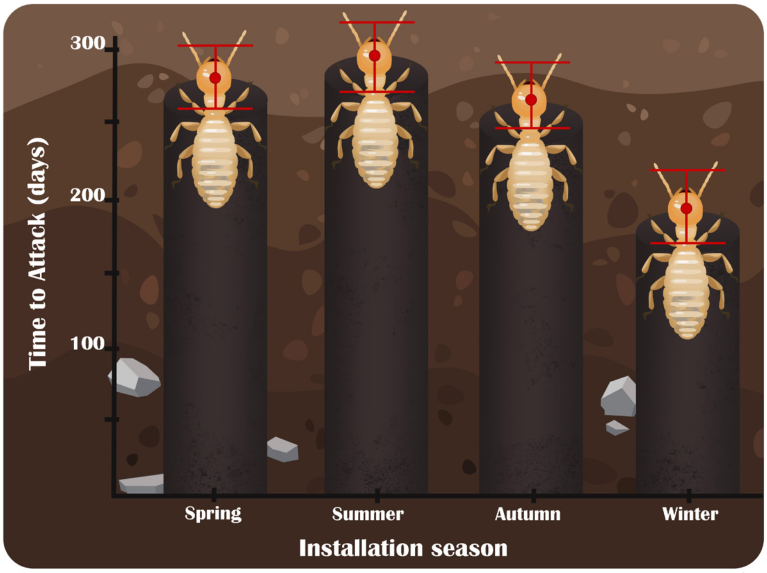


Figure 2. Time required for western subterranean termites (*Reticulitermes* spp.) to begin consuming baits installed during four different seasons in California's San Francisco Bay Area. Red points on termite heads represent the average time-to-attack (number of days between installation and first observation of bait consumption). Red bars extending above and below each point represent standard error of the mean.

insects

MDPI

Article

Installation Season May Significantly Impact Time Required for Subterranean Termites to Find and Feed on In-Ground Baits

Andrew M. Sutherland *, Casey Hubble and Molly Barber

Division of Agriculture and Natural Resources, University of California, Davis, CA 95618, USA; cwhubble@ucanr.edu (C.H.); mabarber@ucdavis.edu (M.B.)
* Correspondence: amsutherland@ucanr.edu; Tel.: +1-(510)-499-2930

Simple Summary: Insecticide baits for use against subterranean termites have been shown to be highly effective, but the time required for termites to find and feed on baits may be a barrier to adoption in some areas. One explanation for this "time-to-attack" problem is that termite foraging near the soil surface may be limited during inhospitable periods. In California, characterized by a hot-summer Mediterranean climate, western subterranean termites have mostly been observed near the surface during the wet season, suggesting that baits installed in summer may sit uninvestigated for many months. To test this hypothesis, we established research plots in areas of known termite incidence, installing baits on four different dates over a one-year period and then recording termite activity every 60 days for two years. As expected, most foraging in these stations was observed in winter and spring. Time-to-attack for stations installed at the beginning of winter was significantly less than for stations installed at the beginning of summer (194 d vs. 296 d). These findings may help pest control operators in regions with pronounced dry periods to optimize their use of bait station systems by targeting specific installation seasons.

Citation: Sutherland, A.M.; Hubble, C.; Barber, M. Installation Season May Significantly Impact Time Required for Subterranean Termites to Find and Feed on In-Ground Baits. *Insects* **2022**, *13*, 445. https://doi.org/10.3390/insects13050445

Academic Editors: Vernard Richard Lewis, Wakako Ohmura and Chow-Yang Lee

Received: 1 April 2022
Accepted: 5 May 2022
Published: 7 May 2022

Abstract: Rhinotermitid termites, serious pests of wooden structures throughout the world, are commonly controlled with chitin synthesis inhibitor bait systems. Seasonal termite foraging patterns in some regions may prolong bait interception time, however, significantly decreasing colony elimination speed. We hypothesized that installing baits immediately prior to the season of highest foraging activity will minimize interception time when baiting for *Reticulitermes* spp. in California, a region characterized by a hot-summer Mediterranean climate. To test this theory, we installed three different bait systems on four dates corresponding to the major seasons (spring, summer, autumn, winter) at five field locations known to harbor the target species. We then recorded initial termite discovery events every 60 days for two years, considering effects of installation season, bait system, site, and distance from previously observed termite incidence on bait interception time. Observed foraging activity in bait stations was highest during late winter and spring. Baits installed during winter exhibited interception times more than 100 days shorter than those of baits installed during summer. From these findings, we conclude that colony elimination speed and perceived CSI bait utility may be increased in Mediterranean climate regions when baits are installed immediately prior to the wet season.

Keywords: rhinotermitidae; chitin synthesis inhibitors; bait interception time

1. Introduction

Subterranean termites (Blattodea: Rhinotermitidae), widely distributed in temperate and tropical regions worldwide, are the most significant of wood-destroying pests, causing more than USD 30 billion in damage and control expenses globally each year [1–3]. Commonly, subterranean termites have been deterred from attacking wooden structures by physical or chemical barriers placed under or around buildings [4,5]. Physical exclusion tactics, such as sand or other particle barriers, require maintenance and are prone to failure in some environments [4]. Chemical barriers, such as liquid termiticides applied to subsurface soil around structures, are commonly provided by pest control operators and may result in short-term control or repellency [4]. In some cases, however, liquid termiticides may repel termites from structures but fail to eliminate their colonies, meaning termites may return to attack treated structures when termiticide residues have degraded [6]. Baits for subterranean termites, consisting of cellulose matrices that contain slow-acting insecticides, have been considered valuable alternatives to liquid termiticides for decades [7]. Modern termite baits usually employ chitin synthesis inhibitors (CSIs), growth regulator chemicals that prevent insects from successfully forming new exoskeleton tissue, resulting in death during molting [1]. Subterranean termite workers may molt many times per year; in *Coptotermes formosanus* Shiraki, an estimated 1.7% of termite workers in a given colony molt each day [8]. Therefore, consumption of CSI baits by foraging workers (and subsequent spread throughout the colony via trophallaxis) has the theoretical capacity to eliminate the worker caste in as little as 60 d (100%/1.7% = 58.8). Soldiers, larvae, and reproductive castes reliant upon workers for nutrition eventually die of starvation [7]. Furthermore, new research [9] suggests that CSI consumption significantly reduces egg production by queens, egg size, and egg viability, accelerating colony elimination. Applications of CSI baits have been shown to eliminate entire colonies of rhinotermitid termites in both the laboratory [1,9] and the field [10,11], sometimes in periods as short as 60–90 d [12,13].

Time required for colony elimination is determined by three temporal factors: interception time, toxicant acquisition time, and lethal time [14]. The initial major determinant, *bait interception time*, or the time required for termites to find and begin feeding on bait, is highly variable and likely dependent upon foraging patterns [15]. Bait interception times reported by field researchers have varied from less than 60 d [11,16] to more than 400 d [17]. Once termites have been detected in bait stations, however, apparent colony elimination was usually reported in one year or less [10,18,19]. Long bait interception times may lead practitioners to conclude that colony elimination is too slow for CSI baits to be considered viable tactics for remedial pest control. In California, this conclusion has been shared with the authors by pest control operators as an explanation for the low industry adoption of baits in the region. California is characterized by a hot-summer Mediterranean climate [20], with almost all precipitation occurring during the cooler winter months. The primary target pest species in western North America, *Reticulitermes hesperus* Banks, is known to exhibit foraging patterns that likely correspond to seasonal differences in temperature and soil moisture [21]. In general, the observed pattern for *Reticulitermes* spp. in California is increased foraging activity during late winter and early spring months coupled with decreased foraging activity during autumn and early winter months [5,16]. This pattern may be pronounced in wildland areas as compared with irrigated urban areas [21]. Given that foraging activity drives initial termite discovery of potential new resources, we hypothesize that baits targeting *Reticulitermes* spp. in California that are installed at the beginning of winter will have reduced interception times as compared to those installed at the beginning of summer.

2. Materials and Methods

We established five field sites at the Richmond Field Station, a 40 ha University of California, Berkeley research station located 500 m from the San Francisco Bay, characterized by a mild Mediterranean climate with significant marine influences (temperature range: 6–24 °C, average precipitation = 63.4 cm). Average distance between sites was 160 m (range: 47–253 m) (Figure 1). Each of these sites was centered on a specific location where foraging subterranean termites, identified as *Reticulitermes* spp. (*R. hesperus* species complex, see [22]), were observed and collected during January 2019.

Figure 1. Five sites were established in 2019 at the University of California, Berkeley; Richmond Field Station; a sparsely-vegetated 40 ha property used for institutional and industrial purposes.

At each site, we installed stations from three different commercial CSI bait systems at the beginning of four different seasons and at three different distances from the central termite collection locations. Bait matrices within stations were provided by manufacturers and did not contain active ingredients. Bait systems represented included Advance Termite Baiting System (for use with Trelona Compressed Termite Bait: 0.5% novaluron, BASF SE. Florham Park, NJ, USA), Exterra (for use with Isopthor Termite Bait: 0.25% diflubenzuron, Ensystex, Inc. Fayetteville, NC, USA), and Sentricon Always Active (for use with Recruit HD Termite Bait: 0.5% noviflumuron, Corteva, Inc. Indianapolis, IN, USA). Installation dates roughly corresponded to seasonal events in the solar cycle (solstices and equinoxes): 25 March 2019 (spring); 24 June 2019 (summer); 23 September 2019 (autumn); and 16 December 2019 (winter). On these dates, one station from each bait system was installed along each of three concentric circles that were 1 m, 3 m, and 5 m from the centers of each site, for totals of 9 stations per site per season, 45 stations per season, and 180 bait stations overall (Figure 2). In addition, a monitoring station (Isopthor EZE; Ensystex, Inc.) containing wood (*Pinus* spp.) blocks was installed along each concentric circle and at the center of each site on 25 March 2019. All stations were installed so that circular access caps extended approximately 1 cm above the soil surface, with the remaining 20–25 cm underground and in continuous contact with the soil. Installation was accomplished using a ratcheting hand auger (18″ Pro Series Ratcheting Cross Handle, 5/8″ Thread, 3′ Extension Bar, 2 $\frac{1}{2}$″ Open-Face Auger, 2″ Combination Edelman Auger; AMS, Inc. American Falls, ID, USA). Following each installation event, bait stations and monitoring stations were opened and examined for termite activity every 60 days [17] for two years. Bait interception time was considered to be the number of days between station installation and the first observation of feeding on bait matrices by the target species. In cases where termites were present during these inspections, approximately 30 individuals were collected in 95% ethanol for future analysis of molecular characters, especially those associated with colony fidelity [18]. Overall seasonal activity was described by considering the numbered Gregorian dates of initial termite discovery events during the two-year observation period and then continuously fitting these points using a nonparametric density estimation, executed using the *Analyze Distribution > Fit Smooth Curve* command within JMP Statistical Software [23,24]. Bivariate relationships between bait interception time and bait system, site, distance from site center, and bait system of nearest station were all considered using Wilcoxon signed-rank tests [25]. The bivariate relationship between bait interception time and distance from nearest station (a normally distributed continuous variable) was considered using linear regression. The effect of installation season on bait interception time was investigated by considering initial termite discovery events during the first year of observations only, since initial discovery events during the second year were invariably observed in stations that had already been in place for an entire seasonal activity cycle. The relationship between installation season and bait interception time was described using a general linear mixed model (residual maximum likelihood method), with installation season as the fixed effect and with bait system and site considered as random effects [26]. Least-squares means of bait interception times were compared amongst installation seasons using the Tukey honestly significant difference test. All analyses were conducted using JMP Statistical Software (JMP Pro 16, SAS Institute, Inc. Cary, NC, USA) [24].

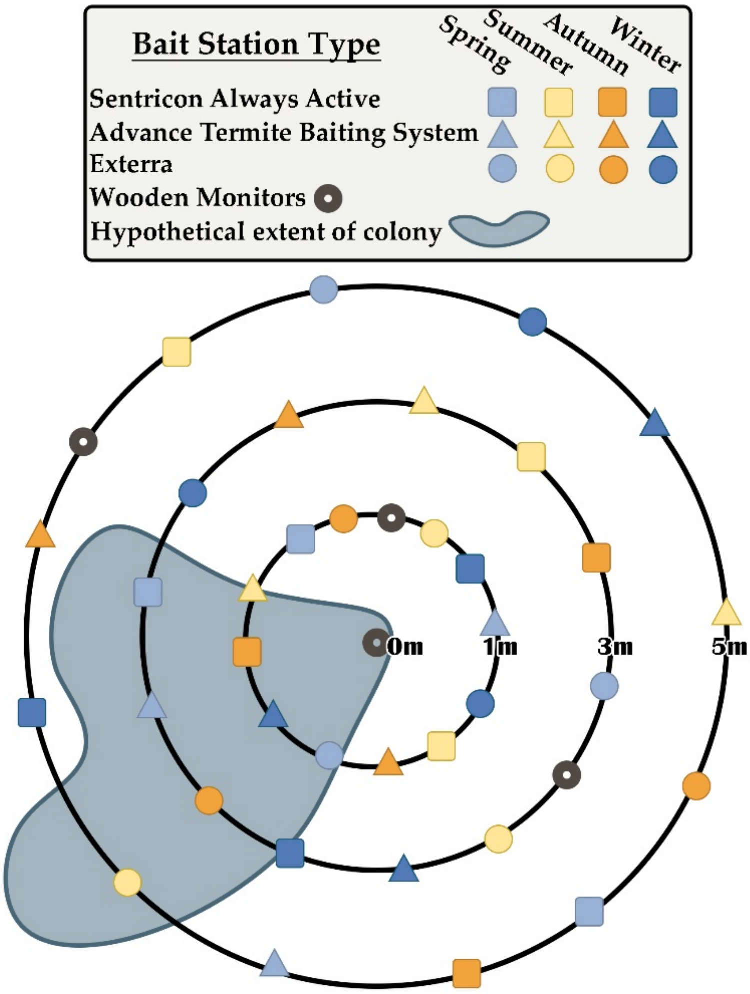


Figure 2. Representative example of study site arrays. Each site was centered on a specific location where subterranean termites had been observed and collected. Three bait station types were installed at three different distances from the site center during four different seasons during 2019 (see corresponding text for specific details and installation dates).

3. Results

Feeding by *Reticulitermes* spp. termites was detected or observed within 43% (78 out of 180) of the bait stations and 45% (9 out of 20) of the monitoring stations installed. Foraging termites were encountered in 29 different stations, resulting in 22 voucher specimen collections.

3.1. Overall Seasonal Activity

Initial termite discovery events, or *first hits*, were observed during all 12 months of both years, though there was a marked trend observed, with most first hits during late winter and spring, a gradual decline in first hits during summer and early autumn, and fewest first hits during late autumn and early winter. A normal mixture density equation using vectors for inspection month means, standard deviations, and probabilities generated a line that continuously fits these data, helping to illustrate the trends observed [23,24] (Figure 3).

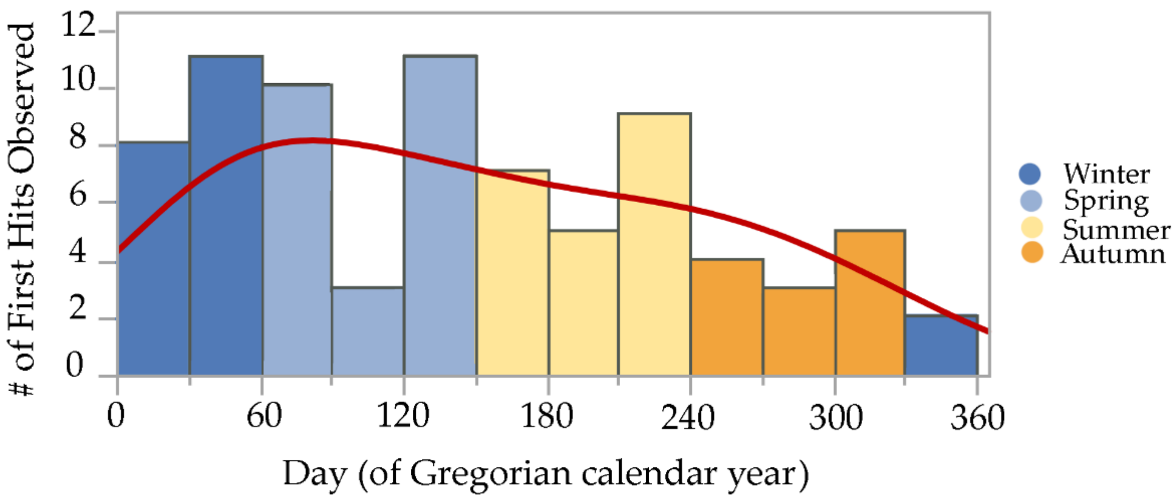


Figure 3. Initial discovery events or "first hits" by *Reticulitermes* spp. termites observed on cellulose bait matrices (without active ingredients) at five sites during 2019–2021 in the San Francisco Bay Area. Histogram colors demarcate the four Mediterranean climate seasons experienced in California: cool wet spring during days 61–150, hot dry summer during days 151–240, warm dry autumn during days 241–330, and cold wet winter during days 331–365 and 1–60. Red line over histogram shows output from a normal mixture density equation that continuously fits the data.

3.2. Observed Bait Interception Time

Two stations were found and fed upon within 60 days, and ten stations were found and fed upon within 120 days. Overall, however, the average bait interception time observed was greater than one year (367 ± 17.4 d, n = 78).

3.2.1. Bivariate Relationships: Effects on Bait Interception Time

There was a significant bivariate relationship detected between site and bait interception time (Wilcoxon χ^2 = 11.3, p = 0.02, df = 4), with overall times observed at Site 5 (292 ± 29.6 d, n = 22) significantly less than times observed at Site 4 (462 ± 46.3 d, n = 13); mean interception times observed at the other three sites were intermediate (all between 349 and 419 d) and statistically inseparable from the other sites. There were no detectable effects of bait system (Wilcoxon χ^2 = 2.61, p = 0.27, df = 2; range: 327–383 d), distance from site center (Wilcoxon χ^2 = 0.04, p = 0.98, df = 2; range: 356–377 d), bait system of nearest station (Wilcoxon χ^2 = 0.30, p = 0.96, df = 2; range: 358–369 d), or distance from nearest station (R^2 = 0.03, n = 78) on bait interception time.

3.2.2. Effect of Installation Season on Bait Interception Time

The mixed model detected a significant fixed effect of installation season on bait interception time (F = 3.00, $p = 0.04$, df = 3) and attributed 9.38% and 0.53% of experimental variation to the random effects bait system and site, respectively. Comparison of least-squares means via Tukey's HSD test revealed significant pairwise differences in bait interception time due to the installation season: bait stations installed on 16 December (winter) exhibited significantly lower interception times (194 ± 26.0 d, $n = 9$) than stations installed on 24 June (summer) (296 ± 24.7 d, $n = 10$). Interception times for stations installed on 25 March (spring) and 23 September (autumn) were statistically intermediate (282 ± 20.2, $n = 15$; and 268 ± 22.5, $n = 12$; respectively). This effect can be visualized using boxplots with means comparison letters, which show generally decreasing median interception times, as stations were installed progressively later in the calendar year, and a significant difference between stations installed in winter and summer (Figure 4).

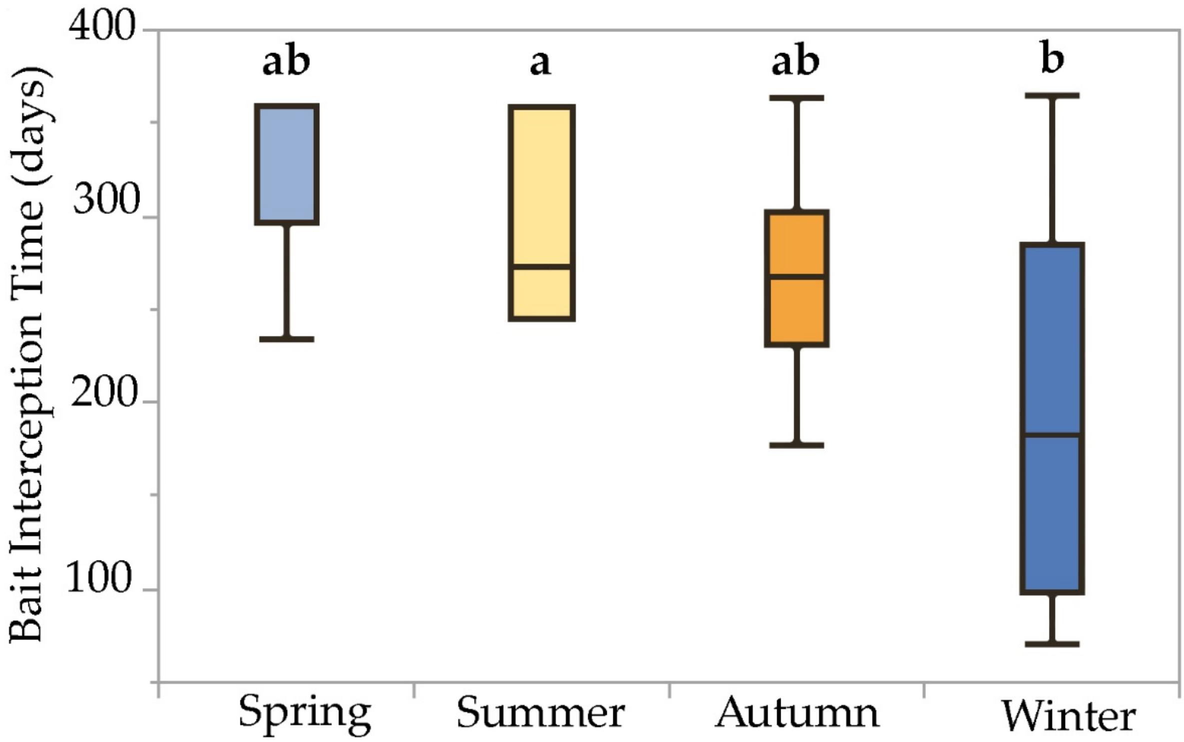


Figure 4. Boxplots illustrating statistical moments associated with bait interception time data collected over a one-year period from termite baits installed during four different seasons in the San Francisco Bay Area. Boxplots with the same letter code are not significantly different (Tukey HSD test on least-squares means, $\alpha = 0.05$). Interception times for baits installed during winter were significantly less than those for baits installed during summer, while interception times for baits installed during spring and autumn were statistically intermediate between winter and summer.

4. Discussion

The main finding of this study was that the season of bait station installation significantly impacted observed bait interception times when targeting *Reticulitermes* spp. In California. It may be that seasonal differences in foraging near the soil surface created differential opportunities for termites to find and begin feeding on recently installed in-ground baits. Specifically, based on our observations, we hypothesize that foraging for new resources near the soil surface by *Reticulitermes* spp. May occur at the greatest frequency during late winter and early spring in California, reducing potential interception times for baits installed just prior to or during the early part of this seasonal period. Our observations are consistent with those previously conducted on *Reticulitermes hesperus* [21] and *Reticulitermes* spp. [16] in California. Soil moisture, soil temperature, and precipitation have been cited as environmental factors likely driving these seasonal activity patterns [21]. Significant differences in bait interception times by *Reticulitermes* spp. And *Coptotermes* spp. In different parts of the United States have also been attributed to environmental factors that vary amongst climatic regions [10]. Though not rigorously measured, air temperature and soil moisture varied widely from season to season during our trial, as expected. Summers were hot and dry, and rainfall occurred exclusively during cooler months. First significant rains were recorded during late November in 2019 and 2020 and during late October in 2021.

An alternative explanation for these results is that bait interception times decreased as cellulose resources (stations installed) within sites became more abundant. This was considered, but a clear linear trend based on this possibility was not detected. For instance, there were no differences in bait interception time between stations installed during spring (initial installation event) and winter (final installation event). Our experiment could be repeated, with different initial installation seasons, to confirm that the installation season rather than resource density was the factor driving interception time.

There were significantly different bait interception times recorded among the five different study sites, which included differences in soil type, vegetation type, and irrigation regimes (see Figure 1). Mean interception time at Site 5, which was in unirrigated sandy soil near a wood building, was 292 d, while mean interception time at Site 4, which was in clay loam soil within an irrigated landscape bed dominated by coast redwood trees (*Sequoia sempervirens* (D. Don) Endl.), was 462 d. The other three sites, which were along a sporadically irrigated linear grove of pine (*Pinus* spp.) and oak (*Quercus* spp.) trees, exhibited intermediate interception times. Our experiment was not designed to determine the site factors that may influence bait interception time, but one hypothetical explanation for the differences observed is that there may have been much more cellulose debris in the landscape bed under the redwood trees than in the sandy and mostly unvegetated area adjacent to the old building, providing ample food for foraging termites and making the baits comparatively less important as resources. A potentially related observation was made with *Reticulitermes* spp. in Mississippi, where foraging termites were more likely to revisit monitoring stations in open grassland than they were in a forested habitat with presumed greater abundance of subterranean food resources [17]. The caveat to this finding was that stations in open grassland exhibited much higher initial interception times (up to 420 d) than stations in the forested habitat (as few as 90 d) [17]. The study referenced installed stations in areas where termite incidence had not been confirmed, while stations in our study were all installed in specific locations known to recently harbor termites.

One concern related to colony elimination speed is that some species of rhinotermitid termites may become repelled from bait stations by too-frequent inspections, which represent repeated disturbances. For instance, *Reticulitermes flavipes* (Kollar) workers were observed to take significantly more time to return to a food resource following a physical disturbance than *C. formosanus* workers [27]. Newer product labels, such as those associated with the bait systems included in this study, allow for inspection frequencies as low as once per year or once per six months, perhaps due to these findings and reports by practitioners. For this work, however, we opted to maximize our data set by utilizing a 60 d inspection frequency. This frequency has been compared to lower frequencies and was considered to have no significant effect on observed activity of *Reticulitermes* spp. workers in in-ground monitoring stations [17].

5. Conclusions

Overall, these findings may help pest control operators to optimize their use of bait station systems as subterranean termite control tactics by targeting specific installation seasons, especially in areas with pronounced dry periods, hot periods, or other periods considered to be inhospitable to foraging near the soil surface. These efforts may reduce bait interception times, leading to overall decreases in colony elimination time [14] and greater perceived efficacy within their client bases. All three of the bait systems represented in this study have been evaluated in the field and considered effective for remedial control of rhinotermitid pest species [10,19,28].

Author Contributions: Conceptualization, A.M.S.; methodology, A.M.S. and C.H.; formal analysis, A.M.S.; investigation, A.M.S., C.H., and M.B.; data curation, A.M.S., C.H. and M.B.; writing, A.M.S., C.H., and M.B.; visualization, C.H.; supervision, A.M.S.; project administration, A.M.S. and C.H.; funding acquisition, A.M.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Structural Pest Control Board, a division of the California Department of Consumer Affairs, Agreement Number 26730.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available at the following Google Drive cloud storage link: https://docs.google.com/spreadsheets/d/1vUjxIuiNnXYsLB35C8Xhol7RB4Wd2DBQ/edit?usp=sharing&ouid=114980821805913012004&rtpof=true&sd=true, accessed on 31 March 2022.

Acknowledgments: Bait matrices that did not contain active ingredients were obtained from bait system manufacturers BASF, Ensystex, and Corteva for specific use in this research.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Kakkar, G.; Su, N.Y. Molting drives mortality in foraging populations of Formosan subterranean termites (Isoptera: Rhinotermitidae) baited with a chitin synthesis inhibitor, noviflumuron. *Pest Manag. Sci.* **2018**, *74*, 219–224. [CrossRef] [PubMed]
2. Rust, M.K.; Su, N.-Y. Managing Social Insects Urban Importance. *Annu. Rev. Entomol.* **2012**, *57*, 535–575. [CrossRef] [PubMed]
3. Ferreira, M.T.; Borges, P.A.; Nunes, L.; Myles, T.G.; Guerreiro, O.; Scheffrahn, R.H. Termites (Isoptera) in the Azores: An overview of the four invasive species currently present in the archipelago. *Arquipélago Life Mar. Sci.* **2013**, *30*, 39–55.
4. Lewis, V.R.; Haverty, M.I.; Carver, D.S.; Fouche, C. Field comparison of sand or insecticide barriers for control of *Reticulitermes* spp. (Isoptera: Rhinotermitidae) infestations in homes in Northern California. *Sociobiology* **1996**, *28*, 327–335.
5. Haverty, M.I.; Getty, G.M.; Copren, K.A.; Lewis, V.R. Seasonal foraging and feeding behavior of *Reticulitermes* spp. (Isoptera: Rhinotermitidae) in a wildland and a residential location in northern California. *Environ. Entomol.* **1999**, *28*, 1077–1084. [CrossRef]
6. Chouvenc, T. Comparative impact of chitin synthesis inhibitor baits and non-repellent liquid termiticides on subterranean termite colonies over foraging distances: Colony elimination versus localized termite exclusion. *J. Econ. Entomol.* **2018**, *111*, 2317–2328. [CrossRef]
7. Quarles, W. IPM for Termites—Termite Baits. *IPM Pract.* **2003**, *25*, 1–9.
8. Kakkar, G.; Chouvenc, T.; Osbrink, W.; Su, N.Y. Temporal assessment of molting in workers of Formosan subterranean termites (Isoptera: Rhinotermitidae). *J. Econ. Entomol.* **2016**, *109*, 2175–2181. [CrossRef]
9. Chouvenc, T.; Lee, S.B. Queen Egg Laying and Egg Hatching Abilities are Hindered in Subterranean Termite Colonies When Exposed to a Chitin Synthesis Inhibitor Bait Formulation. *J. Econ. Entomol.* **2021**, *114*, 2466–2472. [CrossRef]
10. Eger, J.E., Jr.; Lees, M.D.; Neese, P.A.; Atkinson, T.H.; Thoms, E.M.; Messenger, M.T.; Demark, J.J.; Lee, L.C.; Vargo, E.L.; Tolley, M.P. Elimination of subterranean termite (Isoptera: Rhinotermitidae) colonies using a refined cellulose bait matrix containing noviflumuron when monitored and replenished quarterly. *J. Econ. Entomol.* **2012**, *105*, 533–539. [CrossRef]
11. Shults, P.; Richardson, S.; Eyer, P.A.; Chura, M.; Barreda, H.; Davis, R.W.; Vargo, E.L. Area-wide elimination of subterranean termite colonies using a novaluron bait. *Insects* **2021**, *12*, 192. [CrossRef] [PubMed]
12. Evans, T.A.; Iqbal, N. Termite (order Blattodea, infraorder Isoptera) baiting 20 years after commercial release. *Pest Manag. Sci.* **2015**, *71*, 897–906. [CrossRef]
13. Chouvenc, T. Subterranean Termite (*Coptotermes gestroi* (Blattodea: Rhinotermitidae)) colony elimination through exposure to a novaluron CSI bait formulation in laboratory. *J. Econ. Entomol.* **2021**, *114*, 1249–1255. [CrossRef] [PubMed]
14. Su, N.Y. Development of baits for population management of subterranean termites. *Annu. Rev. Entomol.* **2019**, *64*, 115–130. [CrossRef] [PubMed]
15. Su, N.Y.; Monteagudo, E.J. Hyperecdysonism in the Formosan subterranean termite and eastern subterranean termite (Isoptera: Rhinotermitidae). *J. Econ. Entomol.* **2017**, *110*, 1736–1739. [CrossRef]

16. Getty, G.M.; Solek, C.W.; Sbragia, R.J.; Haverty, M.I.; Lewis, V.R. Large-scale Suppression of a Subterranean Termite Community Using the Sentricon® Termite Colony Elimination System: A Case Study in Chats-worth, California, USA. *Sociobiology* **2007**, *50*, 1041–1050.
17. Shelton, T.G.; Wagner, T.L.; Gerard, P.D. Effects of monitor examination intervals on resource affinity by *Reticulitermes* spp. (Isoptera: Rhinotermitidae). *J. Entomol. Sci.* **2011**, *46*, 102–111. [CrossRef]
18. Thoms, E.M.; Eger, J.E.; Messenger, M.T.; Vargo, E.; Cabrera, B.; Riegel, C.; Murphree, S.; Mauldin, J.; Scherer, P. Bugs, baits, and bureaucracy: Completing the first termite bait efficacy trials (Quarterly replenishment of noviflumuron) initiated after adoption of Florida rule. *Am. Entomol.* **2009**, *55*, 29–39. [CrossRef]
19. Keefer, T.C.; Puckett, R.T.; Brown, K.S.; Gold, R.E. Field trials with 0.5% novaluron insecticide applied as a bait to control subterranean termites (*Reticulitermes* sp. and *Coptotermes formosanus* [Isoptera: Rhinotermitidae]) on structures. *J. Econ. Entomol.* **2015**, *108*, 2407–2413. [CrossRef]
20. Kauffman, E. Climate and topography. In *Atlas of the Biodiversity of California*; California Department of Fish and Game: Sacramento, CA, USA, 2003; pp. 12–15.
21. Haagsma, K.A.; Rust, M.K. Colony size estimates, foraging trends, and physiological characteristics of the western subterranean termite (Isoptera: Rhinotermitidae). *Environ. Entomol.* **1995**, *24*, 1520–1528. [CrossRef]
22. Haverty, M.I.; Getty, G.M.; Nelson, L.J.; Lewis, V.R. Flight phenology of sympatric populations of *Reticulitermes* (Isoptera: Rhinotermitidae) in northern California: Disparate flight intervals indicate reproductive isolation among cuticular hydrocarbon phenotypes. *Ann. Entomol. Soc.* **2003**, *96*, 828–833. [CrossRef]
23. Härdle, W.; Werwatz, A.; Müller, M.; Sperlich, S. Nonparametric Density Estimation. In *Nonparametric and Semiparametric Models*; Springer: Berlin, Germany, 2004.
24. JMP® Statistical Software. *Manual for Version Pro 16*; SAS Institute Inc.: Cary, NC, USA, 2021.
25. Woolson, R.F. Wilcoxon Signed-Rank Test. In *Wiley Encyclopedia of Clinical Trials*; D'Agostino, R.B., Sullivan, L., Massaro, J., Eds.; John Wiley & Sons: Hoboken, NJ, USA, 2008.
26. Hox, J.J. *Multilevel Analysis: Techniques and Applications*; Routledge: Oxfordshire, UK, 2010.
27. Hu, X.P.; Appel, A.G.; Traniello, J.F. Behavioral response of two subterranean termites (Isoptera: Rhinotermitidae) to vibrational stimuli. *J. Insect Behav.* **2003**, *16*, 703–715. [CrossRef]
28. Green, F., III; Arango, R.; Esenther, G. Community-wide suppression of *R. flavipes* from Endeavor, Wisconsin-search for the holy grail. *Int. Res. Group Wood Prot.* **2008**, *IRG/WP*, 08-10674.