# CAN KNOWLEDGE OF SPATIAL VARIABILITY IN SLUG POPULATIONS HELP IMPROVE STAND ESTABLISHMENT?

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## Introduction

Slugs have been repeatedly identified as one of the most serious pest problems in a wide variety of Willamette Valley crops, including grasses grown for seed. Objectives of this project were to monitor the timing of slug emergence and evaluate the feasibility of identifying areas within fields with highest populations of slugs to help focus control efforts on situations with the greatest risk of crop damage.

## Materials and Methods

Tests were conducted in the grass seedling establishment phase of three major crop rotations: (1) radish followed by fall seeding of new perennial ryegrass (PR) stands, (2) white clover followed by fall seeding of PR, and (3) established PR taken out of production by conventional tillage and replanted to the same PR variety. Tests were conducted at a total of five sites, two in Polk County and three in Linn County (Table 1). Both no-till and conventional tillage were used in removal of radish and white clover stands. All PR stands were planted by growers.

Weekly counting of slugs, predatory beetles, and earthworms began before crop emergence and continued until stands were well established by mid- to late winter. Slug blankets were placed in grid patterns spaced at approximately one blanket per acre, with a minimum of 30 locations per field. Ground chicken mash was applied beneath each water-soaked blanket on one day, and slugs, worms, and beetles were counted the next day. Plywood squares (16 inches x 16 inches) were used to cover the slug blankets to prevent disturbance by wind or water and to help maintain good levels of moisture within the blankets.

Slugs were counted over a period of 19 weeks from early October through early February, although not all sites could be counted every week due to field conditions. Slug counts were made at sites 1, 2, 3, 4, and 5 a total of 8, 13, 14, 12, and 15 times, respectively, ignoring all counts made before the first slugs were present at the soil surface in early fall. Access to fields was more often a problem in the three conventionally tilled fields than in the two no-till fields. Timing of slug counts in this report refers to the number of weeks since the end of September, with week 1 being the period from September 28 to October 4, 2014. Experiments were terminated once crops were well established and final counts of crop stands had been taken.

Methods explored to quantify the spatial distribution of slugs and crop damage included inverse distance weighting (IDW) maps, Kriging, Getis-Ord Gi-star hot spot analysis, and both normal and geographically weighted regression. The Gi-star hot spot analysis technique provides more useful information on statistical significance than IDW or Kriging and therefore was chosen for mapping slug populations within fields over time. Slug count data were normalized

Table 1. Test site conditions, fall 2014.

| Site no. | County | Previous crop | Seedbed preparation | Planting date | Number of slug counts | Number of times slug bait was applied[1] |
|---|---|---|---|---|---|---|
| 1 | Polk | Perennial ryegrass, 3-year stand | Conventional tillage | Oct. 9 | 8 | 9 |
| 2 | Polk | Radish for seed | Conventional tillage | Oct. 15 | 13 | 4 |
| 3 | Linn | White clover | No-till | Sept. 24 | 14 | 9 |
| 4 | Linn | White clover, 3-year stand | Conventional tillage | Oct. 6 | 12 | 2 |
| 5 | Linn | Radish for seed | No-till | Sept. 29 | 15 | 4 |

[1]Slug bait applications were made at site 1 on Oct. 27, Oct. 28, Oct. 31, Nov. 4, Nov. 7, Nov. 8, Nov. 24, Dec. 12, and Jan. 20; at site 2 on Oct. 21, Nov. 10, Nov. 16, and Dec. 15; at site 3 on Oct. 2, Oct. 8, Oct. 16, Oct. 30, Dec. 10, Dec. 22, Dec. 30, Jan. 7, and Jan. 22; at site 4 on Oct. 31 and Nov. 24; and at site 5 on Sept. 27, Oct. 31, Nov. 7, and Nov. 25. Total rates applied over the season within treated areas were 54, 60, 48, 20, and 32 lb/acre at the five sites. Most applications were broadcast, but some were limited to areas with the worst slug problems.

by converting zero counts into small positive values between 0 and 1 based on average slug counts and the fraction of plots with non-zero counts at a given site on a given day, followed by log transformation of the revised slug count numbers.

Soil moisture was measured gravimetrically using surface 2-inch-deep soil samples taken each time slugs were counted. Crop stands were evaluated by counting the number of missing 1-inch-long sections of row in a total of 3,120 inches of row at each plot in a rectangle around the target flag, skipping the center 10 feet x 9 feet because of soil sampling disturbance and crop damage under the plywood squares and slug blankets.

Slug baits were applied by growers based on their own experience and on information we provided to them concerning weekly slug counts.

**Results and discussion**

Maximum soil moisture content (>40%) was reached by early December at all sites.

Results are summarized in Table 2. Predatory beetle populations were highest in the first month of counting, and declined to near 0 when weather cooled in November. Earthworm counts remained high at most sites through early December, although there were large differences among plots at any site and also among the five sites.

Slugs were never uniformly distributed across any of the sites on any date, and counts varied from a minimum of 0 to a maximum of 86 slugs per blanket. Slug counts (both raw and log-transformed data) were significantly affected by date and by plot location within each site. Bait applications typically reduced slug counts by approximately 5-fold (e.g., 25 slugs per blanket before treatment and 5 slugs after treatment).

There were many ways to analyze and display slug count and crop stand data, and not all results can be presented in this report. We tested multiple relationships between crop stand gaps and slug counts at each site, and have shown the best models at each site in Figures 1–5.

At site 1 (conventional tillage into a three-year stand of PR), crop stand loss was generally low and showed no sign of any relationship with slug counts (Figure 1). Problems accessing the field limited us to a total of eight counts over the entire period, seven fewer than at the most easily accessed field. Serious feeding by cutworms was seen in some areas of the field in mid-fall, prompting the grower to apply insecticide on November 26 to save his crop. We were unable to obtain detailed information on the distribution of cutworms, but it seems probable that most of the small patches of missing crop in the field were caused by cutworms rather than by slugs.

At site 2 (conventional tillage into radish), crop stand loss was best explained by a combination of slug counts at weeks 3, 4, and 6 (Figure 2), with an $r^2$ value of 51.5%. This particular site had the greatest amount of stand damage seen at any of the sites, and many patches in the field suffered close to 100% stand loss. These patches were irregularly shaped, but were often 10 to 20 feet in one direction by 50 to 100 feet perpendicularly. Slug counts with the strongest relationships to stand loss were those taken from mid-October through early November, corresponding with emergence and early growth of PR seedlings. There was a dense stand of volunteer radish at this site, likely

Table 2. Test site results, fall 2014.

| Site no. | Average weekly slug count, entire season | Highest weekly --- average slug counts --- | | Slug counts from period most closely related to crop loss | | Average counts of other organisms | |
|---|---|---|---|---|---|---|---|
| | | Week[1] | Average number | Weeks included | Average number | Predatory beetles (weeks 3–6) | Earthworms (weeks 4–11) |
| 1 | 1.4 | 6 | 2.8 | 5 | 1.4 | 0.8 | 8.1 |
| 2 | 7.2 | 9 | 21.1 | 3, 4, 6 | 9.4 | 1.5 | 0.6 |
| 3 | 4.1 | 3 | 9.8 | 3, 4, 6–11 | 4.6 | 0.1 | 4.2 |
| 4 | 3.9 | 5 | 7.9 | 4, 5 | 4.3 | 3.1 | 14.6 |
| 5 | 1.3 | 5 | 2.3 | 4 | 1.0 | 0.1 | 18.3 |

[1]Week 1 of fall establishment season is defined as Sept. 28 to Oct. 4, 2014.

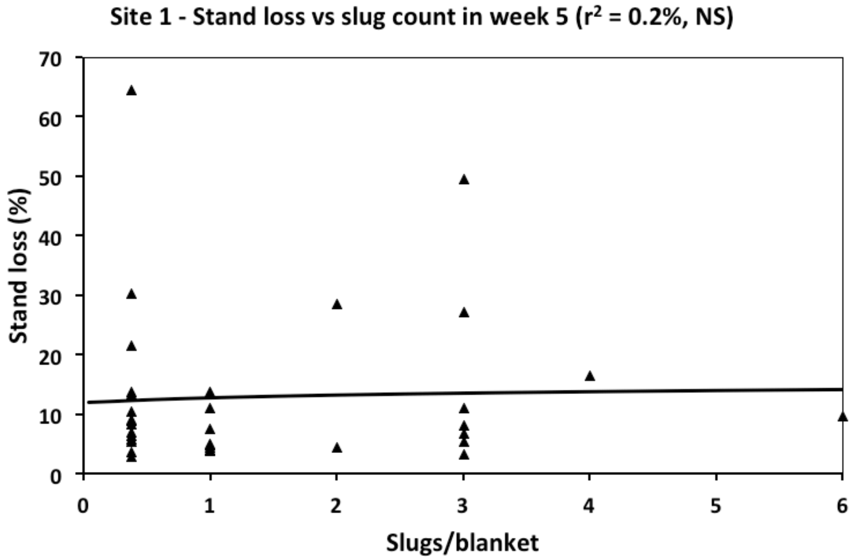


Figure 1. Stand loss from slugs at site 1.

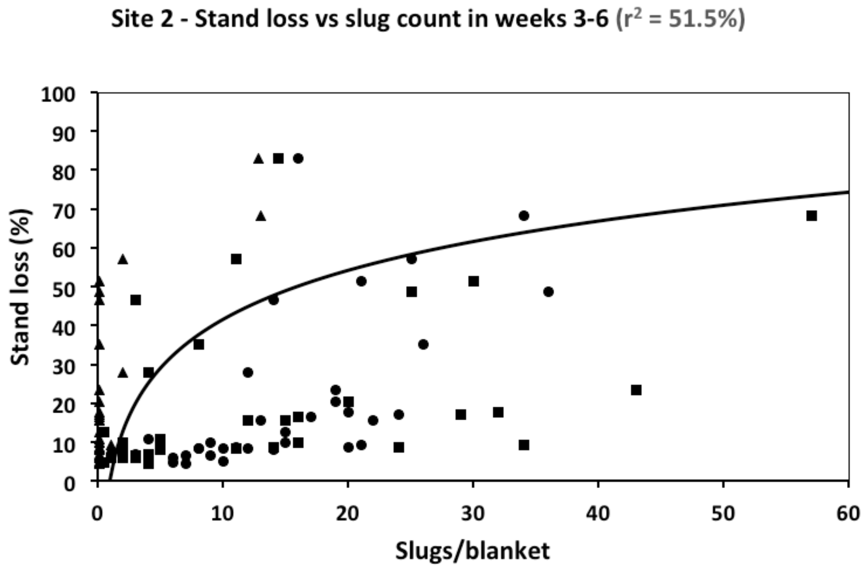


Figure 2. Stand loss from slugs at site 2.

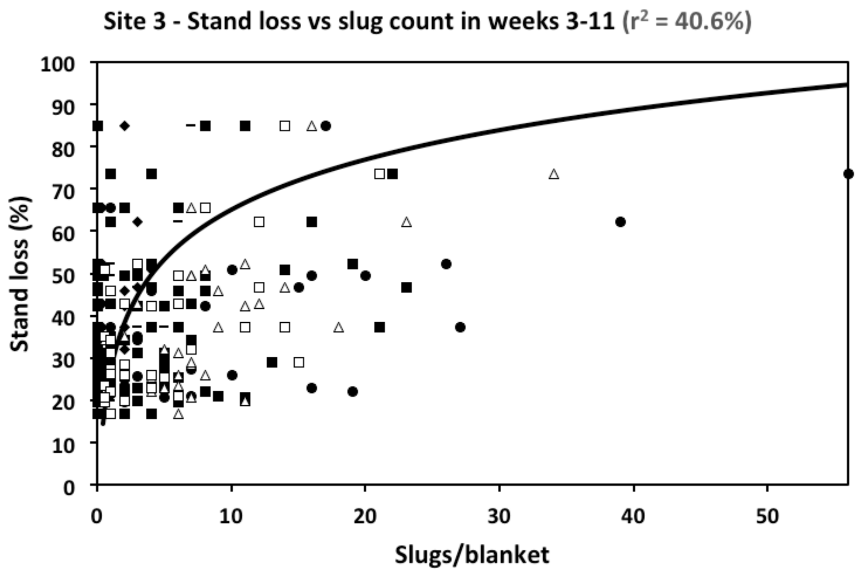


Figure 3. Stand loss from slugs at site 3.

maintaining relatively good moisture conditions on the soil surface throughout the daytime hours in mid-fall, thereby maximizing slug activity. This was the only site at which new slug egg masses were found on the soil surface during the fall.

Site 3 was a no-till planting into a dense stand of white clover. It suffered from highly variable crop emergence, probably related to poor soil moisture at planting time and erratic seed/soil contact. Germination was spread out over many weeks, and the dense stand of white clover suppressed development of PR seedlings for several months before it was finally killed by herbicides. Crop stand loss at site 3 was best explained by slug counts over the period of time from week 3 through 11 (Figure 3), with an $r^2$ value of 40.6%. The combined result of slow emergence and heavy competition apparently left seedling PR vulnerable to slug feeding/damage over a prolonged period of time. The firm soil, however, allowed the grower good access to the field to repeatedly apply slug baits, and moderately good crop stands eventually developed over much of the field.

Stand loss at site 4 (conventional tillage into white clover) and site 5 (no-till into radish) was much less serious than at sites 2 and 3. Crop emergence was relatively uniform and prompt at sites 4 and 5, with no competition from weeds at site 4 and only temporary competition at site 5 until herbicides were applied to control the volunteer radish. Crop stand loss was most strongly related to slug counts in weeks 4 and 5 at site 4 (Figure 4) and to those in week 4 at site 5 (Figure 5), with $r^2$ values of 39.1 and 36.0%, respectively. Weeks 4 and 5 represented the point at which soils had received

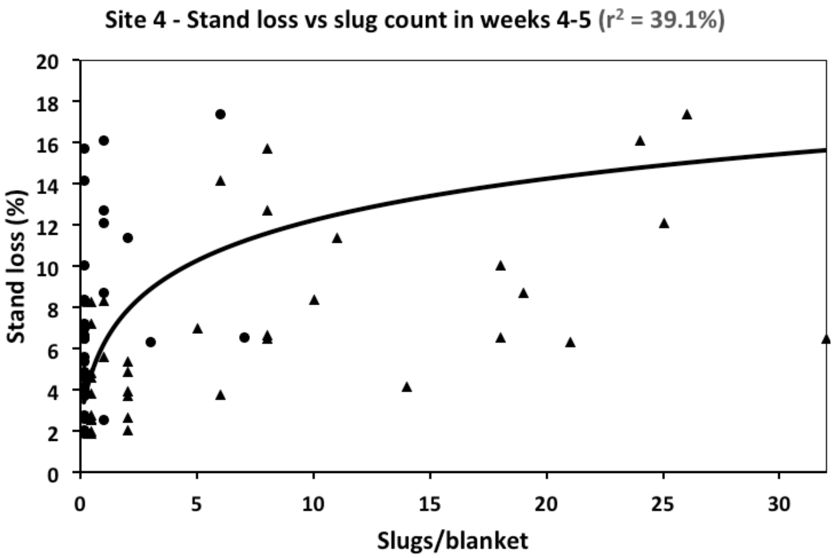


Figure 4. Stand loss from slugs at site 4.

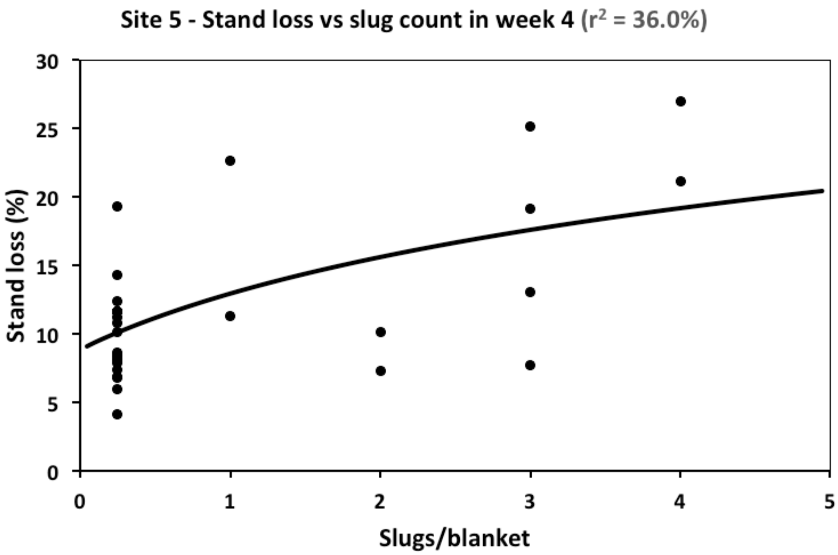


Figure 5. Stand loss from slugs at site 5.

enough rain to become good environments for slugs to safely forage for food while the weather was still warm enough for the slugs to be active. Soil moisture at site 4 climbed from 14% on October 10 to 37% by October 31. Growers at both sites 4 and 5 maintained relatively good control over slugs with timely application of slug baits. Although slug counts at site 4 included five cases of more than 20 slugs per blanket, PR stand damage was less than 18% even in the worst plots, in contrast to multiple plots with more than 80% stand loss at sites 2 and 3.

Knowing that the critical period (as defined by when small crop plants are most easily destroyed by slugs) was usually only the first month after planting reduced our concern about the stability of slug hot spots over the entire period from early fall through midwinter. However, situations such as delayed crop emergence or excessive competition from established plants or volunteer seedlings of previous stands could extend the period of vulnerability past the first month. In that case, the stability of slug populations would become more important.

Figures 6–10 show the statistical significance of clustering by slugs into hot (and occasionally cold) spots over multiple periods of time. The center bulls-eye of each ring in Figures 6–10 shows significance for weeks 11 to 19 of slug counts, the next larger ring shows significance for weeks 7 to 10, and the third ring shows significance for the first 6 weeks. In Figures 7–10, the outermost (largest) ring of each circle shows clustering significance of slugs at the period of time most strongly linked to crop stand loss. In many cases, there was at least some similarity in location of hot spots over time. It was relatively uncommon, however, for hot spots to remain at the same locations over the entire four-month period.

Most slugs seen at the five sites hatched over a month-long period from early October through early November. Factors causing juvenile slugs to appear at the soil surface in variable and sometimes damaging numbers over this period of time are uncertain, but likely include the depth at which eggs were laid in the spring, the degree of mortality from predatory beetles, and local spatial variability in soil moisture and temperature regimes.

Once slugs hatched and began feeding on crop seedlings and other vegetation, variations in uniformity of slug bait application rates and patterns of earthworm feeding on slug baits probably induced further spatial variability in slug populations by allowing some juveniles to survive and develop while others were killed. Some stand damage due to cutworms also occurred, although growers at the two sites most impacted by cutworms quickly brought them under control by timely insecticide applications. Cutworms were most serious at site 1, where spatial variation in stand loss was unrelated to slug counts on any date or range of dates.

Several results stand out from this research regarding general recommendations for applying slug control baits to new grass plantings. First, the most critical period for applying slug baits is when soils first become thoroughly wet and eggs hatch out into hungry neophytes. In the fall of 2014, this point in time was preceded by approximately four weeks of intermittent, light rainfall that germinated PR seedlings while maintaining a generally dry soil surface. Heavier rains soon after planting likely would shorten the time period in which seedlings are safe from slugs, probably leading to greater crop damage. Second, no-till has distinct advantages over conventional tillage in allowing access to fields when needed. In conventional tillage systems, access is limited to times when rainfall patterns allow equipment to drive on the fields. Third, multiple applications of slug bait were required at all sites, particularly when crop germination was extended over a lengthy period or early applications were somewhat ineffective. Fourth, growers limited some of their slug baiting efforts to spot treatments rather than whole-field applications, but with mixed results. Treating only those parts of a field firm enough to drive on would be an invitation to slugs to damage crops in the rest of the field. In contrast, treating areas with known slug populations and leaving other areas untreated worked reasonably well as long as all areas of the field were accessible for monitoring.

Analysis is continuing in an attempt to identify reasons for the patchiness of slug populations and crop damage. Until a predictive model can be developed, the best that growers can do is to initially treat entire fields and then continue treating areas with noticeable damage in order to maintain adequate stands of newly planted crops such as PR. Shifting locations of slug hot spots in the early weeks of the fall growing season suggest that hatching and emergence are delayed or promoted by factors such as soil moisture, soil texture, depth of tillage, composition of pre-existing vegetation, and prevalence of predators. Further research into these factors will be crucial for developing predictive models useful in designing variable rate and hot spot application programs for slug baits.

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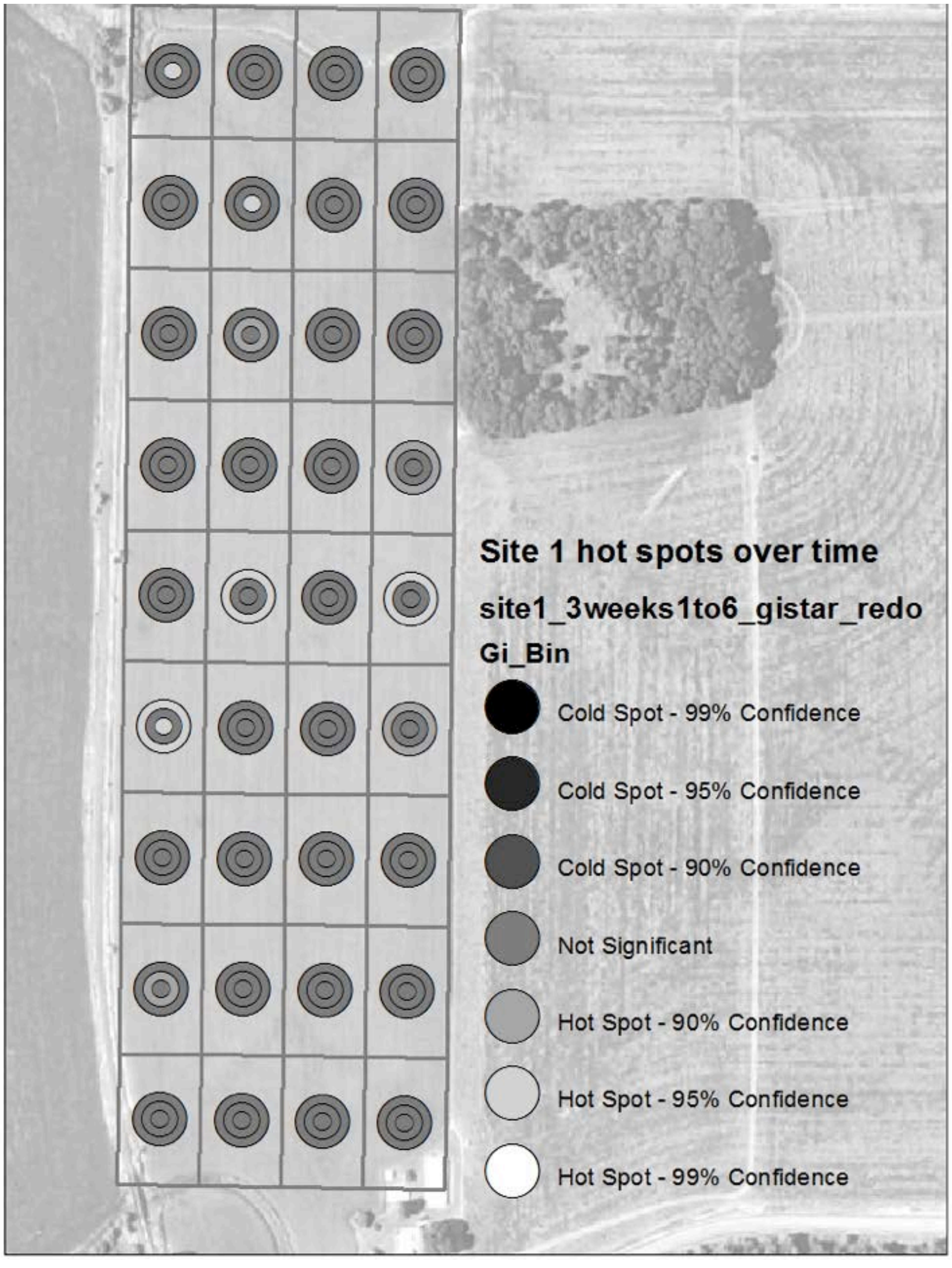


Figure 6. Significance of slug hot spots over time at site 1.

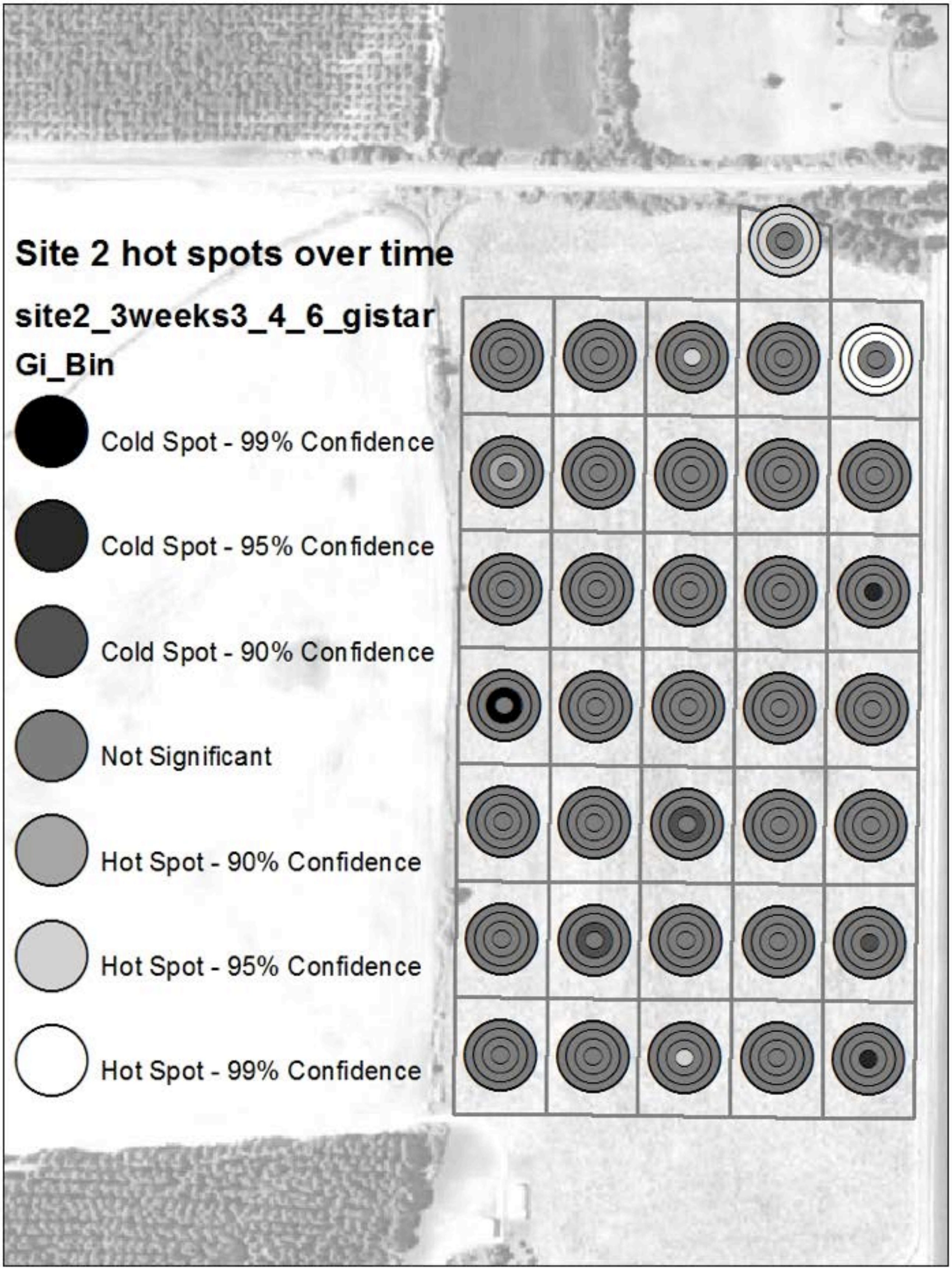

Figure 7. Significance of slug hot spots over time at site 2.

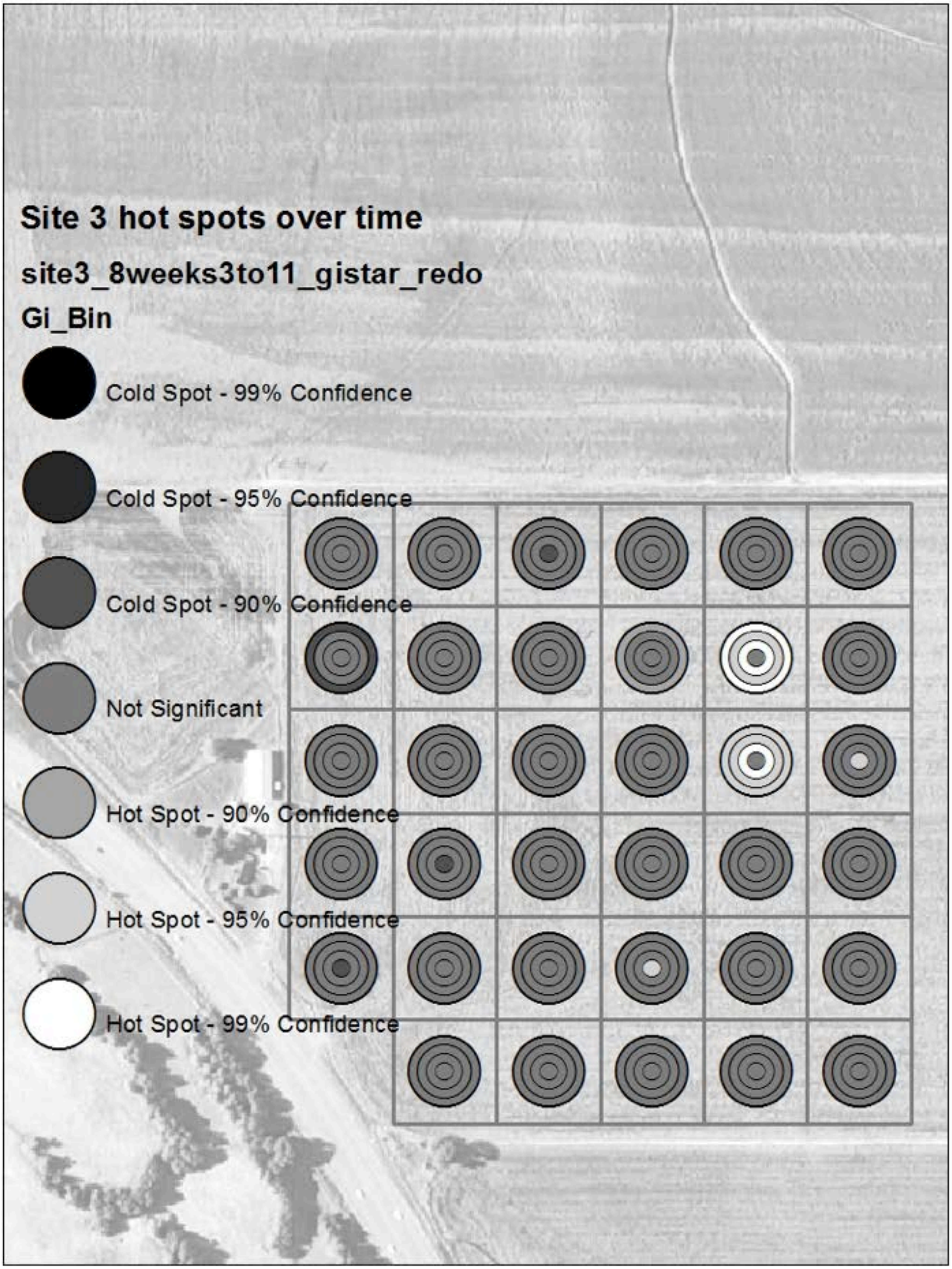


Figure 8. Significance of slug hot spots over time at site 3.

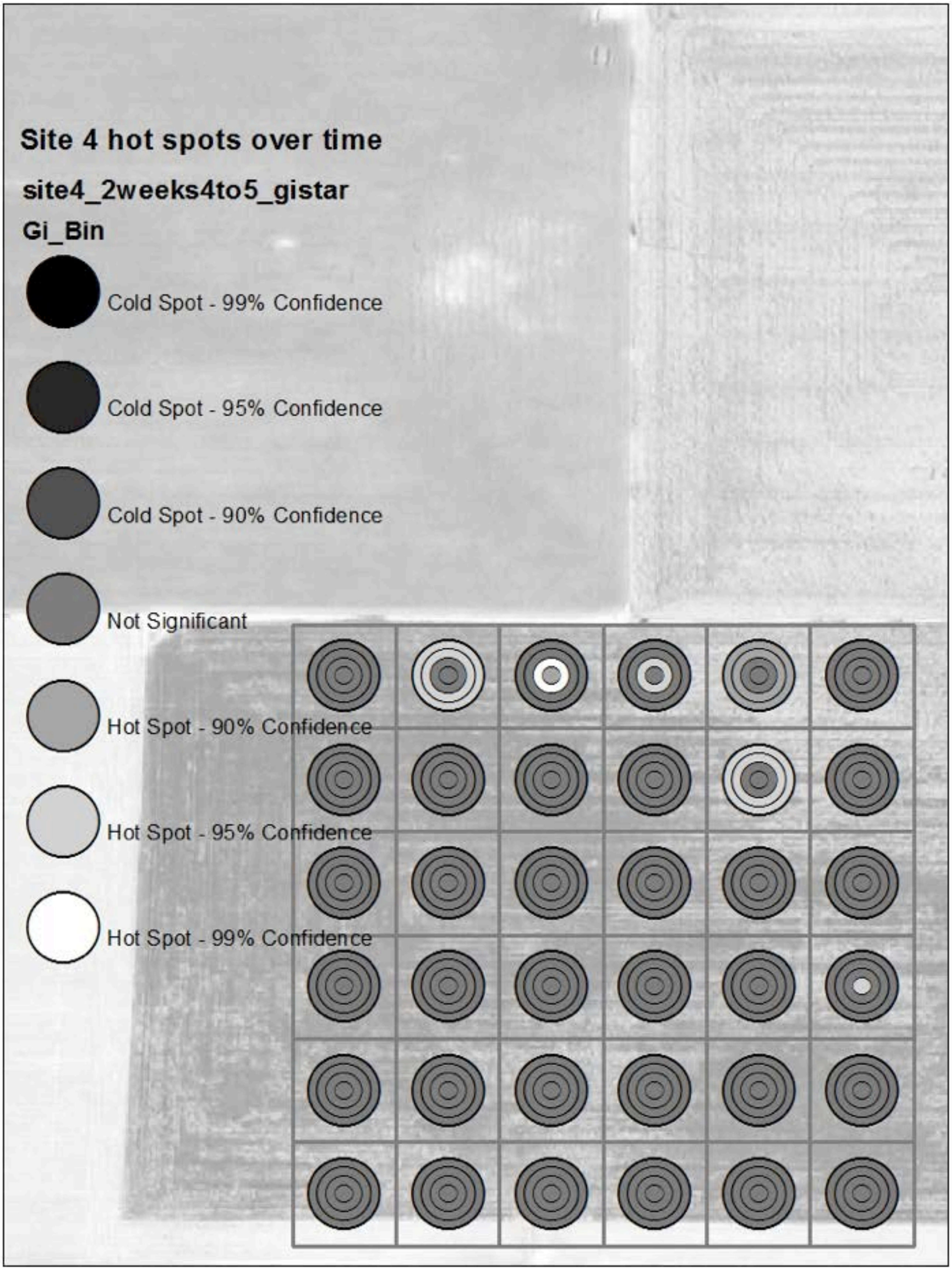


Figure 9. Significance of slug hot spots over time at site 4.

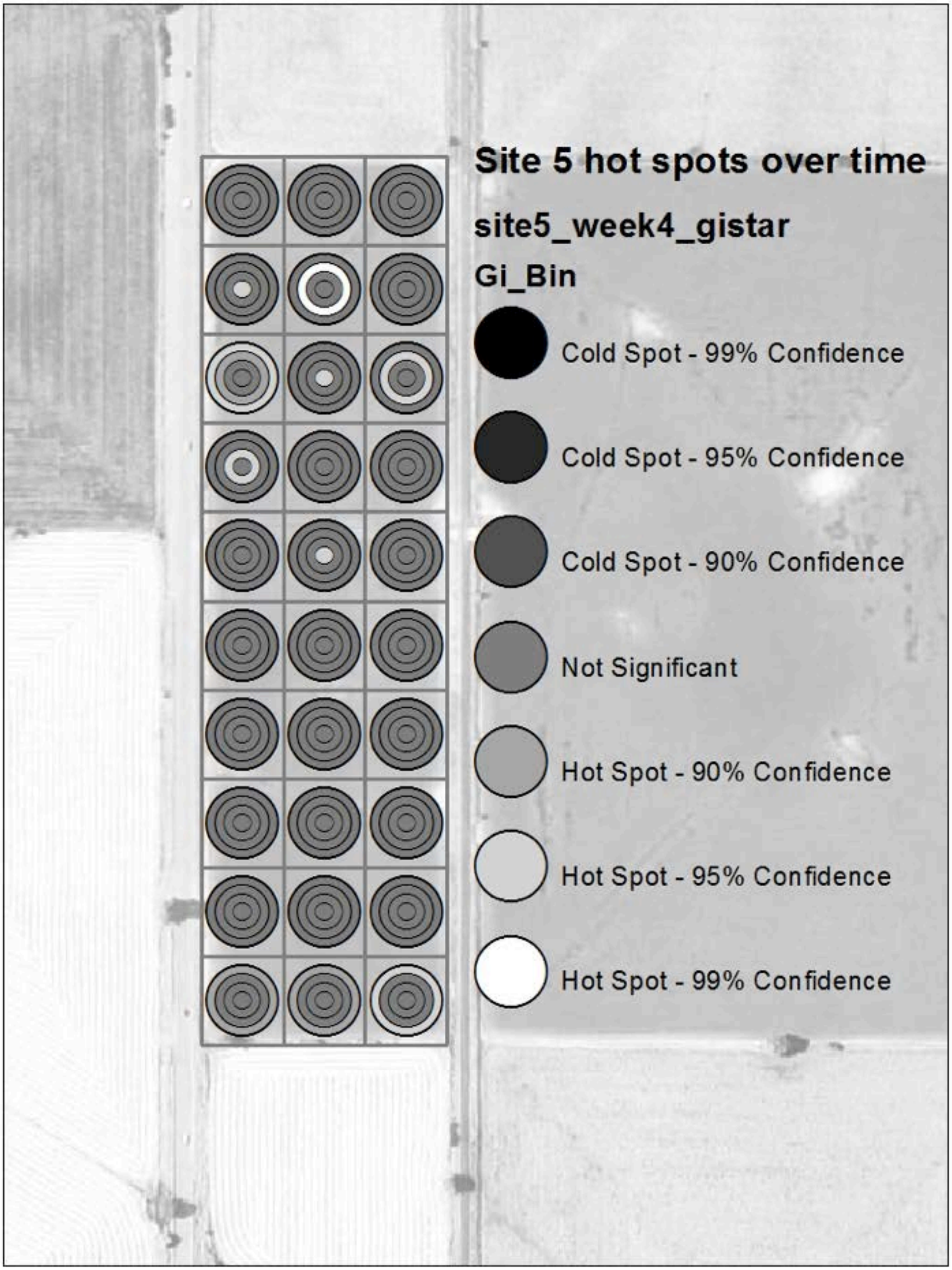


Figure 10. Significance of slug hot spots over time at site 5.