Responses of Breeding Grassland Bird Densities to Land Management on the Lowry Ranch

Report

June 2026



Connecting People, Birds and Land
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Colorado State Land Board Agreement Number:
PO,PCAA,202400008604

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Bird Conservancy of the Rockies

Connecting people, birds and land

Mission: Conserving birds and their habitats through science, education and land stewardship

Vision: Native bird populations are sustained in healthy ecosystems

Bird Conservancy of the Rockies conserves birds and their habitats through an integrated approach of science, education, and land stewardship. Our work radiates from the Rockies to the Great Plains, Mexico and beyond. Our mission is advanced through sound science, achieved through empowering people, realized through stewardship, and sustained through partnerships. Together, we are improving native bird populations, the land, and the lives of people.

Core Values:

1. Science provides the foundation for effective bird conservation.
2. Education is critical to the success of bird conservation.
3. Stewardship of birds and their habitats is a shared responsibility.

Goals:

1. Guide conservation action where it is needed most by conducting scientifically rigorous monitoring and research on birds and their habitats within the context of their full annual cycle.
2. Inspire conservation action in people by developing relationships through community outreach and science-based, experiential education programs.
3. Contribute to bird population viability and help sustain working lands by partnering with landowners and managers to enhance wildlife habitat.
4. Promote conservation and inform land management decisions by disseminating scientific knowledge and developing tools and recommendations.

Suggested Citation:

Latif, Q. S., B. L. Nuse, M. F. McLaren, and J. Timmer. 2026. Responses of breeding grassland bird densities to land management on Lowry Ranch: Report. Bird Conservancy of the Rockies. Brighton, Colorado, USA.

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Executive Summary

The Lowry Ranch is a 25,955-acre property in Arapahoe County, Colorado managed by the Colorado State Board of Land Commissioners with grassland bird conservation as an established management objective. Regenerative grazing was initiated on Lowry Ranch in 2014. Bird Conservancy of the Rockies evaluated the effectiveness of this management for grassland birds by leveraging the Integrated Monitoring in Bird Conservation Regions (IMBCR) program, which conducted breeding bird surveys at Lowry Ranch in 2012–2014 and 2024–2025 before and after initiation of grazing management, respectively.

Management effects on population densities for 31 grassland bird species were estimated following a before-after, control-impact (BACI) design, comparing temporal changes in bird densities at Lowry Ranch to concurrent changes in bird densities at reference samples representing grasslands in the surrounding region within the Colorado portion of BCR 18. Multiple reference samples were compiled representing two different geographic scopes (local and regional) and three alternative criteria (based on vegetation class) for identifying reference samples comparable with Lowry Ranch samples to support robust inference.

Of 31 species, we estimated consistently positive management effects for 11 species (Barn Swallow, Brewer's Blackbird, Brown-headed Cowbird, Cassin's Kingbird, Cliff Swallow, Grasshopper Sparrow, Lark Bunting, Mountain Plover, Red-tailed Hawk, Say's Phoebe, Swainson's Hawk), consistently negative effects for 11 species (American Kestrel, Burrowing Owl, Cassin's Sparrow, Eastern Kingbird, Horned Lark, Mourning Dove, Red-winged Blackbird, Savannah Sparrow, Western Kingbird, Western Meadowlark, Wilson's Snipe), a mix of positive and negative effects for 1 species (Dickcissel) depending on the reference sample, and no statistically supported effects for 8 species (a lack of detected effect does not necessarily mean no real effect, as statistical power to detect differences varied among species). Notably, positive effects were detected for species representing contrasting grassland conditions — Grasshopper Sparrow, which favors taller grass, and Lark Bunting and Mountain Plover, which favor shorter grass — suggesting that Lowry Ranch management supports habitat heterogeneity that benefits a broad array of grassland birds.

Attributing these effects specifically to grazing management is complicated by a variety of development activities at Lowry Ranch, including oil and gas, and by uncertainty about land use activities in the surrounding region. Nevertheless, positive effects spanning species with differing habitat requirements, robust across reference geographies and matching approaches, provide encouraging evidence that Lowry Ranch management contributes to regional grassland bird conservation. Species-specific plots comparing Lowry Ranch and reference populations provide additional information for hypothesis generation for future research, for which incorporating clearer controls for potentially confounding factors could further refine our evaluation.

Acknowledgements

Funding for this study, including Lowry Ranch bird sampling, data analysis, and writing was provided by the Colorado State Board of Land Commissioners. This study was made possible with the contributions of partners, field technicians, and landowners to the Integrated Monitoring in Bird Conservation Regions (IMBCR) program. Lindsey Brandt provided critical input and feedback during data analysis and report writing. Raquel Wertsbaugh provided the photos in the cover image of this report.

Introduction

The Lowry Ranch (hereafter Lowry Ranch) is a 25,955 acre (40 square mile) property in Arapahoe County managed by the Colorado State Board of Land Commissioners (hereafter State Land Board; Figure 1). An asset management plan written by the State Land Board describes management of the property in detail (State Land Board 2020). Land use activities permitted on Lowry Ranch and when initially permitted are listed in Table 1. Lowry Ranch primarily consists of grasslands, and grassland birds are of particular conservation concern, so conservation of habitat for grassland birds is one management objective established for Lowry Ranch by the State Land Board.

Considering this management objective, the State Land Board commissioned Bird Conservancy of the Rockies (hereafter Bird Conservancy) to evaluate management effectiveness in contributing habitat for grassland birds. Bird Conservancy leveraged the Integrated Monitoring in Bird Conservation Regions (IMBCR) program to measure bird population densities at Lowry Ranch, allowing comparison of Lowry Ranch population densities to relevant reference populations in Colorado represented in IMBCR background samples (Timmer et al. 2026). The management activity of central interest was regenerative grazing initiated in 2014 between initial (2012–2014) and final bird sampling (2024–2025) at Lowry Ranch (Table 1). Having sampled before and after initiation of grazing management, we estimated grazing management effects following a before-after, control-impact (BACI) design (Stewart-Oaten et al. 1986), wherein IMBCR background samples provided control data (i.e., the 'C' in BACI). BACI-based management effects consisted of estimating differences in population trajectories (changes from before to after management initiation, i.e., between 2012–2014 to 2024–2025 periods at Lowry Ranch) between impact (Lowry Ranch) and control (region surrounding Lowry Ranch) samples. The BACI design controls for background spatial (control versus impact) and temporal (before to after) variability, supporting stronger inference of management effects than would either spatial or temporal comparisons alone.

Having estimated management effects for individual species, we need to decide how species-specific effects should inform our evaluation of overall effectiveness of Lowry Ranch management for creating bird habitat. A simple approach would be to consider the relative frequency of positive versus negative species-specific management effects, and declare management to be generally effective if we estimate more positive than negative effects. However in grasslands, different bird species occupy different habitat conditions; for example, Lark Bunting and Mountain Plover favor heavily grazed, short-grass conditions (Knopf and Wunder 2020, Shane 2020) whereas Grasshopper Sparrow favors taller grasses (Vickery 2020). Thus, grazing practices that maintain heterogeneity historically characteristic of grassland systems inclusive of both short- and tall-grass conditions will benefit the widest array of bird species and thus contribute the most to conservation (Fuhlendorf et al. 2006). Thus, in addition to the relative frequency of positive versus negative species-specific effects, we also considered whether we estimated positive effects for species representing different habitat conditions.

Although BACI supports stronger inference than either spatial or temporal comparisons alone, BACI is not equivalent to a true experiment. In particular for this evaluation, Lowry Ranch samples

lack replication (there is only one Lowry Ranch) and background samples are not true controls (i.e., they do not represent equivalent lands minus management). Because background samples did not represent true controls, we refer to them as reference rather than control samples. Moreover, evaluation of management effectiveness would be bolstered by evaluating hypotheses for mechanisms underlying management effects estimated here (i.e., how and why population trajectories differed between Lowry Ranch and control samples). Hypothesizing mechanisms requires understanding the populations and conditions represented by control samples. The IMBCR sampling design ensures background samples represent bird populations across the landscape as a whole, so a BACI analysis with these samples as controls estimates management effects relative to average conditions across the region. Such effects support inference of management contributions to regional populations, but we lacked detailed information on how grasslands are managed across the region, so we had limited ability to evaluate mechanisms underlying estimated effects. We therefore display population densities and differences in densities between Lowry Ranch and reference samples (hereafter "contrasts") in appendices to support hypothesis generation. We describe how to leverage the information in this report along with existing knowledge of species ecology to hypothesize mechanisms underlying estimated management effects, and we describe potential future research for testing these hypotheses.

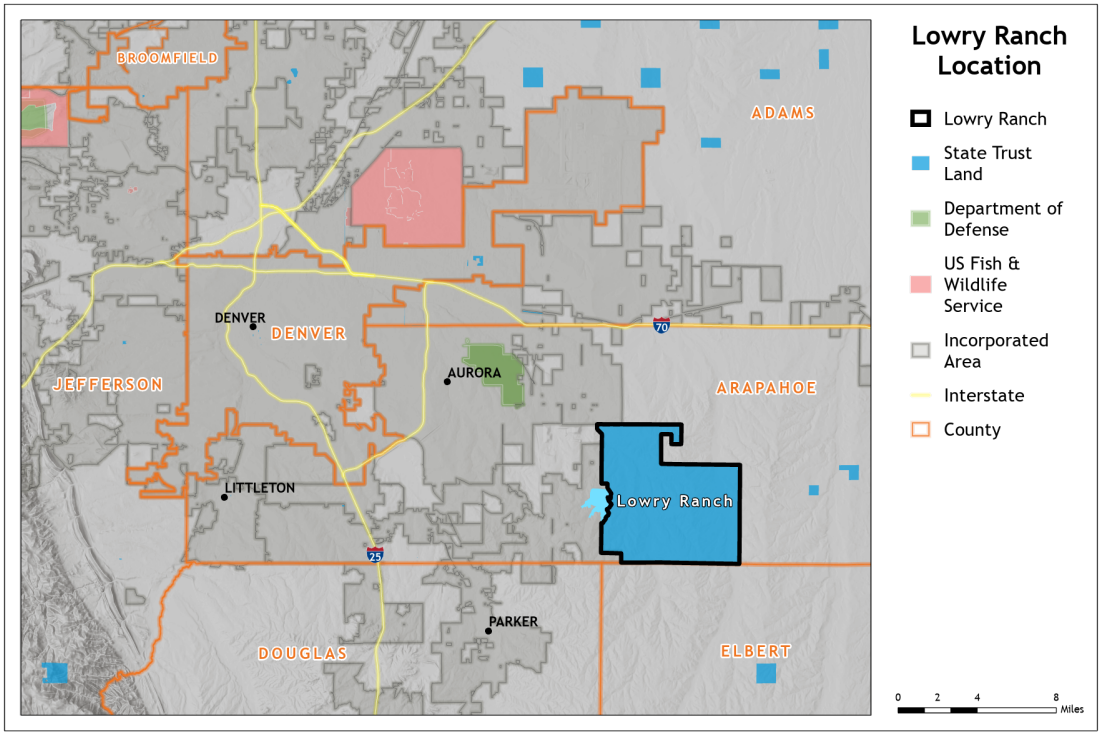


Figure 1. Map showing the location of Lowry Ranch within the broader Denver metro area.

Table 1. History of land use activities allowed at Lowry Ranch, and when they were initiated. All listed activities remained ongoing through the most recent (2024–2025) survey period.

Land use type	Start year	Additional information
"Traditional" oil and gas development	1970	Throughout property, includes individual wells, pumpjacks, buried pipelines, and other infrastrucutre.
Electrical transmissions line rights-of-way	1975	
Water development	1982	Includes wells, creek diversions, pipelines, storage ponds, etc.
Buried communications and pipeline rights-of-way	1982	
Communications tower	2008	Far northwest corner of the ranch
Department of Military and Veterans Affairs - helicopter flyover training area	2009	Property-wide
Radio-controlled model airplane club	2010	Localized area but does overlap one grid cell
English style horse-mounted fox "hunting"	2012	Property-wide. Traditional hunting style using dogs, no actual harvest or take.
Small glider airplane club	2012	Localized area
"Modern" oil and gas development	2012	Throughout property, inclues directional drilling with multiple wells on a larger well pad. Reduced surface footprint compared to traditional development.
Regenerative cattle grazing	2015	Rotational and regenerative grazing to improve soil and grassland health. Traditional cattle grazing was removed from the ranch in 2007.
Solar arrays	2017	Localized to western portion of the ranch south of E Quincy Avenue

Objectives

1. Evaluate effects of Lowry Ranch land management activities on grassland bird population densities, with particular focus on regenerative grazing.
2. Evaluate whether species representing different habitat conditions (i.e., short- and tall-grass conditions) exhibit positive management effects, and thus whether Lowry Ranch represents the heterogeneity characteristic of historical grasslands that is expected with regenerative grazing.
3. Suggest how to leverage available information in this report to hypothesize the reasons (i.e., mechanisms) underlying estimated management effects along with potential future research for testing such hypotheses.

Methods

IMBCR sampling and bird surveys

The IMBCR sampling design is described in detail by Pavlacky et al. (2017). Sampling units are 1 km^2 grid cells containing a 4×4 array of evenly spaced (250 m) survey points. Sampling units are selected using a spatially balanced algorithm (*sensu* Stevens and Olsen 2004) from within strata,

which are distinct geographies of interest to management agency partners. All strata are nested within state × Bird Conservation Region (BCR) intersections. This design allows estimation of bird population parameters (e.g., densities and trend) at scales of management interest, and derivation of population parameters at larger scales corresponding with groups of strata (a.k.a. superstrata; e.g., states or BCRs). Additionally, auxiliary sampling can be implemented to address particular questions (hereafter overlay sampling), including effectiveness of management activities within units where activities are occurring (e.g., Lowry Ranch).

Bird surveys consist of visiting points within grid cells for 6 min during the breeding season (May–July) from 0.5 h before to 5 h after official sunrise. Seasonal survey timing varies by elevation to coincide with peak breeding activity, and surveys are not performed during rain or extreme winds (McLaren et al. 2025). Surveyors record all birds detected by species, radial distances (m) to detected individuals (measured with laser range finders), and the minute interval (1–6) when individuals were first detected (for details see McLaren et al. 2025). Surveyors visit points in sampled grid cells once per year. Often, <16 points in a grid cell are visited due to failure to obtain landowner permission, unsafe terrain, adverse weather, inability to adequately hear bird vocalizations because of ambient noise, or lack of time (occurred in both Lowry Ranch and reference samples).

Management sample

The Lowry Ranch sample is an overlay sample of $n = 20$ grid cells surveyed in 2012–2014 and again in 2024–2025. We compared changes in population densities between these two periods on Lowry Ranch to changes recorded on various reference samples (described below) to support inference of management effects.

Reference samples

We compiled several reference samples from IMBCR background data collected in the same years as Lowry Ranch (2012–2014 and 2024–2025) and in relevant local geographies. We restricted reference samples to one of two geographies, 1) IMBCR strata within 30 km of Lowry Ranch (i.e., local) and 2) all IMBCR strata within the Colorado portion of BCR 18 (i.e., regional).

We classified both Lowry Ranch and reference survey points into primary habitat types (PHTs; classified by field surveyors and described in McLaren et al. 2025), then restricted reference samples to PHTs also represented at Lowry Ranch (Figure 2). Because Lowry Ranch primarily represented grasslands, this restriction returned reference samples largely constrained to the grassland PHT. During 15% of point surveys, however, Lowry points were classified as non-grassland PHTs (Barren, Herbaceous Meadow, Riparian, Shrubland, or Wetland). Survey points were potentially classified in different PHTs in different years where classification was ambiguous. We therefore compiled variables quantifying the proportion of years each survey point was classified into each PHT represented at Lowry Ranch (hereafter PHT variables). We then applied three filters representing different

approaches for matching reference to management samples based on PHT variables: 1) a model-based approach implemented through the MatchIt R package (Ho et al. 2011), optimizing the statistical match between reference and Lowry Ranch samples with respect to mean PHT variable values (hereafter model-matched sample); 2) restricting Lowry Ranch and reference samples to survey points classified as the grassland PHT in every year (hereafter always-grassland sample); and 3) restricting Lowry Ranch and reference samples to survey points classified as the grassland PHT in at least one year, with reference points further restricted in years they were not grassland to PHTs also represented at Lowry Ranch in that year (hereafter grassland-associated sample). Crossing these three filters with the two reference geographies yielded five reference samples (and corresponding Lowry Ranch-reference comparisons): a model-matched sample (regional geography only), and always-grassland and grassland-associated samples at both local and regional geographies (Table 2).

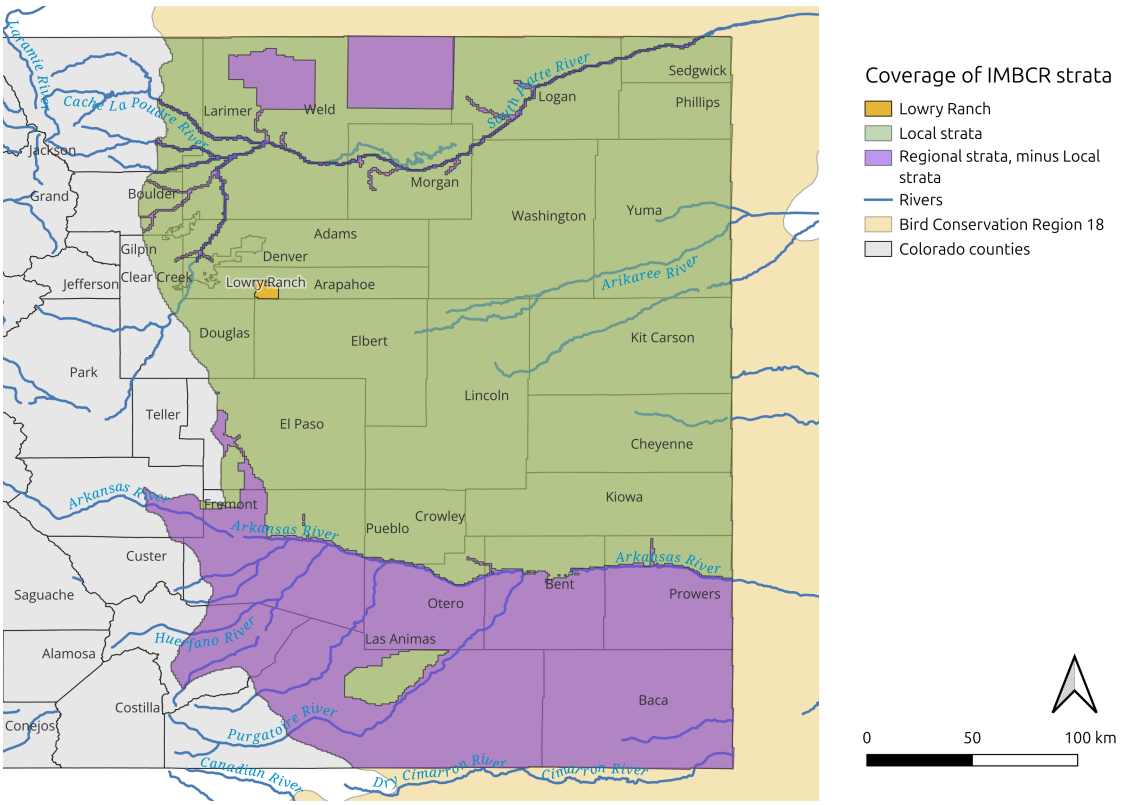


Figure 2. Map of IMBCR strata defining the local and regional reference geographies relative to Lowry Ranch (orange). "Local strata" (green) is the area coinciding with the collection of IMBCR strata whose boundaries are within 30 km of Lowry Ranch. "Regional strata" (purple + green) is the area coinciding with the collection of IMBCR strata comprising the Colorado portion of Bird Conservation Region 18 (tan). Purple shows the portion of the regional geography that falls outside the local geography for visual clarity, but the local geography is a subset of the regional geography.

Table 2. Sample sizes for evaluating management effects on bird population densities at Lowry Ranch. Listed sample sizes are for the five impact-control comparisons in the context of before-after, control-impact (BACI) estimation of management effects. Reference samples were restricted to either 'local' strata (within 30 km of Lowry Ranch) or 'regional' strata (the entire Colorado portion of BCR 18). 'Filter' indicates the primary habitat filter applied to both Lowry Ranch and reference samples: 'model-matched' = reference sample matched to Lowry habitat composition based on a statistical model; 'always grassland' = both samples restricted to points classified as grassland in every year; 'grassland associated' = both samples restricted to points classified as grassland in at least one year (described further in 'Reference samples' section). 'Grid cells' is the number of unique grid cells sampled, and 'Points' is the maximum number of survey points within grid cells surveyed in any given year.

		Lowry		Reference	
Geography	Filter	Grid cells	Points	Grid cells	Points
regional	model-matched	20	300	87	516
local	always grassland	20	258	27	171
regional	always grassland	20	258	95	634
local	grassland associated	20	289	27	183
regional	grassland associated	20	289	98	729

Statistical Analysis

We drew upon existing population estimates from the IMBCR annual analysis (Timmer et al. 2026), which we further processed to derive estimates for the intended Lowry Ranch and reference samples (Table 2) using post-stratification (Appendix A). We derived density estimates for individual years and averaged densities across years for Lowry Ranch and reference samples before (2012–2014) and after (2024–2025) implementation of grazing management on Lowry Ranch. Following the BACI approach (Stewart-Oaten et al. 1986), we estimated differences in density estimates between Lowry Ranch and reference samples (hereafter contrasts), and further estimated the change in these contrasts from before to after grazing management (hereafter management effects). Thus, a positive management effect would indicate bird density increased more (or declined less) at a Lowry Ranch sample compared to the corresponding reference sample from before (2012–2014) to after (2024–2025), and a negative effect would indicate the opposite. We considered estimated management effects whose 90% credible intervals excluded zero to be statistically supported.

Results

Survey Summary

We recorded 14660 detections on Lowry and 44799 detections in background surveys conducted across the Colorado portion of BCR 18 for 31 grassland bird species with population density estimates from the IMBCR annual analysis (Table 3).

Table 3. Bird species included in analysis of Lowry Ranch management effects on population densities. 'Lowry' gives the sum of counts recorded at IMBCR surveys conducted on Lowry Ranch in 2012–2014 and 2024–2025. 'Reference' gives the sum of counts recorded at all IMBCR surveys conducted in 2012–2014 and 2024–2025 within the Colorado portion of BCR 18. Both sums represent totals prior to filtering by primary habitat type. 'SWAP status' gives each species' status under Colorado's 2025 State Wildlife Action Plan as a Species of Greatest Conservation Need (SGCN): Tier 1, Tier 2, or Species of Greatest Information Need (SGIN); species not designated SGCN are denoted 'Not listed.'

			Sum of counts	
Code	Species	SWAP status	Lowry	Reference
AMKE	American Kestrel	Tier 2	45	48
BARS	Barn Swallow	Not listed	46	421
BHCO	Brown-headed Cowbird	Not listed	129	597
BRBL	Brewer's Blackbird	Not listed	35	81
BUOW	Burrowing Owl	Tier 2	3	43
CAKI	Cassin's Kingbird	Not listed	75	139
CASP	Cassin's Sparrow	Not listed	314	2832
CLSW	Cliff Swallow	SGIN	54	1274
CONI	Common Nighthawk	Not listed	97	132
DICK	Dickcissel	Not listed	13	61
EAKI	Eastern Kingbird	Not listed	103	134
FEHA	Ferruginous Hawk	SGIN	1	5
GRSP	Grasshopper Sparrow	Not listed	955	1137
HOLA	Horned Lark	Not listed	2428	11531
KILL	Killdeer	SGIN	129	474
LARB	Lark Bunting	Tier 2	1979	8765
LASP	Lark Sparrow	Not listed	220	851
LOSH	Loggerhead Shrike	Not listed	14	37
MODO	Mourning Dove	Not listed	1093	2743
MOPL	Mountain Plover	Tier 1	1	31
NOHA	Northern Harrier	Tier 2	3	10
PRFA	Prairie Falcon	Tier 1	1	3
RTHA	Red-tailed Hawk	Not listed	72	112
RWBL	Red-winged Blackbird	Not listed	490	2322
SAPH	Say's Phoebe	Not listed	49	142
SAVS	Savannah Sparrow	SGIN	5	10
SWHA	Swainson's Hawk	Not listed	45	99
VESP	Vesper Sparrow	SGIN	515	88
WEKI	Western Kingbird	SGIN	604	1141
WEME	Western Meadowlark	Not listed	5135	9529
WISN	Wilson's Snipe	SGIN	7	7

Estimated management effects

Across all 31 species and reference sample comparisons, there were 43 positive and 45 negative management effects detected (Table 4, Appendix B). At the species level, 11 species showed consistently positive effects across all contrasts (Barn Swallow, Brewer's Blackbird, Brown-headed Cowbird, Cassin's Kingbird, Cliff Swallow, Grasshopper Sparrow, Lark Bunting, Mountain Plover, Red-tailed Hawk, Say's Phoebe, Swainson's Hawk), 11 showed consistently negative effects (American Kestrel, Burrowing Owl, Cassin's Sparrow, Eastern Kingbird, Horned Lark, Mourning Dove, Red-winged Blackbird, Savannah Sparrow, Western Kingbird, Western Meadowlark, Wilson's Snipe), 1 showed a mix of positive and negative effects depending on the reference sample used (Dickcissel), and 8 showed no detected effects in any comparison (Common Nighthawk, Ferruginous Hawk, Killdeer, Lark Sparrow, Loggerhead Shrike, Northern Harrier, Prairie Falcon, Vesper Sparrow; Table 5).

Table 4. Lowry management effects on bird densities. Full bird species names are listed in Table 3. Effects describe the change in the Lowry-minus-reference population density contrast from before (2012–2014) to after (2024–2025) initiation of regenerative grazing management. Positive effects (90% credible interval above zero) indicate the contrast became more positive over the study period (i.e., density increased more or declined less at Lowry relative to reference); negative effects indicate the opposite. Column definitions are given in the table footnotes. Species are ordered by SWAP status.

			Always grassland[c]		Grassland associated[d]	
Species	SWAP status[a]	Model-matched[b]	Local[e]	Regional[f]	Local[e]	Regional[f]
MOPL	Tier 1	positive	positive	positive	positive	positive
PRFA	Tier 1	none	none	none	none	none
AMKE	Tier 2	negative	negative	negative	negative	negative
BUOW	Tier 2	negative	negative	negative	negative	negative
LARB	Tier 2	positive	none	positive	none	positive
NOHA	Tier 2	none	none	none	none	none
CLSW	SGIN	positive	positive	positive	positive	positive
FEHA	SGIN	none	none	none	none	none
KILL	SGIN	none	none	none	none	none
SAVS	SGIN	none	negative	none	negative	none
VESP	SGIN	none	none	none	none	none
WEKI	SGIN	negative	negative	negative	negative	negative
WISN	SGIN	negative	–	negative	–	negative
BARS	Not listed	none	positive	positive	positive	positive
BRBL	Not listed	none	positive	positive	positive	none
BHCO	Not listed	none	none	positive	none	positive
CAKI	Not listed	positive	none	positive	none	positive
CASP	Not listed	negative	negative	negative	negative	negative
CONI	Not listed	none	none	none	none	none
DICK	Not listed	negative	positive	negative	positive	negative
EAKI	Not listed	none	negative	none	negative	none
GRSP	Not listed	positive	positive	positive	positive	positive
HOLA	Not listed	negative	none	negative	none	negative
LASP	Not listed	none	none	none	none	none
LOSH	Not listed	none	none	none	none	none
MODO	Not listed	none	negative	none	negative	none
RTHA	Not listed	positive	positive	positive	positive	positive
RWBL	Not listed	negative	negative	negative	negative	negative
SAPH	Not listed	positive	positive	positive	positive	positive
SWHA	Not listed	positive	none	none	none	none
WEME	Not listed	negative	negative	negative	negative	negative

[a] SWAP status: species designation under Colorado's 2025 State Wildlife Action Plan as a Species of Greatest Conservation Need (SGCN) — Tier 1, Tier 2, or Species of Greatest Information Need (SGIN); species not designated SGCN are denoted 'Not listed.'

[b] Model-matched: reference sample matched to Lowry based on a generalized linear model.

[c] Always grassland: Lowry and reference samples restricted to survey points classified as grassland in every year.

[d] Grassland associated: Lowry and reference samples restricted to survey points classified as grassland in at least one year.

[e] Local: IMBCR strata within 30 km of Lowry Ranch.

[f] Regional: Colorado portion of Bird Conservation Region 18.

Table 5. Summary of population density contrasts and management effects for each species across the five reference sample comparisons in Table 4. 'Contrasts' columns give the direction of the Lowry-minus-reference population density contrast in the pre-management (2012–2014) and post-management (2024–2025) periods, summarized across the five comparisons. 'Management effects' describes the overall pattern of BACI management effects (i.e., change in contrast from pre- to post-management) across the five comparisons. For all three columns: 'Consistent positive'/'Consistent negative' indicates all supported values were in the same direction across comparisons; 'Mixed' indicates both positive and negative values were detected depending on the comparison; 'None detected' indicates no comparison yielded a statistically supported value. The 2024–2025 contrasts column may additionally carry a directional qualifier (e.g., 'Consistently less positive', 'Consistently more negative') when both pre- and post-management contrasts fall in the same direction category and the reason for the management effect would otherwise be unclear. 'SWAP status' gives each species' status under Colorado's 2025 State Wildlife Action Plan as a Species of Greatest Conservation Need (SGCN): Tier 1, Tier 2, or Species of Greatest Information Need (SGIN); species not designated SGCN are denoted 'Not listed.' Species are ordered by SWAP status.

		Contrasts (Lowry minus Reference)		
Species	SWAP status	2012–2014	2024–2025	Management effects
Mountain Plover	Tier 1	Consistent negative	None detected	Consistent positive
Prairie Falcon	Tier 1	None detected	None detected	None detected
American Kestrel	Tier 2	Consistent positive	None detected	Consistent negative
Burrowing Owl	Tier 2	None detected	Consistent negative	Consistent negative
Lark Bunting	Tier 2	Consistent negative	Consistently less negative	Consistent positive
Northern Harrier	Tier 2	None detected	None detected	None detected
Cliff Swallow	SGIN	Consistent negative	None detected	Consistent positive
Ferruginous Hawk	SGIN	None detected	None detected	None detected
Killdeer	SGIN	None detected	Consistent positive	None detected
Savannah Sparrow	SGIN	Consistent positive	None detected	Consistent negative
Vesper Sparrow	SGIN	Consistent positive	Consistent positive	None detected
Western Kingbird	SGIN	Consistent positive	Consistently less positive	Consistent negative
Wilson's Snipe	SGIN	Consistent positive	None detected	Consistent negative
Barn Swallow	Not listed	Consistent negative	Consistently less negative	Consistent positive
Brewer's Blackbird	Not listed	None detected	Consistent positive	Consistent positive
Brown-headed Cowbird	Not listed	None detected	Consistent positive	Consistent positive
Cassin's Kingbird	Not listed	Consistent positive	Consistently more positive	Consistent positive
Cassin's Sparrow	Not listed	Consistent negative	Consistently more negative	Consistent negative
Common Nighthawk	Not listed	Consistent positive	Consistent positive	None detected
Dickcissel	Not listed	None detected	Mixed	Mixed
Eastern Kingbird	Not listed	Consistent positive	Consistently less positive	Consistent negative
Grasshopper Sparrow	Not listed	Consistent positive	Consistently more positive	Consistent positive
Horned Lark	Not listed	Consistent negative	Consistently more negative	Consistent negative
Lark Sparrow	Not listed	Consistent positive	Consistent positive	None detected
Loggerhead Shrike	Not listed	None detected	None detected	None detected
Mourning Dove	Not listed	Consistent positive	Consistently less positive	Consistent negative
Red-tailed Hawk	Not listed	Consistent positive	Consistently more positive	Consistent positive
Red-winged Blackbird	Not listed	Consistent positive	Consistently less positive	Consistent negative
Say's Phoebe	Not listed	Consistent negative	Consistent positive	Consistent positive
Swainson's Hawk	Not listed	None detected	Consistent positive	Consistent positive
Western Meadowlark	Not listed	Consistent positive	Consistently less positive	Consistent negative

Discussion

Our results suggest a mix of positive and negative benefits of management at Lowry Ranch for grassland birds, and thus variable contributions to regional bird conservation depending on species. We did see positive management effects for species that require different grassland conditions, namely Lark Bunting and Mountain Plover, which favor short-grass (e.g., heavily grazed) conditions (Knopf and Wunder 2020, Shane 2020), and Grasshopper Sparrow, which favor taller grass conditions (Vickery 2020). Positive management effects for this range of species suggests Lowry Ranch management promotes or at least maintains heterogeneity in conditions needed to support a broad array of grassland species. Moreover, these results were robust to reference geography and to how reference samples were matched to Lowry Ranch based on vegetation class (i.e., PHTs).

Considering the mechanisms underlying estimated management effects requires understanding the differences between Lowry Ranch and reference populations. To clearly attribute estimated effects to grazing management, control samples would need to represent grasslands equivalent to Lowry Ranch except for the presence of a regenerative grazing program. Grasslands across BCR 18 in Colorado are subject to various levels of grazing management, but assuming grazing management regionally was constant over the study period (2012–2025), estimated management effects may still be attributable to the initiation of grazing management on Lowry Ranch. We were also uncertain about how other management activities at reference samples compared to those at Lowry Ranch (Table 1). In particular, modern methods of oil and gas development were initiated at Lowry Ranch in 2012, coinciding somewhat with initiation of grazing management. Future analyses employing clearer controls over the timing of grazing management and other management activities may provide clearer evaluation of the Lowry Ranch grazing management program. In particular, matching a subset of IMBCR background samples based on the distribution of oil and gas development (Colorado Energy and Carbon Management Commission 2026) and other remotely sensed environmental attributes could more effectively control for potentially confounding factors.

Density estimates and differences in density between Lowry Ranch and reference samples (i.e., contrasts; Table 5; Appendices B–E) provide additional information to support generating hypotheses to explain estimated management effects for further investigation. We note that positive or negative management effects can reflect various population trajectories on Lowry Ranch and reference samples (Table 5). For example, the positive management effect for Grasshopper Sparrow reflected a greater increase in density at Lowry Ranch compared to reference samples (Table 5; Appendix D13), whereas positive effects for Lark Bunting and Mountain Plover reflected population declines in reference samples not paralleled at Lowry Ranch (Table 5; Appendices D16, D20). Thus, underlying mechanisms for Grasshopper Sparrow likely reflect habitat improvement on Lowry Ranch, whereas mechanisms for Lark Bunting and Mountain Plover may instead reflect maintenance of habitat conditions that were lost elsewhere in the region. Further consideration of the particular years when population differences emerged (Appendices C, E) and the timing of environmental changes may help narrow the range of viable hypotheses to test in future research. Lastly, a lack of detected effect can reflect two different situations: high confidence that there truly is little or no difference

between Lowry Ranch and reference samples (a precise estimate centered near zero, representing a firm conclusion), or insufficient statistical power to detect a real difference (an imprecise estimate, often due to small sample size or high uncertainty). Summaries of management effects and contrasts (Table 4 and Table 5) do not discriminate between these cases; doing so requires checking figures (Appendices B–E) and sample size (Table 2) for a species. Ferruginous Hawk provides an example where lack of effect in this study likely reflects low power due to a small sample size.

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Appendices

Appendix A — Post-stratification methods for estimating bird population densities

The following pages describe the generalized post-stratification methods used to derive the bird population density estimates analyzed in this report. Although accurate, this description will likely be revised for clarity, and ultimately presented in a dynamic and updatable location for reference in future reports (e.g., an appendix within the IMBCR annual report).

General method for post-stratification of bird densities resulting from analysis of IMBCR survey data

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Bird Conservancy of the Rockies

June 30, 2026

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1 Introduction

Bird Conservancy of the Rockies has since 2009 conducted breeding bird surveys throughout the U.S. Great Plains and Rocky Mountains, via the Integrated Monitoring in Bird Conservation Regions program (IMBCR; Pavlacky et al., 2017). Site selection for IMBCR surveys follows a nested, stratified-random design with two levels of spatial stratification. The higher-level grouping is according to *sections*, that is, the intersections of Bird Conservation Regions and

U.S. state boundaries. Sections are non-overlapping, and so divide the set of potential sites within the IMBCR footprint in a mutually-exclusive manner (every potential site belongs to at most one section). Sections also fill the entire footprint, and so cover the set of potential sites exhaustively (every potential site belongs to at least one section). Within sections are *strata*, which are mutually exclusive (non-overlapping) and exhaustive within each section. Within each stratum, survey sites are chosen according to a spatially-balanced sampling design, the Generalized Random Tessellation Stratified algorithm (GRTS; Olsen et al., 2012; Stevens & Olsen, 2004). Sites chosen in this way are referred to as the *background* IMBCR sample.

In addition to the background sample, IMBCR also supports surveys within project-based *overlays*. These are groups of sites that occur within spatial boundaries that do not conform to boundaries of strata or sections, but instead may overlap them. Because overlays do not exhaustively cover the IMBCR footprint, and are not mutually-exclusive of each other or the background strata, they are not themselves true strata. However, overlays may be divided into strata that do fit these criteria within the context of the overlay project boundary. If an overlay is large enough in extent, sites will be selected within it according to the GRTS algorithm (or, if it is stratified, within each stratum).

An IMBCR site (or grid cell, so called because the sampling frame across the IMBCR footprint is a 1-km^2 grid) contains a 4-by-4 array of survey stations, or *points*. Each site is surveyed once per summer; during that visit, six-minute point counts are conducted at as many of the 16 points as are accessible.

Then in autumn, an analysis is conducted of all site visits from throughout the entire history and extent of the IMBCR program (including all overlays), including data gathered in the current year. This *Annual Analysis* (AA) fits a Bayesian state-space model to the data and produces abundance estimates at each survey site; because the effective survey area can be derived from the data, abundances can be converted to densities. Furthermore, because the selection of sites is random and spatially balanced, the mean density can be estimated for each stratum (whether background or overlay), even when effort (sampling intensity) varies among strata.

Mean density across larger collections of strata (called *superstrata*) can then be estimated by taking a weighted average across component strata, with geographic area as the stratum weights. The process of deriving estimates for groups of sites that were not part of the original survey design is called *post-stratification* (PS) (Little, 1993).

Deriving mean estimates for superstrata is the simplest use of post-stratification. A more sophisticated application accommodates the categorization of survey points (*not* entire grid cells) by some factor, to produce estimates that apply within each level of that factor. We call this approach *categorical post-stratification*; it allows, for example, the derivation of density estimates according to habitat type.

2 Notation

There are a lot of quantities (data 'objects') defined in this report, so a guide to the notational conventions and the quantities themselves are defined here (Tables 1–3).

Note that subscripts of non-scalar quantities (vectors, matrices, arrays) are always lowercase; an uppercase subscript represents a label.

Finally, in explanations that apply to subsets of the quantities involved, for example where it has been explicitly stated that the discussion applies 'for each species', the subscripts that define these subsets (s in this case) will be dropped for the remainder of the explanation. This is to streamline notation without (it is hoped) sacrificing clarity.

Table 1: Notational conventions for types of quantity in this report.

Name	Display convention	Examples
Scalar	Italicized character, upper- or lowercase	a, A
Vector	Bold, lowercase	$\mathbf{a}$
Matrix	Bold, uppercase	$\mathbf{A}$
Array (> 2 dimensions)	Calligraphic script, uppercase	$\mathcal{A}$
Scalar element of a vector, matrix or array	Lowercase, subscripted character	a_{vc}
Row or column of a matrix, a vector	Bold, lowercase character, single subscript	$\mathbf{a}_c$
Slice of an n-dimensional array, a matrix	Bold, uppercase character, with $n-2$ subscripts	$\mathbf{A}_{vc}$
Subset of an n-dimensional array, itself an array	Calligraphic, uppercase character, with $\geq n-3$ subscripts	$\mathcal{A}_{vc}$

Table 2: Indices used in this report. All are integer-valued with range of support $\{1, 2, ..., *\}$ where $* =$ maximum value of the index.

Symbol	Description	Maximum value
i	Grid cell, i.e. IMBCR 'site'	I
t	Year	T
s	Species	S
v	Grid cell visit, i.e., cell-year combination	V
m	MCMC sample	M
c	Category, into which points are distributed	C
y	Epoch, into which study years are distributed	Y
r	Row of the $\mathbf{E}$ matrix of eligible combinations of abundance within categories	R

Table 3: Quantities used in this report.

Symbol	Description	Dimensions	Range of support	Where introduced
$\mathcal{N}$	MCMC samples of grid cell visit abundances	$V \times S \times M$	$\mathbb{N} = \mathbb{Z}^{0+}$	Section 4.1
$\mathbf{K}$	Number of point visits in each category, within each grid cell visit	$V \times C$	$\mathbb{Z}^+$ s.t. $\sum_c k_{vc} = 16$	Section 4.3.2
$\mathcal{L}$	Number of bird observations in each category, within each grid cell visit	$V \times S \times C$	$\mathbb{N}$	Section 4.2
$\mathcal{A}$	Estimated number of birds in each category, that is, for a given species and grid cell visit, the distribution of n_{vs} into the C categories	$V \times S \times C$	$\mathbb{N}$ s.t. $\sum_c a_{vsc} = n_{vs}$	Section 4.2
$\mathbf{G}$	Mapping of grid cell visits into epochs (year groups)	$V \times Y$	$\{0, 1\}$	Section 4.3.3
$\mathbf{E}$	For a given visit and MCMC sample, matrix of possible combinations of abundances across the C categories	C columns; number of rows dependent on n_{vs} and $\mathbf{l}_{vs}$	$\mathbb{N}$ s.t. $\sum_c a_{vsc} = n_{vs}$	Section 5.2
μ	Mean cluster size for each species	S	$\mathbb{R}^+$	Section 5.3
$\mathbf{SE}$	Standard error of mean cluster size for each species	S	$\mathbb{R}^+$	Section 5.3
$\mathcal{F}$	Stochastic conversion factors, to convert abundance to density	$V \times S \times M$	$\mathbb{R}^+$	Section 5.3
$\mathbf{z}$	Area in square kilometers of each stratum	V	$\mathbb{R}^+$	Section 5.4
$\mathbf{H}$	Proportion of each stratum represented in each category	$V \times C$	$[0, 1]$ s.t. $\sum_c h_{vc} = 1$	Section 5.4
$\mathbf{U}$	Product of stratum area and category representation	$V \times C$	$[0, 1]$ s.t. $\sum_c h_{vc} = 1$	Section 5.4
$\mathbf{Q}$, $\mathbf{R}$	Mapping of grid cell visits into entity-epoch combinations: $\mathbf{Q}$ for treatment, $\mathbf{R}$ for reference	$V \times Y$	$\{0, 1\}$	Section 5.5
$\mathbf{W}_Q$, $\mathbf{W}_R$	Weighted versions of $\mathbf{Q}$ and $\mathbf{R}$	$V \times Y$	$[0, 1]$ s.t. $\sum_v w_{vy} = 1$	Section 5.5
$\mathcal{X}$	Estimated contrast, for each species, category and MCMC iteration	$S \times C \times M$	$\mathbb{R}$	Section 5.5

3 Overview of categorical post-stratification

The aim of categorical PS is to estimate the difference between a bird species' density within a focal, or *treatment*, group of site visits (i.e., grid cell visits) and its density within a *reference* group. These groups are collectively called *entities* and their difference is called a *contrast*. Contrasts might be taken across all years of the study (all visits in each site group lumped together regardless of year), within each year, or within groups of years called *epochs*.

Categorical PS estimates these contrasts separately for each category in a *classification system*. These categories might be thought of as 'filters' that are applied to points within grid cells. These filters could be constructed according to any discrete factor, so long as it follows a one-to-one mapping of site visit into factor group. In other words classes within the system are mutually exclusive. An example might be a CS with three groups: one for predominantly grassland points, one for riparian points, and one for any other habitat type.

Because the AA produces estimates of abundance and other parameters at the grid cell level, a crucial step in PS is estimating the number of bird observations within the estimated abundance for a grid cell, into the various categories in the CS.

Estimation in the PS context refers to the formal statistical production of both an expected value (point estimate) and uncertainty about that expected value (variance). Because PS relies on the outputs from a Bayesian model fit using Markov Chain Monte Carlo (MCMC) methods, both point estimates and variance can be estimated *after* model fitting because functions of MCMC samples will retain and propagate the statistical features of their component parameters. That means that throughout the PS procedure, hundreds or even thousands of instances of each intermediate quantity will be retained; only at the very end, once all necessary calculations have been performed, will summaries across MCMC samples be taken. These will usually include the mean, median and quantiles such as the 5th and 95th percentiles (to produce a 90% Bayesian credible interval).

4 Inputs

4.1 Annual Analysis output

The IMBCR Annual Analysis (as of 2025) produces estimates of abundance, n_{ist}, at each grid cell $i \in \{1, 2, ..., I\}$ (within both background and overlay strata), for species $s \in \{1, 2, ..., S\}$ during year $t \in \{1, 2, ..., T\}$; it does not estimate abundance at the point level (Timmer et al., 2026, Appendix D). However the classification system applied in the cat PS procedure occurs at the point level. This scale mis-match necessitates an extra estimation step during post-stratification; aside from this the procedure consists of manipulating AA output. To simplify notation, site-year (i, t) combinations will here be combined into a single index of *site visits*, $v \in \{1, 2, ..., V\}$ (which can be easily done because there is only one site visit per year). This re-indexing results in a matrix with elements n_{vs}.

Because AA model fitting is done using Markov Chain Monte Carlo (MCMC), the model output consists of a series of MCMC samples, for each parameter of interest. In this case, those parameters are the integer-valued grid cell abundances; tracking MCMC sample $m \in \{1, 2, ..., M\}$ gives the input object to the post-stratification procedure, an array $\mathcal{N}$ with elements n_{vsm}.

An important note regarding n_{vsm} is that it is the abundance of the grid cell during visit v, and thus independent of the number of points that were visited.

4.2 Raw survey data

Estimating bird density for categories of points also requires access to the raw survey data (the original inputs to the Annual Analysis). Three pieces of information are required for each point visit:

1. the identity of the grid cell visit to which the point visit belongs;

2. the covariate value for the point visit, that will be used to determine the category to which it belongs (for example, habitat type);

3. for each focal species in the PS exercise, the number of observations.

During the application of a given classification system (section 4.3.2), point visits will be aggregated up to the level of grid cell visits.

4.3 Contrast definitions

When post-stratification is applied in the context of an overlay project, the goal is normally to compare the overlay sites (or a subset thereof) to a suitable reference sample, in an impact-reference design framework. Such a comparison might take many forms, but it should have three main components:

1. the classification system applied at the point level;

2. the focal, or 'treatment' set of surveys (i.e., the overlay);

3. the reference set of surveys;

4. the epoch definition, which distributes years into groups.

Often, multiple such contrasts will be calculated for a given overlay project; each contrast may provide a somewhat different perspective on the set of questions at hand, or lead to different interpretation of the outcome.

4.3.1 Entities

Contrasts represent the difference between the mean density of a species within a treatment group, minus that within a reference group. Collectively, these groups are called *entities*; they are normally defined by some geographic boundary within which grid cells are considered members of the entity.

Entity definitions could be simple (e.g., a single, rectangular ranch) or complex (a set of polygons defined by an elevation threshold). Establishing membership of particular grid cells in entity

groups is part of the preparation for post-stratification, however, not part of the exercise itself. If multiple contrasts are to be estimated, an entity could appear in more than one (e.g., where a treatment is to be compared to two distinct reference areas).

4.3.2 Classification system

Each contrast includes a classification system (CS) as part of its definition. The CS is applied to raw survey data, and sorts survey point visits within grid cell visits (section 4.2) unambiguously into non-overlapping categories $c \in \{1, 2, ..., C\}$; the totals in each category are k_c. The final category C is always the number of points that were not visited during grid cell visit v, that is, $16 - \sum_{c=1}^{C-1} k_c$. The CS is applied to visits in both the treatment and the reference entity. The outcomes of the CS are two: for each grid cell visit,

1. the C-vector $\mathbf{k}$ giving the number of visited points in each category;

2. for each species, a C-vector giving the number of bird observations made in point visits within each category.

Across cell visits v, the above CS outcomes are collected into, respectively, a $V \times C$ matrix $\mathbf{K}$, and a $V \times S \times C$ array $\mathcal{L}$.

4.3.3 Epoch definition

Contrasts are differences between entities, but they are usually applied during particular time periods we name *epochs*. Contrasts may be calculated for every year t of the study, but years could also be grouped together, for instance into a pre-treatment and a post-treatment period. Or a comparison across all years might be desired. Suppose the epochs are indexed by $y \in \{1, 2, ..., Y\}$ and that each is a mapping of year(s) into a group (if every year is in its own group, then $Y = T$). Now suppose those mappings are expanded to apply to visits, and these are gathered into a $V \times Y$ matrix $\mathbf{G}$ with elements in $[0, 1]$: column y represents a mapping of visits into epoch y.

5 Estimation of contrasts

Given the input data described above (section 4), there are four main tasks to estimating a particular contrast:

1. apply the classification system (CS) to the entity groups of grid cell visits

2. estimate the abundance at each visit, for each category in the CS

3. convert abundance to density

4. weight each visit, within each category

5. calculate contrast within each category and epoch

Descriptions of these tasks follow, in the context of conducting a *single contrast for a single species*. A post-stratification analysis typically addresses multiple species and consists of a number of contrasts, either because multiple reference areas are of interest or because multiple reference area definitions could address the research questions motivating the analysis.

5.1 Applying the classification system

Point visits and their associated bird counts are first sorted into categories according to the CS associated with a given contrast (section 4.3.2). This is done for the superset of grid cell visits $v \in \{1, 2, ..., V\}$ that includes both the treatment and reference entities.

5.2 Estimating abundance within grid cell and category

For each species, the Annual Analysis produces an abundance n_{vm} for each grid cell visit v during each MCMC iteration m; these are gathered into matrix $\mathbf{N}_s$. The goal of the present task is to find the most probable distribution of n_{vm} into the C categories, that is, the C-vector $\mathbf{a}_{vm}$. Aside from $\mathbf{N}_s$, the requisite quantities are:

1. the raw counts in each category, the $V \times C$ matrix $\mathbf{L}_s$;

2. the number of point visits in each category, $V \times M$ matrix $\mathbf{K}$;

First note that any parameters that apply to every point visit within the grid cell visit and MCMC iteration are irrelevant to estimating $\mathbf{a}$, since they would have the same value for every point. This includes detection probability p_{vm} and the abundance parameter λ_{vm} (both of which are estimated by the Annual Analysis), which can both be ignored.

Secondly, note that the process of distributing n_{vm} into $\mathbf{a}_{vm}$ could be done by assuming that the allotment into categories should be proportional to the number of point visits in each, that is, according to the relevant row of L_s, denoted $\mathbf{l}_v$. But a second approach might be to assume that allotment is proportional to the number of bird observations in each, that is, according to the relevant row of $\mathbf{K}$, or $\mathbf{k}_v$. The approach taken here balances the two by constructing a likelihood function that incorporates both processes. Furthermore, the number of observations l_{vsc} provide a constraint in the form of a lower bound on the abundance in each category.

For a given visit and MCMC sample (a particular value of v and m; these subscripts are omitted for the remainder of this section), the full set of possible distributions of n into the categories is first enumerated, in a C-column matrix $\mathbf{E}$ (E for 'eligible'). Each element of $\mathbf{E}$ is integer-valued, and each row sums to n. Moreover, the minimum value of each column is equal to the corresponding total number of observations in that category, l_c. The number of rows of $\mathbf{E}$ thus depends on both n and $\mathbf{l}_c$; let these rows be indexed by $r \in \{1, 2, ..., R\}$ and a particular row be denoted $\mathbf{e}_r$.

A likelihood function is defined that includes expressions of the probability of a given row of $\mathbf{E}$ given the value of $\mathbf{k}$,

$$Pr(\mathbf{e}_r|\mathbf{k}) = \text{Multinom}\left(\mathbf{e}_r; \frac{\mathbf{k}}{\sum_c k_c}\right), \tag{1}$$

and the probability of $\mathbf{l}$ given $\mathbf{e}_r$,

$$Pr(\mathbf{l}|\mathbf{e}_r) = \text{Multinom}\left(\mathbf{l}; \frac{\mathbf{e}_r}{\sum_c e_{rc}}\right) . \tag{2}$$

The full likelihood of $\mathbf{e}_r$ given point visits $\mathbf{k}$ and bird observations $\mathbf{l}$ in each category is

$$L(\mathbf{e}_r|\mathbf{k},\mathbf{l}) = \text{Multinom}\left(\mathbf{l}; \frac{\mathbf{e}_r}{\sum_c e_{rc}}\right) \times \text{Multinom}\left(\mathbf{e}_r; \frac{\mathbf{k}}{\sum_c k_c}\right) . \tag{3}$$

This likelihood function is applied to each row of $\mathbf{E}$, and the row with the highest value is retained as $\mathbf{a}_{vm}$, the estimated distribution of n into the C categories, for that particular visit, species and MCMC iteration:

$$r^* = \underset{r}{\text{argmax}}\, L(\mathbf{e}_r|\mathbf{k},\mathbf{l}) \tag{4}$$

and

$$\mathbf{a} = \mathbf{e}_{r^*} . \tag{5}$$

In this way, the choice of $\mathbf{a}_{vm}$ is also dependent on the estimated grid cell abundance, since each row in $\mathbf{E}$ sums to n.

The process of constructing an $\mathbf{E}$ matrix and choosing the most likely row is then repeated for each MCMC sample. Estimated abundance n changes across these iterations m, but $\mathbf{k}$ and $\mathbf{l}$ do not. The outcome is a set of M vectors $\mathbf{a}$, which are gathered into matrix $\mathbf{A}_{vs}$.

The above loop through MCMC iterations is then repeated for each grid cell visit, resulting in a $V \times M \times C$ array $\mathcal{A}_s$, Finally, this process is repeated for each species, yielding the $S \times V \times M \times C$ array $\mathcal{A}$.

5.3 Conversion to density

Bird observations in the IMBCR program are not the same as individual birds; rather, they represent *clusters* of birds that were observed near to one another in space and time. The Annual Analysis estimates the mean of the size of these clusters, μ_s along with the standard error of the mean SE_s; cluster size is assumed to be normally-distributed. Also reported (though not actually estimated) by the AA is the effective area of a point count, A_s, which varies by species because they vary in terms of perceptibility.

To convert grid cell abundance $\mathbf{A}_s$ to density a $V \times M$ matrix of conversion factors $\mathbf{F}_s$ is produced according to

$$f_{vm} \sim \text{Norm}\left(A_s \times \mu_s, SE_s\right) . \tag{6}$$

Uncertainty regarding average cluster size is thus accommodated by using random deviates based on estimated parameters.

The grid cell abundance and conversion arrays are then multiplied element-wise, with the same conversion factor applying to all categories within each visit and MCMC iteration:

$$d_{vsmc} = \frac{a_{vsmc}}{k_{vc}} \times f_{vsm} . \tag{7}$$

Dividing by k_{vc} is necessary since $\mathcal{A}$ contains total abundances across all the point counts in each category.

5.4 Weighting grid cells

Summarizing density estimates at the grid cell visit level up to the entity level requires taking weighted averages. The weights are tied to stratum membership, and depend on two quantities for each stratum: its geographic size, and the proportion of points within it that belong to a given category c. Suppose those quantities have been replicated and assigned to visits, resulting in V-vector $\mathbf{z}$ of stratum areas and $V \times C$ matrix $\mathbf{H}$ giving representation of each category in the visit's parent stratum.

Define a matrix $\mathbf{U}$ as the element-wise product of stratum area and category representation:

$$\mathbf{U} = (\mathbf{z}\mathbf{1}^\top) \odot \mathbf{H} \tag{8}$$

where $\mathbf{1}$ is a C-vector of 1's. The product $\mathbf{z}\mathbf{1}^\top$ results in a $V \times C$ matrix each of the columns of which is equal to $\mathbf{z}$; '$\odot$' indicates element-wise multiplication (Hadamard product).

Matrix $\mathbf{U}$ is the precursor to the entity-specific weight matrices described below.

5.5 Calculation of contrasts

Calculating a contrast for species s and category c requires two vectors with elements $\in \{0, 1\}$ that indicate membership in the entities involved (section 4.3.1). Suppose that $\mathbf{q}$ defines the the treatment entity and $\mathbf{r}$ the reference. And let $\mathbf{u}_c$ be the column of $\mathbf{U}$ corresponding to category c. These entity definitions are combined with the epoch definitions $\mathbf{G}$ to produce $V \times Y$ matrices with elements $\in [0, 1]$:

$$\mathbf{Q} = \mathbf{q}\mathbf{1}^\top \odot \mathbf{G} \tag{9}$$

for the treatment and

$$\mathbf{R} = \mathbf{r}\mathbf{1}^\top \odot \mathbf{G} \tag{10}$$

for the reference, with $\mathbf{1}$ a length-Y vector of 1's.

To get the weighted versions of $\mathbf{Q}$ and $\mathbf{R}$—call them $\mathbf{W}_Q$ and $\mathbf{W}_R$—we first define the element-wise product of each with $\mathbf{u}_c$. Call these $\mathbf{Q}_P$ and $\mathbf{R}_P$:

$$\mathbf{Q}_P = \mathbf{u}_c\mathbf{1}^\top \odot \mathbf{Q} \tag{11}$$

and

$$\mathbf{R}_P = \mathbf{u}_c\mathbf{1}^\top \odot \mathbf{R}\,. \tag{12}$$

So $\mathbf{W}_Q$ and $\mathbf{W}_R$ have dimensions $V \times Y$, as do the weighted versions resulting from normalizing the columns:

$$\mathbf{W}_Q = \mathbf{Q}_P \mathrm{Diag}(\mathbf{Q}_P^\top \mathbf{1})^{-1} \tag{13}$$

and

$$\mathbf{W}_R = \mathbf{R}_P \mathrm{Diag}(\mathbf{R}_P^\top \mathbf{1})^{-1}\,. \tag{14}$$

The contrast is calculated for each MCMC iteration, thus:

$$\mathbf{X}_{sc} = \mathbf{W}_Q^\top \mathbf{D}_{sc} - \mathbf{W}_R^\top \mathbf{D}_{sc} \tag{15}$$

Matrix $\mathbf{X}_{sc}$ thus has dimensions $Y \times M$; repeating the calculation across species and categories results in a $S \times C \times Y \times M$ array $\mathcal{X}$.

Estimates of the contrast within each epoch are then found by calculating summary statistics for each row of $\mathbf{X}_{sc}$ (e.g., mean, percentiles). Because the columns of $\mathbf{X}_{sc}$ are functions of MCMC samples returned from a Bayesian model, these summaries are equivalent to estimating the contrasts within the model itself. Variance is propagated from the source quantities (the grid cell abundances) to the derived ones (the contrasts) but covariance among parameters is also accounted for. Percentiles of the derived quantities can also interpreted as probabilities, since they are formal Bayesian credible intervals.

This procedure is repeated for each species s and category c, resulting in $S \times C \times Y$ distinct estimates for each desired contrast.

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Stevens, D. L., Jr, & Olsen, A. R. (2004). Spatially balanced sampling of natural resources. *Journal of the American Statistical Association*, *99*(465), 262–278.

Timmer, J. M., Reese, J., McLaren, M. F., Smith, M., Walker, T., White, C. M., Latif, Q., Jr., P., & D. C., R. A., Sparks. (2026). *Integrated Monitoring in Bird Conservation Regions (IMBCR): 2025 Field Season Report* (tech. rep.). Bird Conservancy of the Rockies. Brighton, Colorado. https://bird-conservancy-of-the-rockies.github.io/IMBCR_AnnualReport_2025/

Appendix B — Figures showing contrasts between Lowry Ranch and reference population densities before (2012–2014) versus after (2024–2025) initiation of grazing management.

Each figure displays five panels corresponding to the reference sample comparisons summarized in Table 2 and Table 4. Panel headers indicate the grassland classification filter applied to the comparison ("model-matched," "always.GR" [Always grassland], or "GR.assoc" [Grassland associated]) and the geographic scope of the reference sample ("local" or "regional"). Within each panel, points and error bars show the estimated difference in population density (Lowry minus reference, birds/sqkm) with 90% credible intervals before (pre, 2012–2014) and after (post, 2024–2025) initiation of grazing management; the horizontal gray line marks a difference of zero (i.e., no effect).

American Kestrel

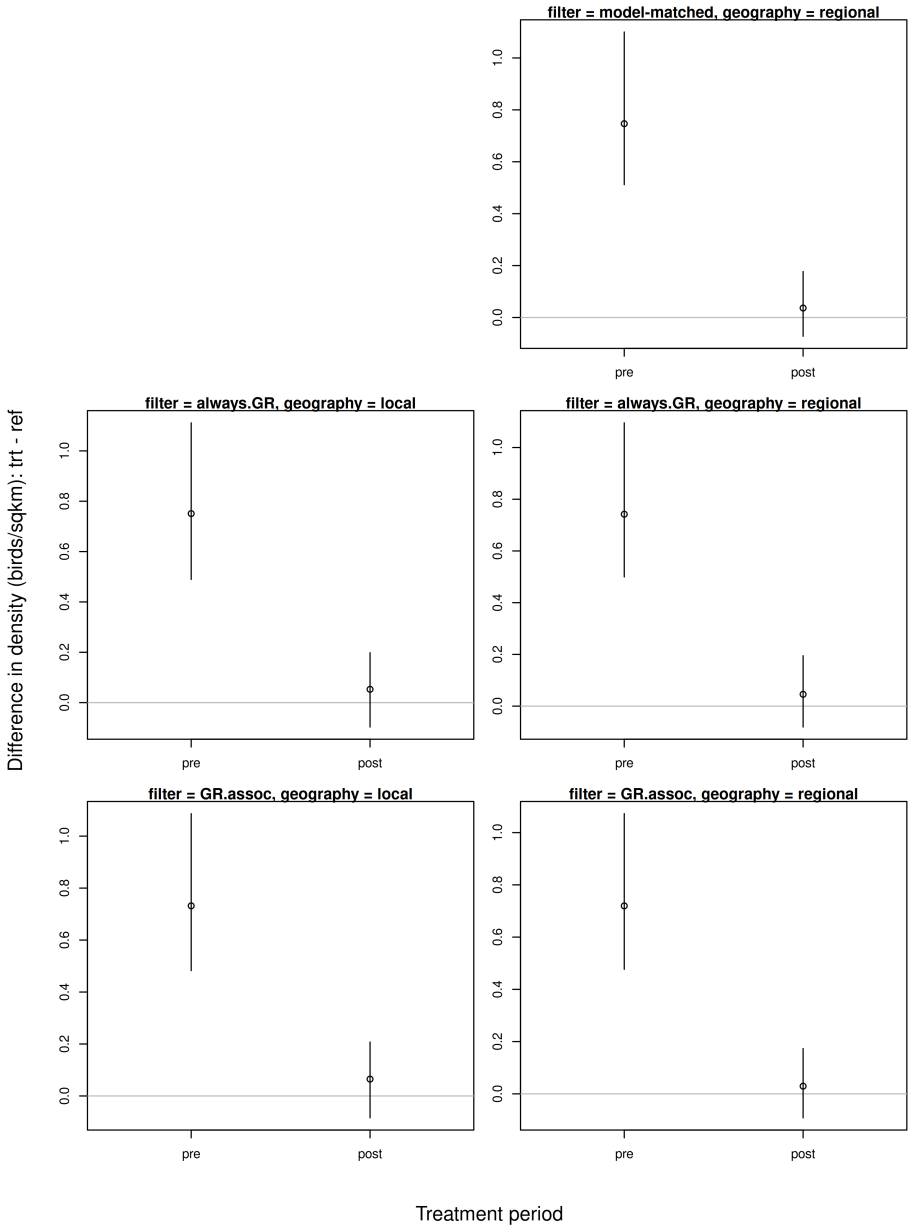


Figure B1. Differences in population densities before (pre) versus after (post) initiation of grazing management for American Kestrel.

Barn Swallow

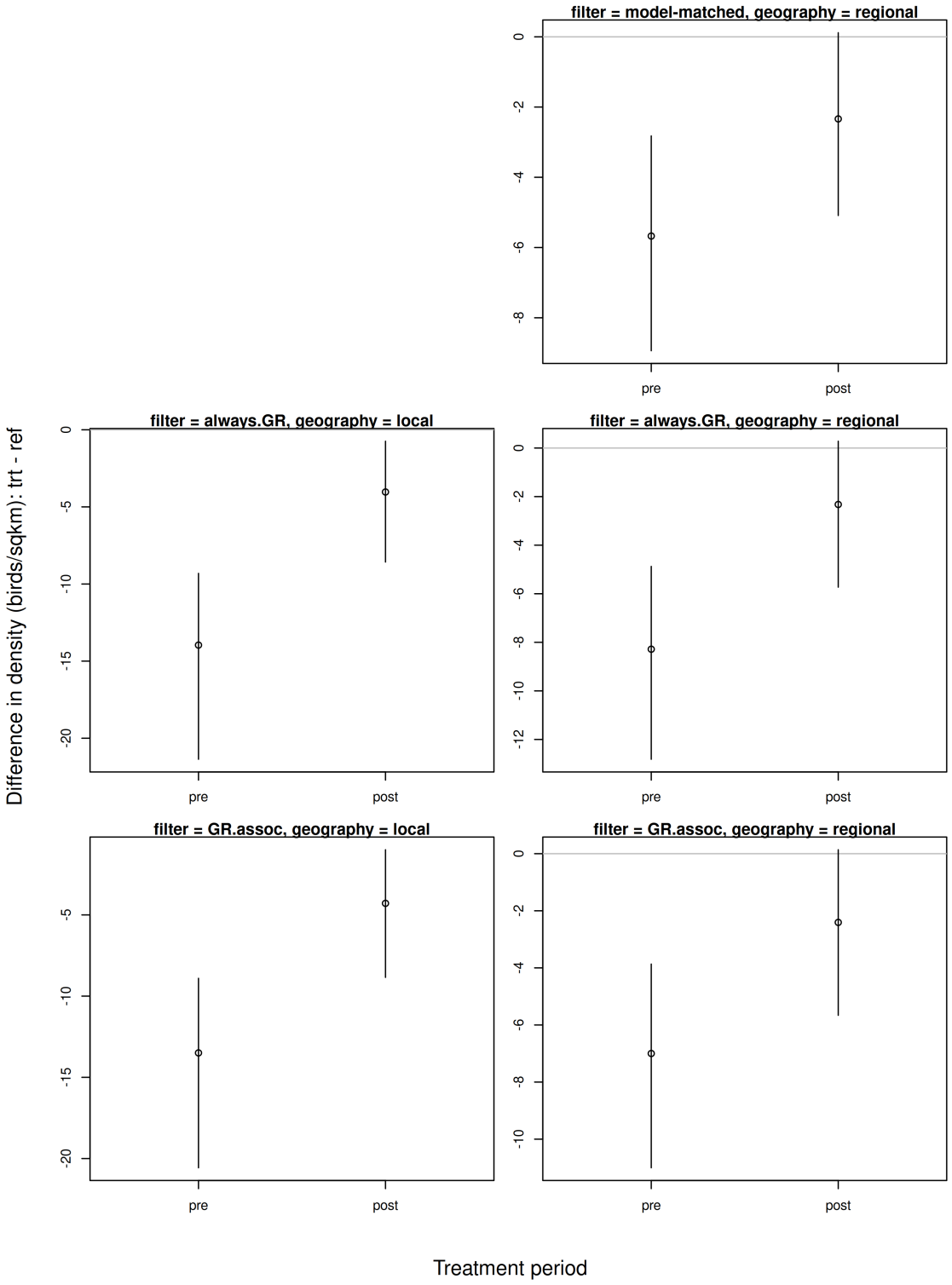


Figure B2. Differences in population densities before (pre) versus after (post) initiation of grazing management for Barn Swallow.

Brown-headed Cowbird

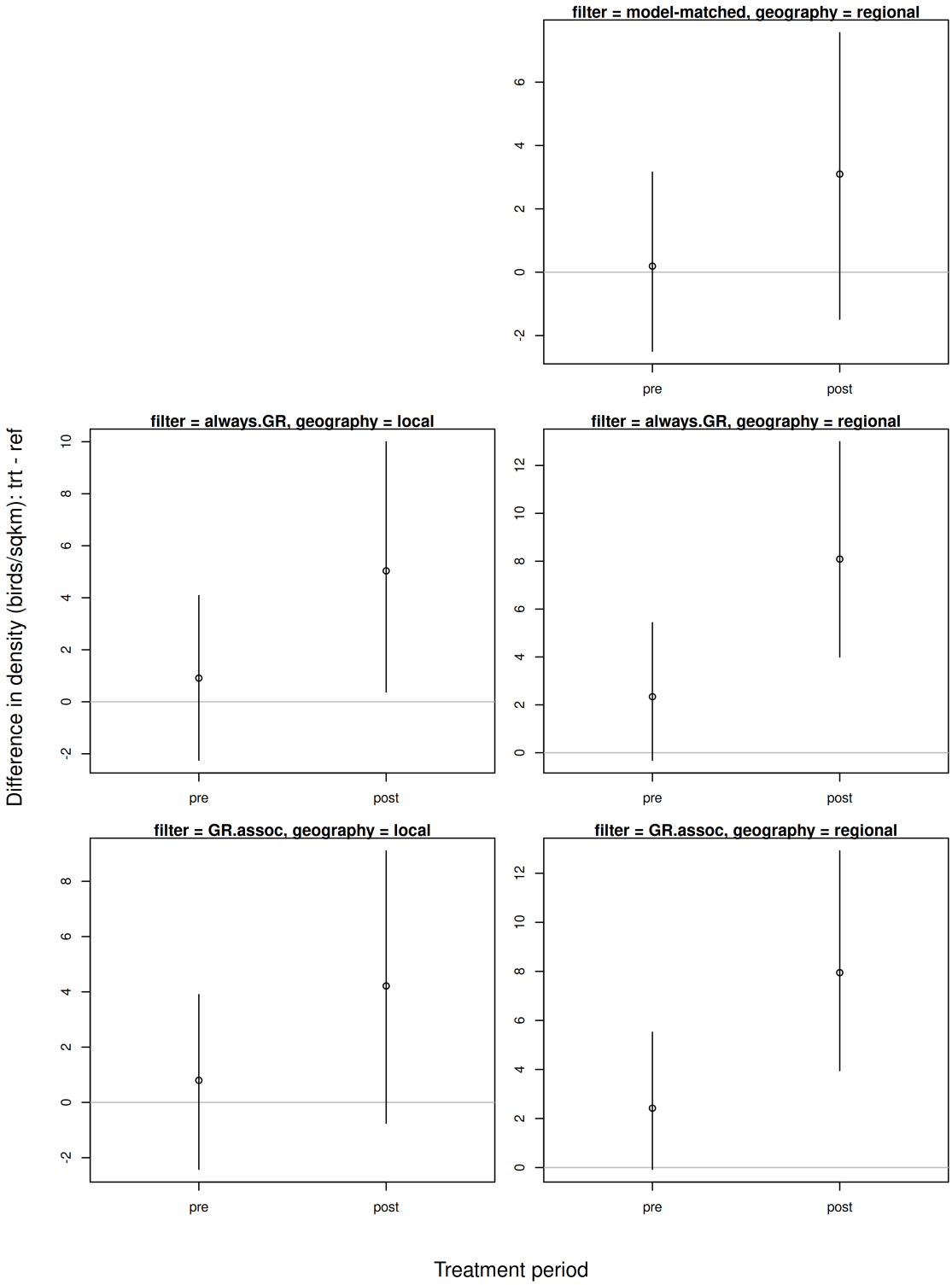


Figure B3. Differences in population densities before (pre) versus after (post) initiation of grazing management for Brown-headed Cowbird.

Brewer's Blackbird

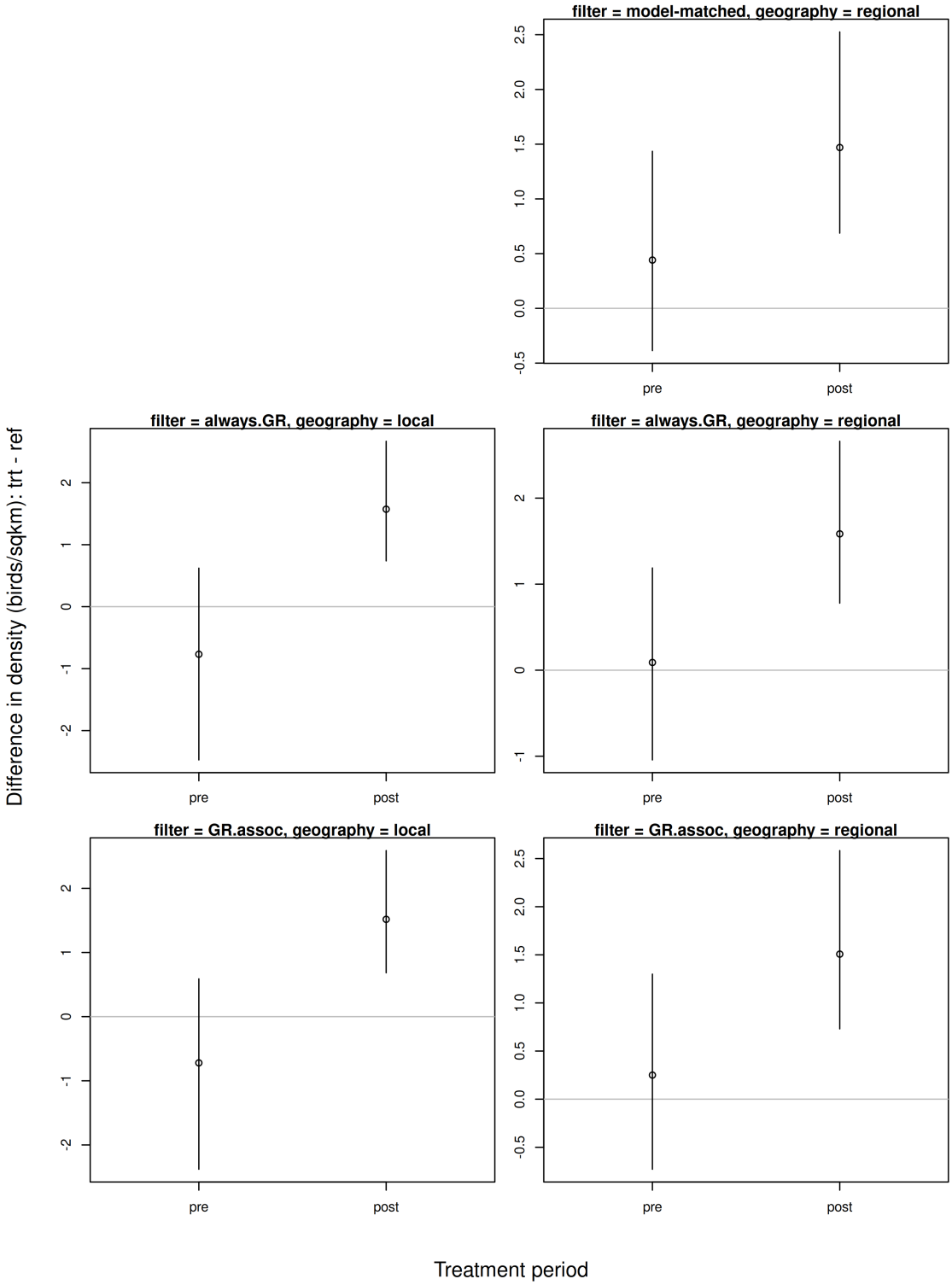


Figure B4. Differences in population densities before (pre) versus after (post) initiation of grazing management for Brewer's Blackbird.

Burrowing Owl

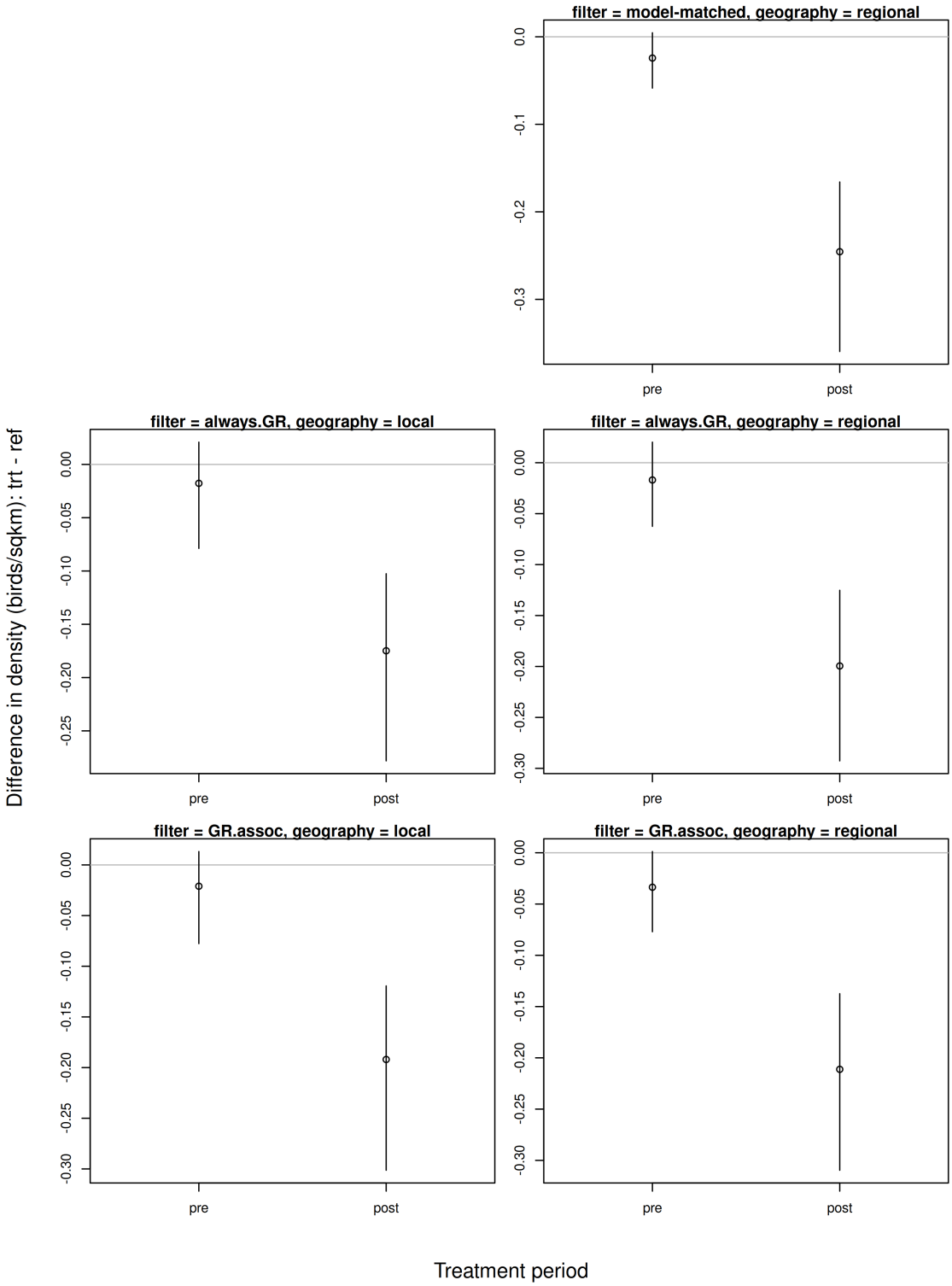


Figure B5. Differences in population densities before (pre) versus after (post) initiation of grazing management for Burrowing Owl.

Cassin's Kingbird

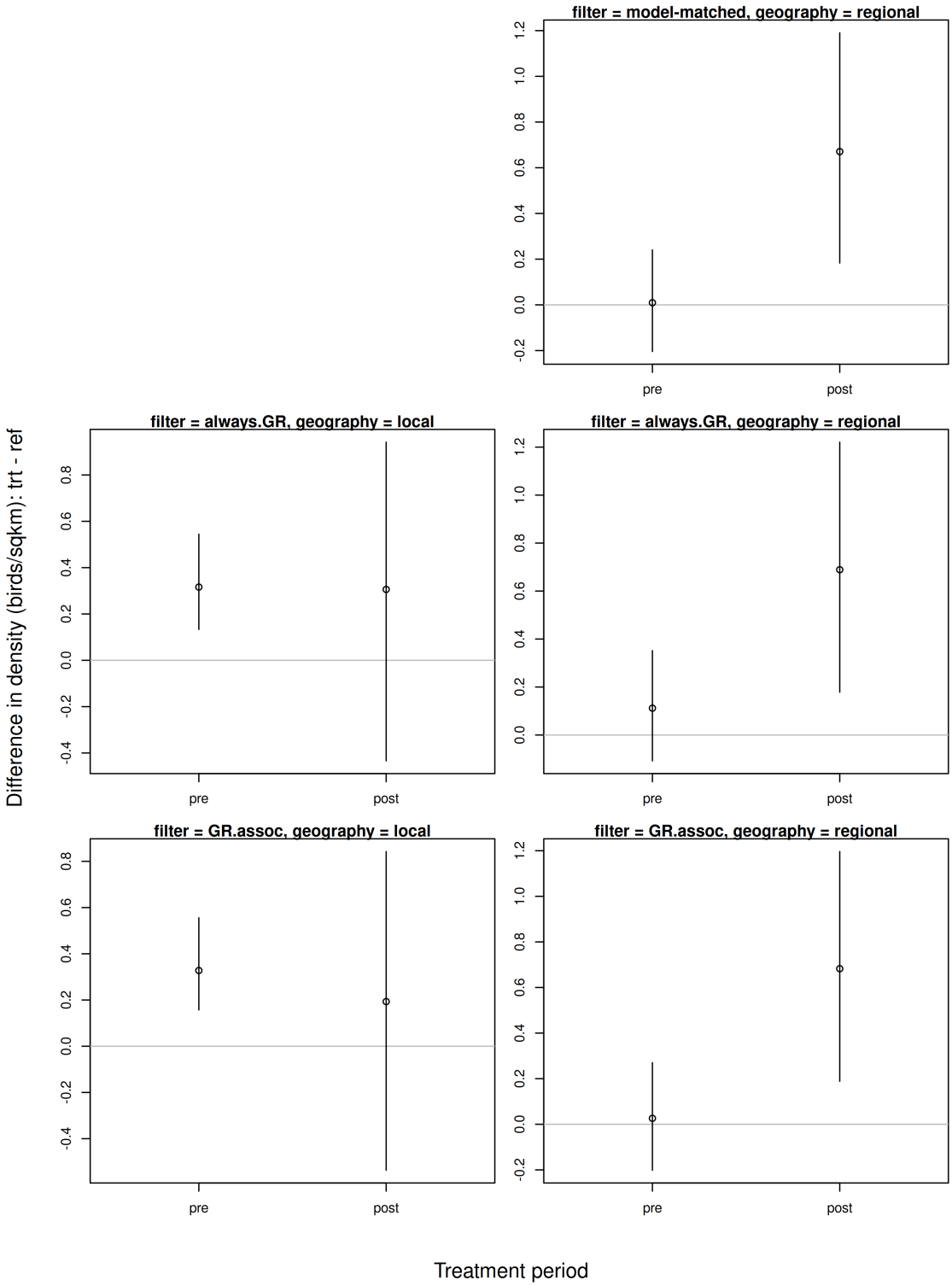


Figure B6. Differences in population densities before (pre) versus after (post) initiation of grazing management for Cassin's Kingbird.

Cassin's Sparrow

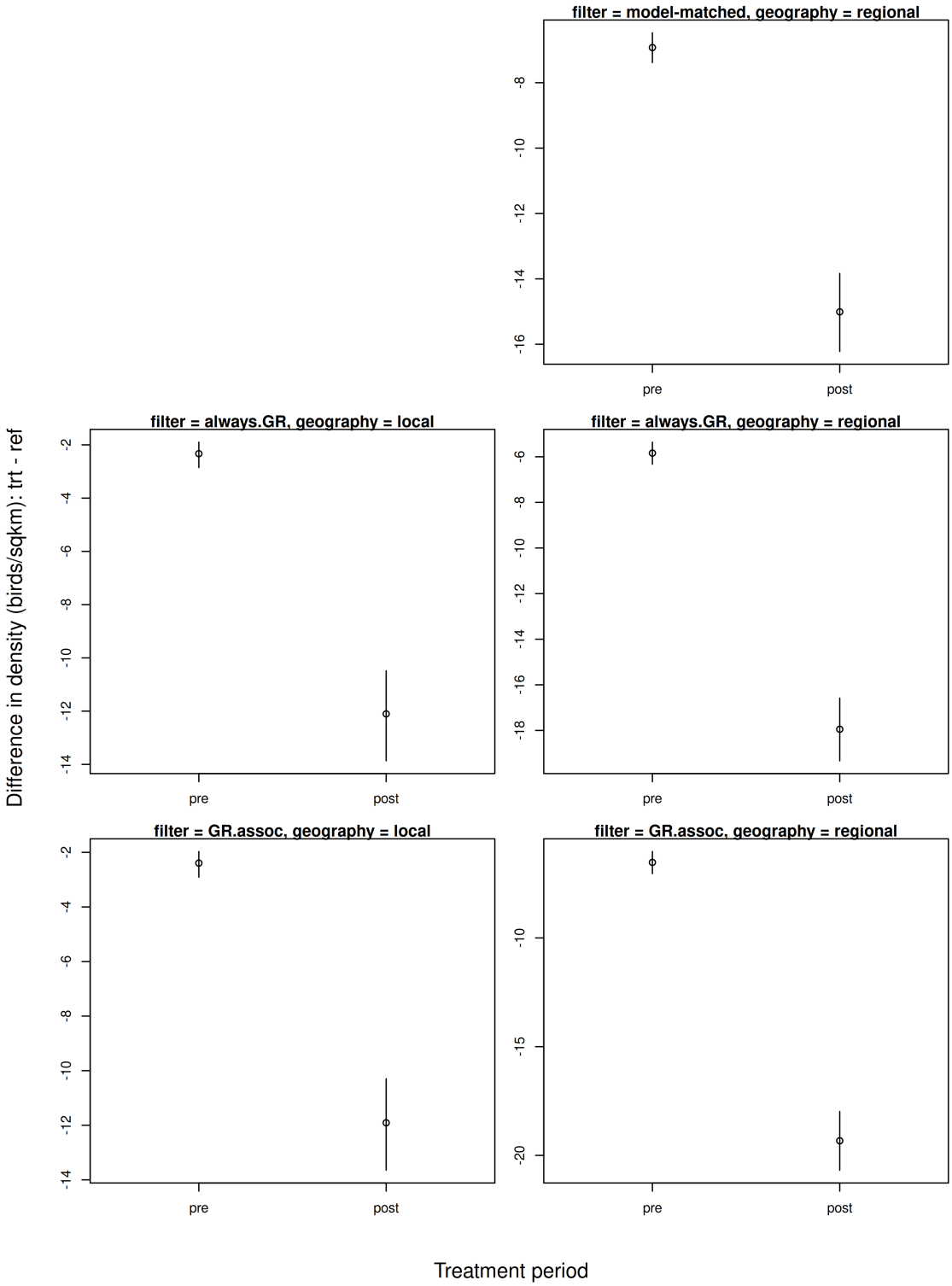


Figure B7. Differences in population densities before (pre) versus after (post) initiation of grazing management for Cassin's Sparrow.

Cliff Swallow

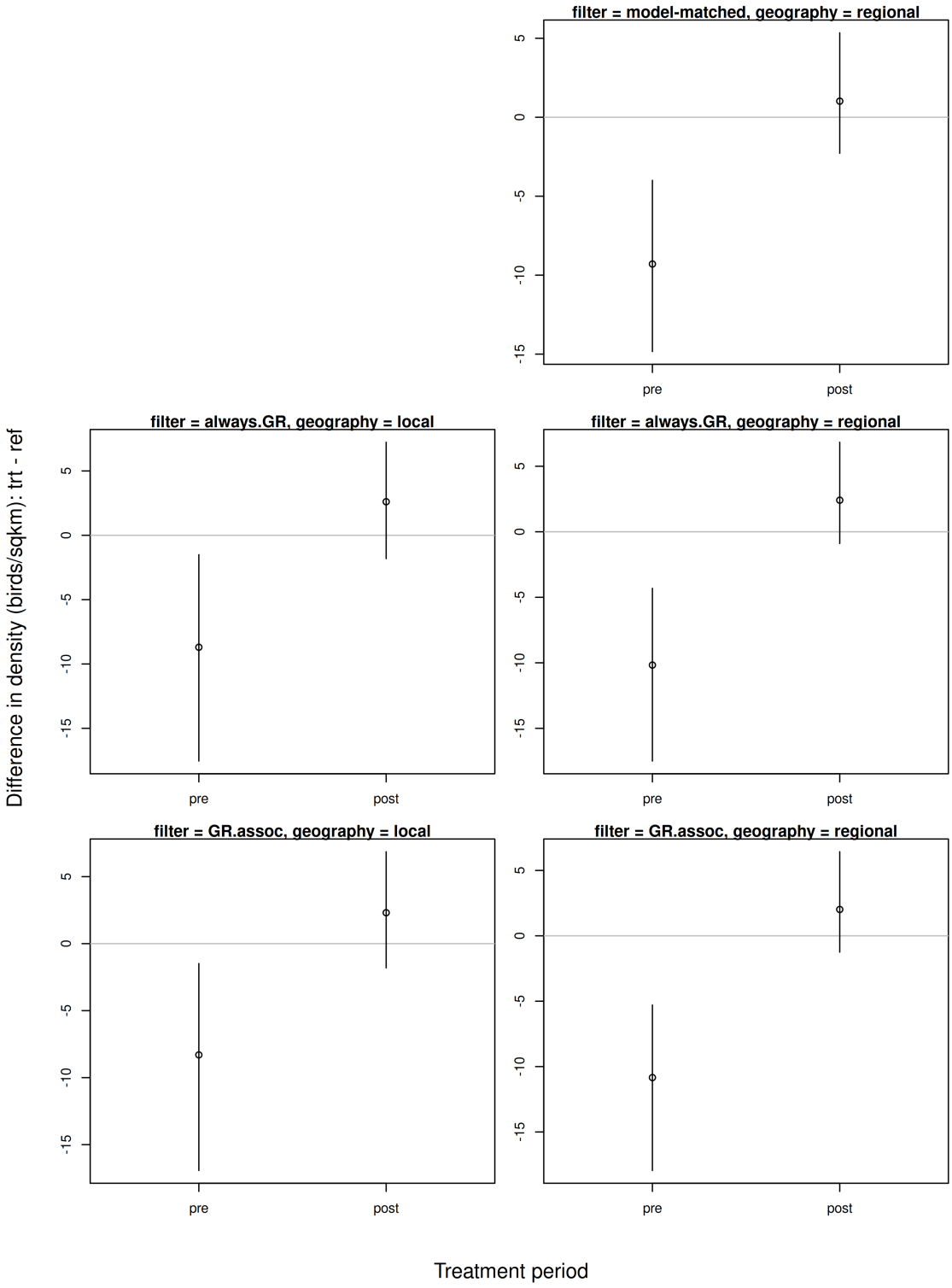


Figure B8. Differences in population densities before (pre) versus after (post) initiation of grazing management for Cliff Swallow.

Common Nighthawk

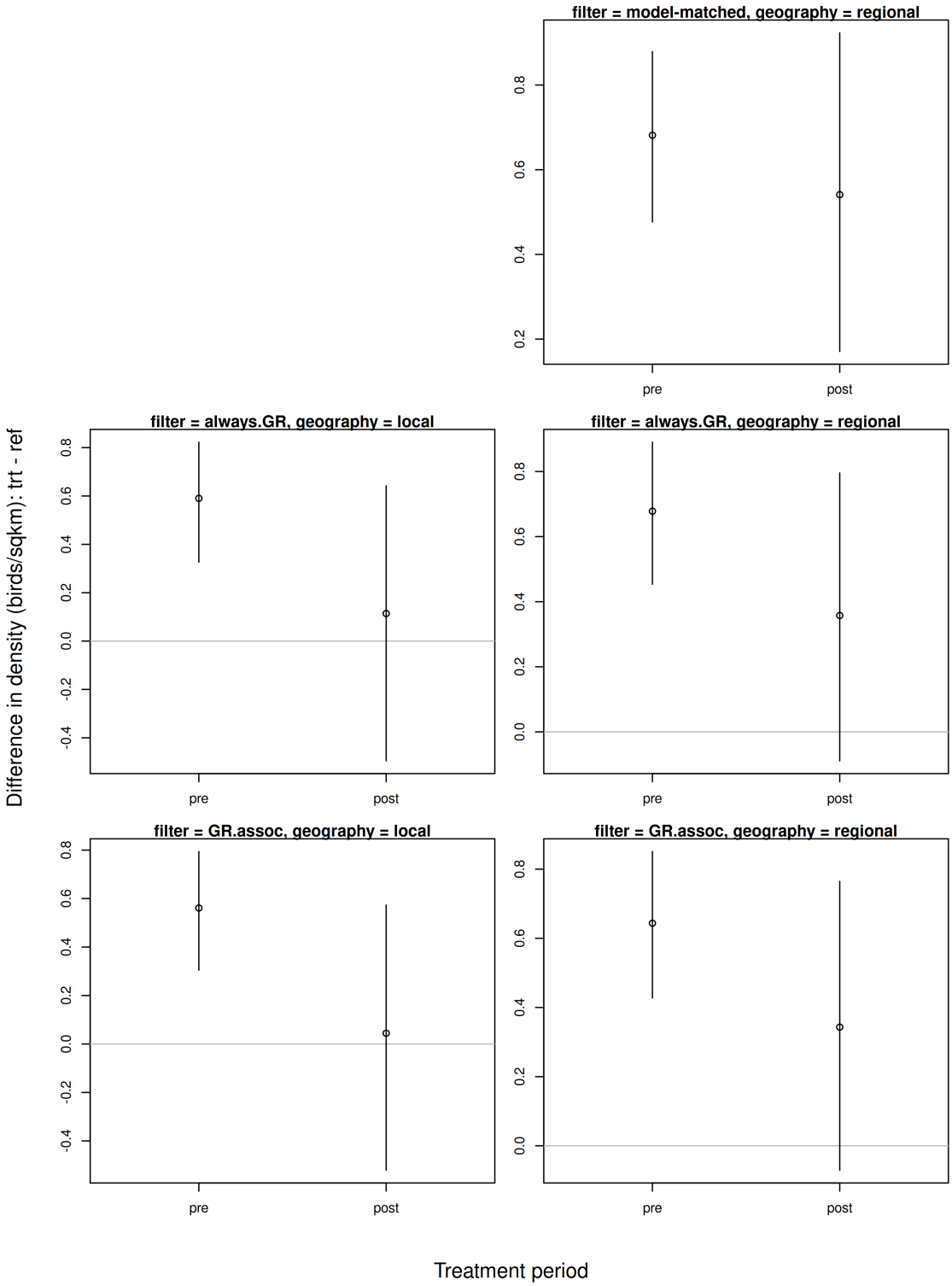


Figure B9. Differences in population densities before (pre) versus after (post) initiation of grazing management for Common Nighthawk.

Dickcissel

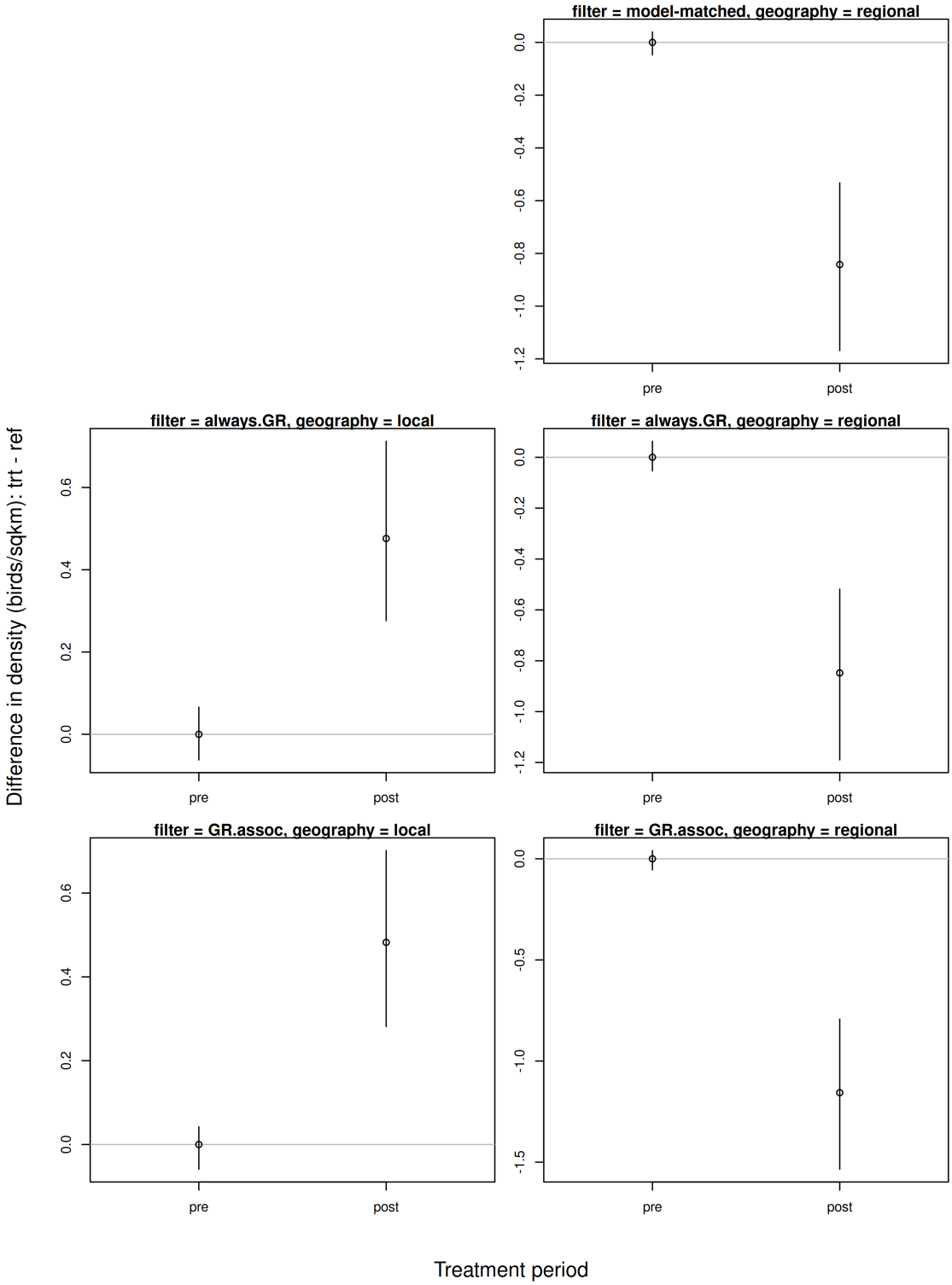


Figure B10. Differences in population densities before (pre) versus after (post) initiation of grazing management for Dickcissel.

Eastern Kingbird

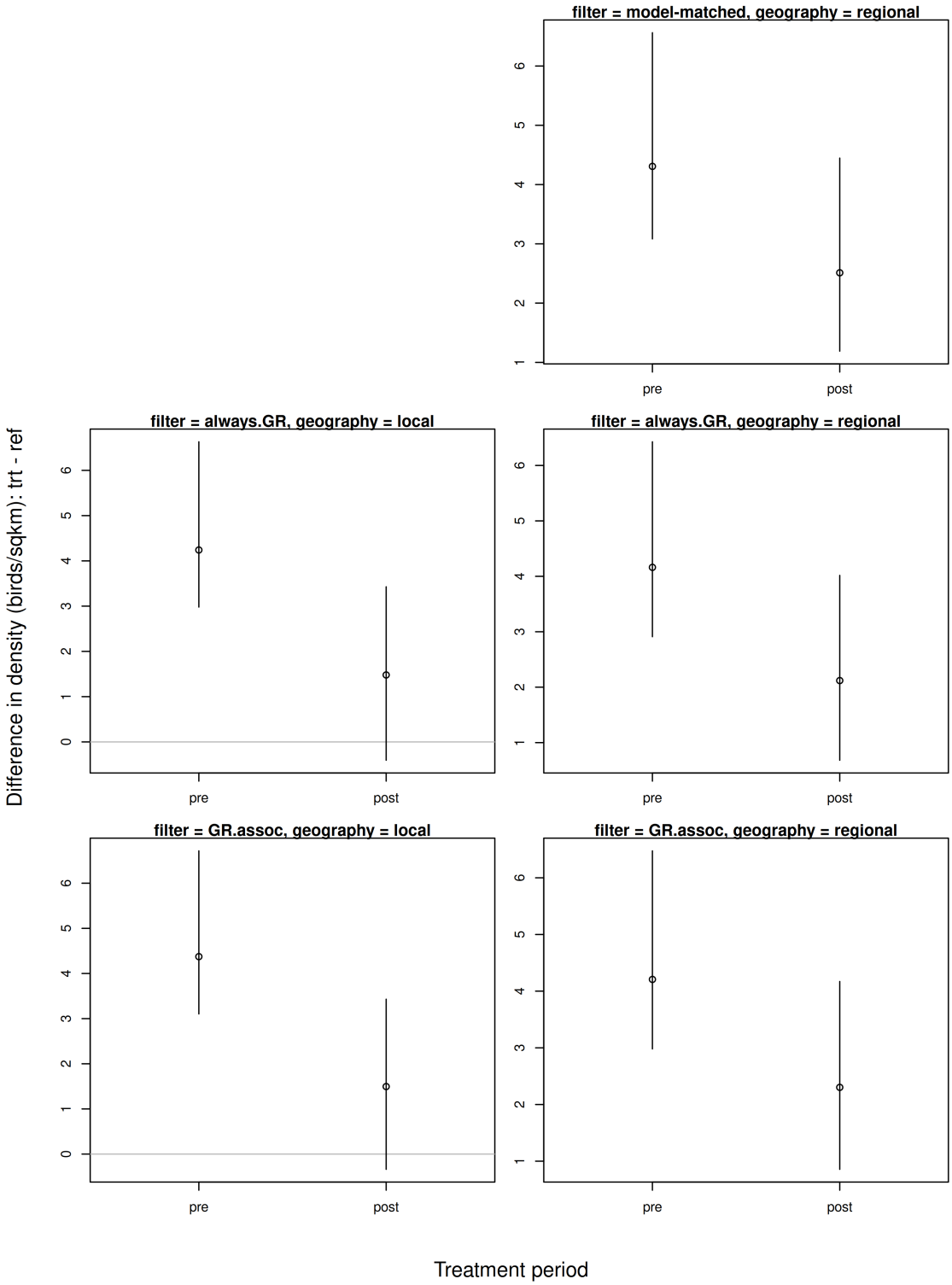


Figure B11. Differences in population densities before (pre) versus after (post) initiation of grazing management for Eastern Kingbird.

Ferruginous Hawk

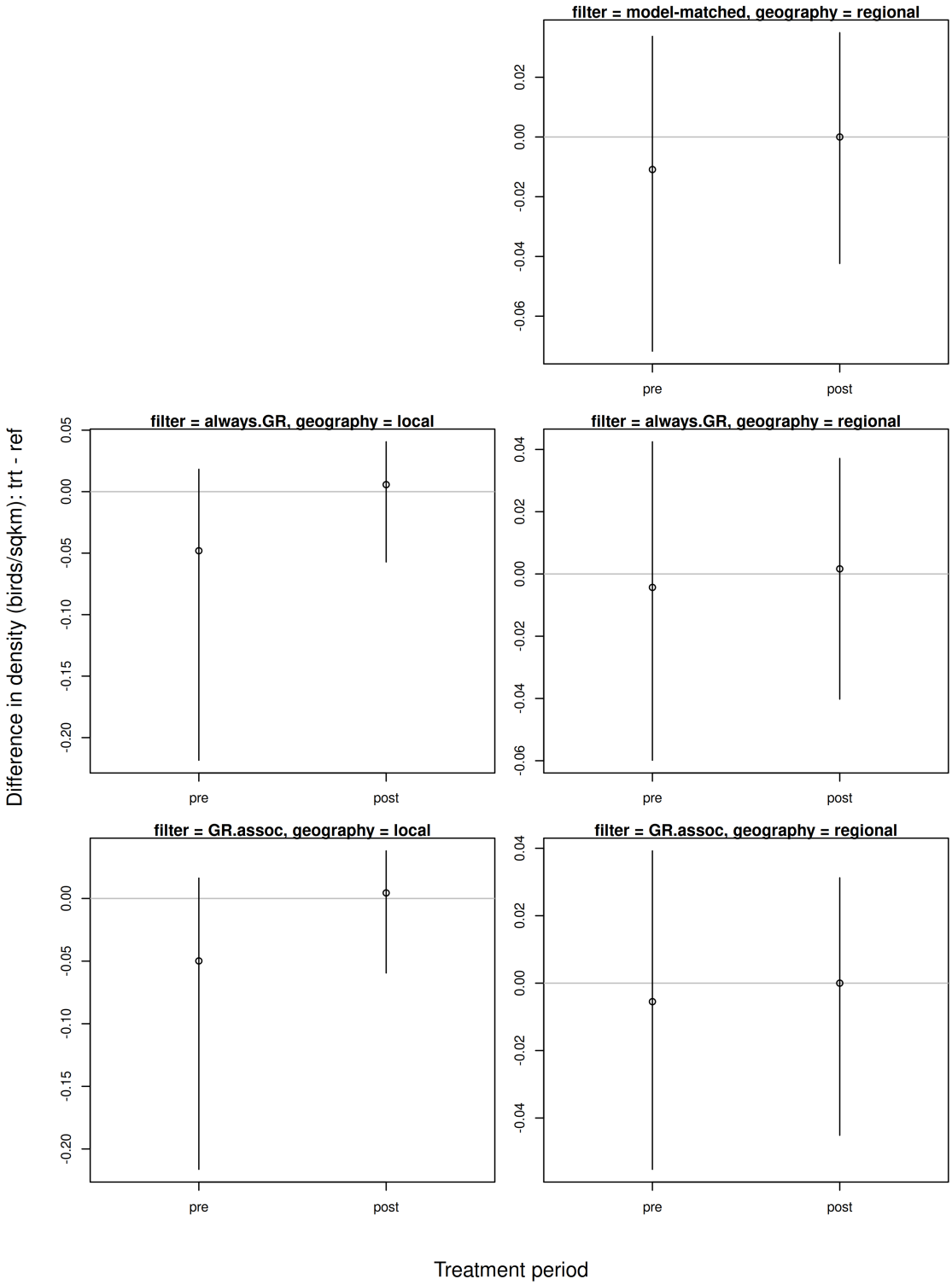


Figure B12. Differences in population densities before (pre) versus after (post) initiation of grazing management for Ferruginous Hawk.

Grasshopper Sparrow

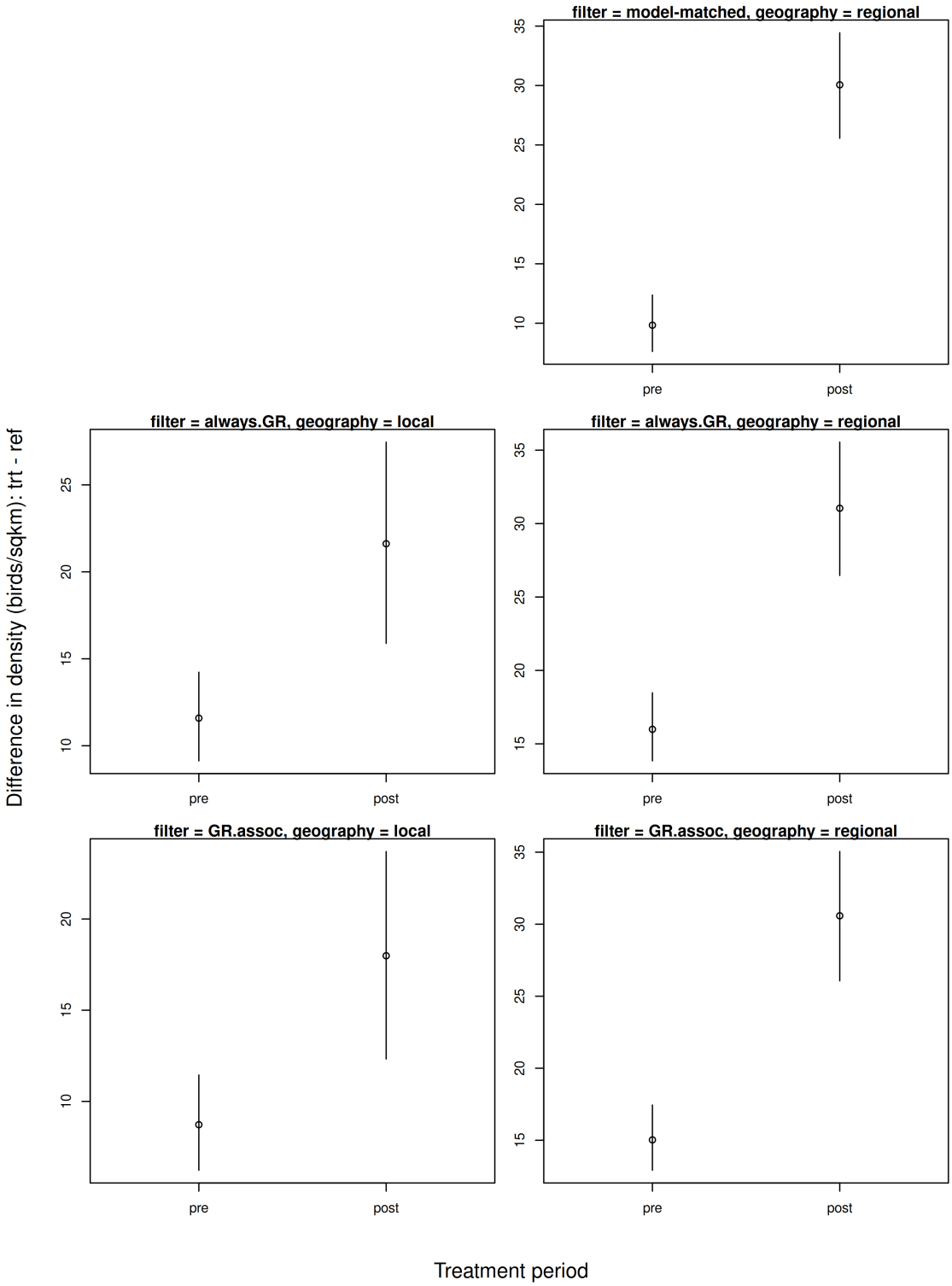


Figure B13. Differences in population densities before (pre) versus after (post) initiation of grazing management for Grasshopper Sparrow.

Horned Lark

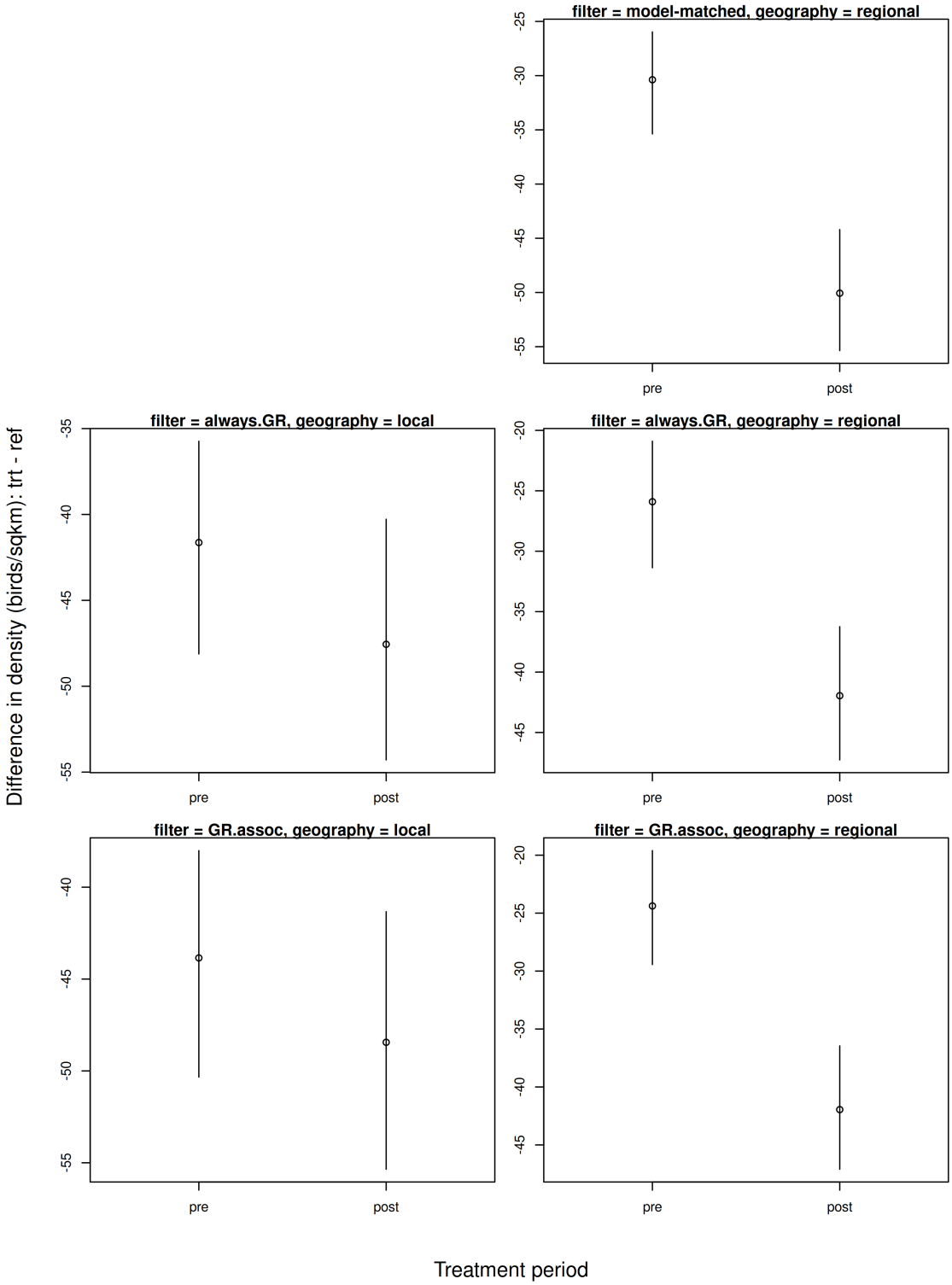


Figure B14. Differences in population densities before (pre) versus after (post) initiation of grazing management for Horned Lark.

Killdeer

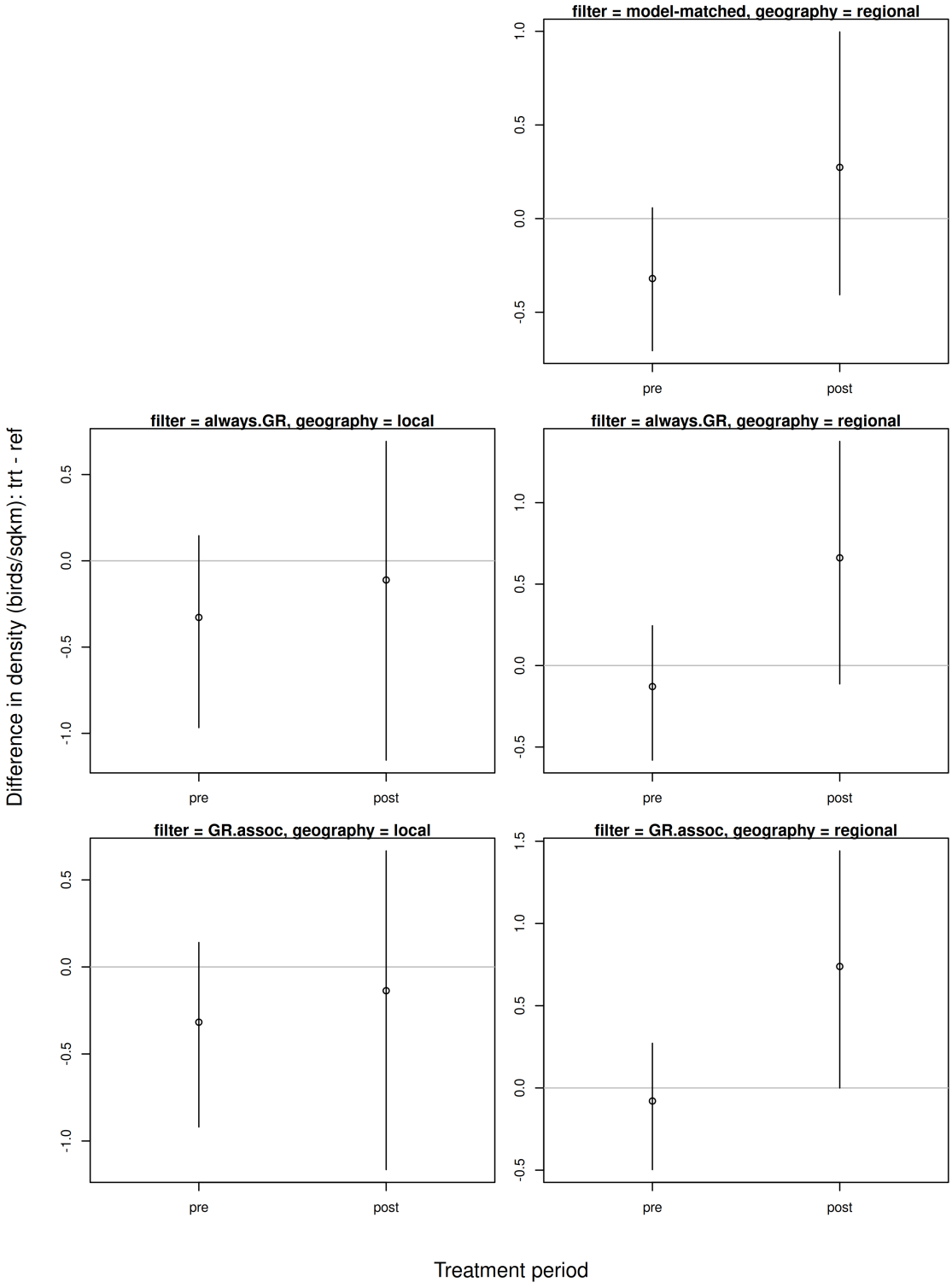


Figure B15. Differences in population densities before (pre) versus after (post) initiation of grazing management for Killdeer.

Lark Bunting

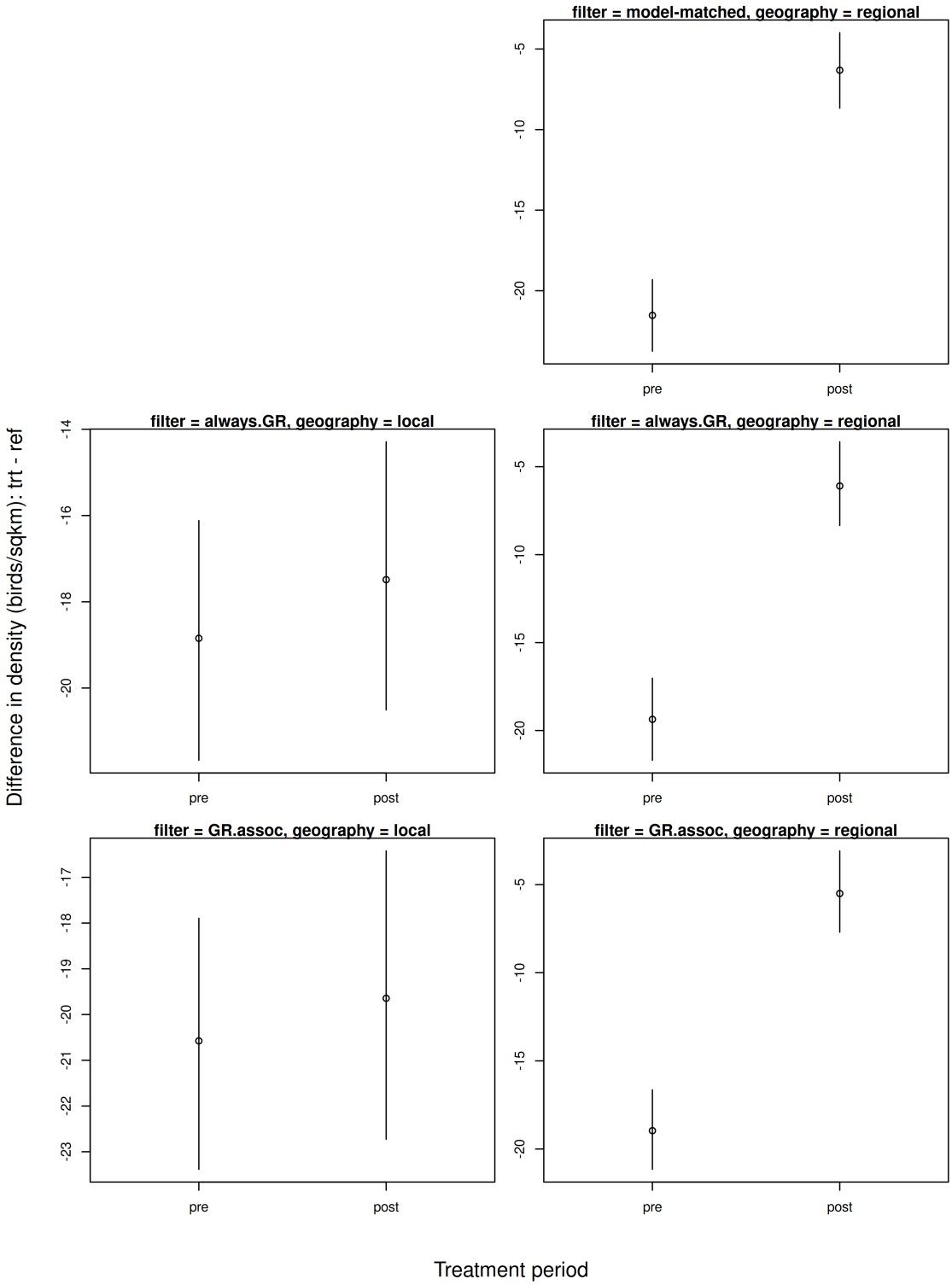


Figure B16. Differences in population densities before (pre) versus after (post) initiation of grazing management for Lark Bunting.

Lark Sparrow

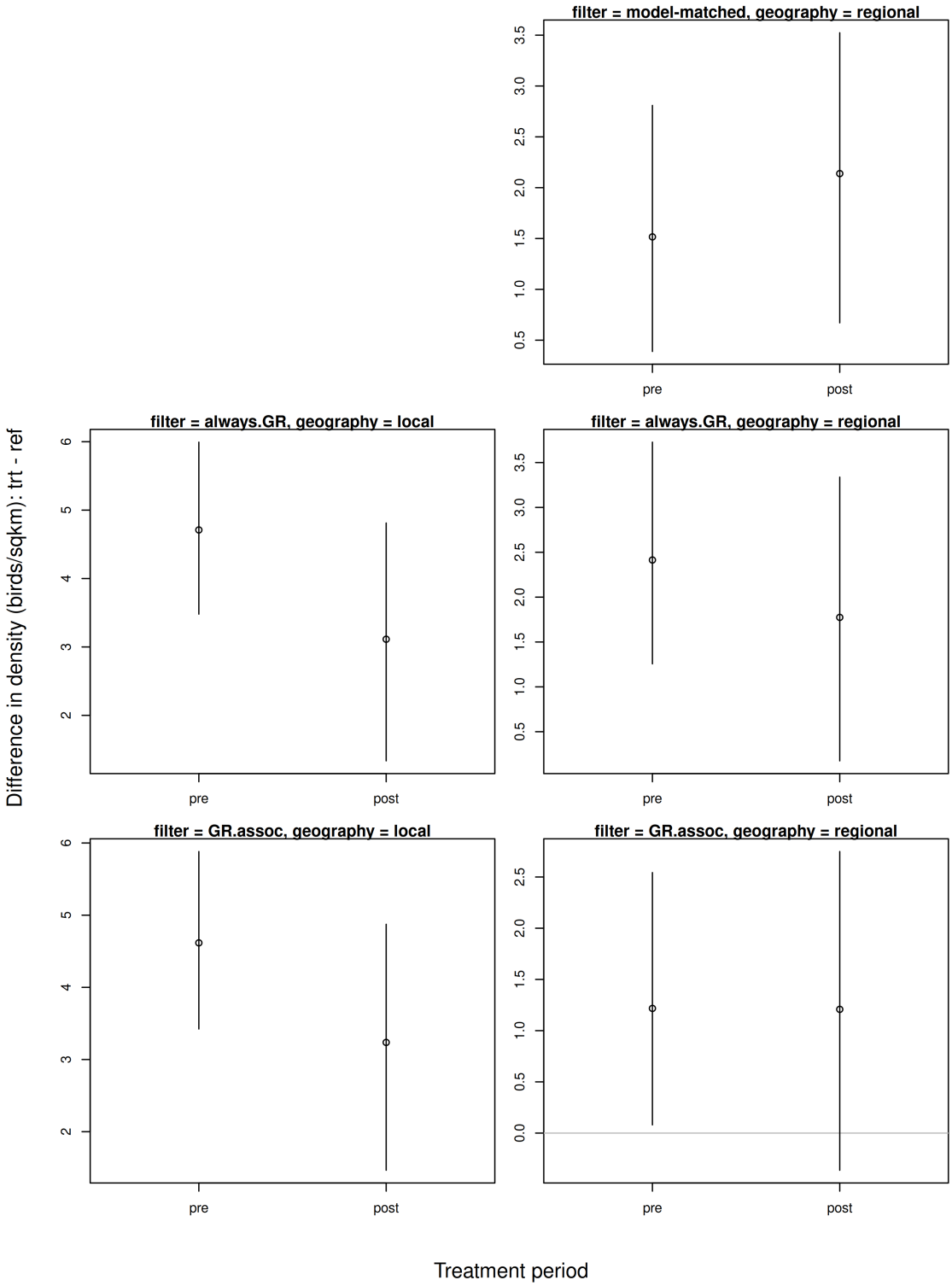


Figure B17. Differences in population densities before (pre) versus after (post) initiation of grazing management for Lark Sparrow.

Loggerhead Shrike

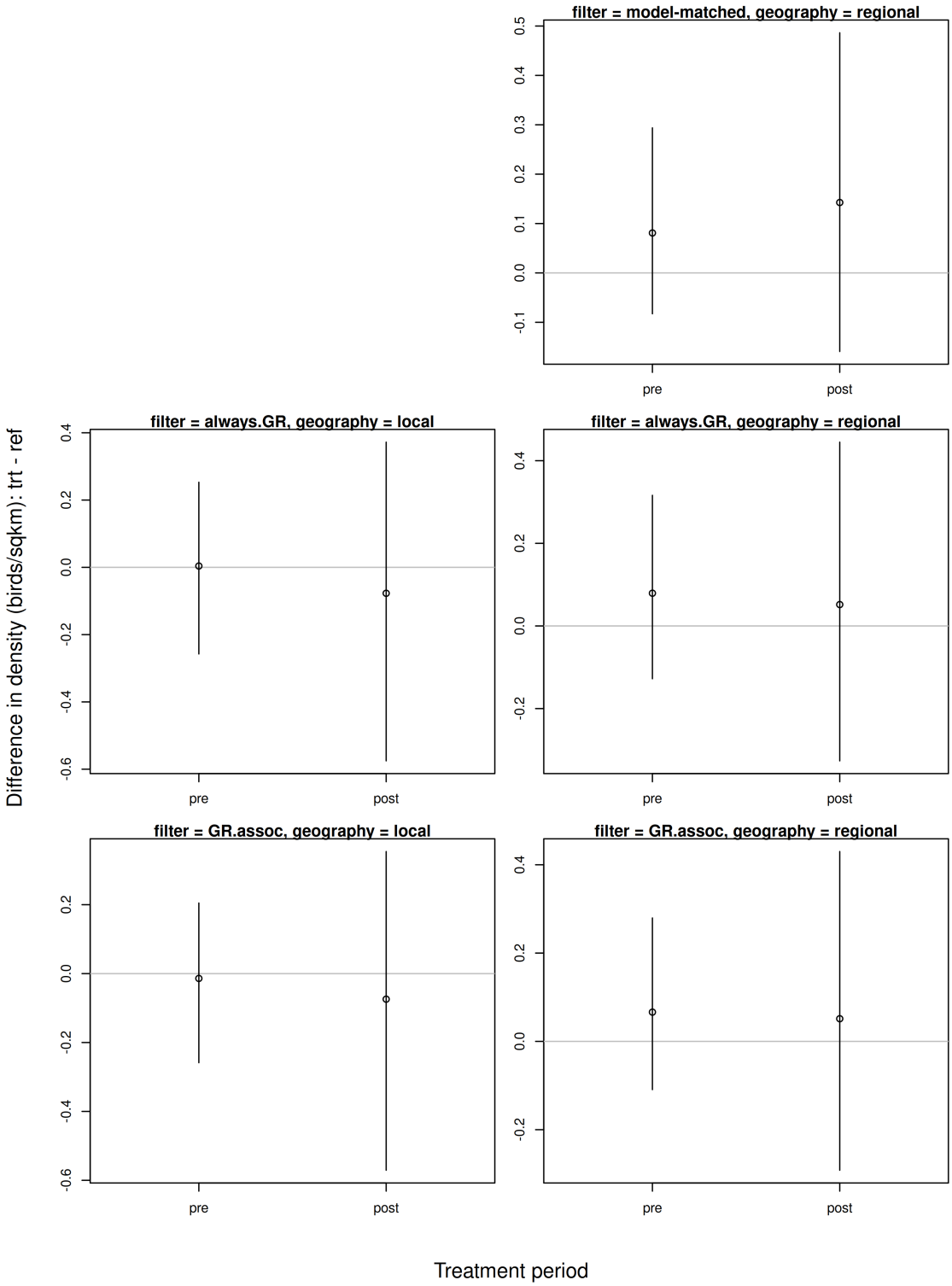


Figure B18. Differences in population densities before (pre) versus after (post) initiation of grazing management for Loggerhead Shrike.

Mourning Dove

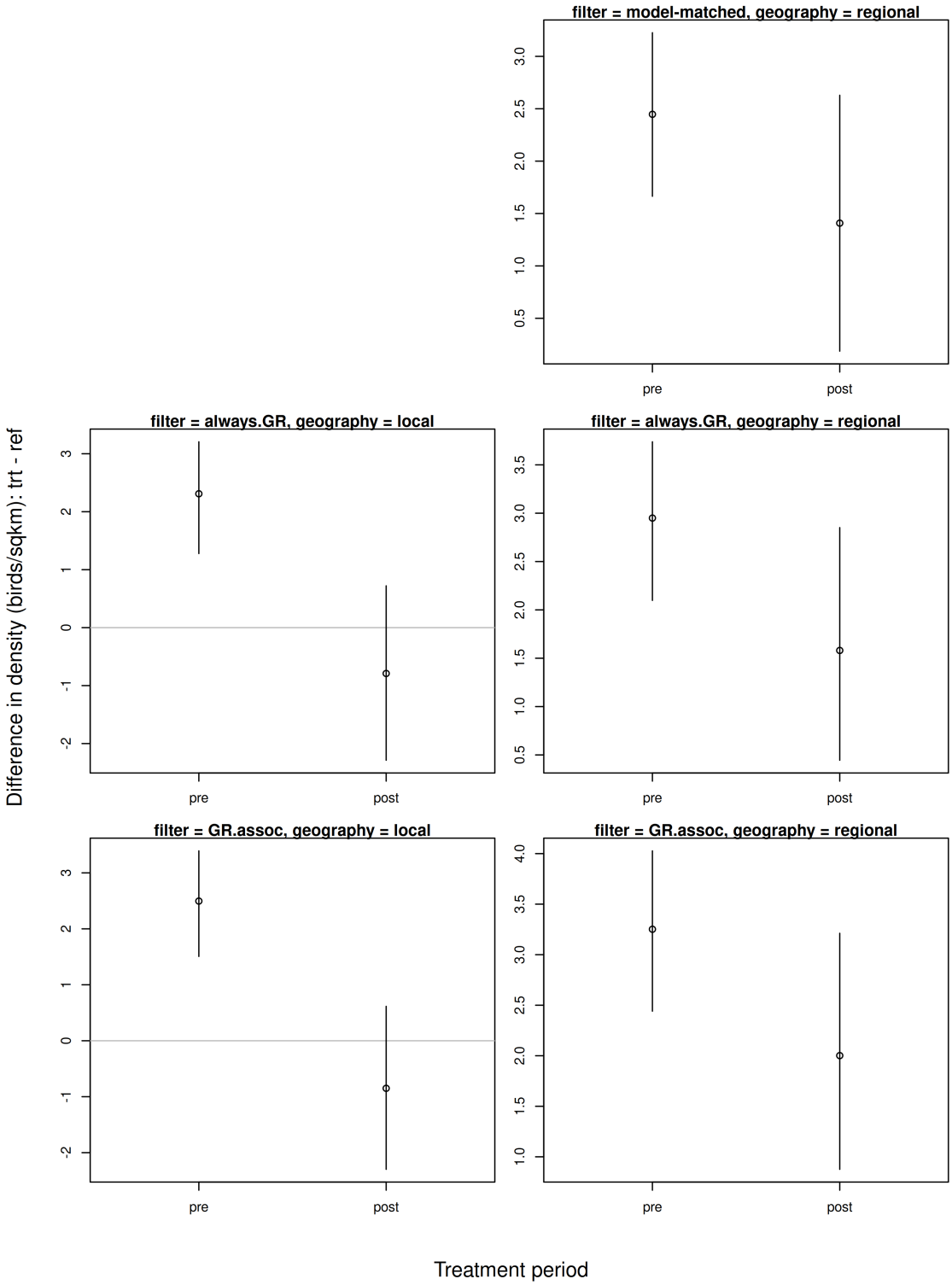


Figure B19. Differences in population densities before (pre) versus after (post) initiation of grazing management for Mourning Dove.

Mountain Plover

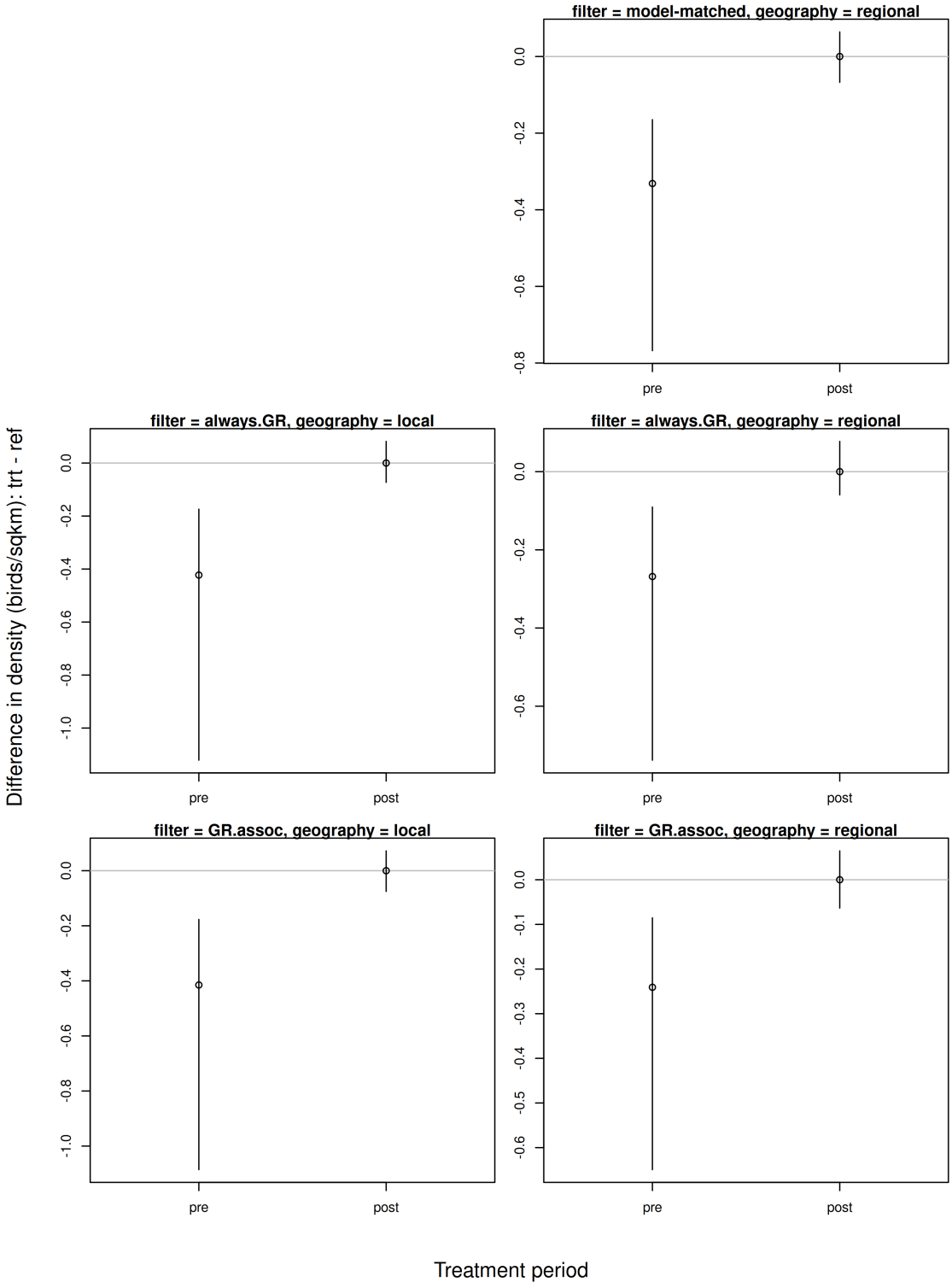


Figure B20. Differences in population densities before (pre) versus after (post) initiation of grazing management for Mountain Plover.

Northern Harrier

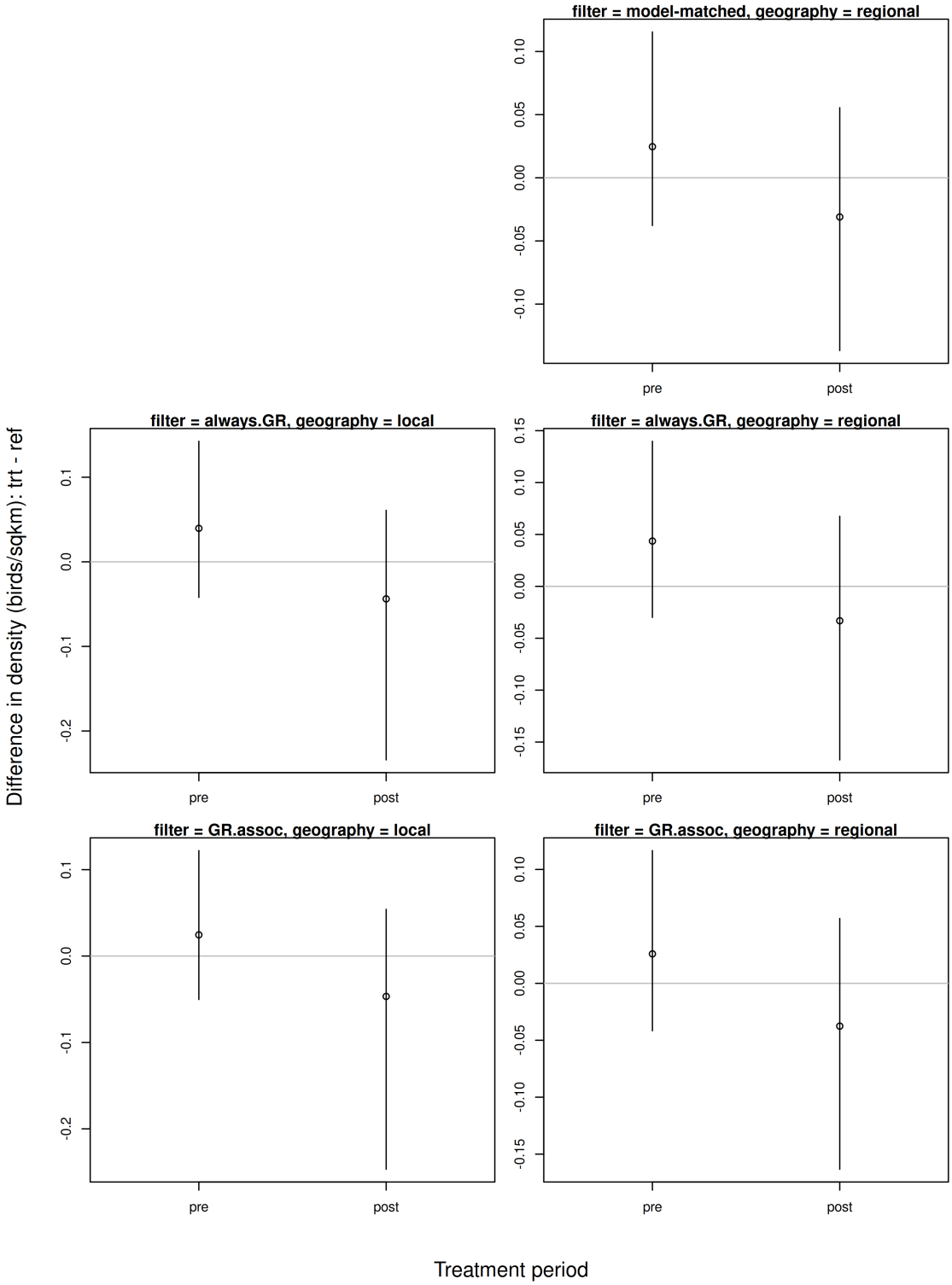


Figure B21. Differences in population densities before (pre) versus after (post) initiation of grazing management for Northern Harrier.

Prairie Falcon

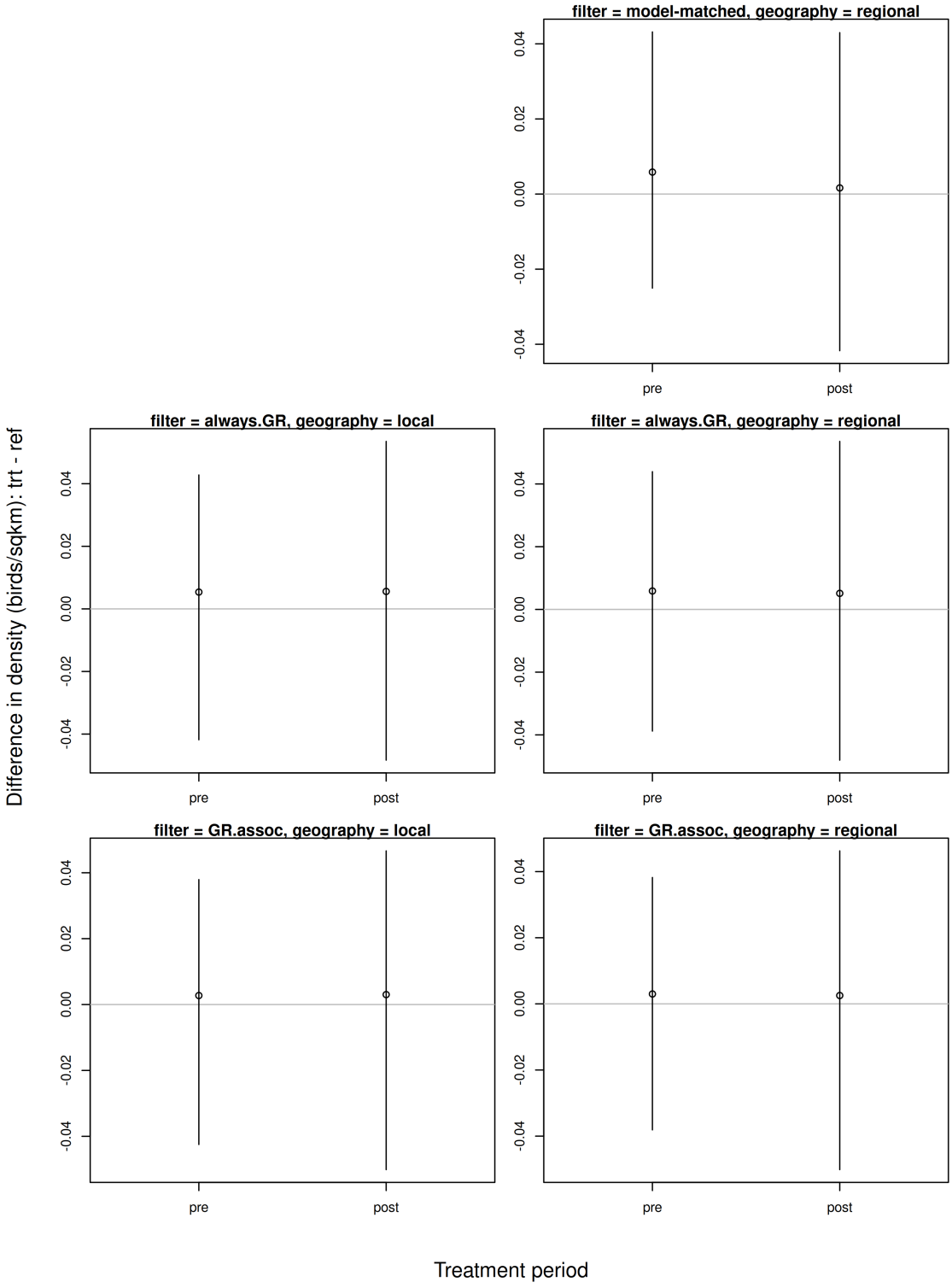


Figure B22. Differences in population densities before (pre) versus after (post) initiation of grazing management for Prairie Falcon.

Red-tailed Hawk

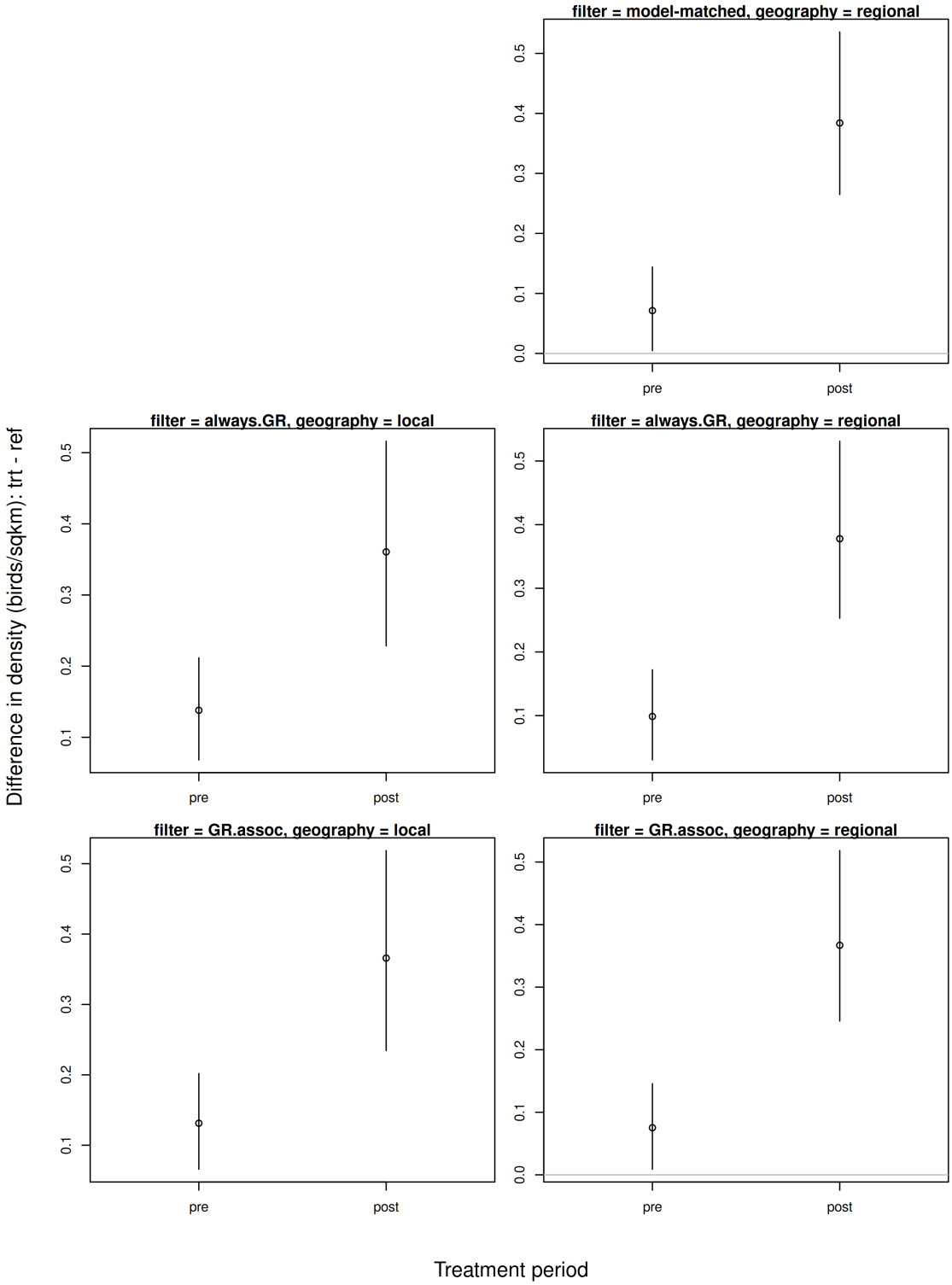


Figure B23. Differences in population densities before (pre) versus after (post) initiation of grazing management for Red-tailed Hawk.

Red-winged Blackbird

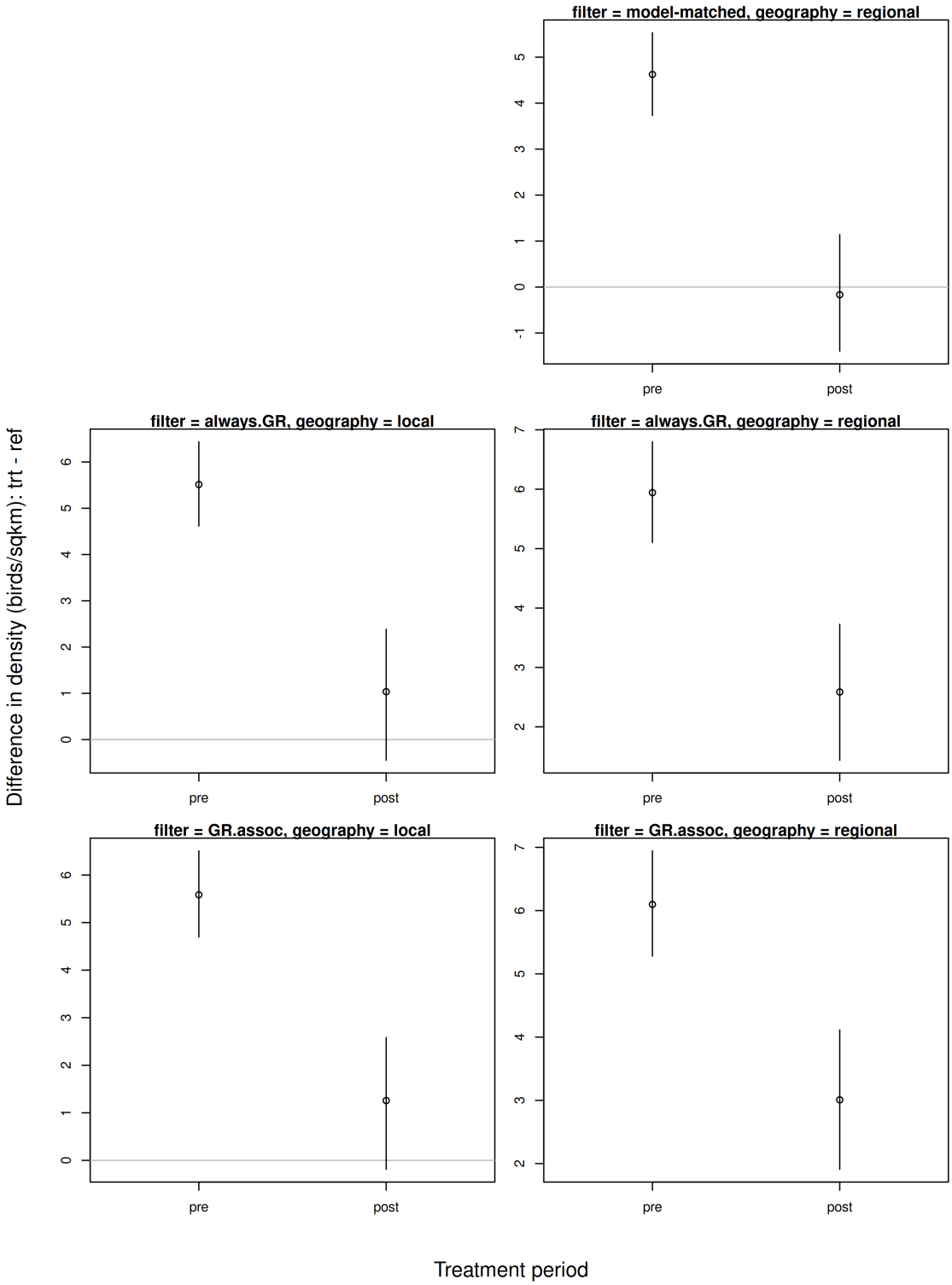


Figure B24. Differences in population densities before (pre) versus after (post) initiation of grazing management for Red-winged Blackbird.

Say's Phoebe

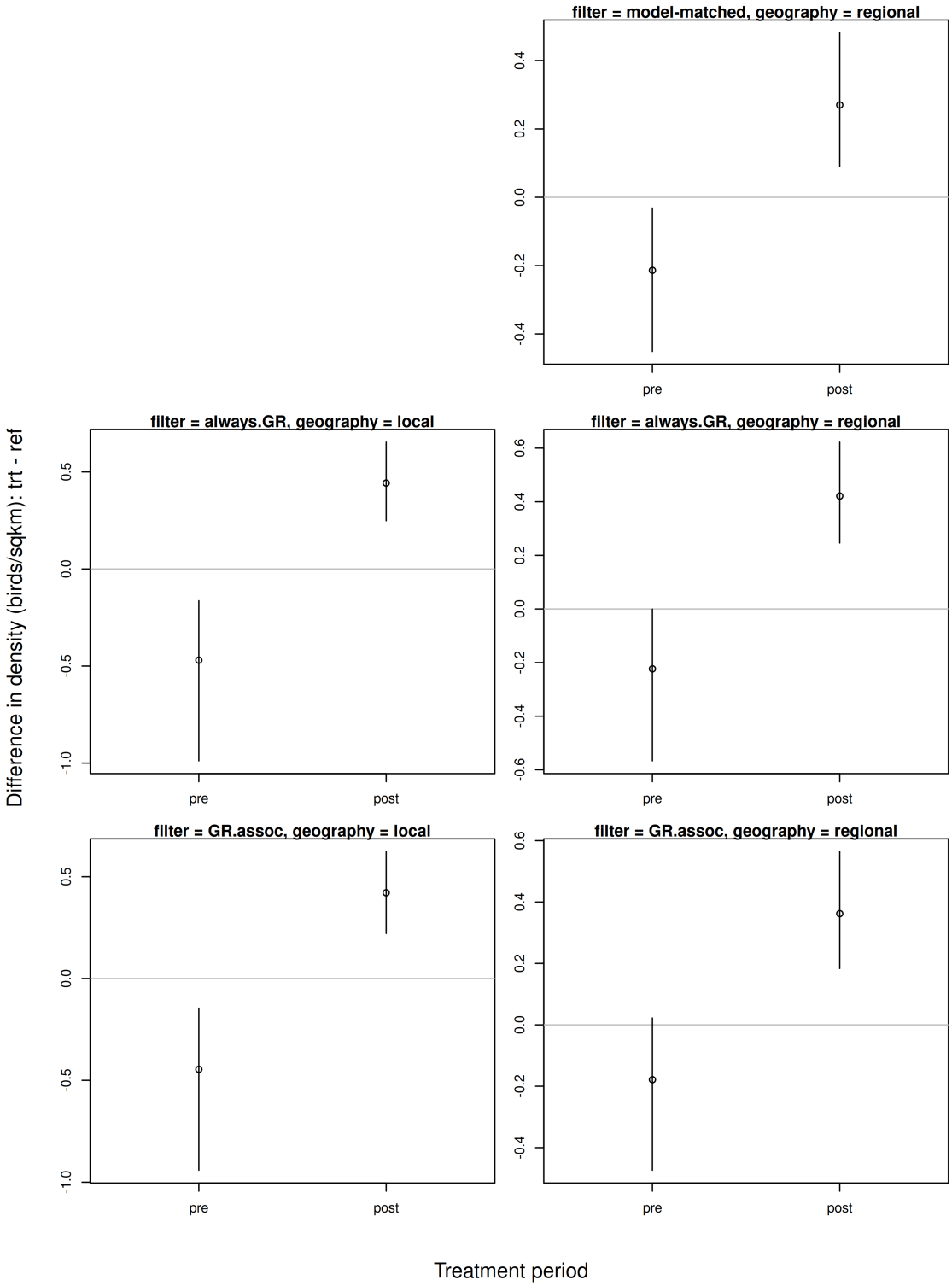


Figure B25. Differences in population densities before (pre) versus after (post) initiation of grazing management for Say's Phoebe.

Savannah Sparrow

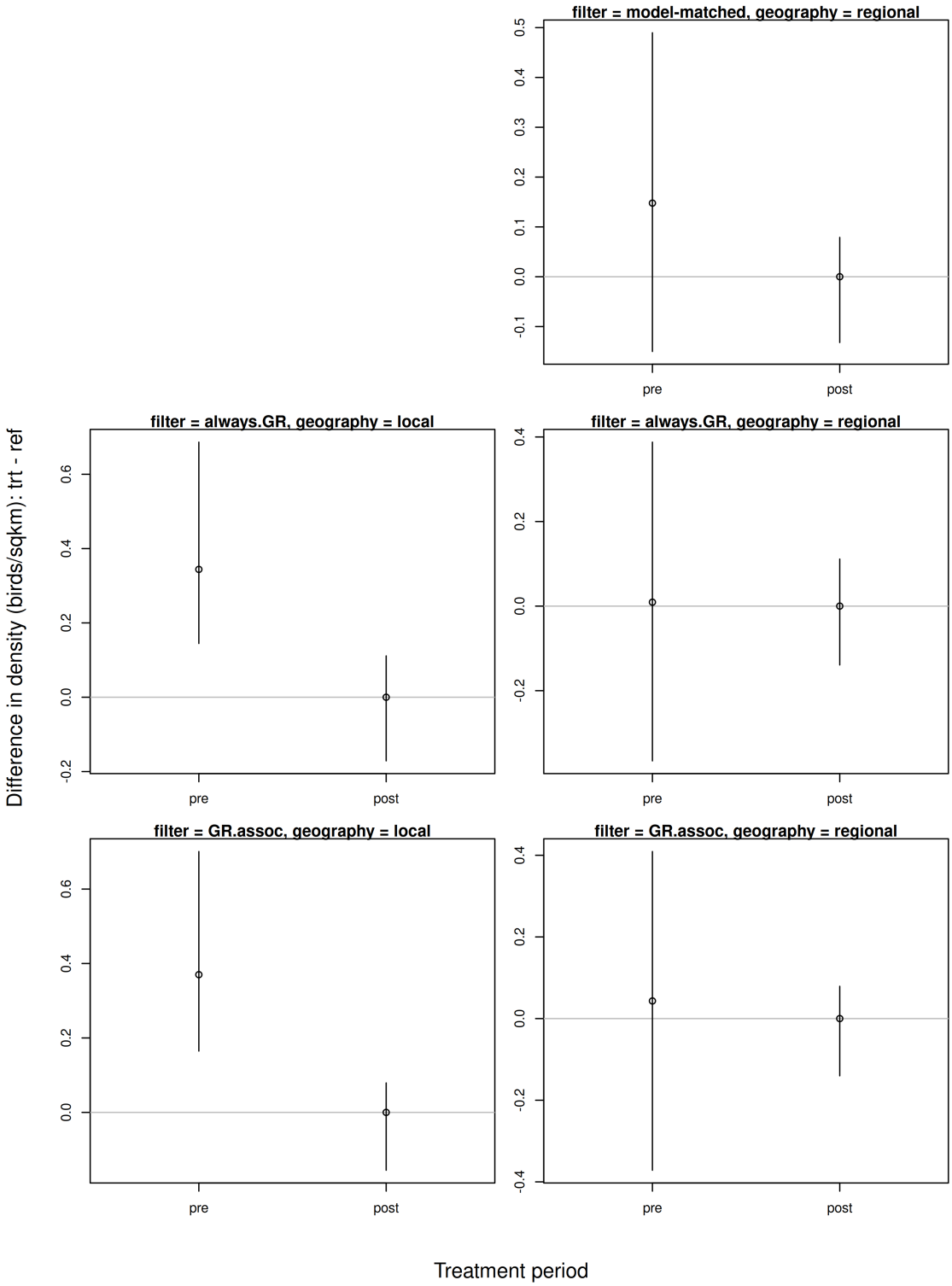


Figure B26. Differences in population densities before (pre) versus after (post) initiation of grazing management for Savannah Sparrow.

Swainson's Hawk

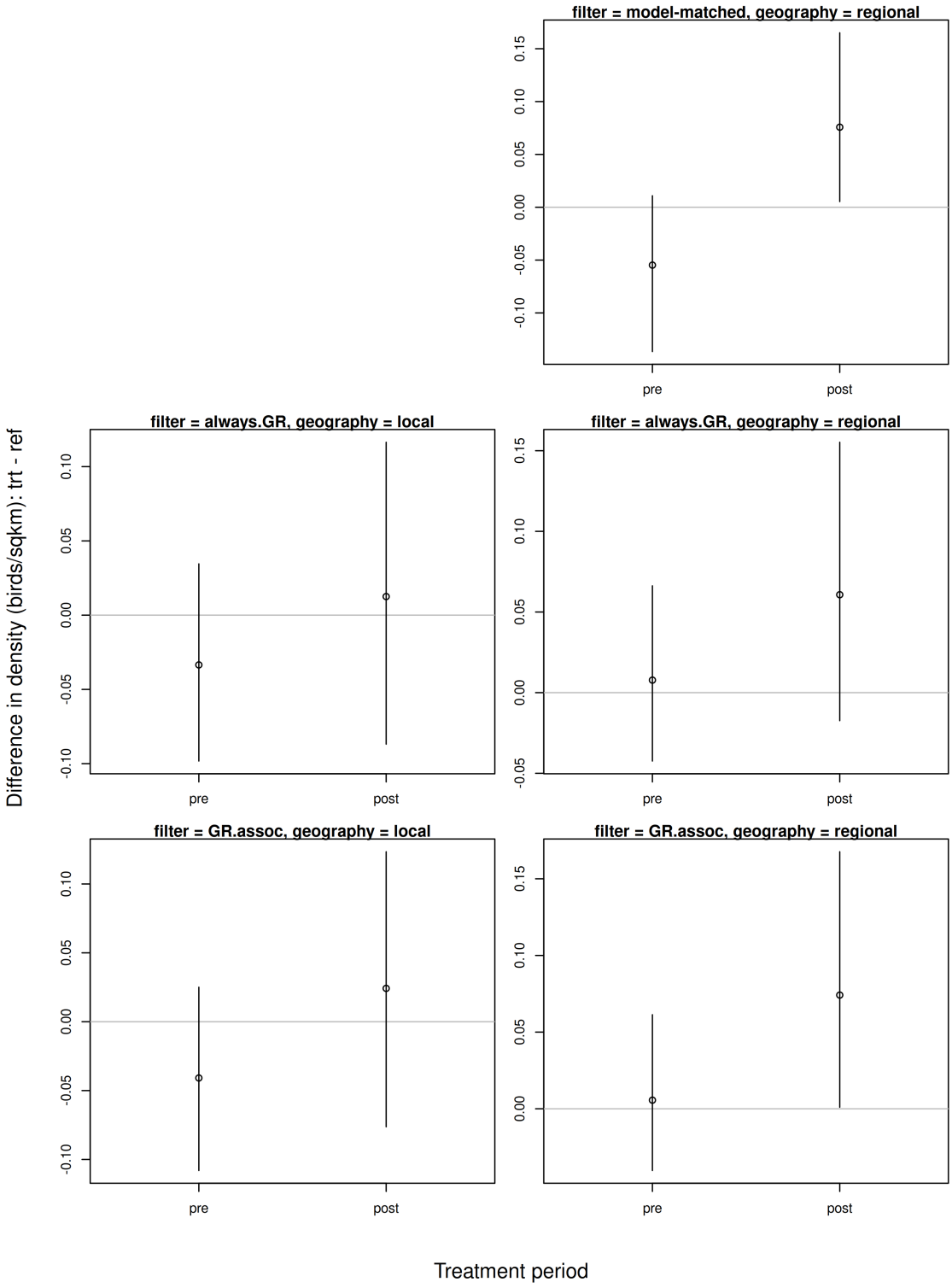


Figure B27. Differences in population densities before (pre) versus after (post) initiation of grazing management for Swainson's Hawk.

Vesper Sparrow

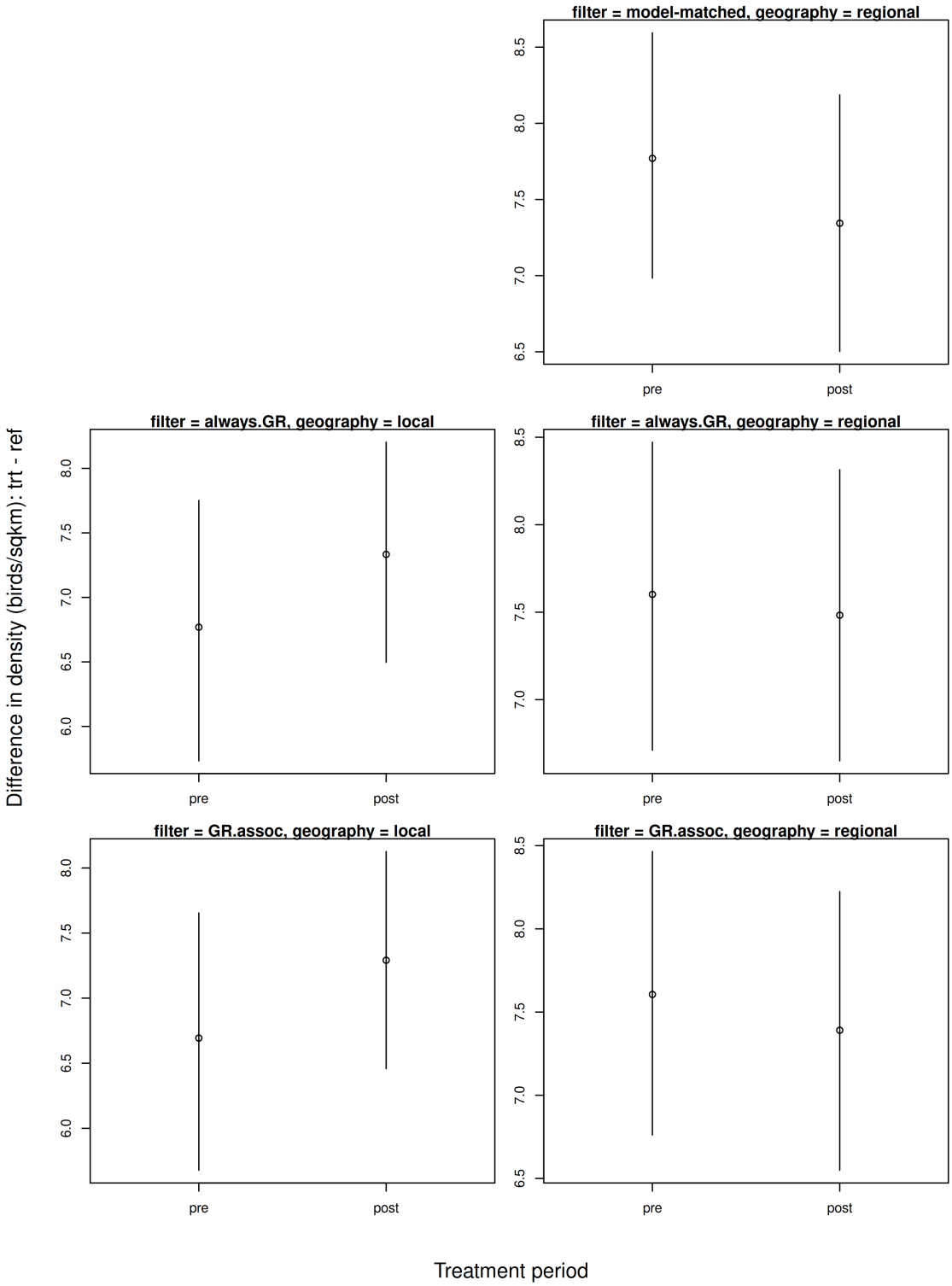


Figure B28. Differences in population densities before (pre) versus after (post) initiation of grazing management for Vesper Sparrow.

Western Kingbird

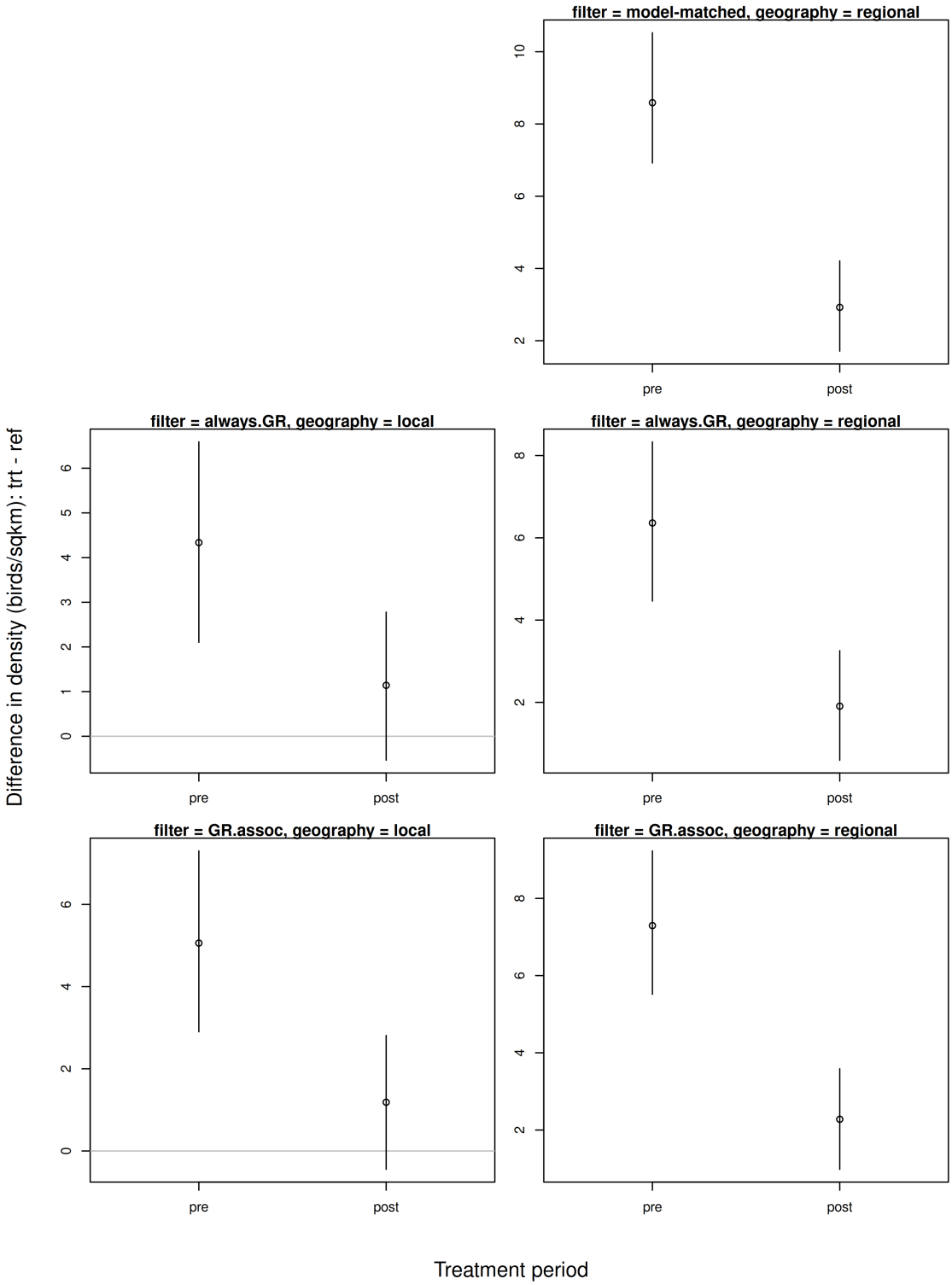


Figure B29. Differences in population densities before (pre) versus after (post) initiation of grazing management for Western Kingbird.

Western Meadowlark

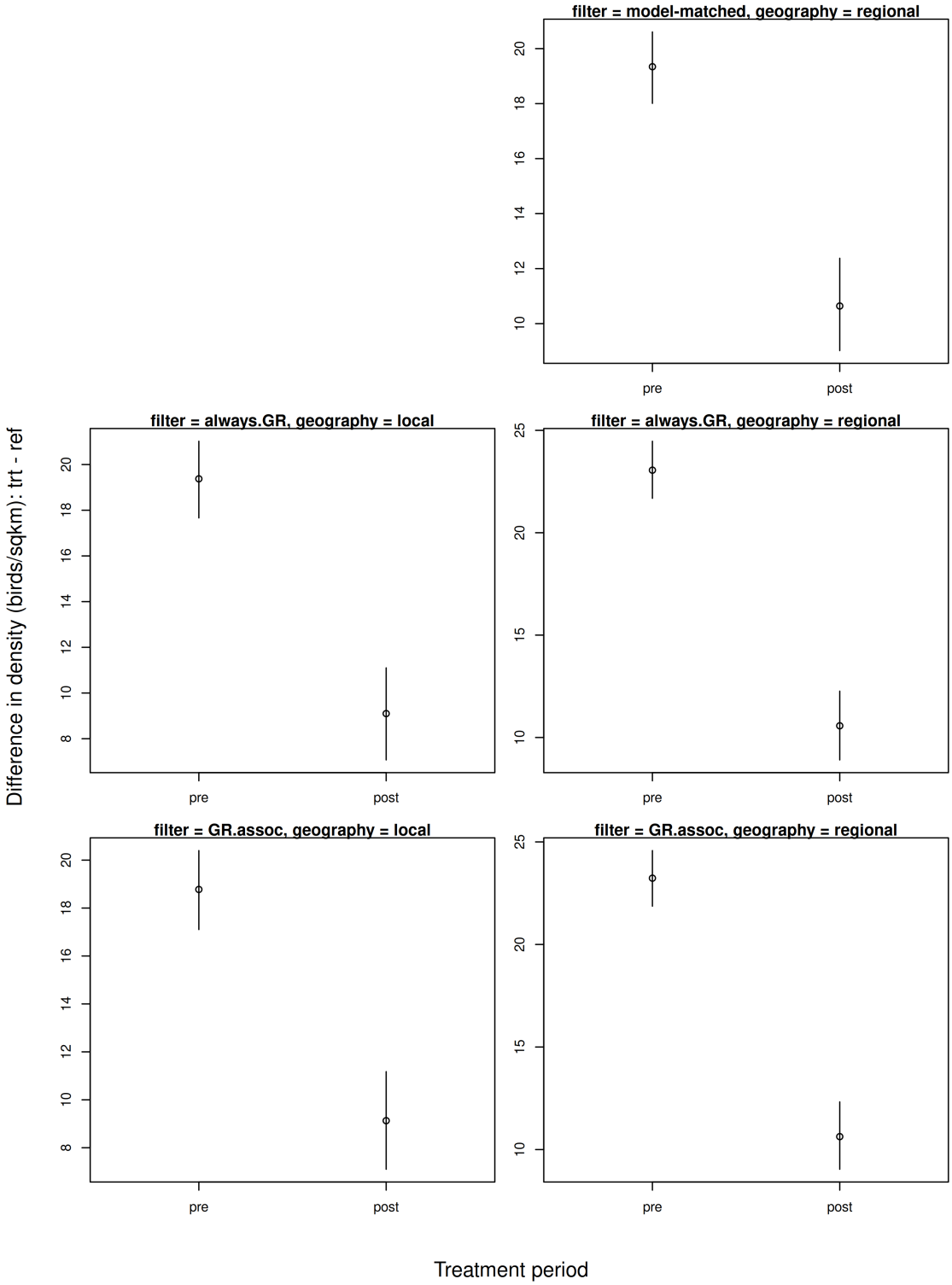


Figure B30. Differences in population densities before (pre) versus after (post) initiation of grazing management for Western Meadowlark.

Appendix C — Figures showing yearly differences between Lowry Ranch and reference population densities before (2012–2014) and after (2024–2025) initiation of grazing management.

Each figure displays five panels corresponding to the reference sample comparisons summarized in Table 2 and Table 4. Panel headers indicate the grassland classification filter applied to the comparison ("model-matched," "always.GR" [Always grassland], or "GR.assoc" [Grassland associated]) and the geographic scope of the reference sample ("local" or "regional"). Within each panel, points and error bars show the estimated difference in population density (Lowry minus reference, birds/sqkm) with 90% credible intervals for each individual survey year; the horizontal gray line marks a difference of zero (i.e., no effect), and the dashed vertical line marks the boundary between the pre-management (2012–2014) and post-management (2024–2025) periods.

American Kestrel

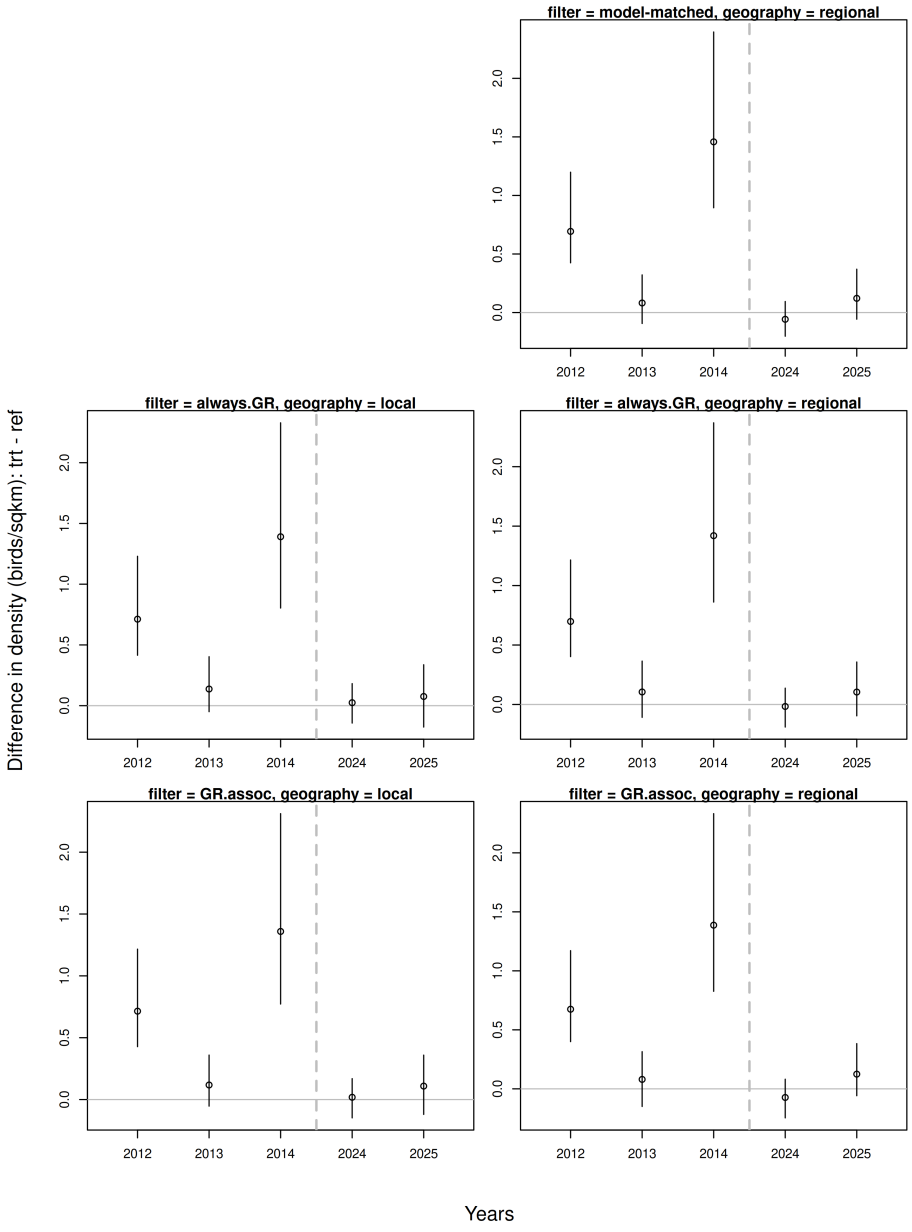


Figure C1. Yearly differences in population densities before (pre) and after (post) initiation of grazing management for American Kestrel.

Barn Swallow

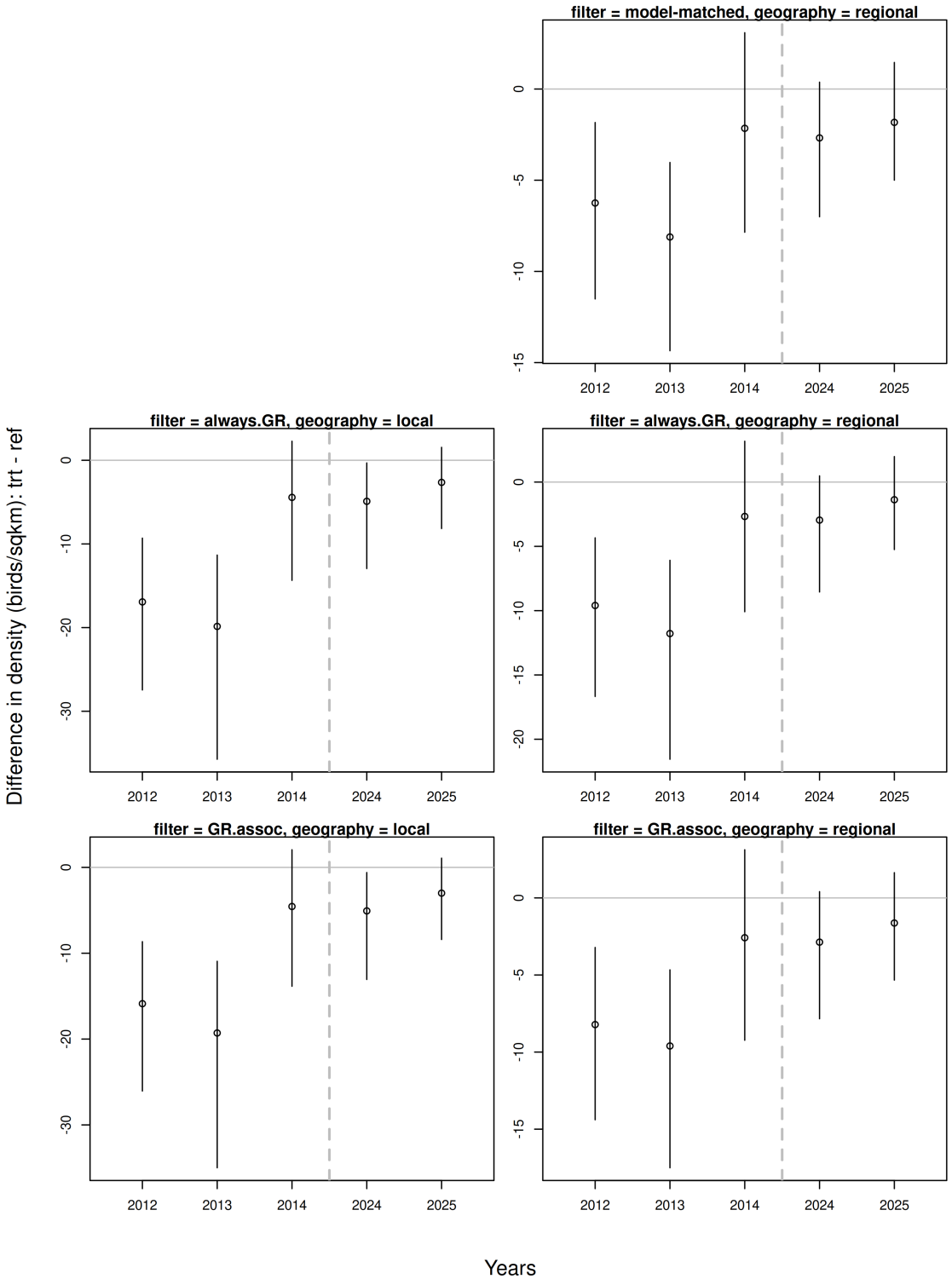


Figure C2. Yearly differences in population densities before (pre) and after (post) initiation of grazing management for Barn Swallow.

Brown-headed Cowbird

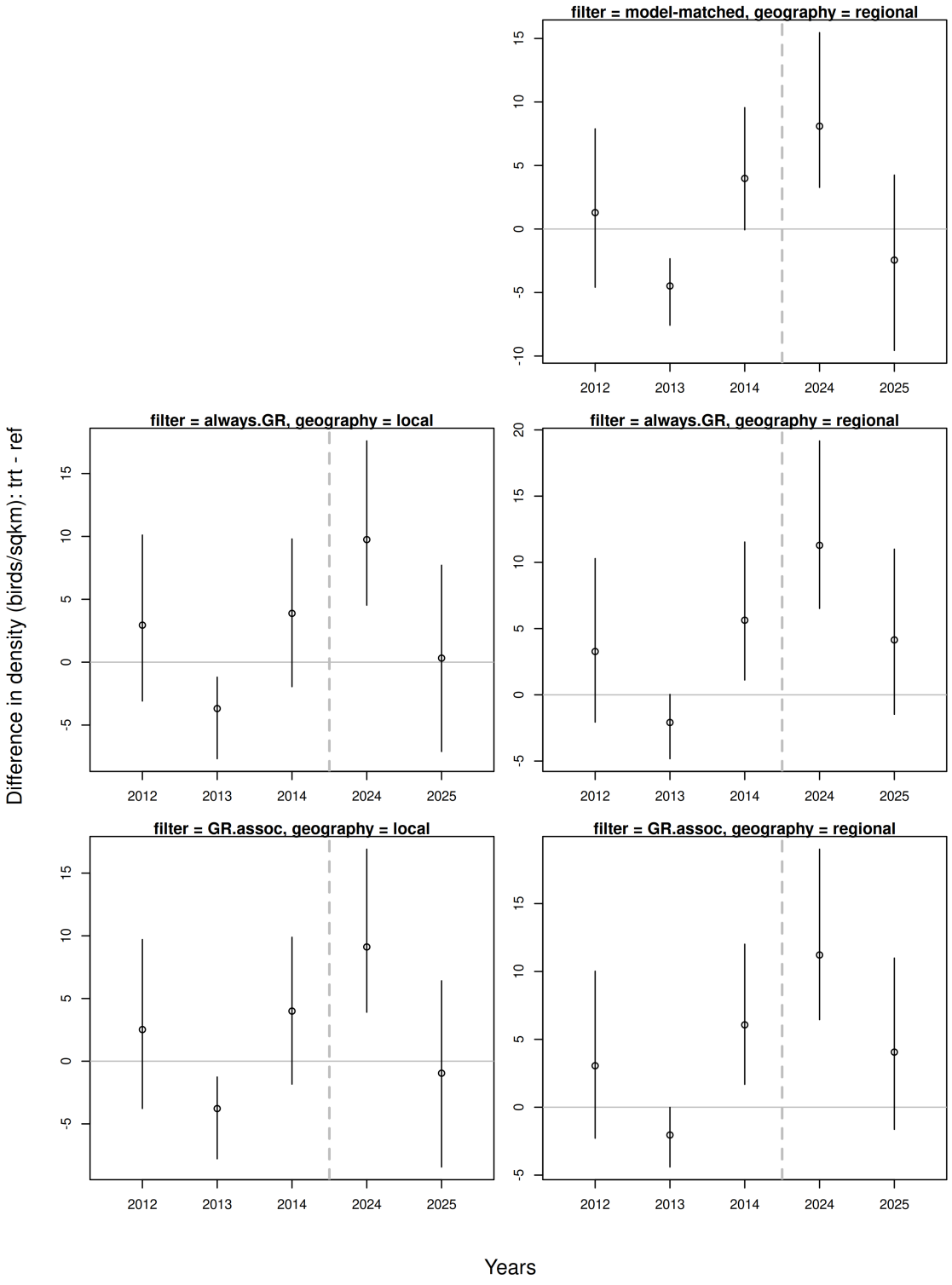


Figure C3. Yearly differences in population densities before (pre) and after (post) initiation of grazing management for Brown-headed Cowbird.

Brewer's Blackbird

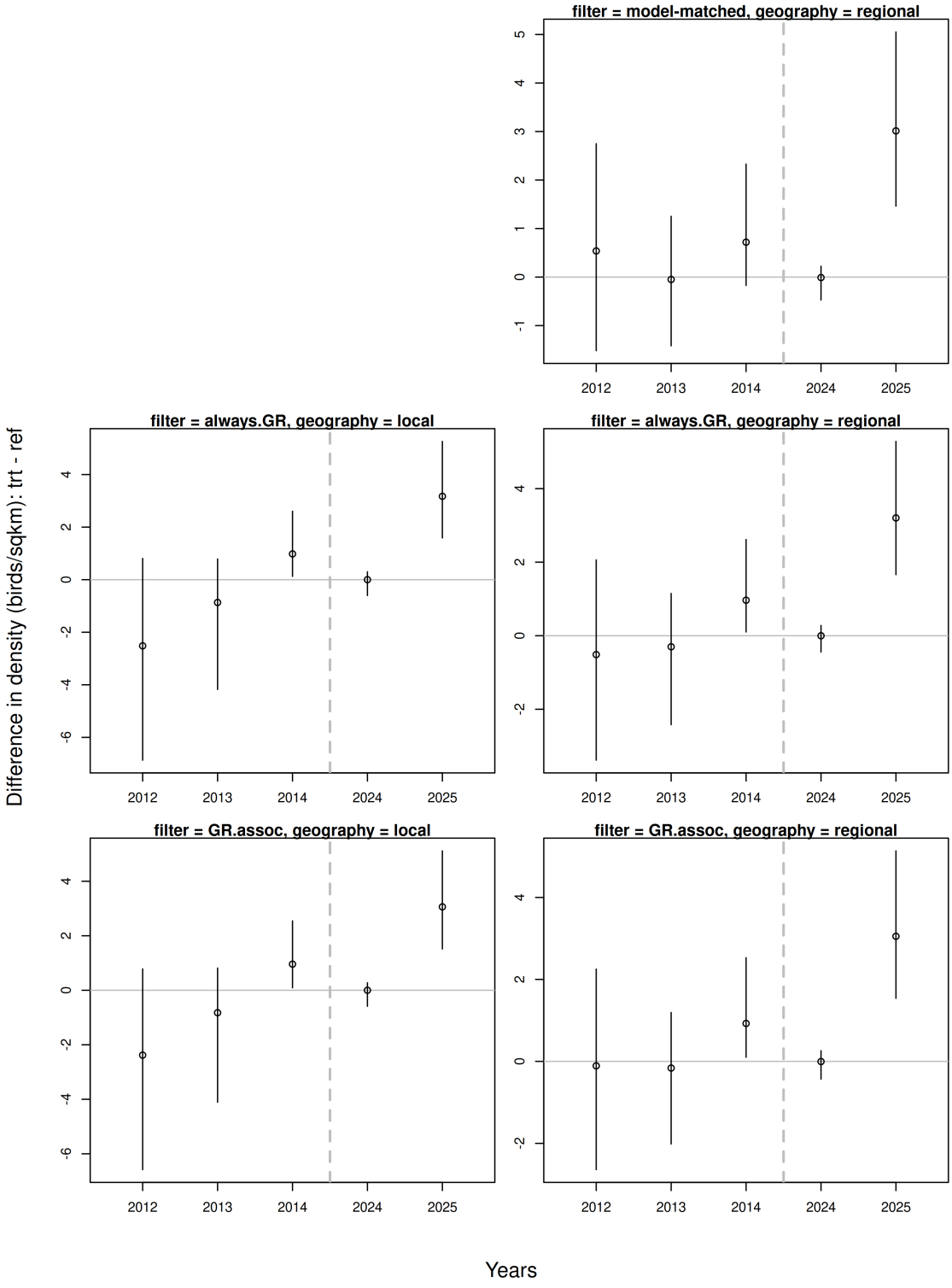


Figure C4. Yearly differences in population densities before (pre) and after (post) initiation of grazing management for Brewer's Blackbird.

Burrowing Owl

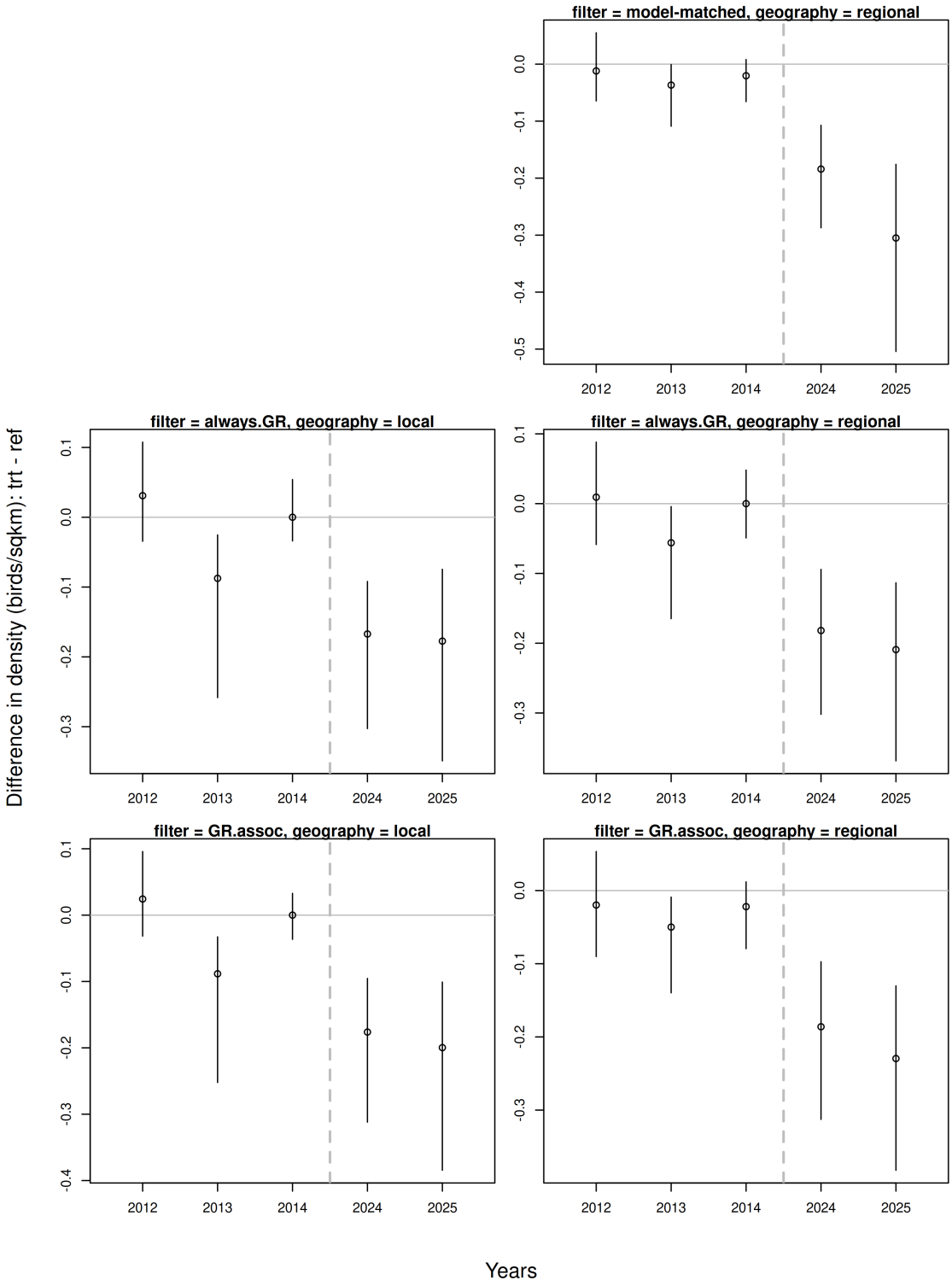


Figure C5. Yearly differences in population densities before (pre) and after (post) initiation of grazing management for Burrowing Owl.

Cassin's Kingbird

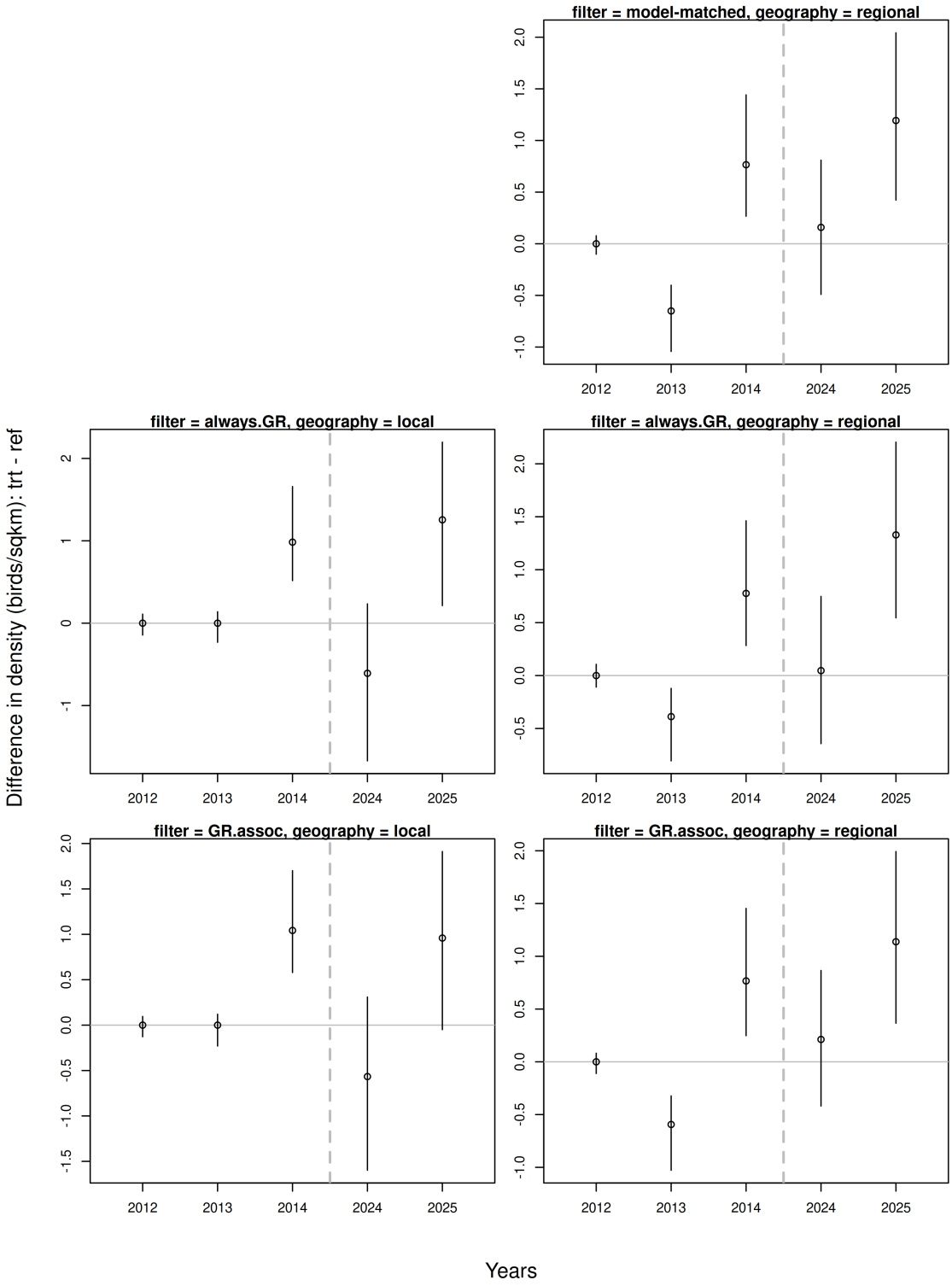


Figure C6. Yearly differences in population densities before (pre) and after (post) initiation of grazing management for Cassin's Kingbird.

Cassin's Sparrow

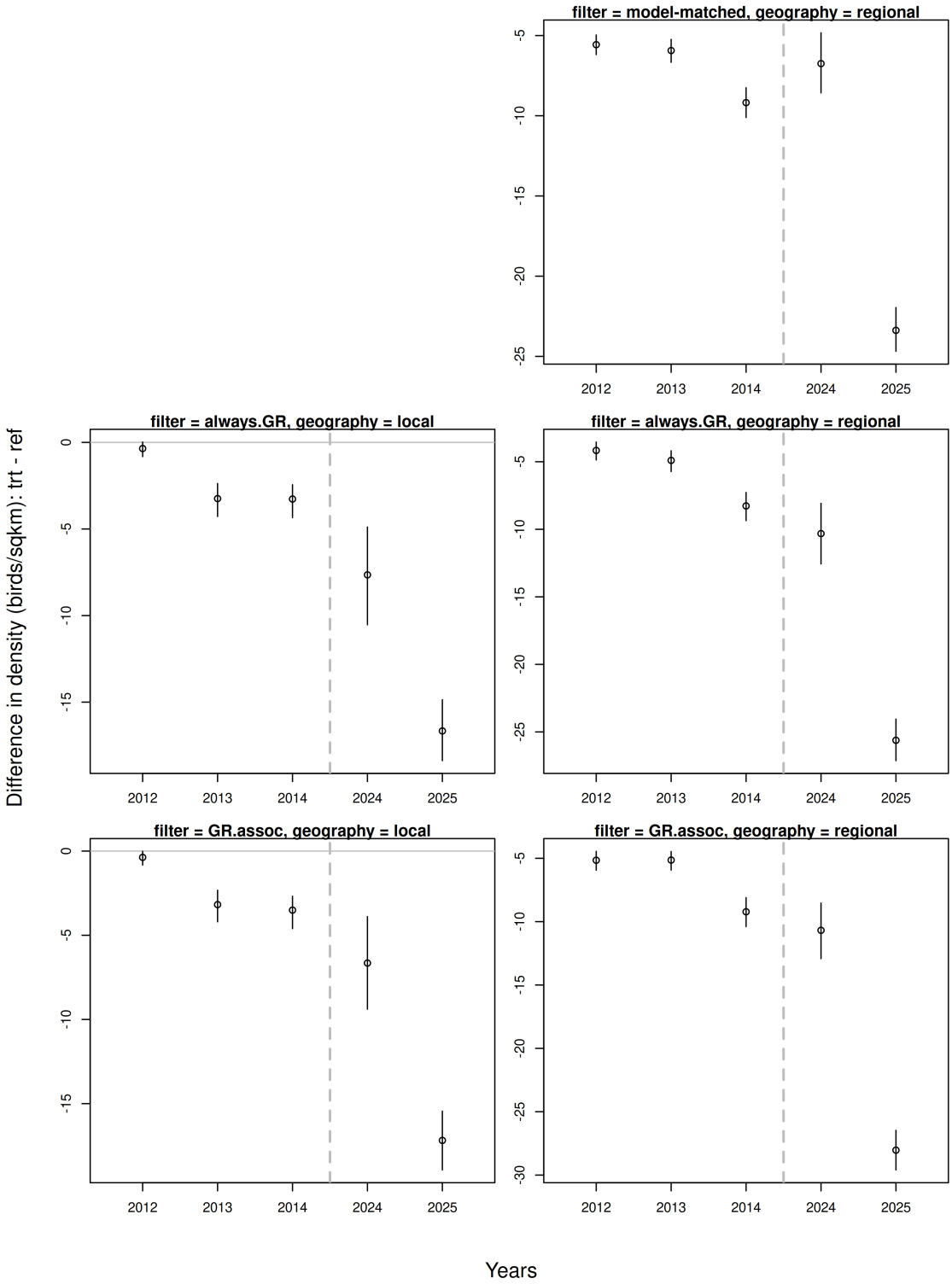


Figure C7. Yearly differences in population densities before (pre) and after (post) initiation of grazing management for Cassin's Sparrow.

Cliff Swallow

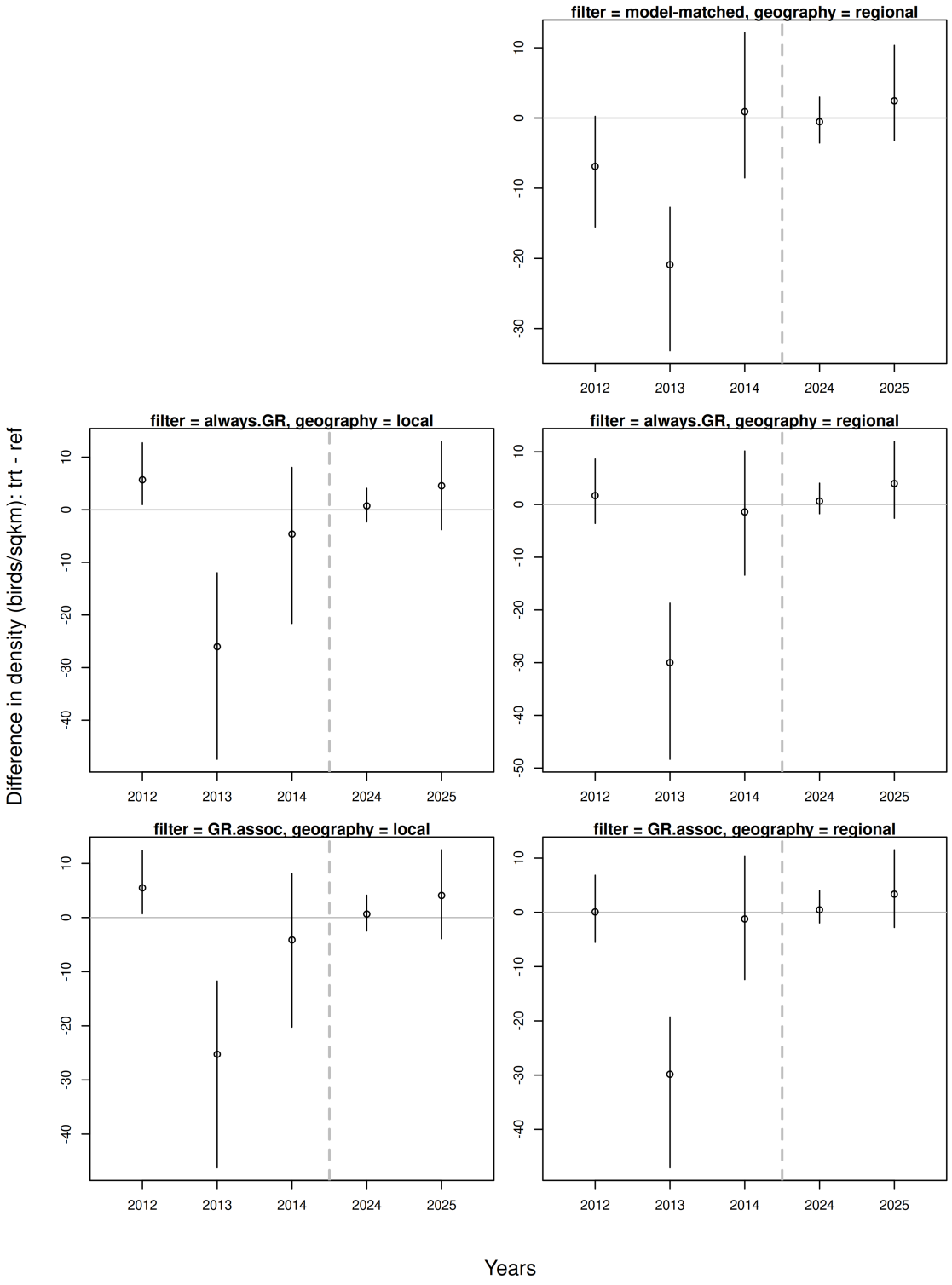


Figure C8. Yearly differences in population densities before (pre) and after (post) initiation of grazing management for Cliff Swallow.

Common Nighthawk

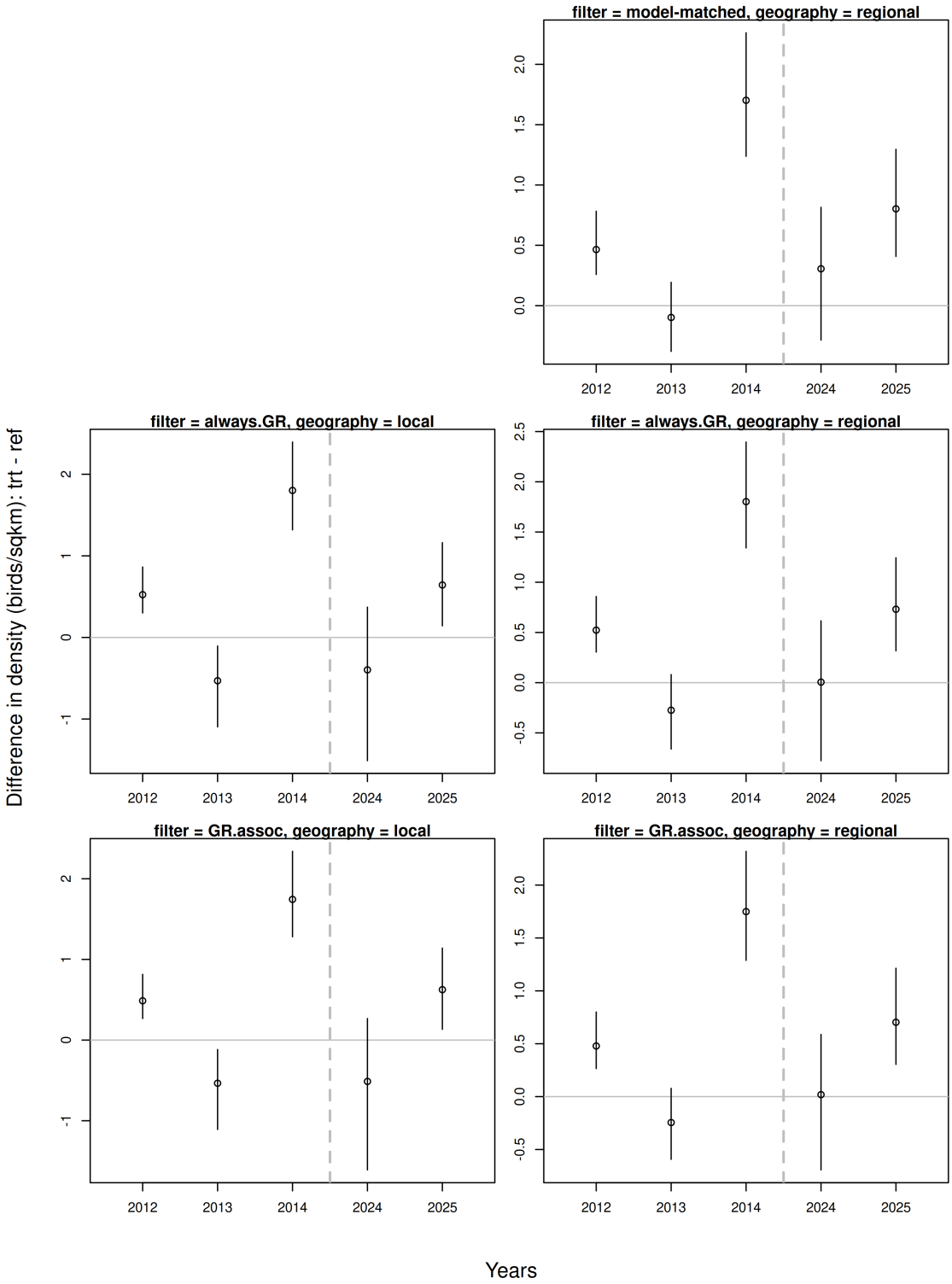


Figure C9. Yearly differences in population densities before (pre) and after (post) initiation of grazing management for Common Nighthawk.

Dickcissel

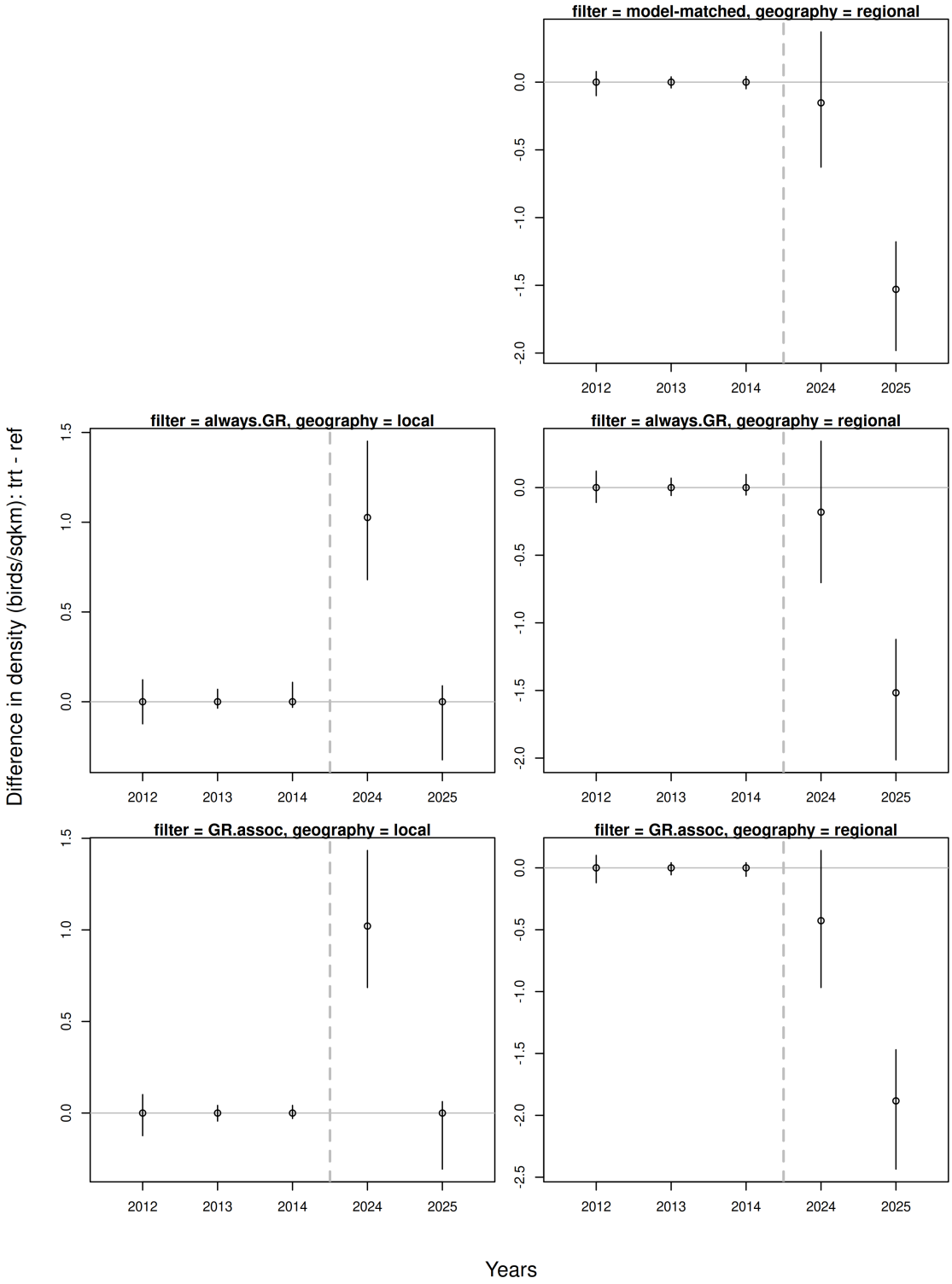


Figure C10. Yearly differences in population densities before (pre) and after (post) initiation of grazing management for Dickcissel.

Eastern Kingbird

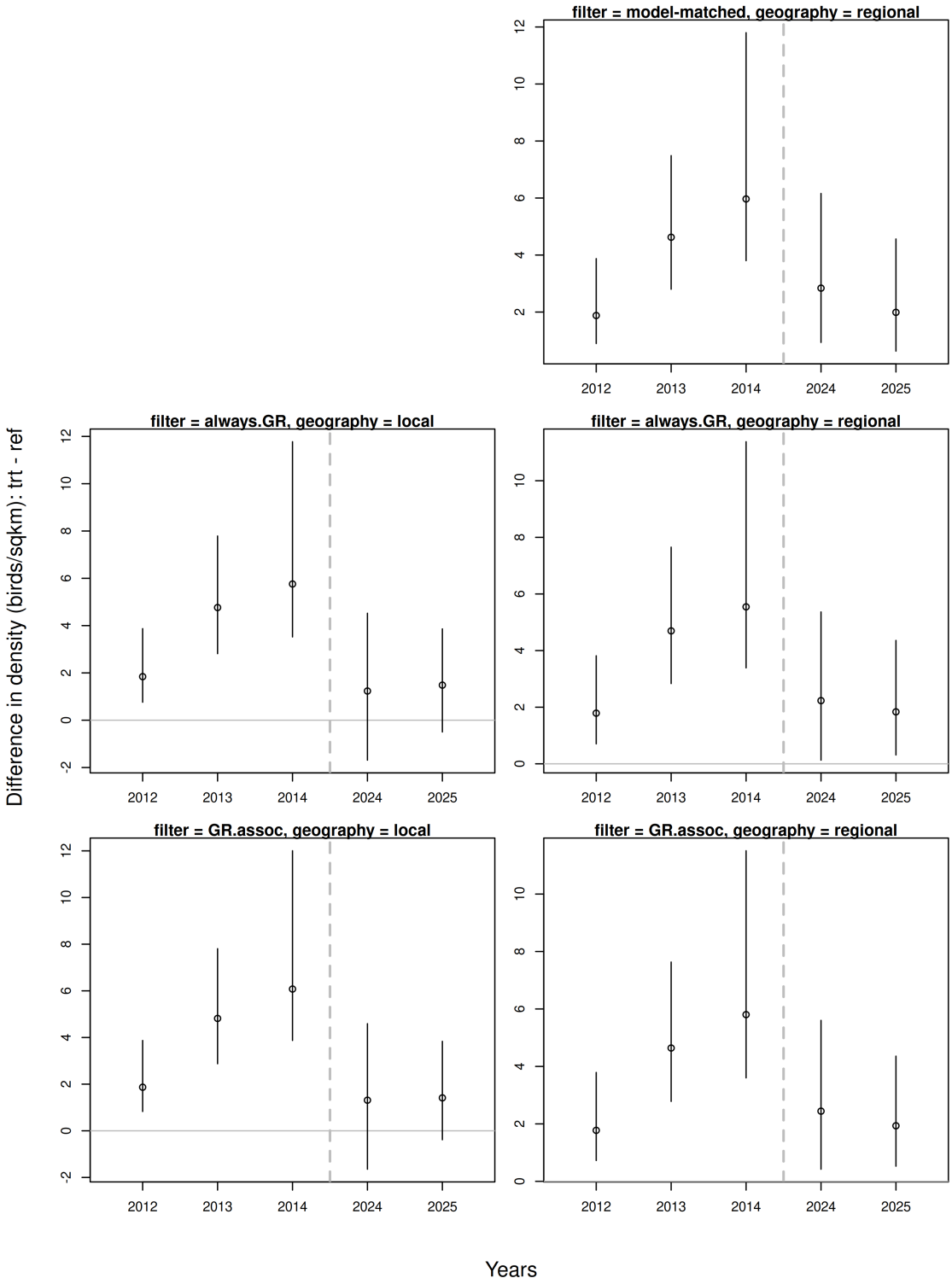


Figure C11. Yearly differences in population densities before (pre) and after (post) initiation of grazing management for Eastern Kingbird.

Ferruginous Hawk

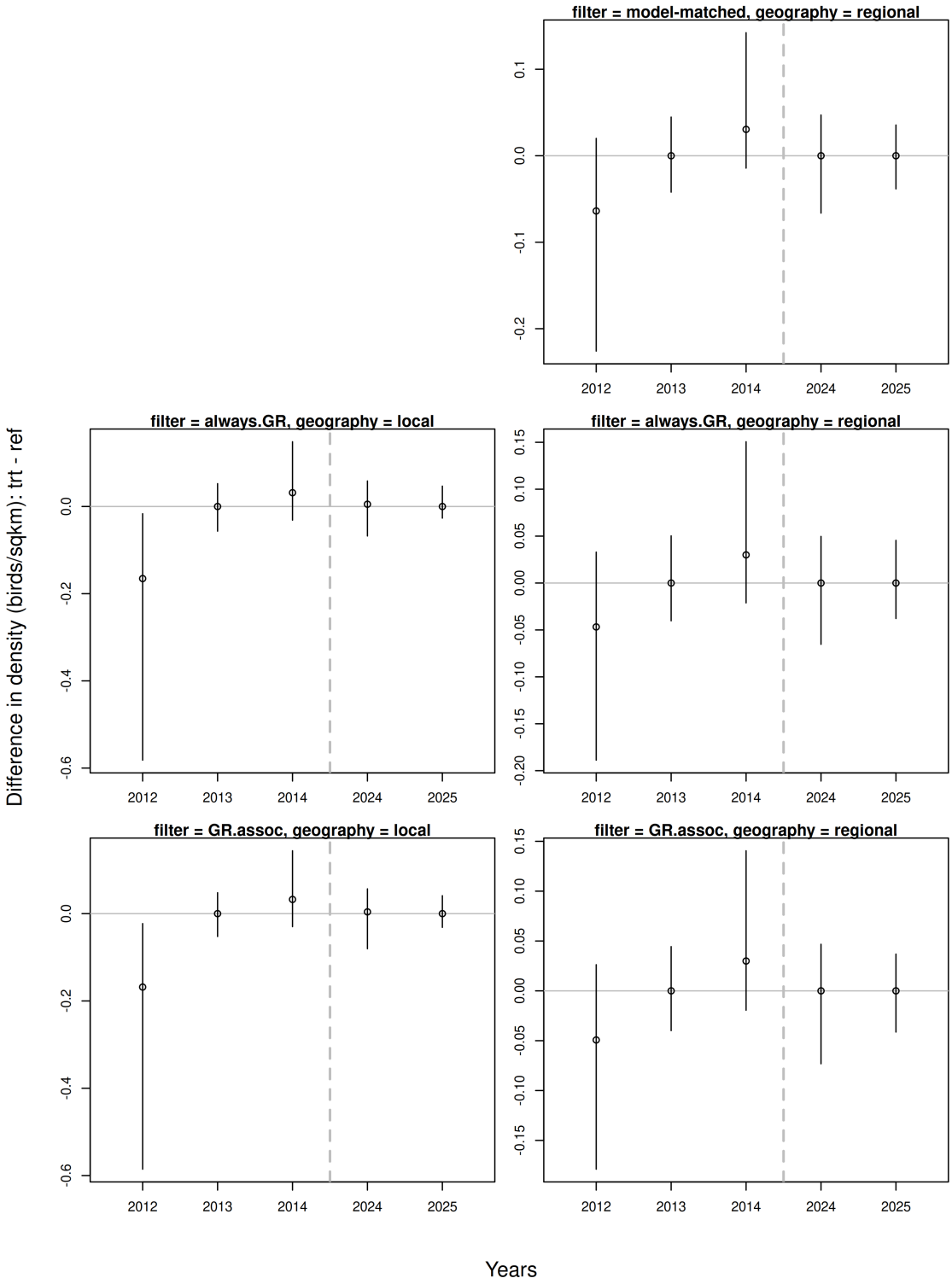


Figure C12. Yearly differences in population densities before (pre) and after (post) initiation of grazing management for Ferruginous Hawk.

Grasshopper Sparrow

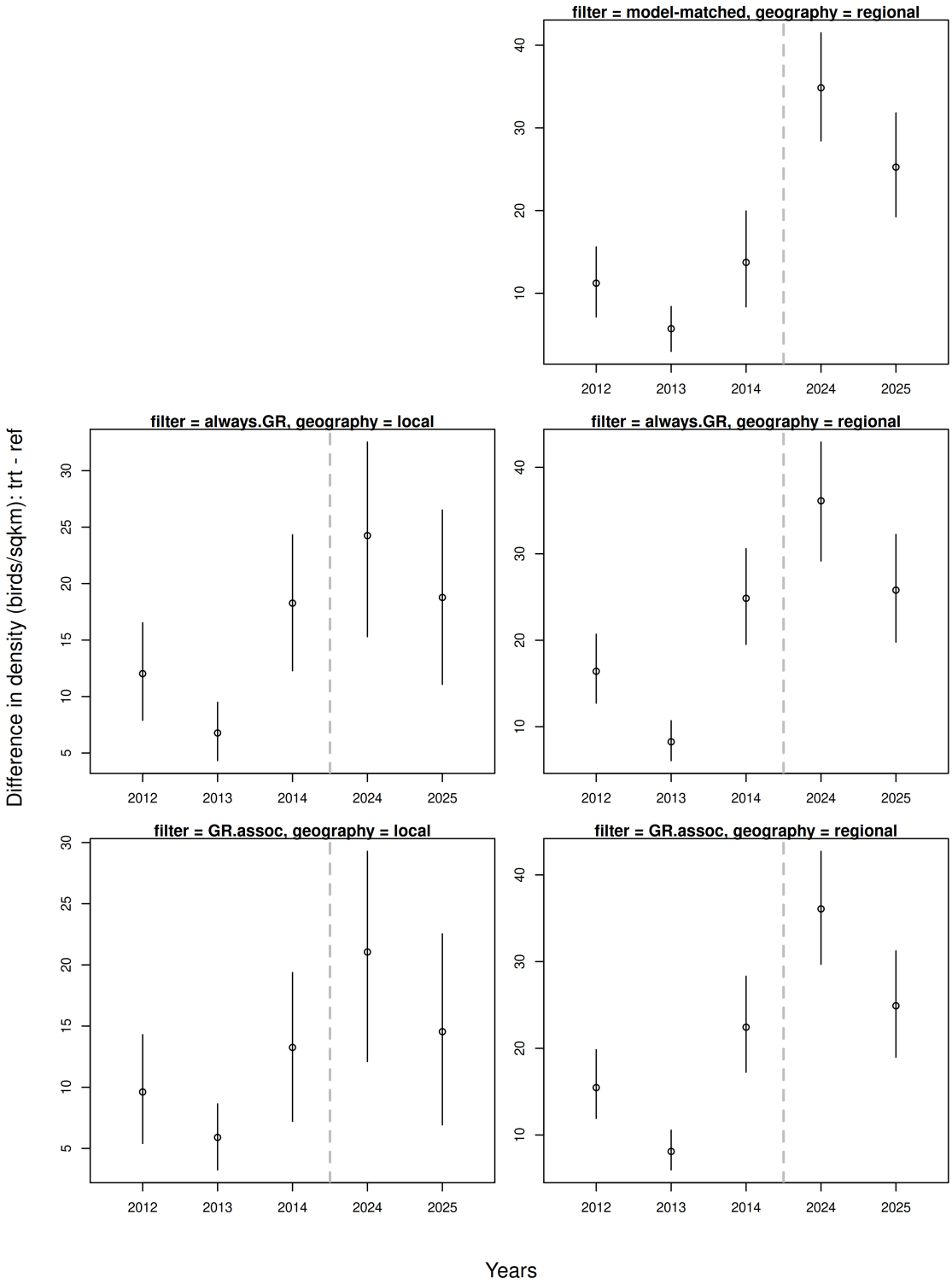


Figure C13. Yearly differences in population densities before (pre) and after (post) initiation of grazing management for Grasshopper Sparrow.

Horned Lark

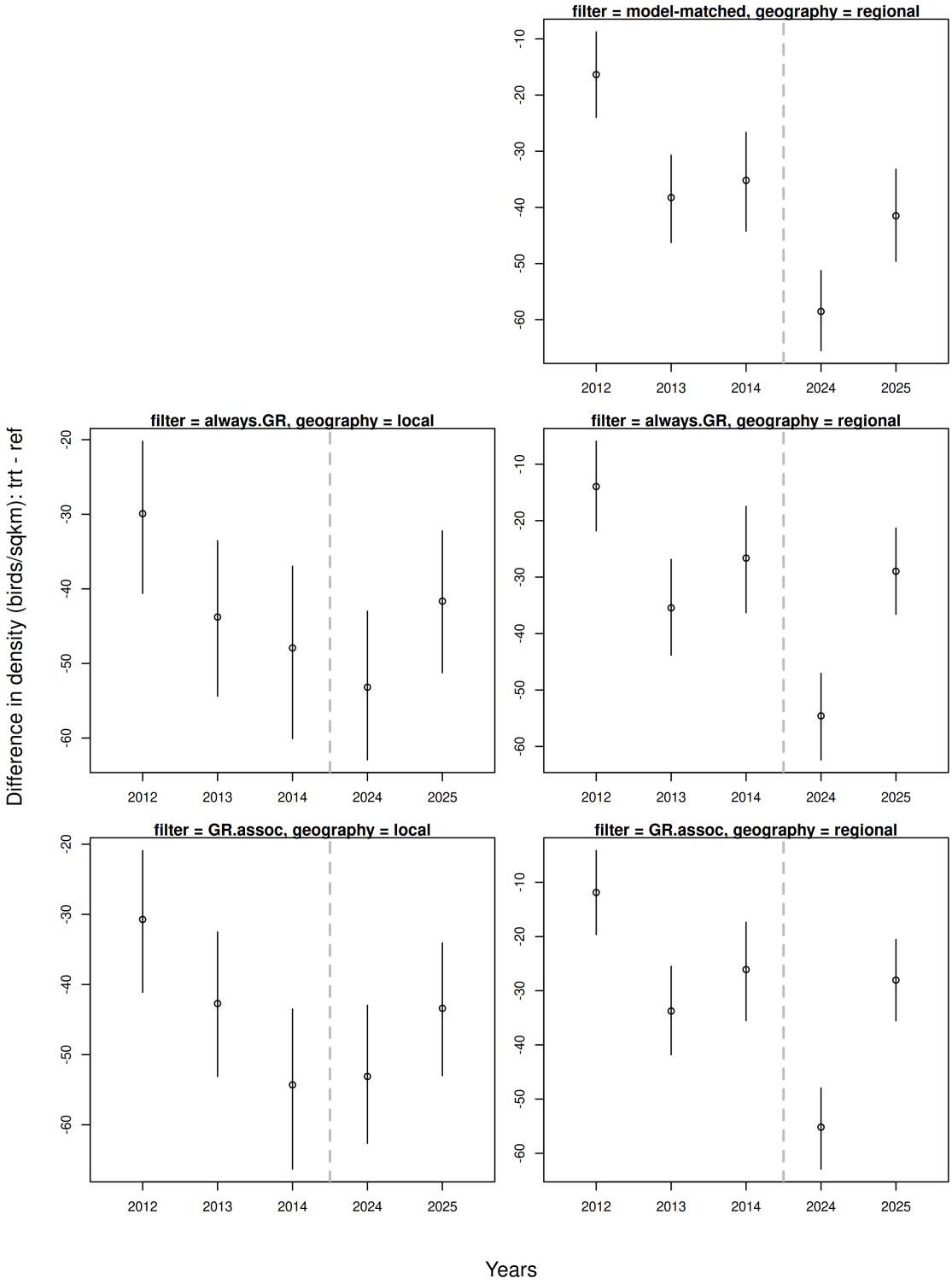


Figure C14. Yearly differences in population densities before (pre) and after (post) initiation of grazing management for Horned Lark.

Killdeer

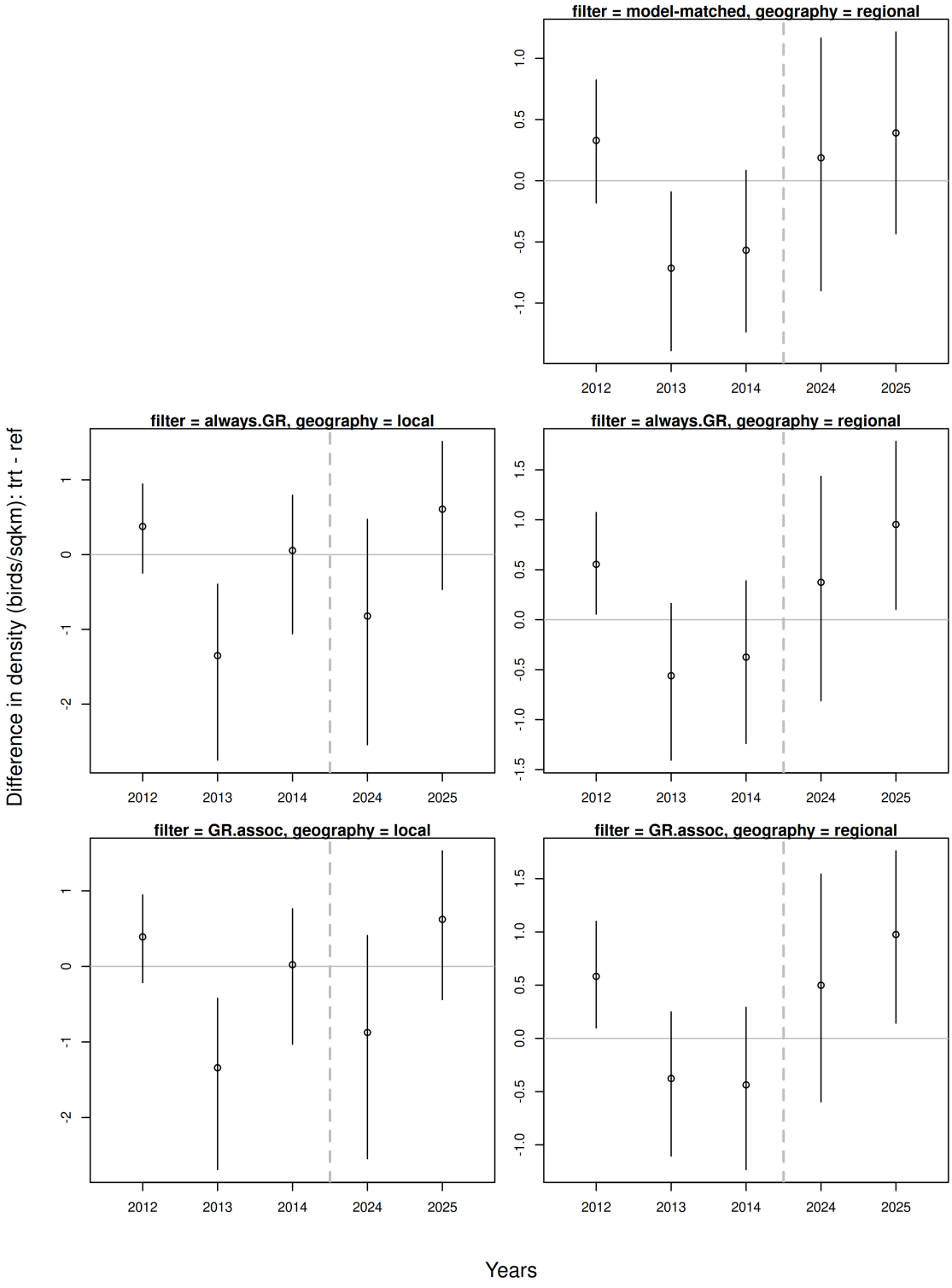


Figure C15. Yearly differences in population densities before (pre) and after (post) initiation of grazing management for Killdeer.

Lark Bunting

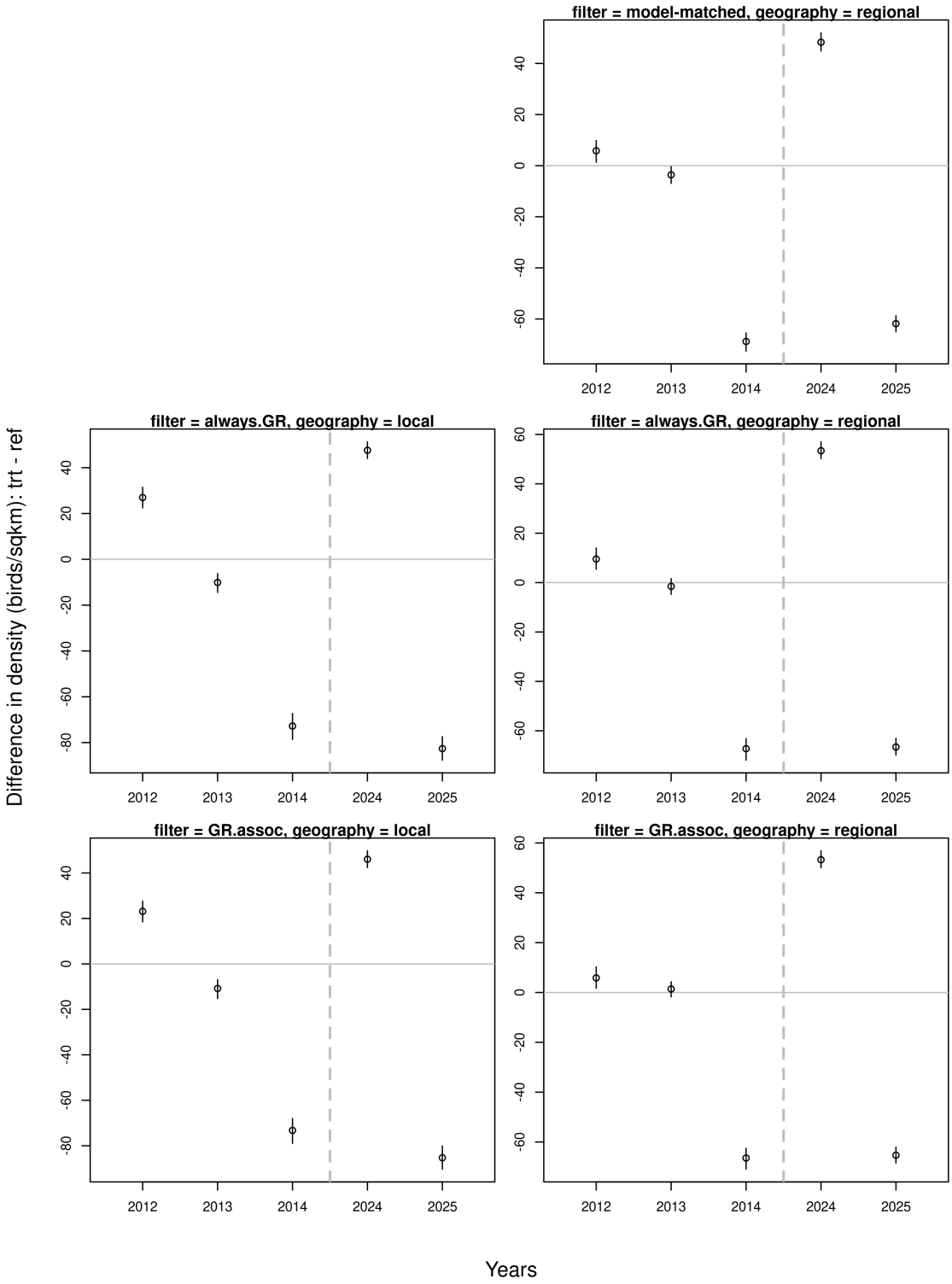


Figure C16. Yearly differences in population densities before (pre) and after (post) initiation of grazing management for Lark Bunting.

Lark Sparrow

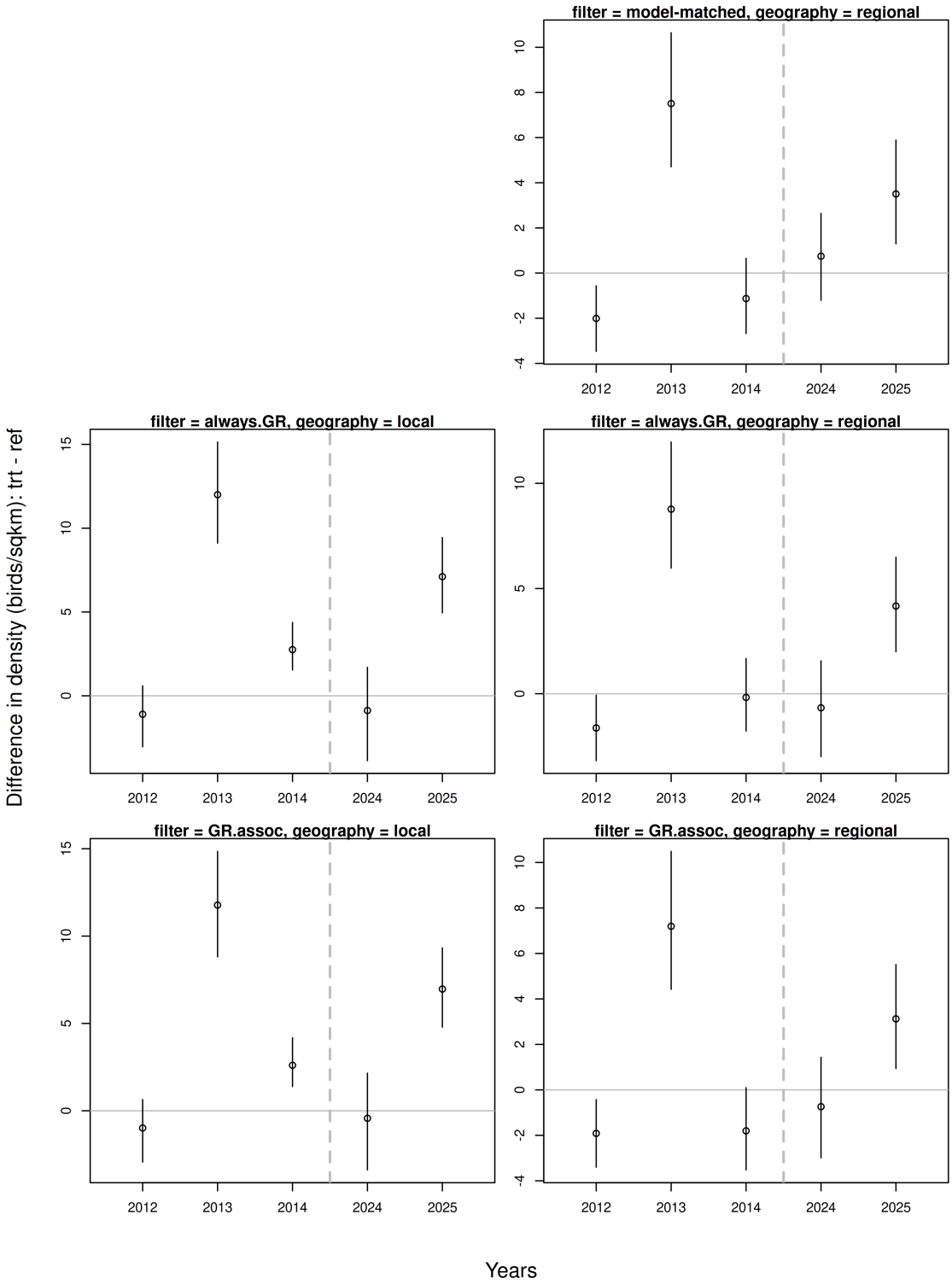


Figure C17. Yearly differences in population densities before (pre) and after (post) initiation of grazing management for Lark Sparrow.

Loggerhead Shrike

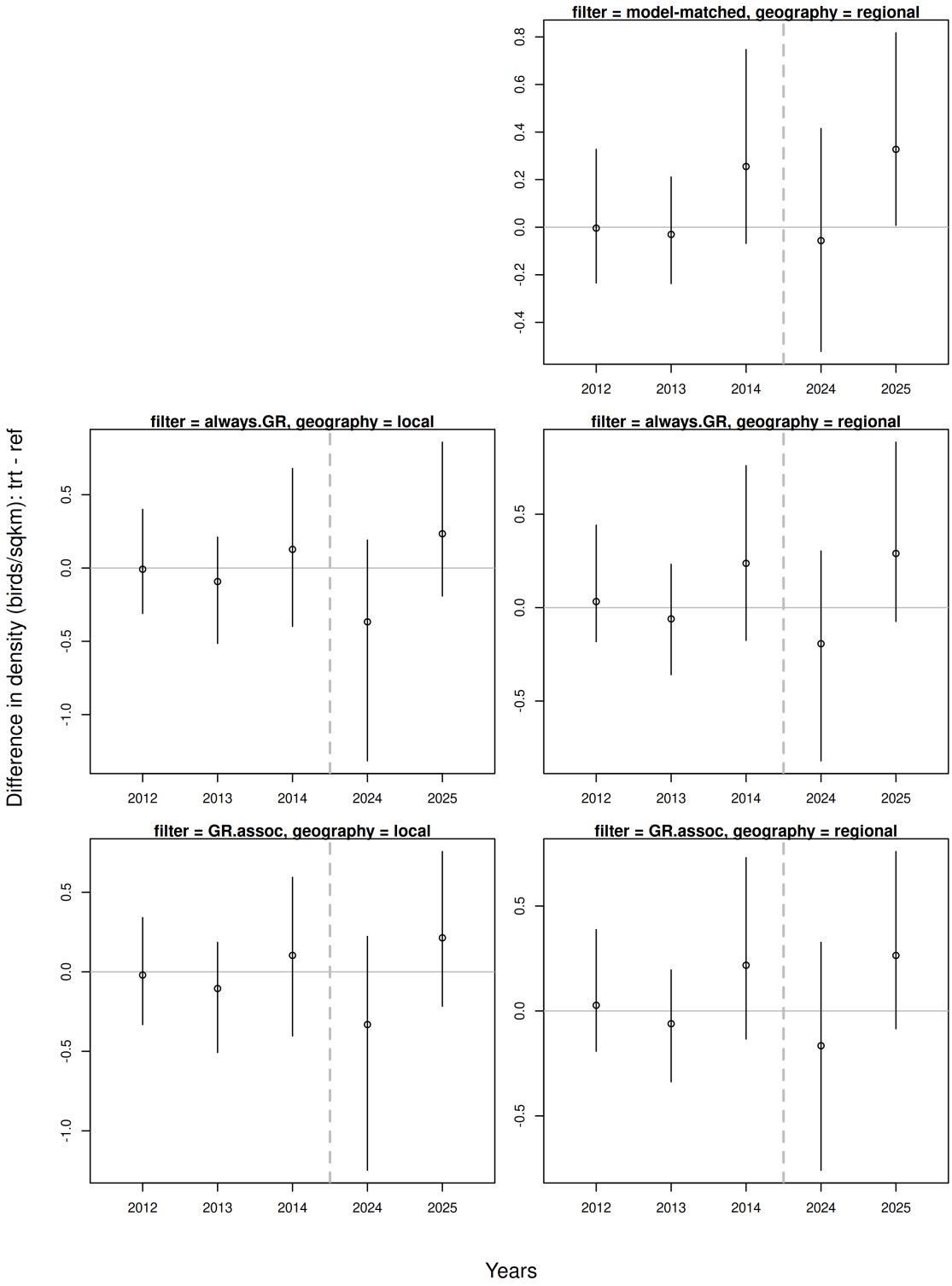


Figure C18. Yearly differences in population densities before (pre) and after (post) initiation of grazing management for Loggerhead Shrike.

Mourning Dove

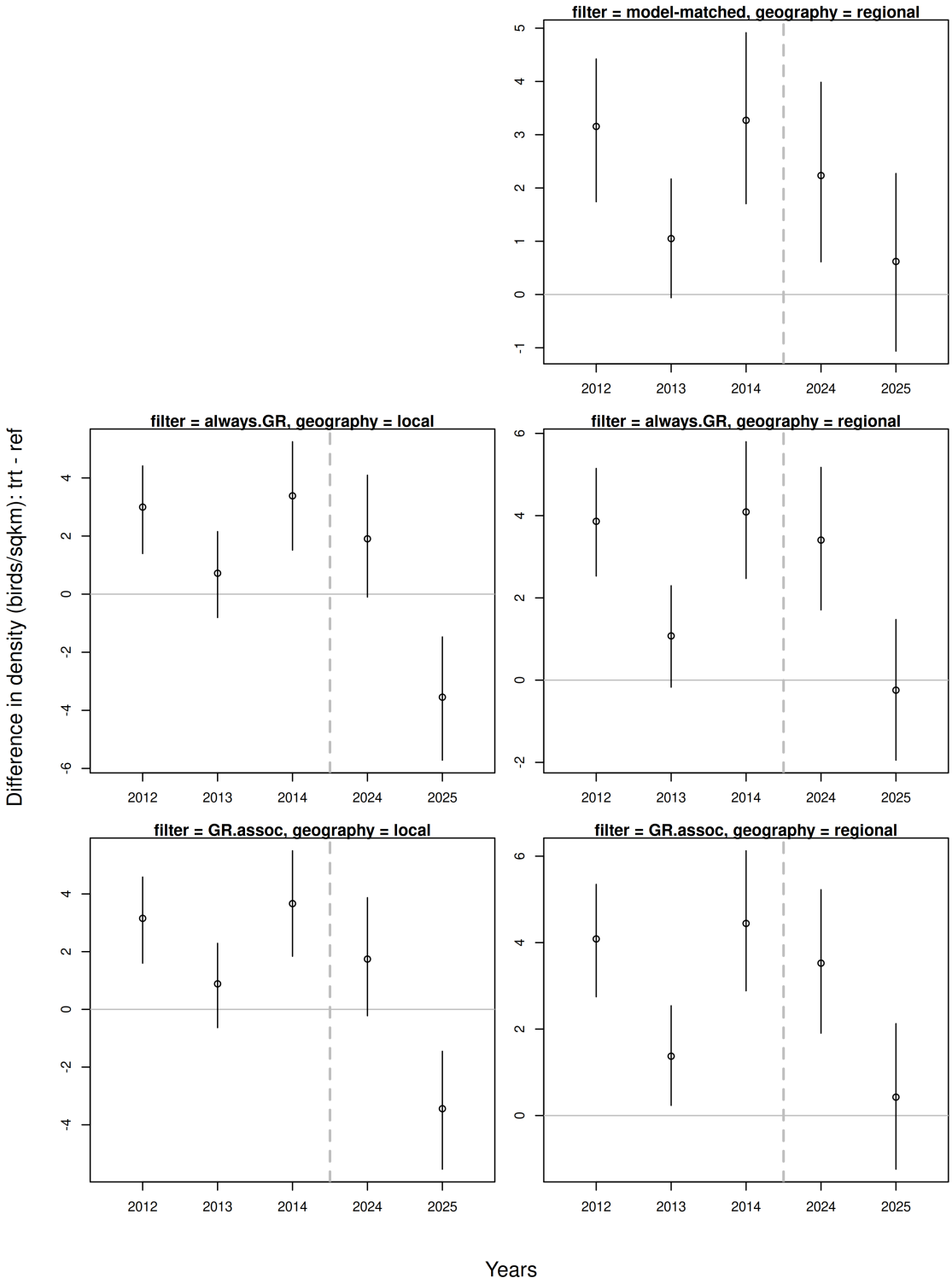


Figure C19. Yearly differences in population densities before (pre) and after (post) initiation of grazing management for Mourning Dove.

Mountain Plover

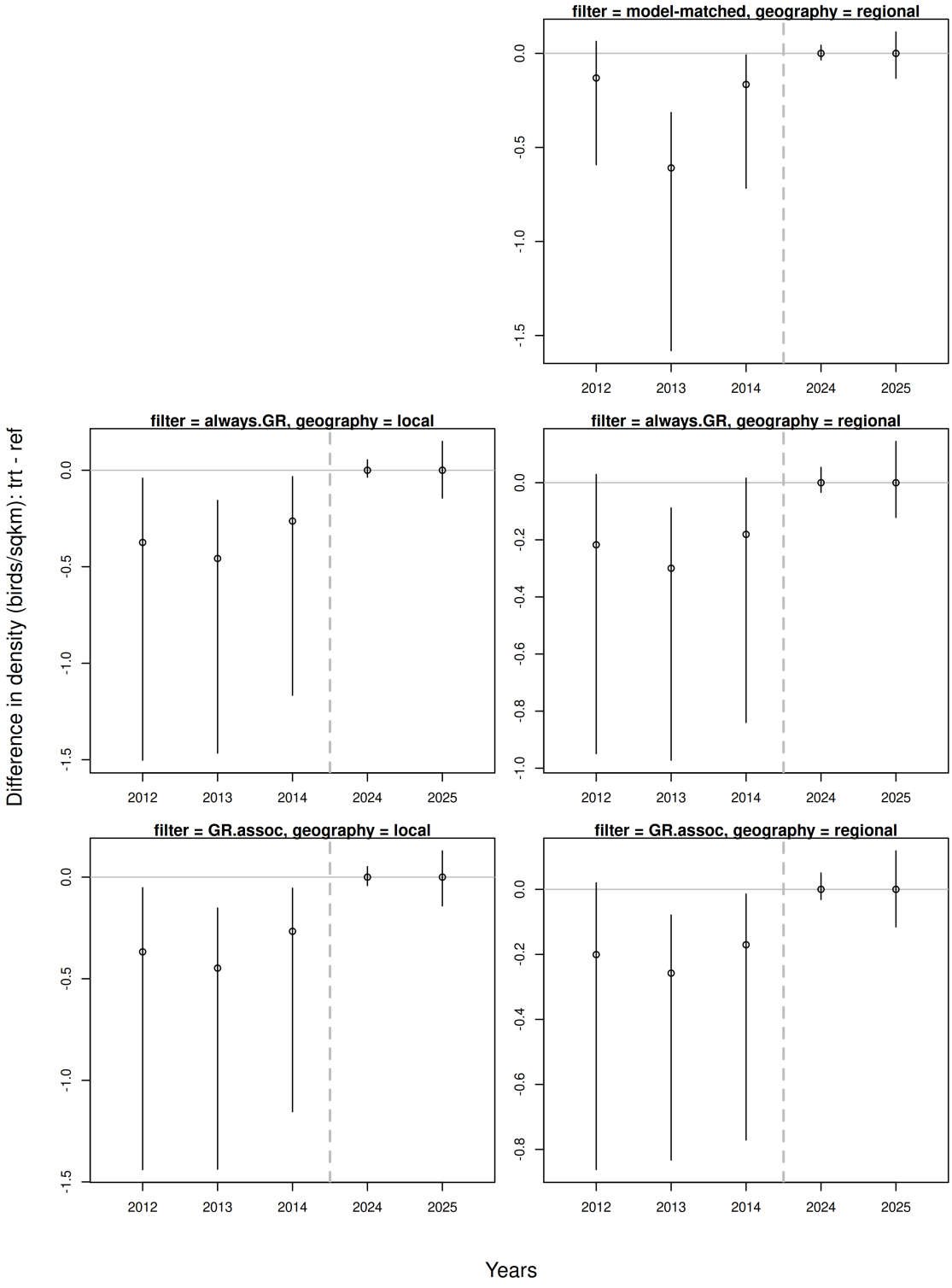


Figure C20. Yearly differences in population densities before (pre) and after (post) initiation of grazing management for Mountain Plover.

Northern Harrier

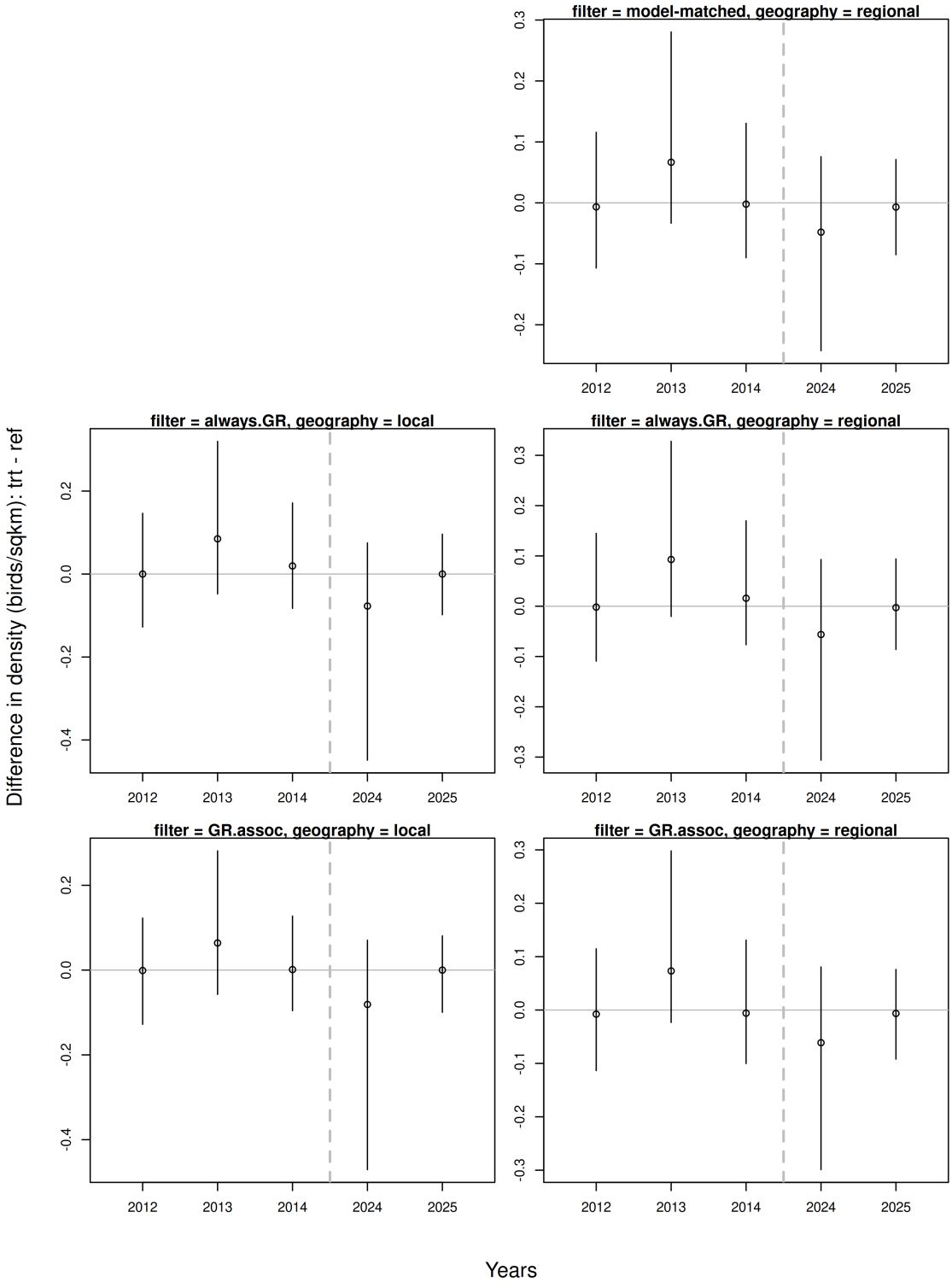


Figure C21. Yearly differences in population densities before (pre) and after (post) initiation of grazing management for Northern Harrier.

Prairie Falcon

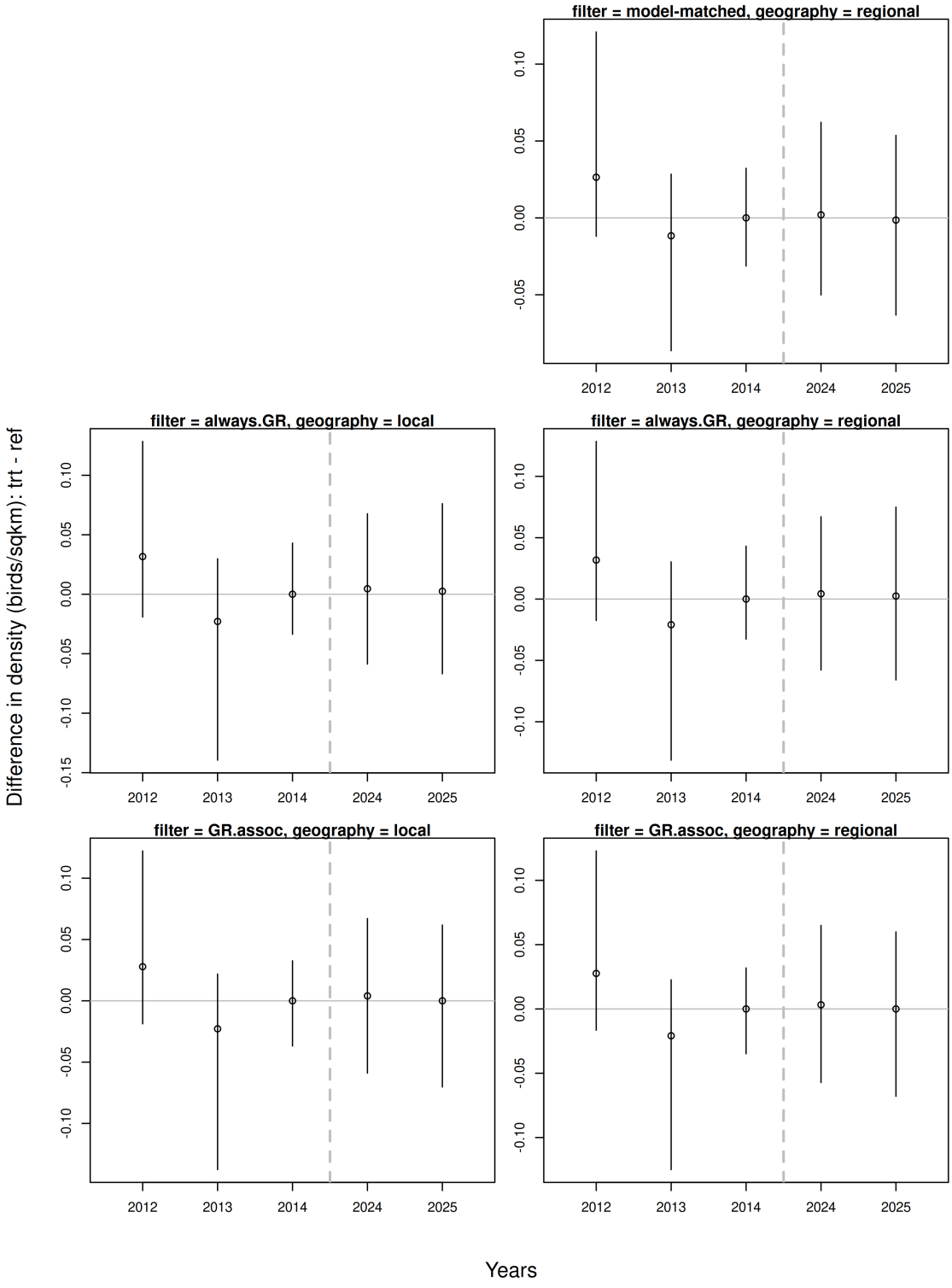


Figure C22. Yearly differences in population densities before (pre) and after (post) initiation of grazing management for Prairie Falcon.

Red-tailed Hawk

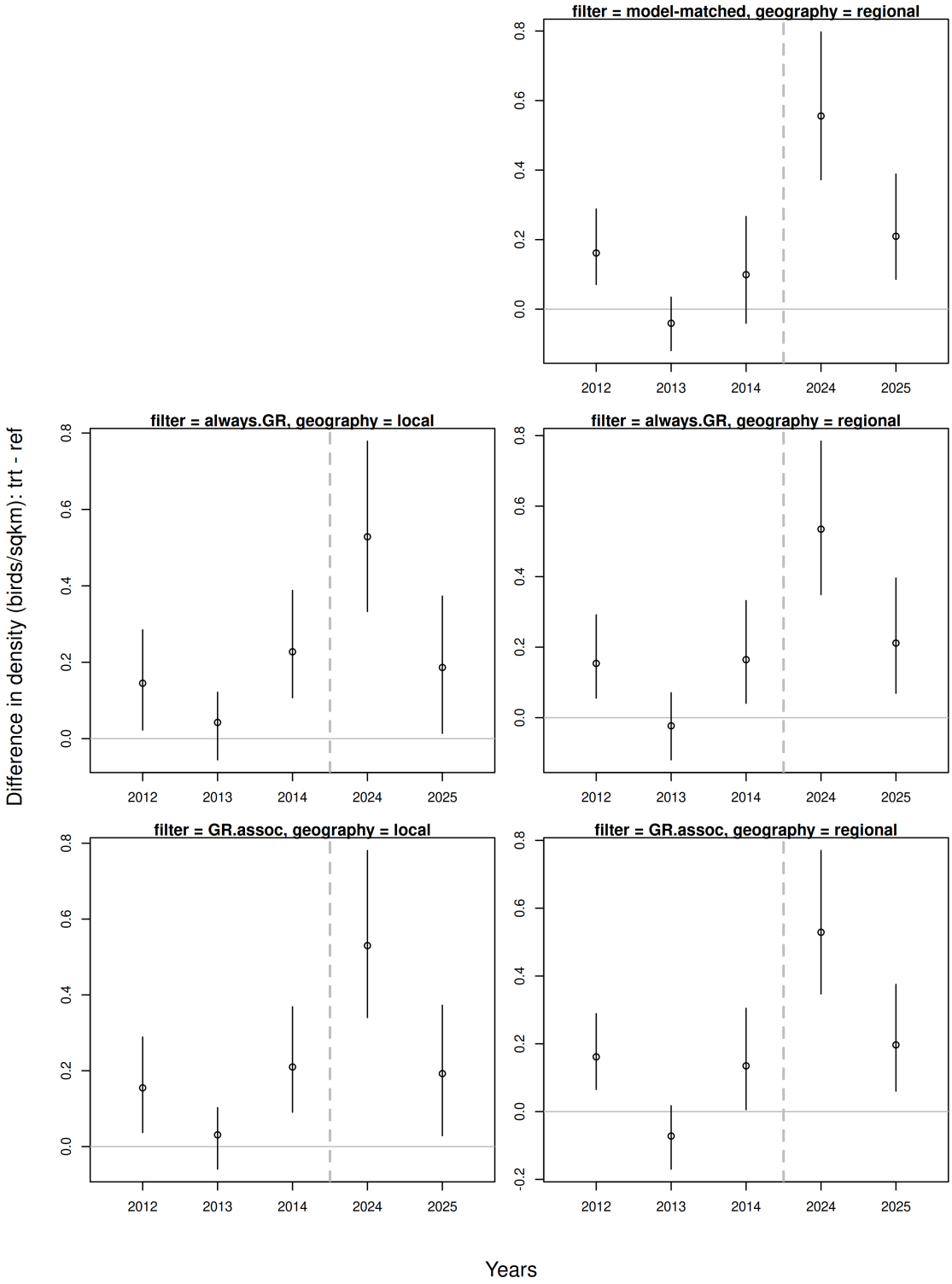


Figure C23. Yearly differences in population densities before (pre) and after (post) initiation of grazing management for Red-tailed Hawk.

Red-winged Blackbird

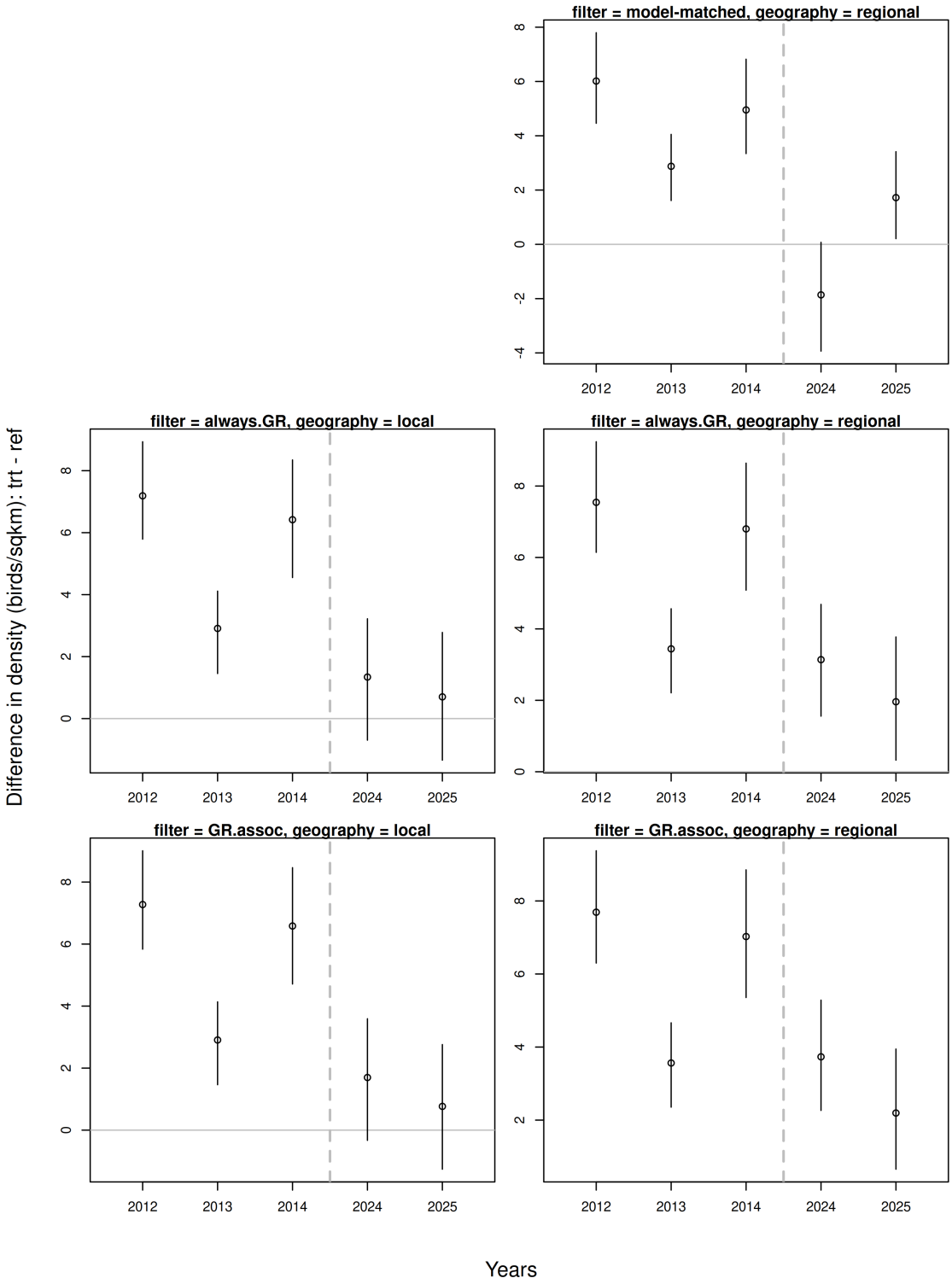


Figure C24. Yearly differences in population densities before (pre) and after (post) initiation of grazing management for Red-winged Blackbird.

Say's Phoebe

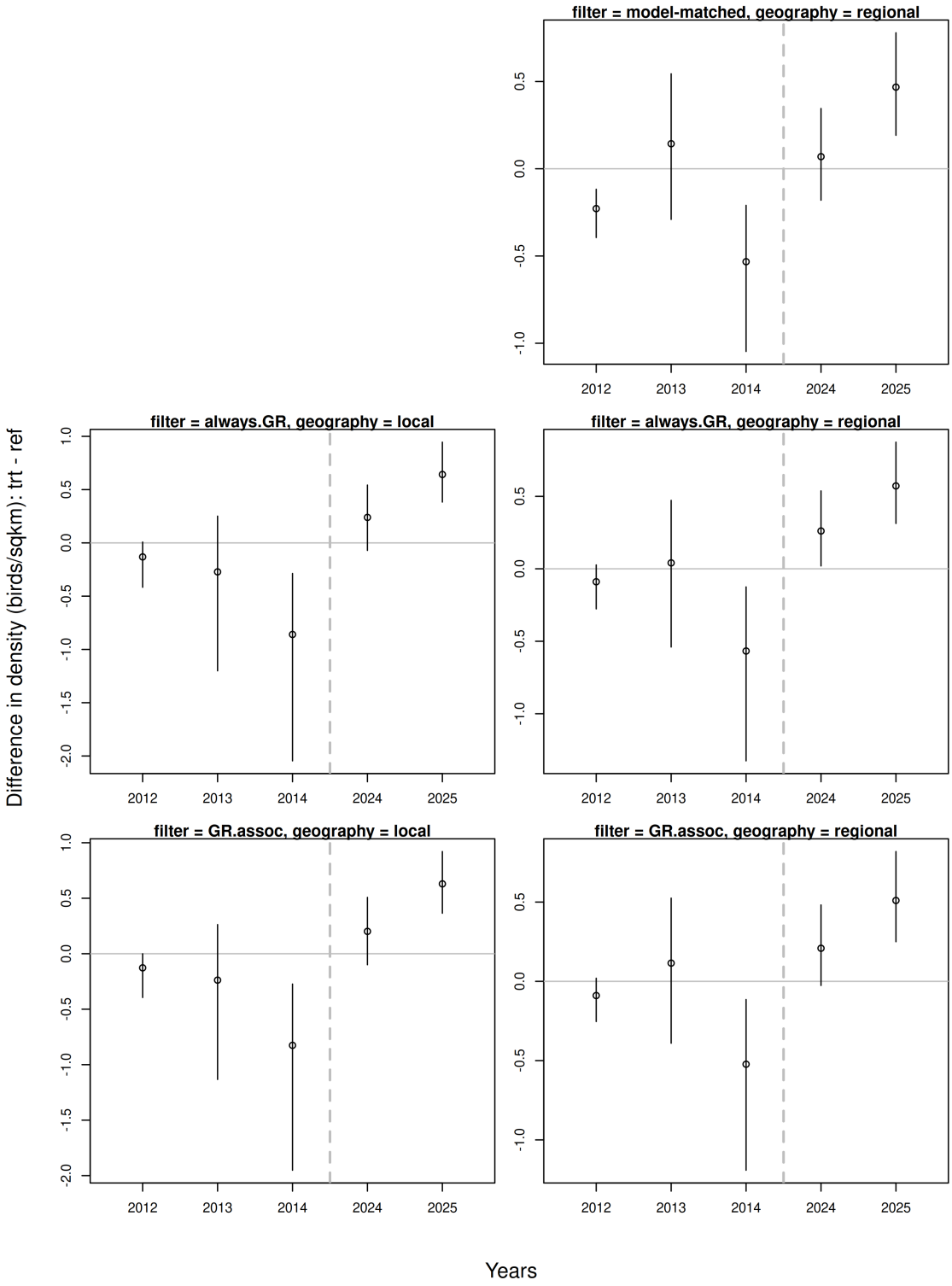


Figure C25. Yearly differences in population densities before (pre) and after (post) initiation of grazing management for Say's Phoebe.

Savannah Sparrow

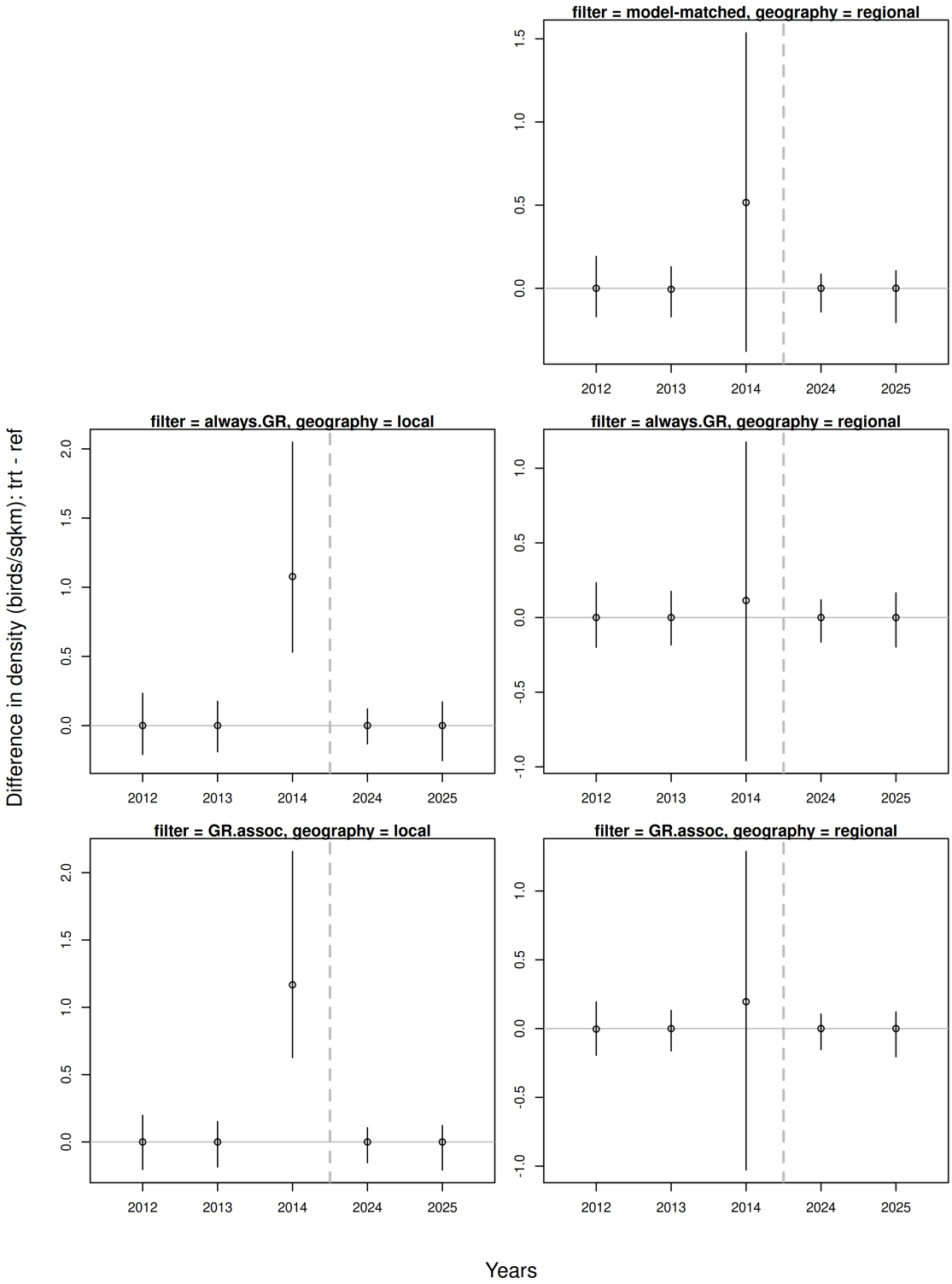


Figure C26. Yearly differences in population densities before (pre) and after (post) initiation of grazing management for Savannah Sparrow.

Swainson's Hawk

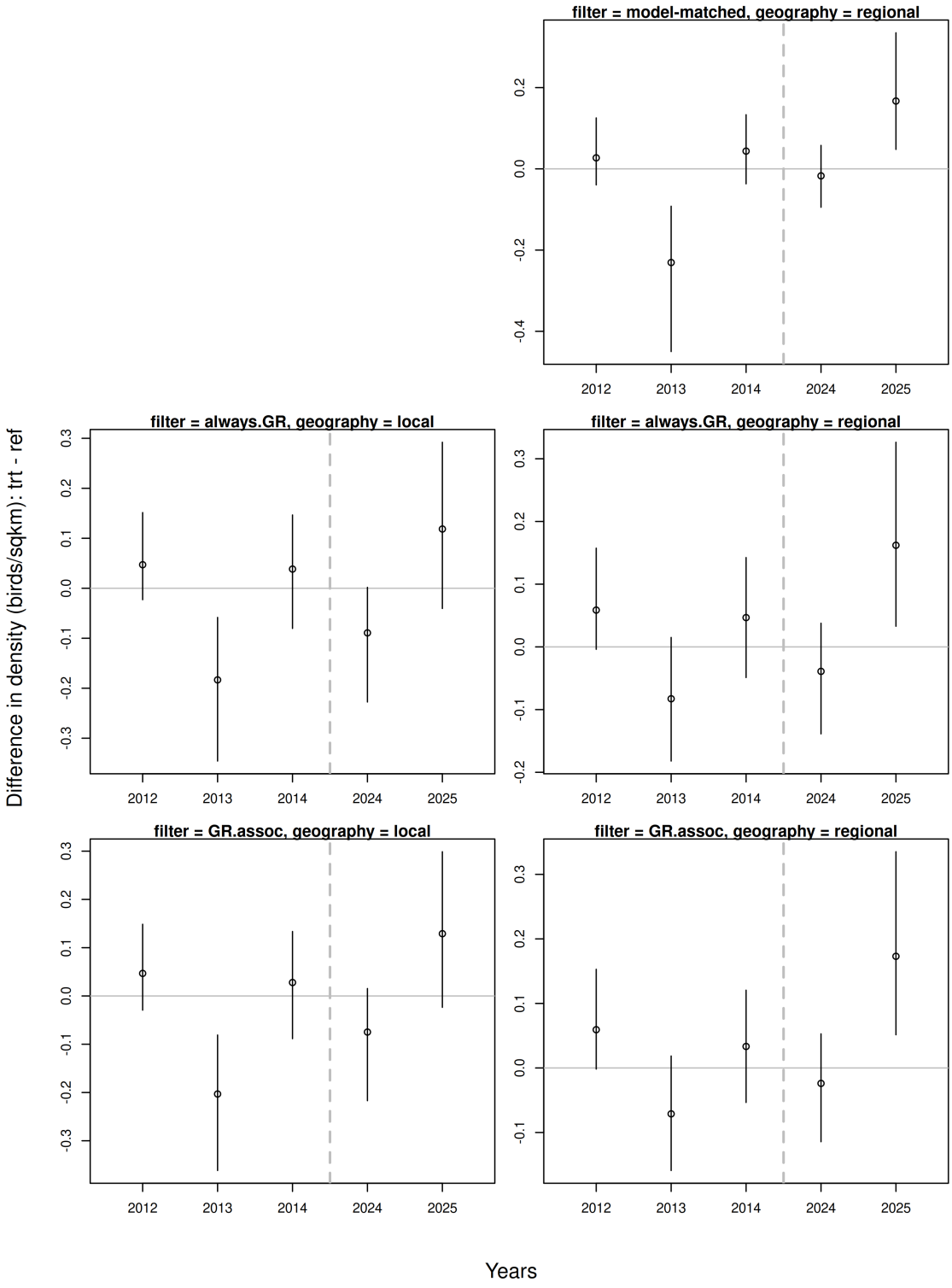


Figure C27. Yearly differences in population densities before (pre) and after (post) initiation of grazing management for Swainson's Hawk.

Vesper Sparrow

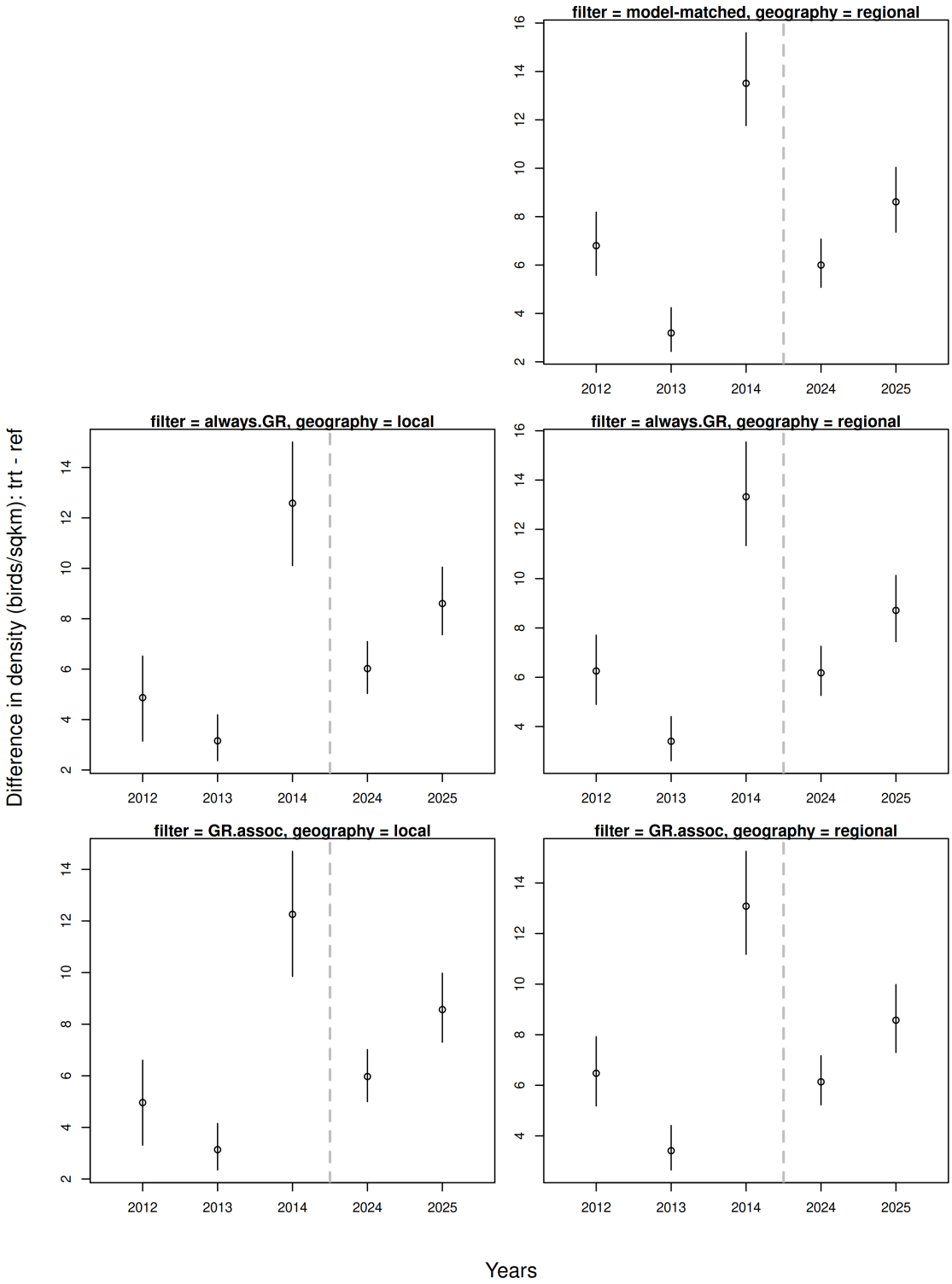


Figure C28. Yearly differences in population densities before (pre) and after (post) initiation of grazing management for Vesper Sparrow.

Western Kingbird

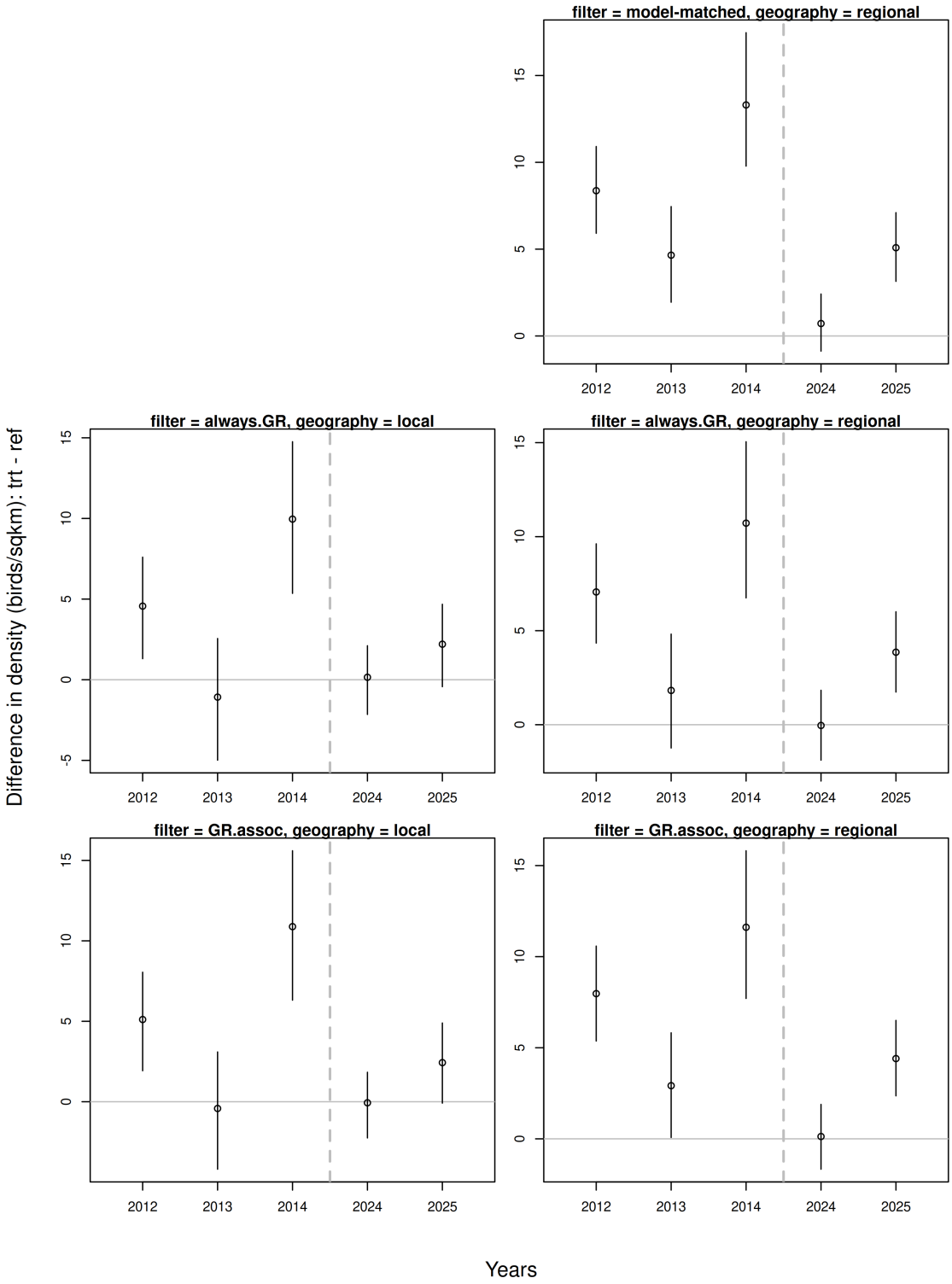


Figure C29. Yearly differences in population densities before (pre) and after (post) initiation of grazing management for Western Kingbird.

Western Meadowlark

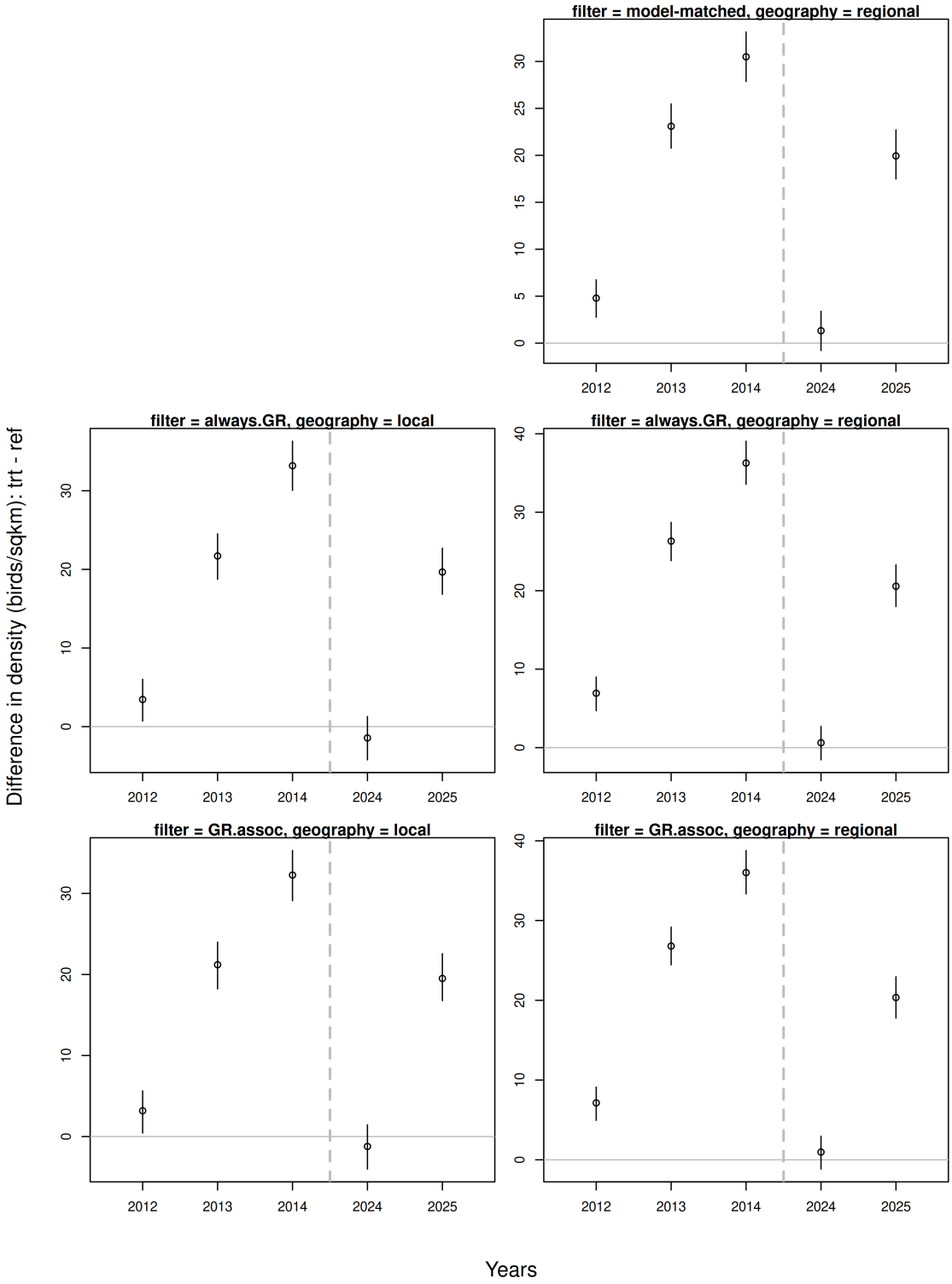


Figure C30. Yearly differences in population densities before (pre) and after (post) initiation of grazing management for Western Meadowlark.

Appendix D — Figures showing Lowry Ranch and reference population density estimates before (2012–2014) versus after (2024–2025) initiation of grazing management.

Each figure displays five panels corresponding to the reference sample comparisons summarized in Table 2 and Table 4. Panel headers indicate the grassland classification filter applied to the comparison ("model-matched," "always.GR" [Always grassland], or "GR.assoc" [Grassland associated]) and the geographic scope of the reference sample ("local" or "regional"). Within each panel, red circles (Trt) and blue squares (Ref) show estimated population densities (birds/sqkm) with 90% credible intervals for Lowry Ranch and reference samples, respectively, before (pre, 2012–2014) and after (post, 2024–2025) initiation of grazing management. The number printed inside each symbol gives the number of survey points contributing to that estimate, which for Lowry estimates was the same but differed for reference samples across species because only points within strata where the species was detected at least once over the course of the IMBCR program were included for analysis.

American Kestrel

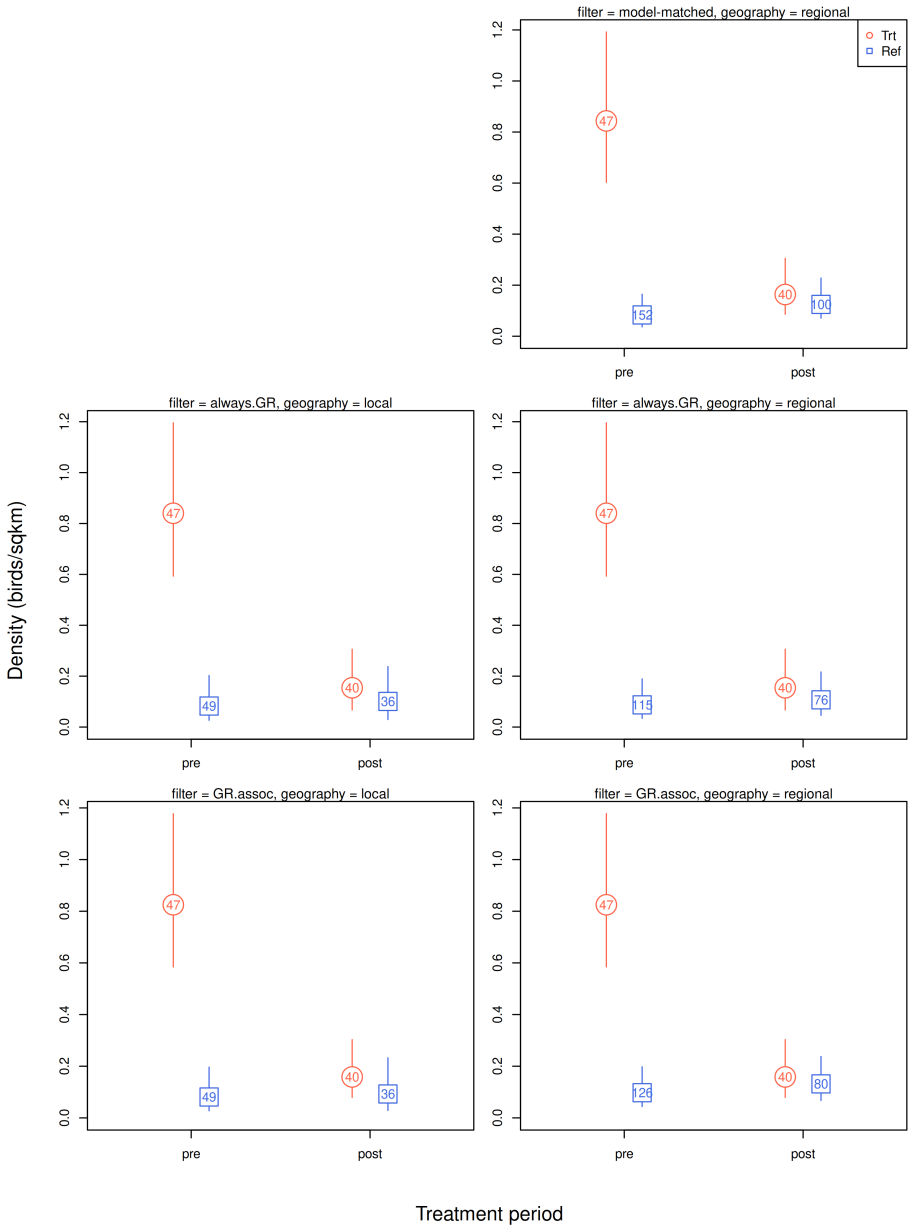


Figure D1. Population density estimates before (pre) versus after (post) initiation of grazing management for American Kestrel.

Barn Swallow

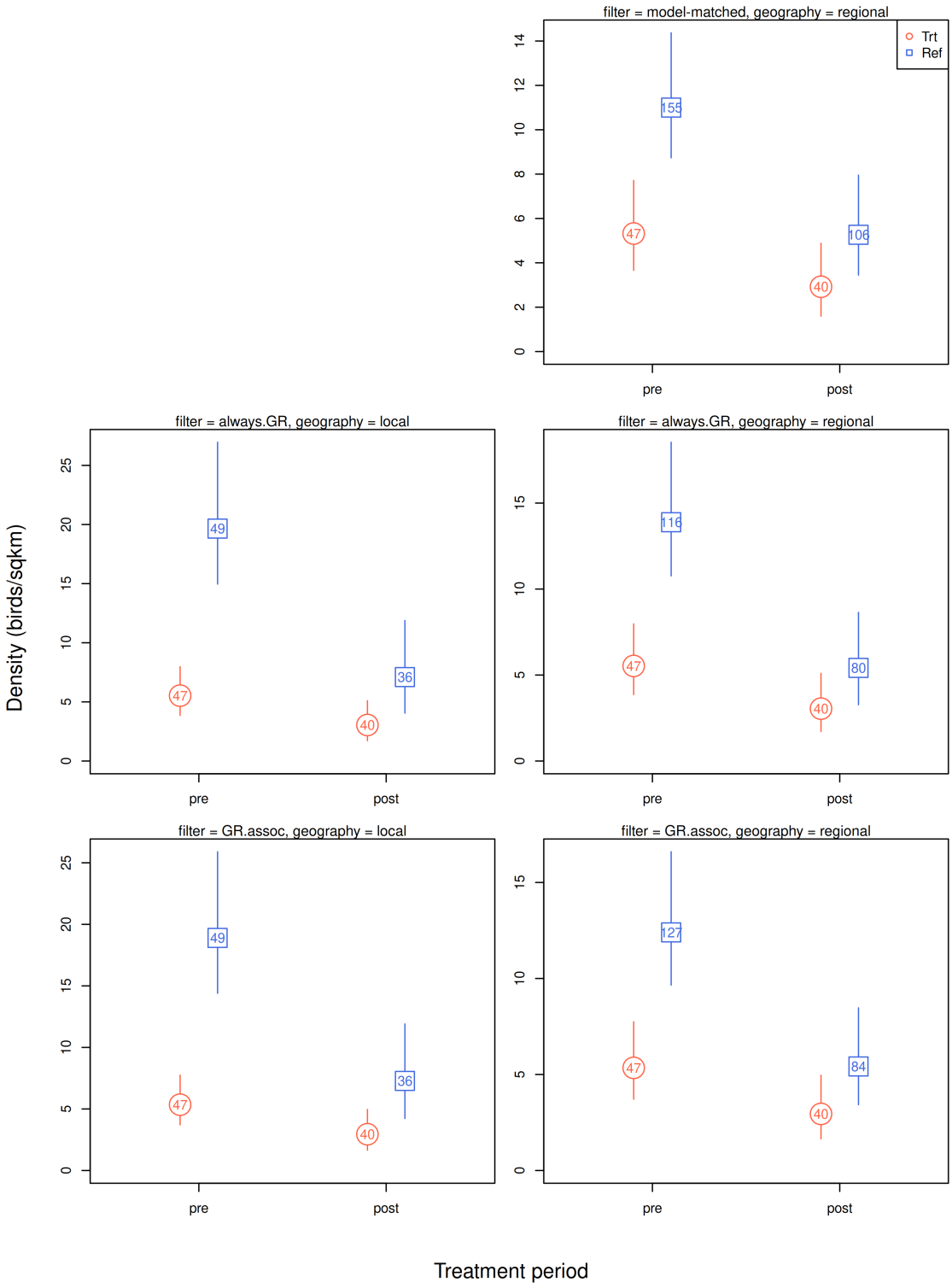


Figure D2. Population density estimates before (pre) versus after (post) initiation of grazing management for Barn Swallow.

Brown-headed Cowbird

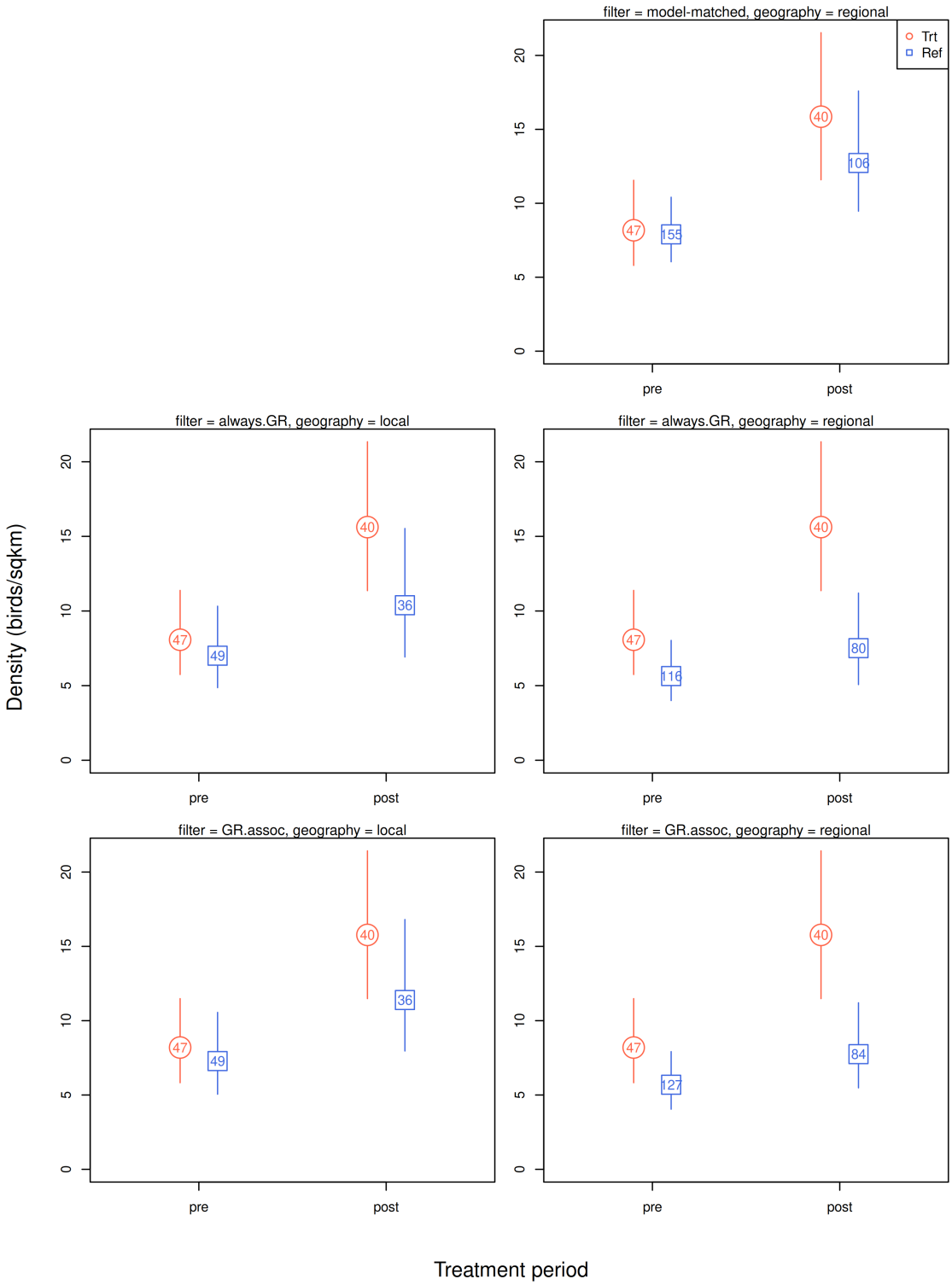


Figure D3. Population density estimates before (pre) versus after (post) initiation of grazing management for Brown-headed Cowbird.

Brewer's Blackbird

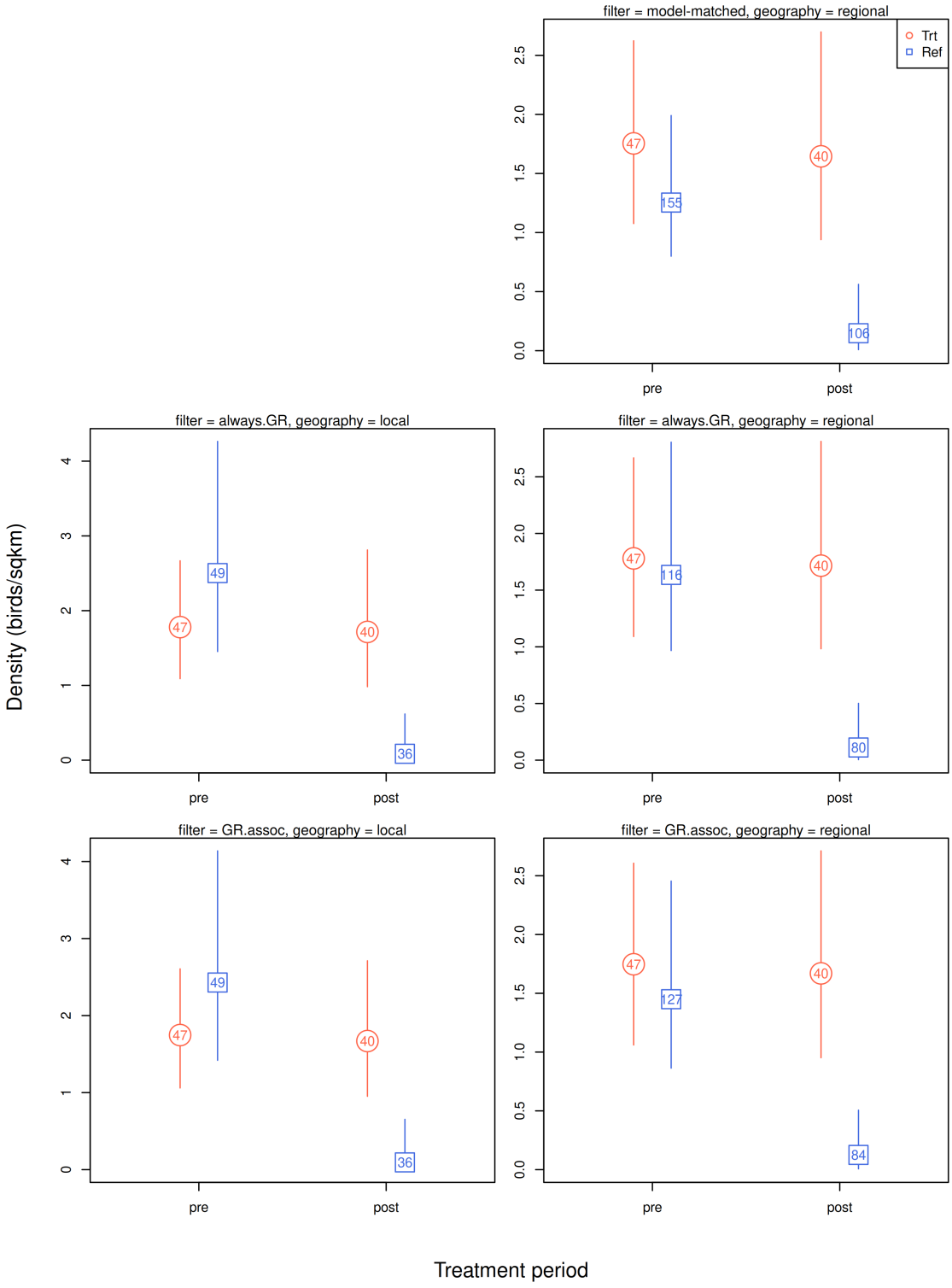


Figure D4. Population density estimates before (pre) versus after (post) initiation of grazing management for Brewer's Blackbird.

Burrowing Owl

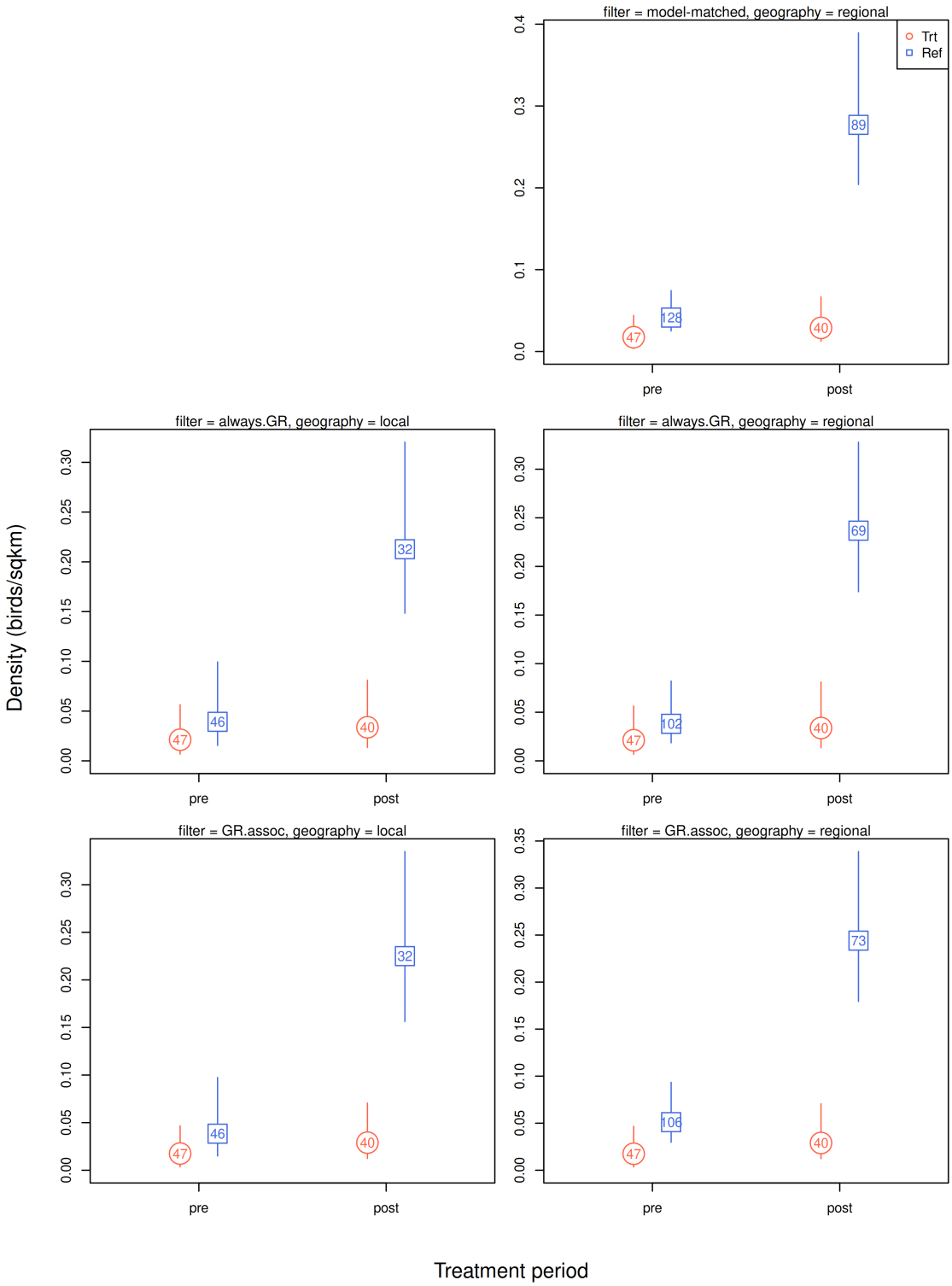


Figure D5. Population density estimates before (pre) versus after (post) initiation of grazing management for Burrowing Owl.

Cassin's Kingbird

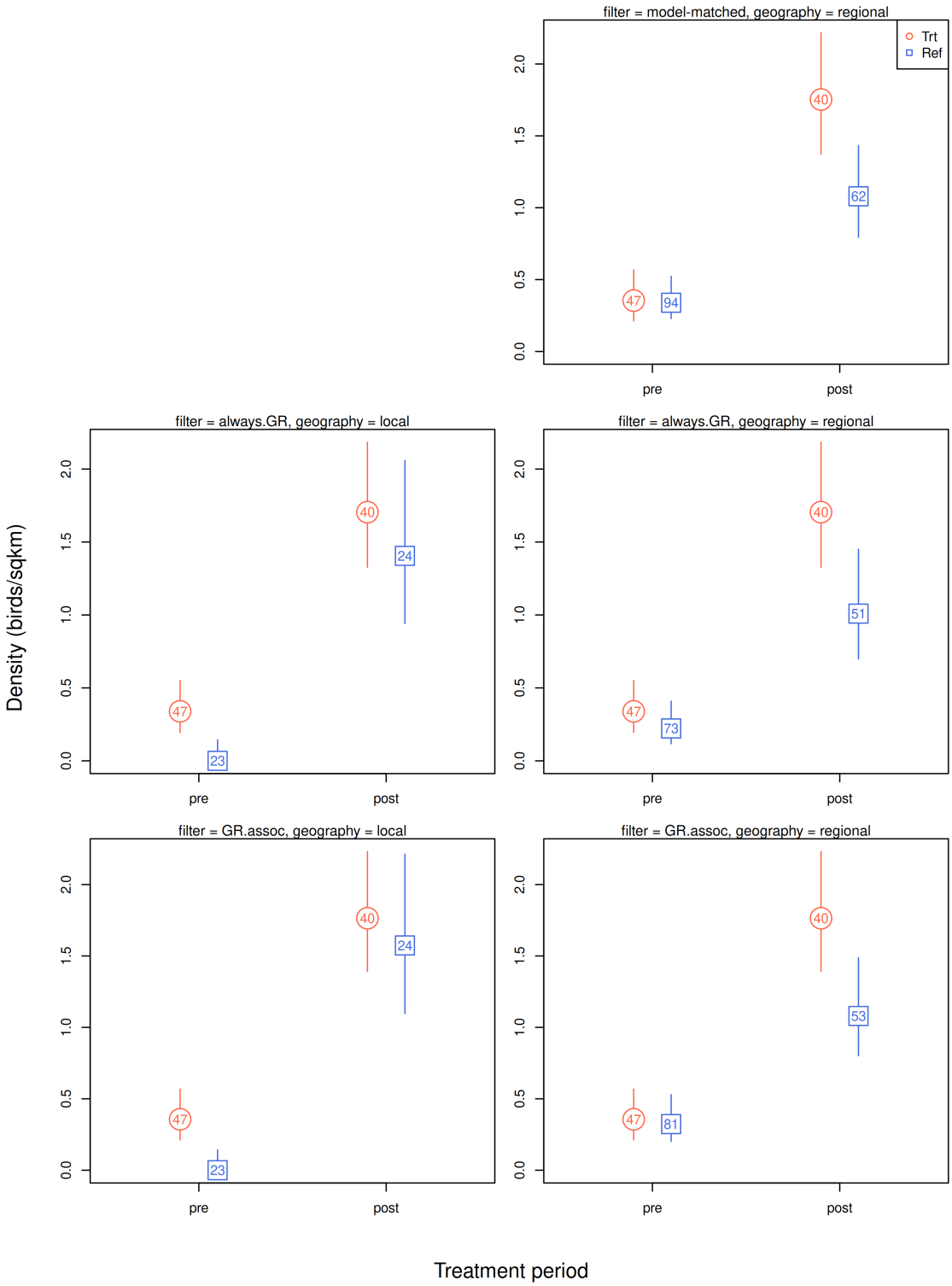


Figure D6. Population density estimates before (pre) versus after (post) initiation of grazing management for Cassin's Kingbird.

Cassin's Sparrow

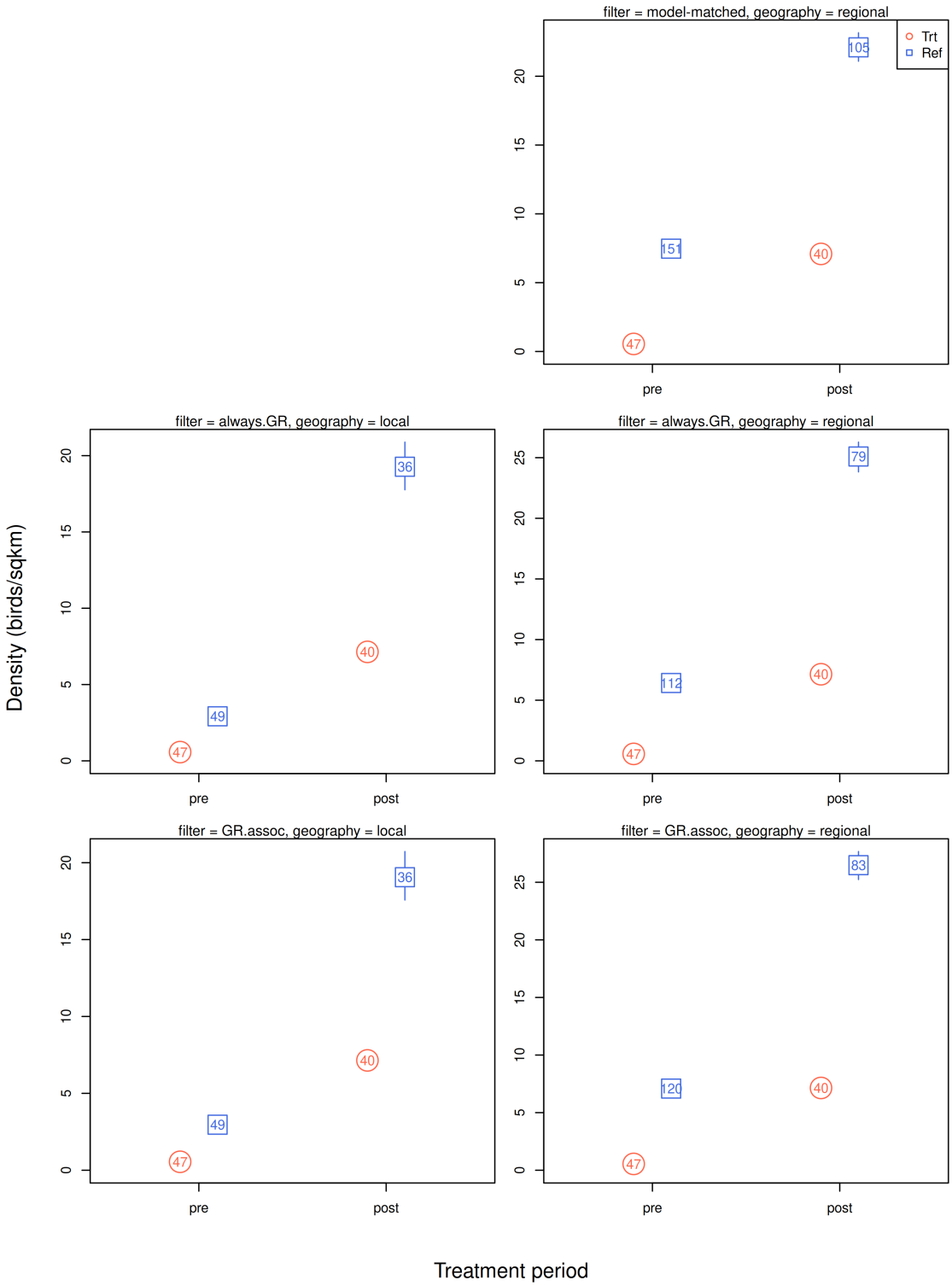


Figure D7. Population density estimates before (pre) versus after (post) initiation of grazing management for Cassin's Sparrow.

Cliff Swallow

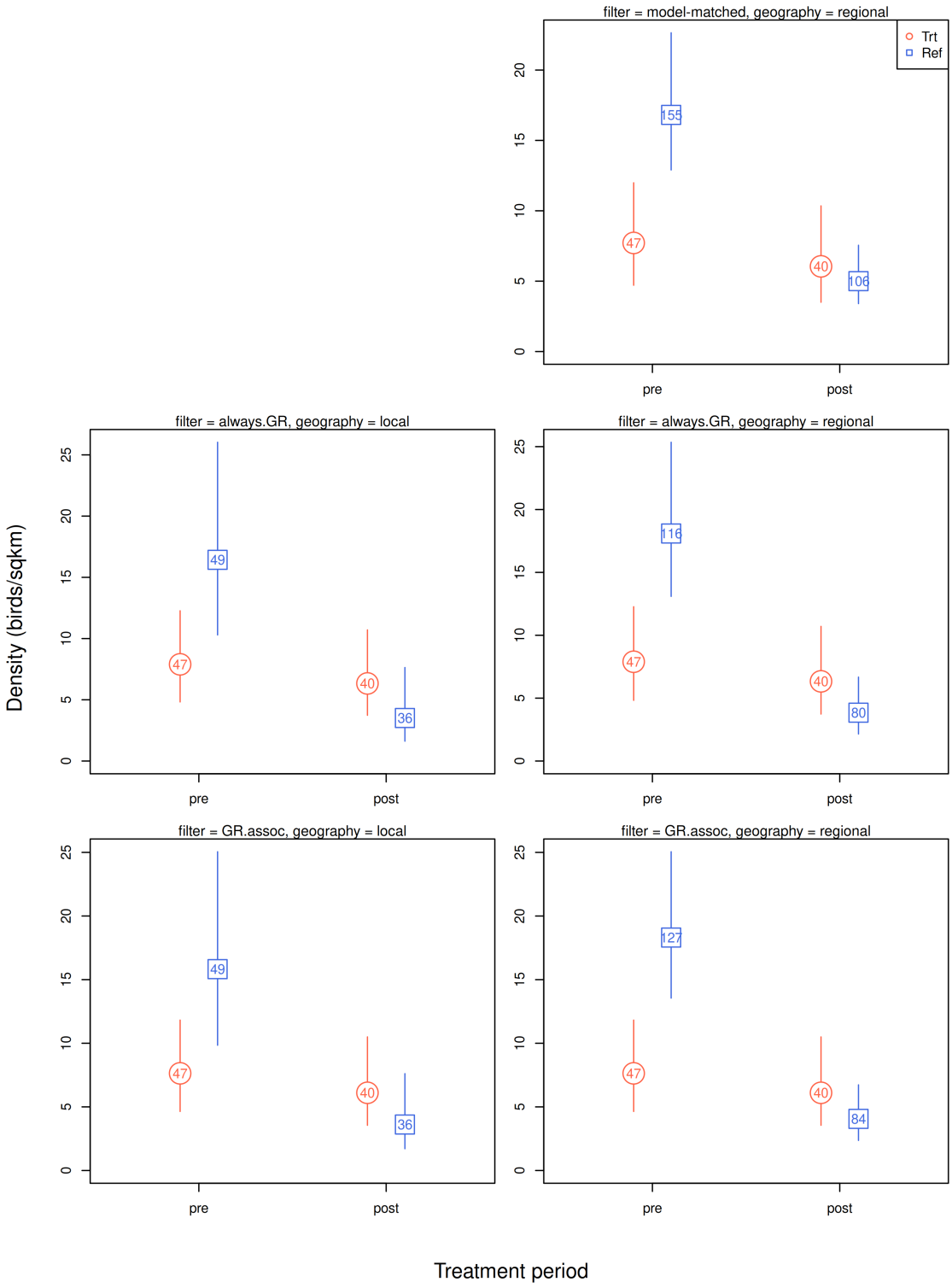


Figure D8. Population density estimates before (pre) versus after (post) initiation of grazing management for Cliff Swallow.

Common Nighthawk

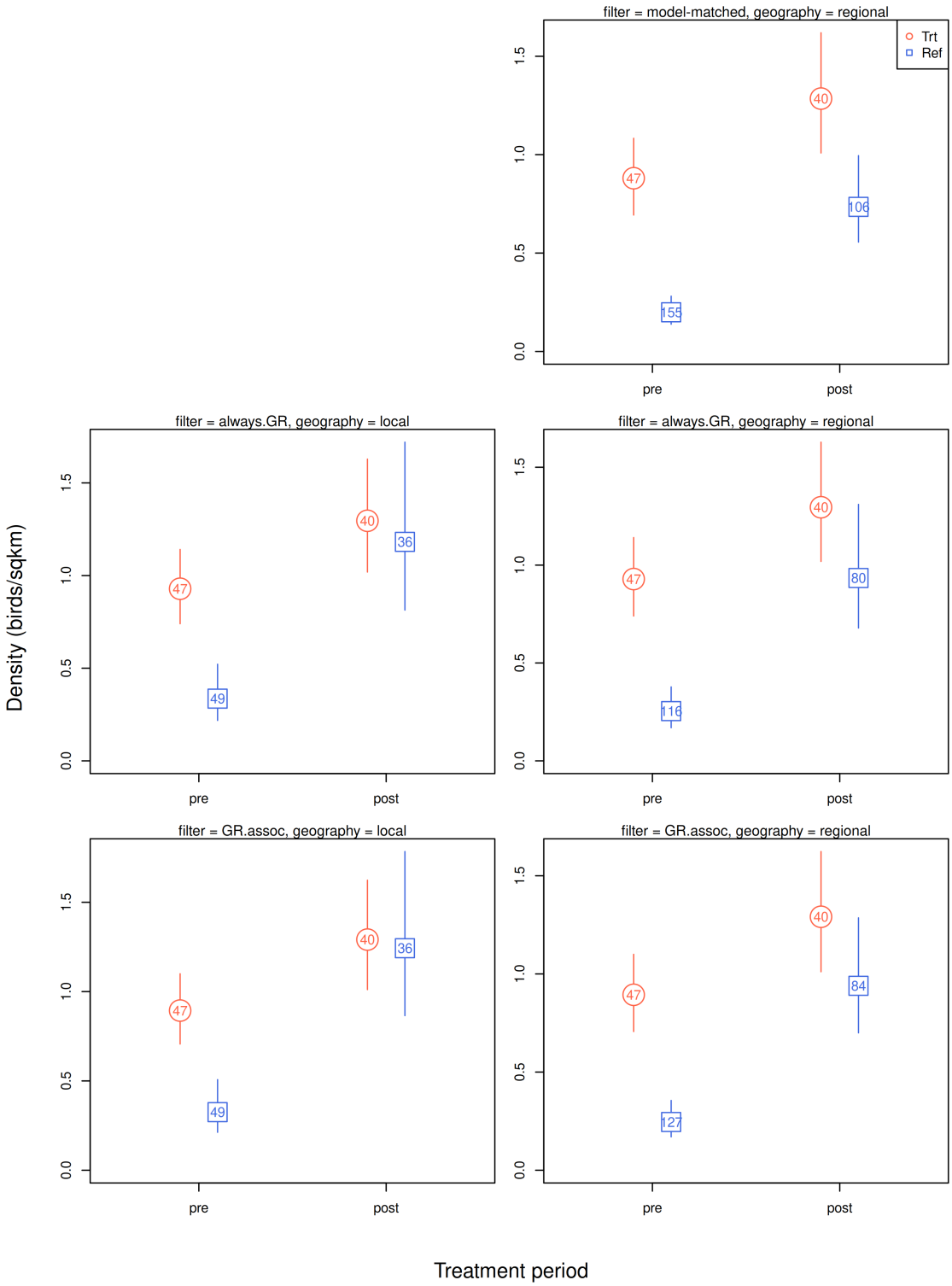


Figure D9. Population density estimates before (pre) versus after (post) initiation of grazing management for Common Nighthawk.

Dickcissel

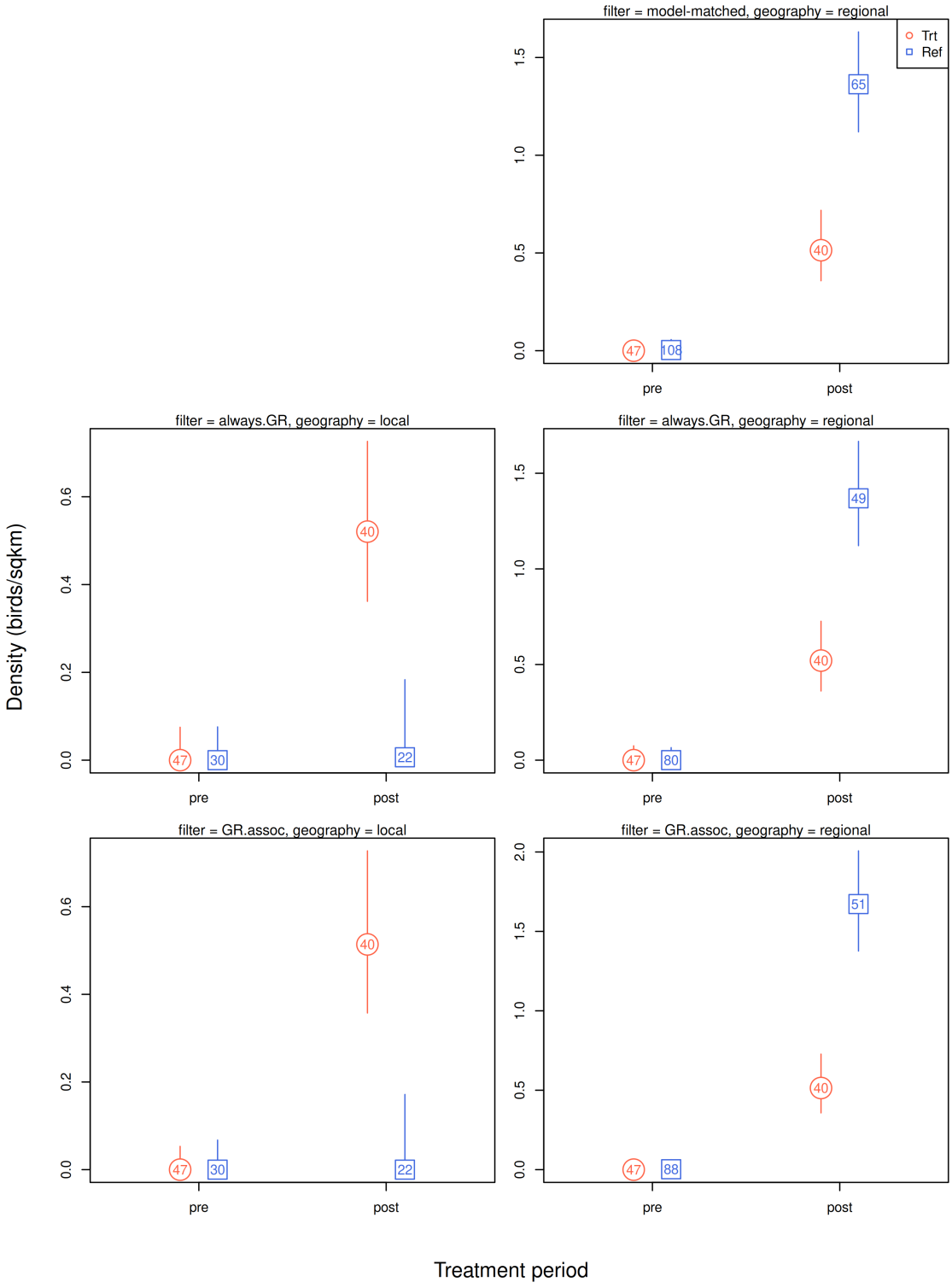


Figure D10. Population density estimates before (pre) versus after (post) initiation of grazing management for Dickcissel.

Eastern Kingbird

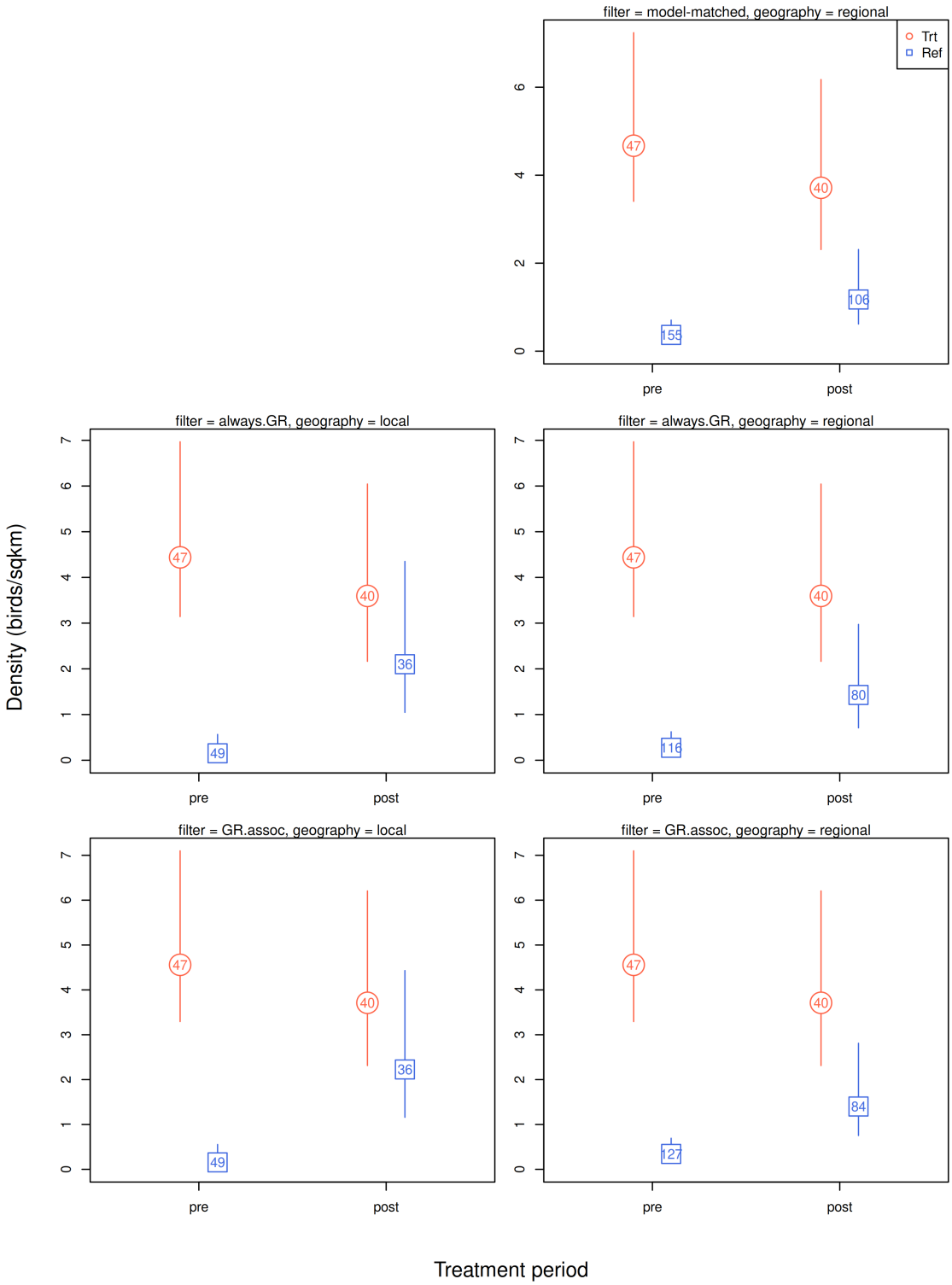


Figure D11. Population density estimates before (pre) versus after (post) initiation of grazing management for Eastern Kingbird.

Ferruginous Hawk

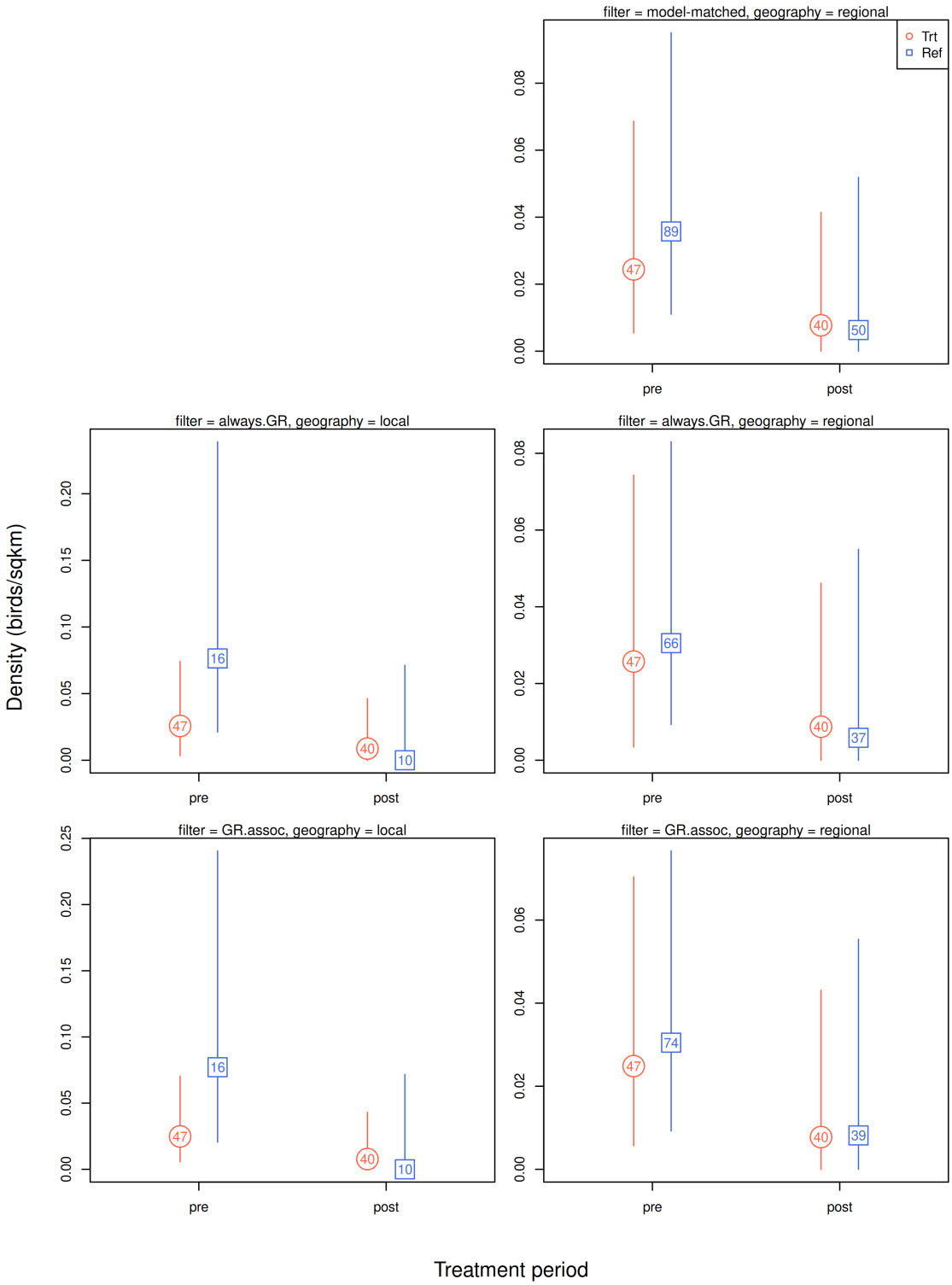


Figure D12. Population density estimates before (pre) versus after (post) initiation of grazing management for Ferruginous Hawk.

Grasshopper Sparrow

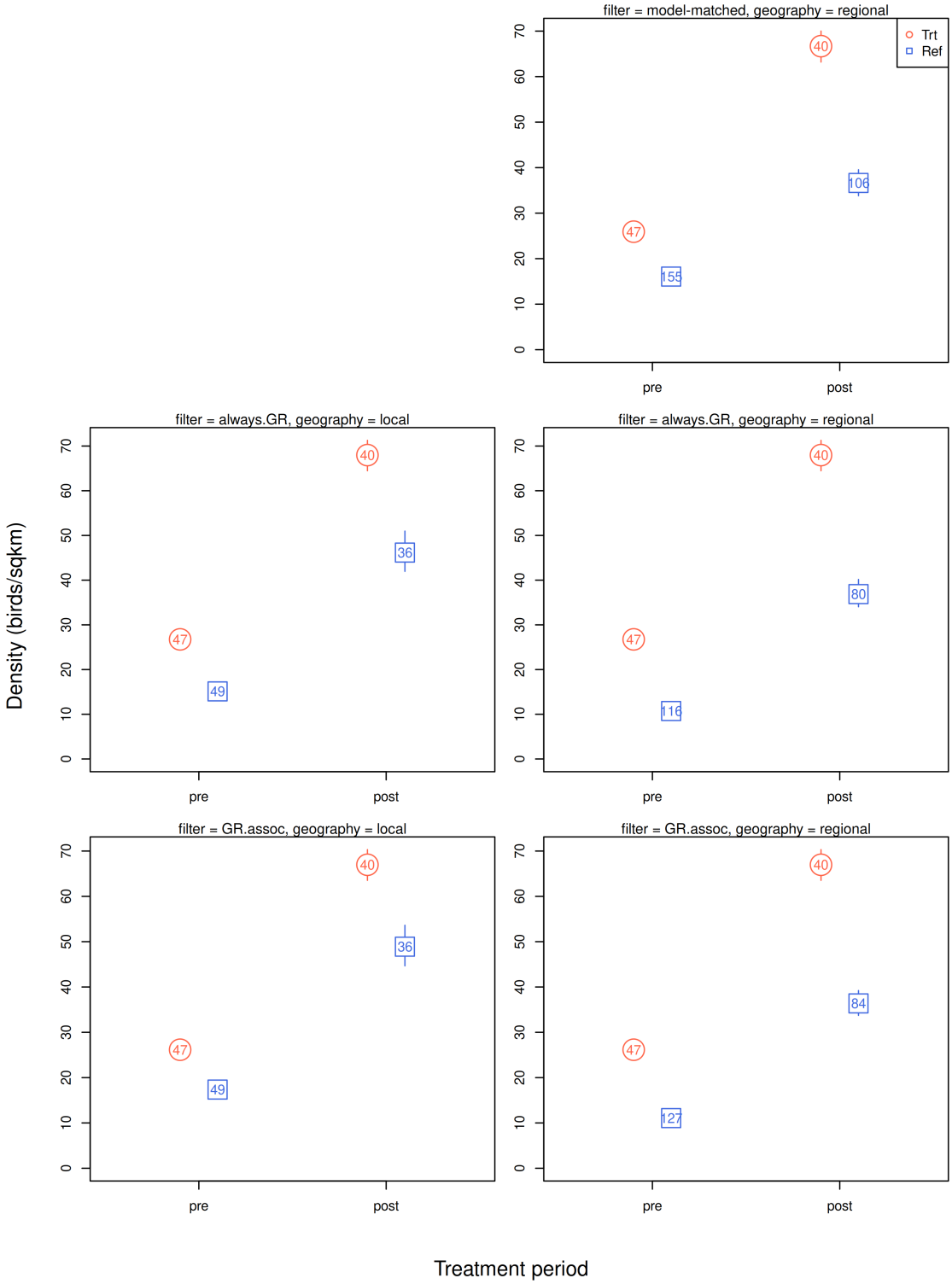


Figure D13. Population density estimates before (pre) versus after (post) initiation of grazing management for Grasshopper Sparrow.

Horned Lark

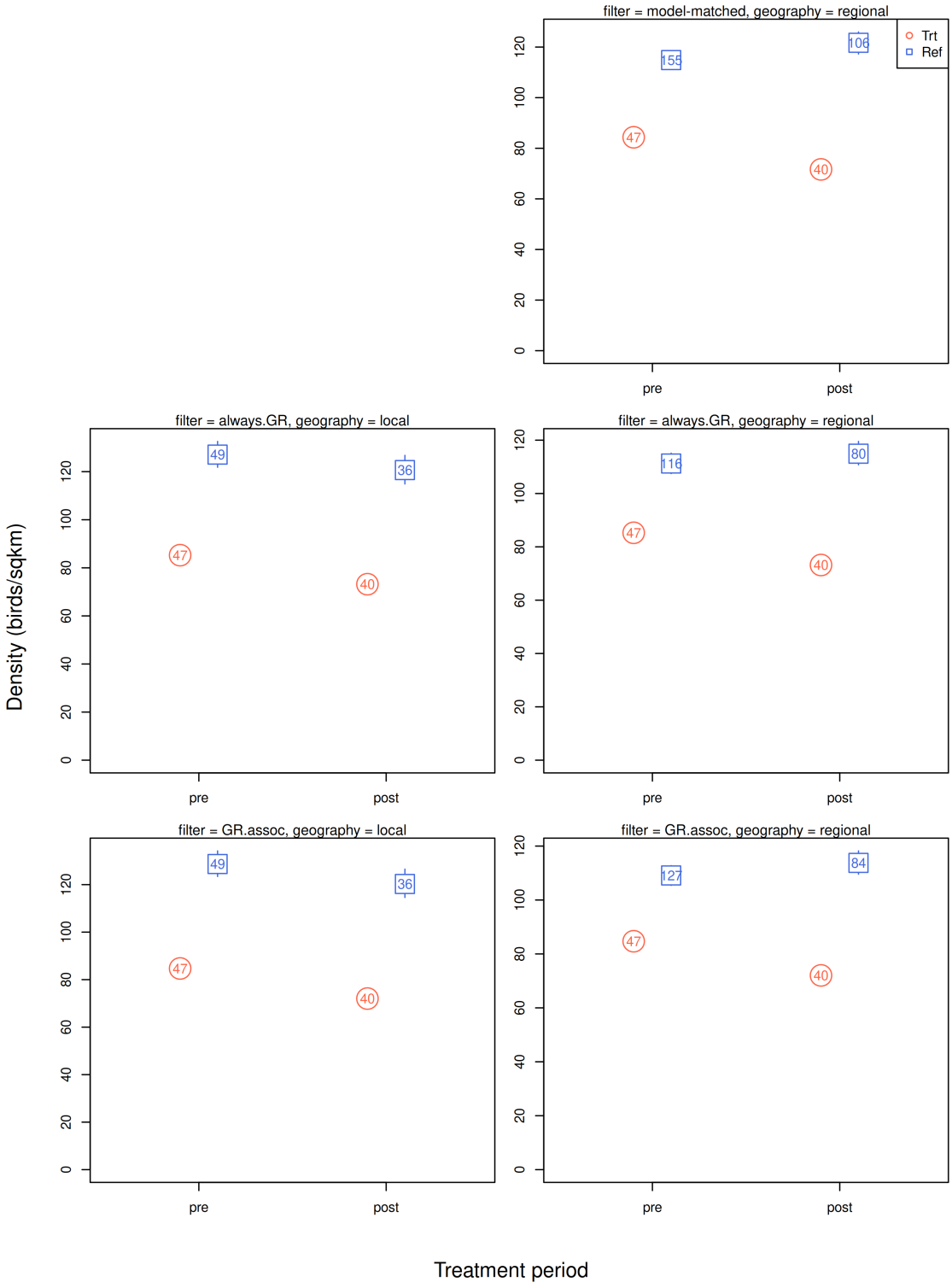


Figure D14. Population density estimates before (pre) versus after (post) initiation of grazing management for Horned Lark.

Killdeer

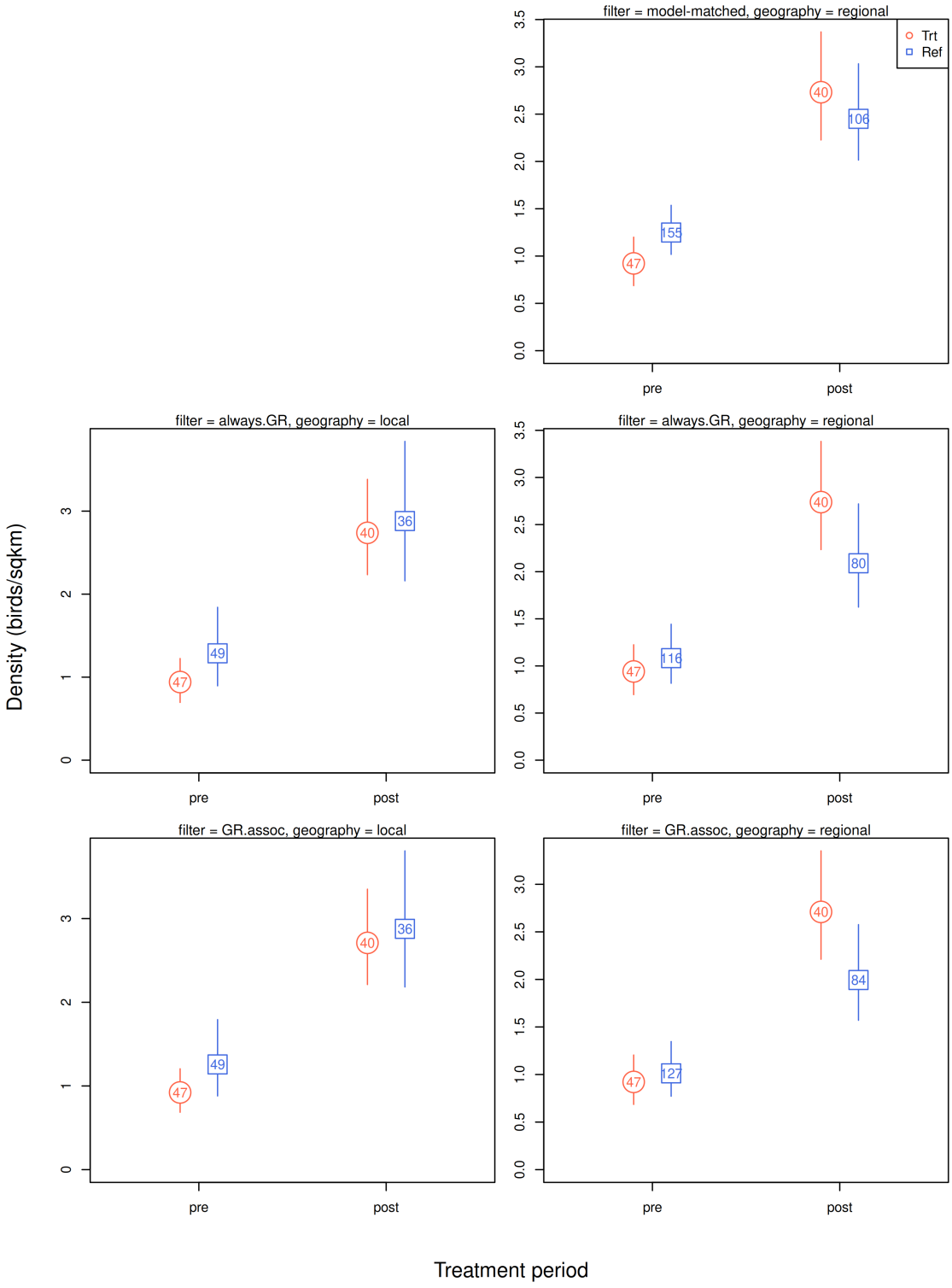


Figure D15. Population density estimates before (pre) versus after (post) initiation of grazing management for Killdeer.

Lark Bunting

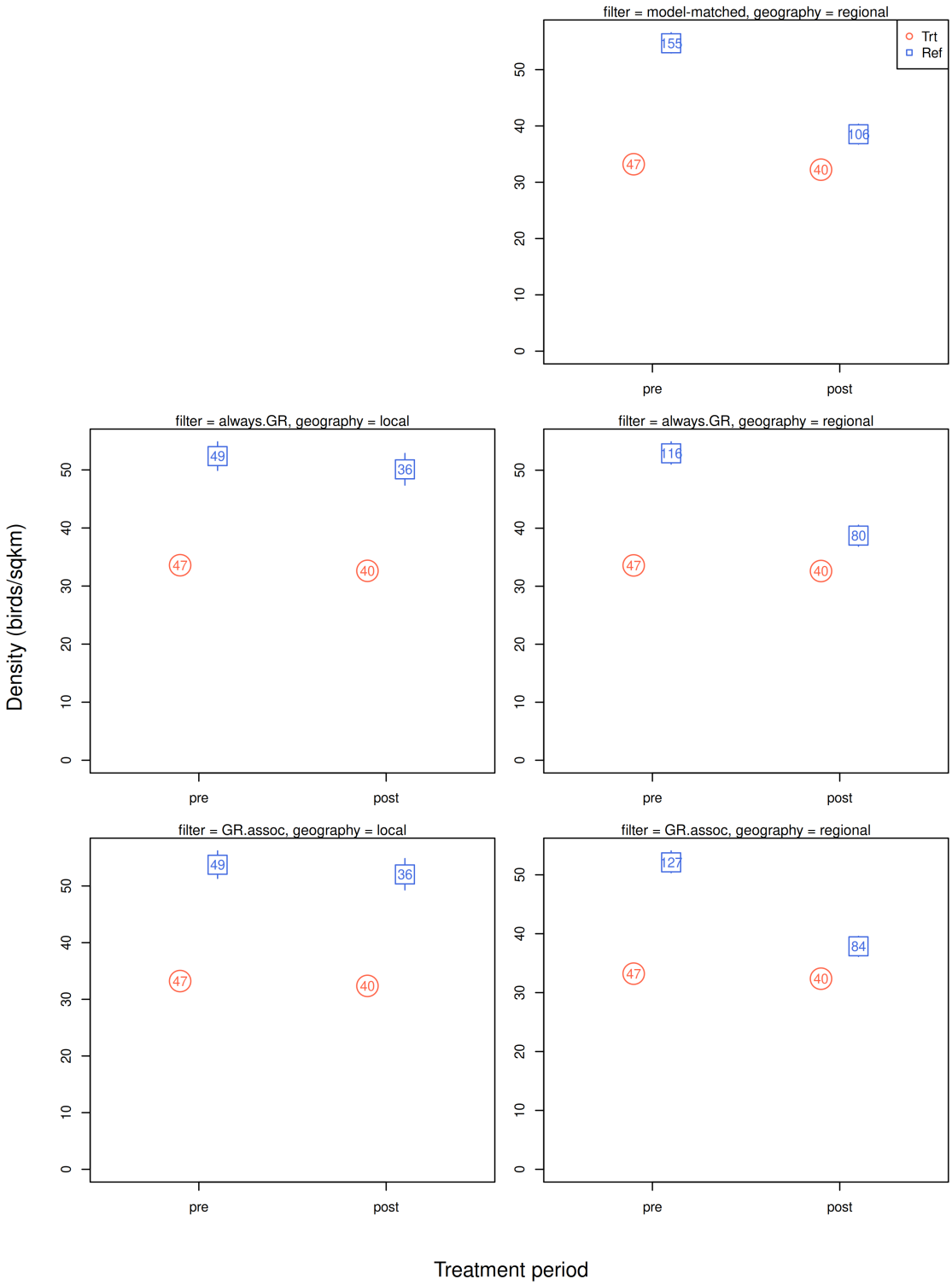


Figure D16. Population density estimates before (pre) versus after (post) initiation of grazing management for Lark Bunting.

Lark Sparrow

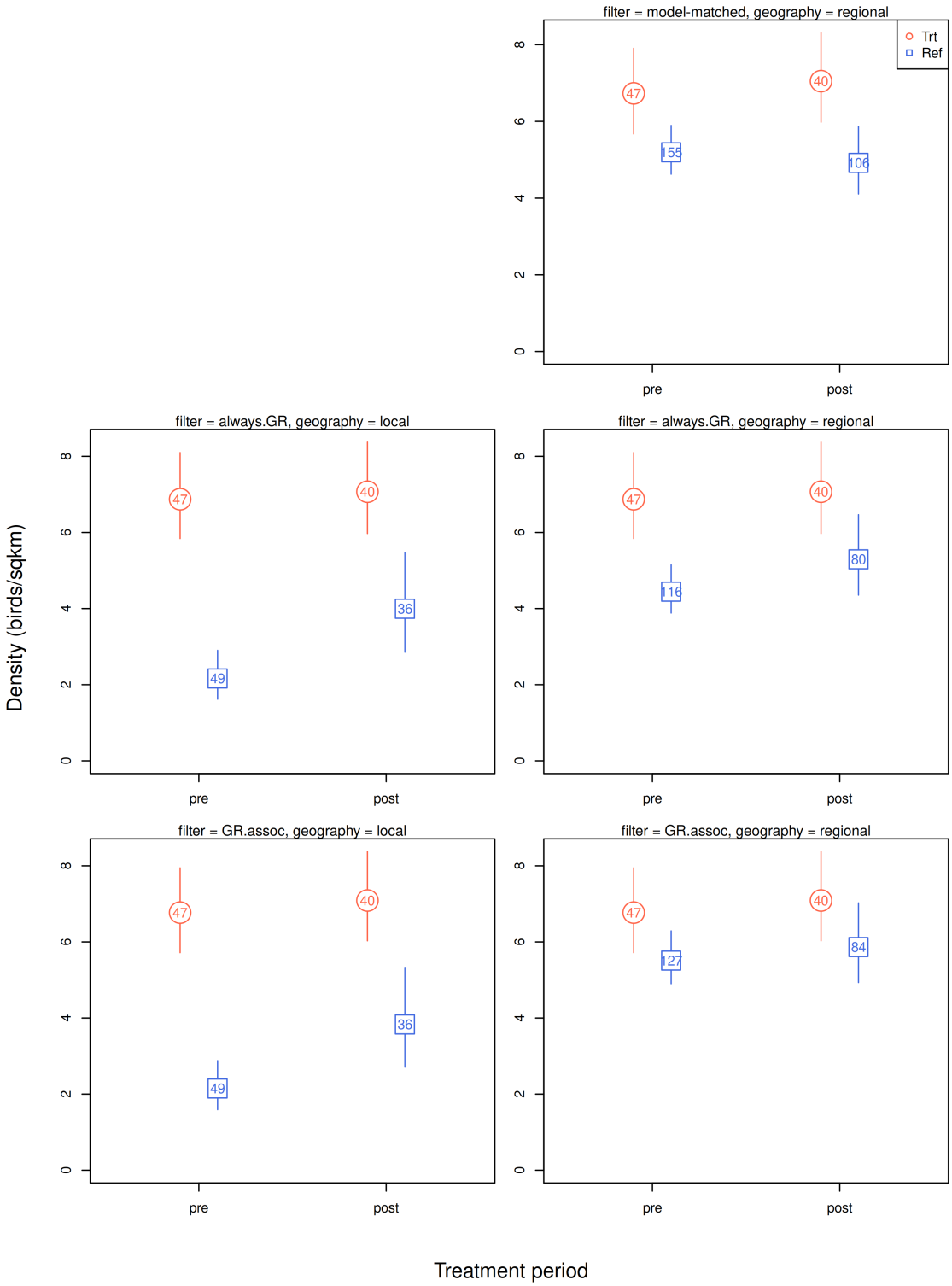


Figure D17. Population density estimates before (pre) versus after (post) initiation of grazing management for Lark Sparrow.

Loggerhead Shrike

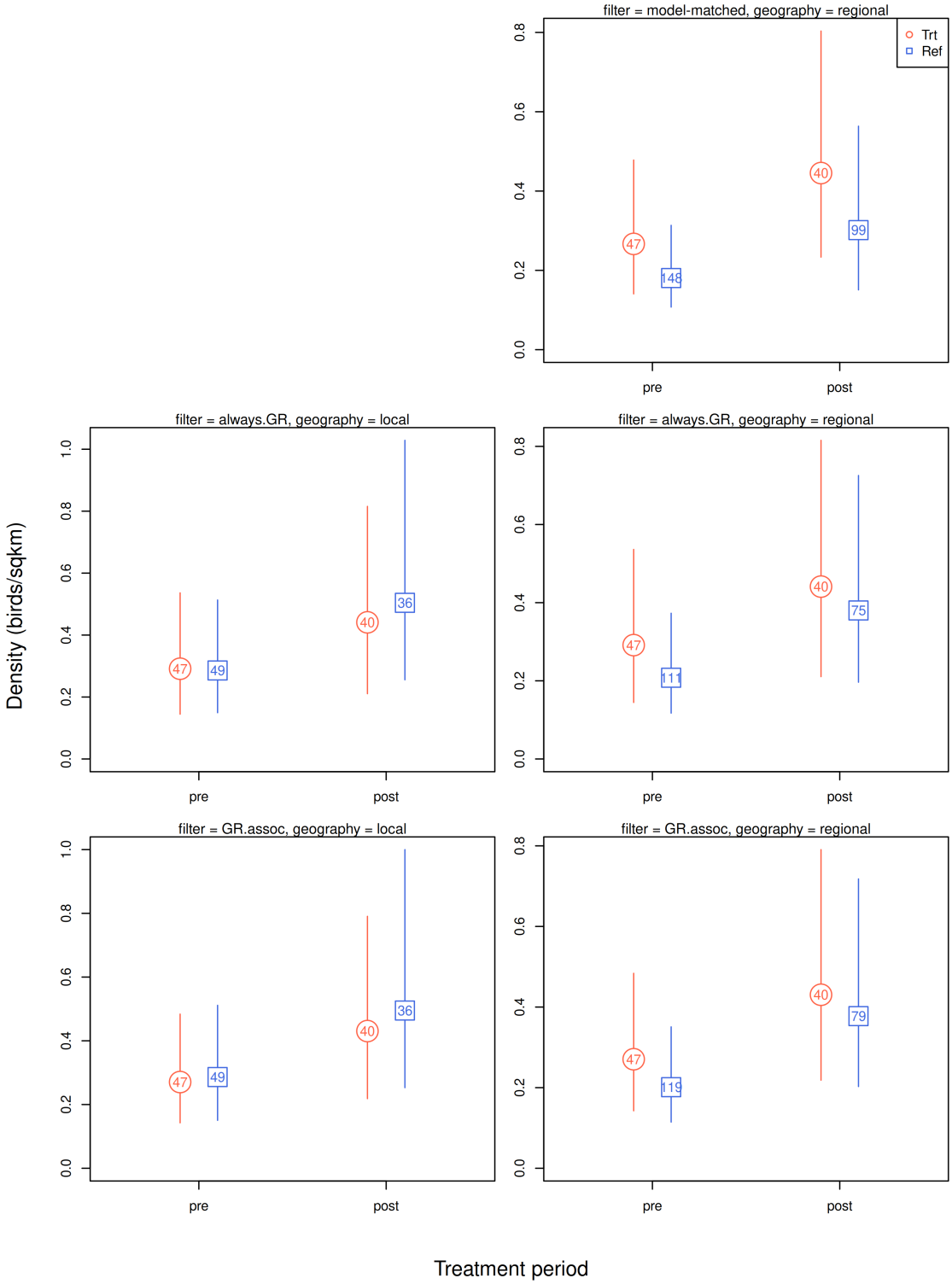


Figure D18. Population density estimates before (pre) versus after (post) initiation of grazing management for Loggerhead Shrike.

Mourning Dove

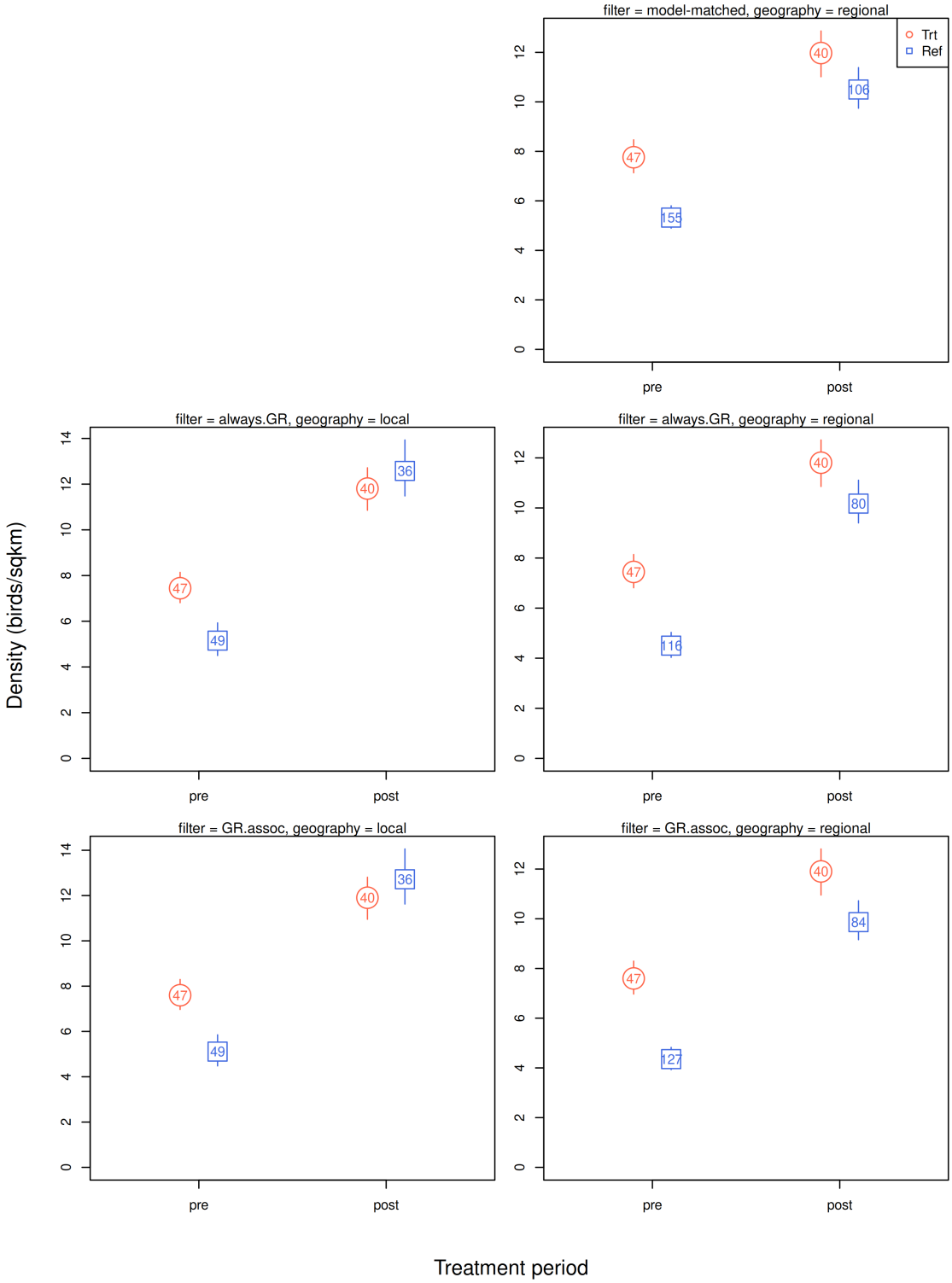


Figure D19. Population density estimates before (pre) versus after (post) initiation of grazing management for Mourning Dove.

Mountain Plover

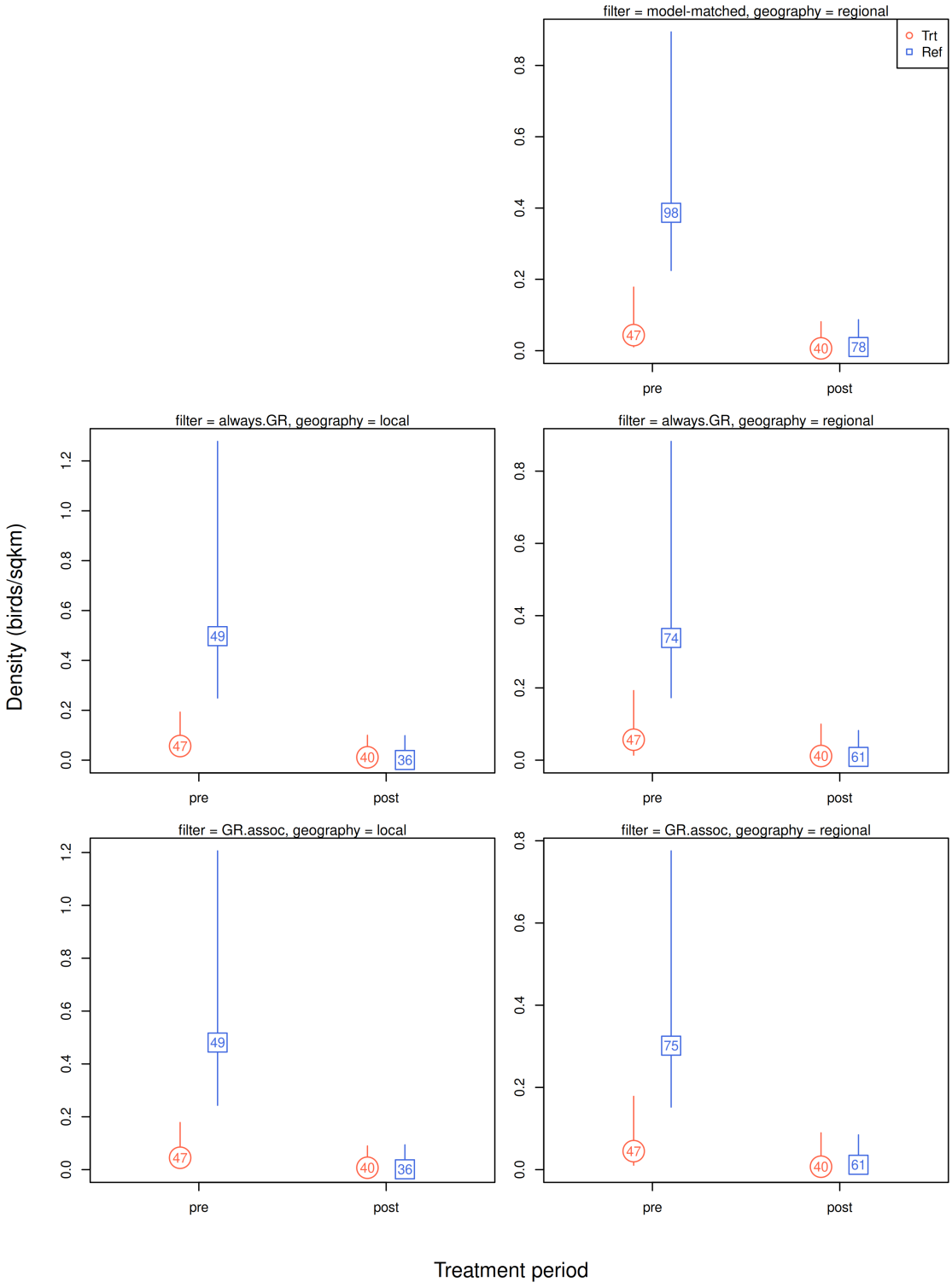


Figure D20. Population density estimates before (pre) versus after (post) initiation of grazing management for Mountain Plover.

Northern Harrier

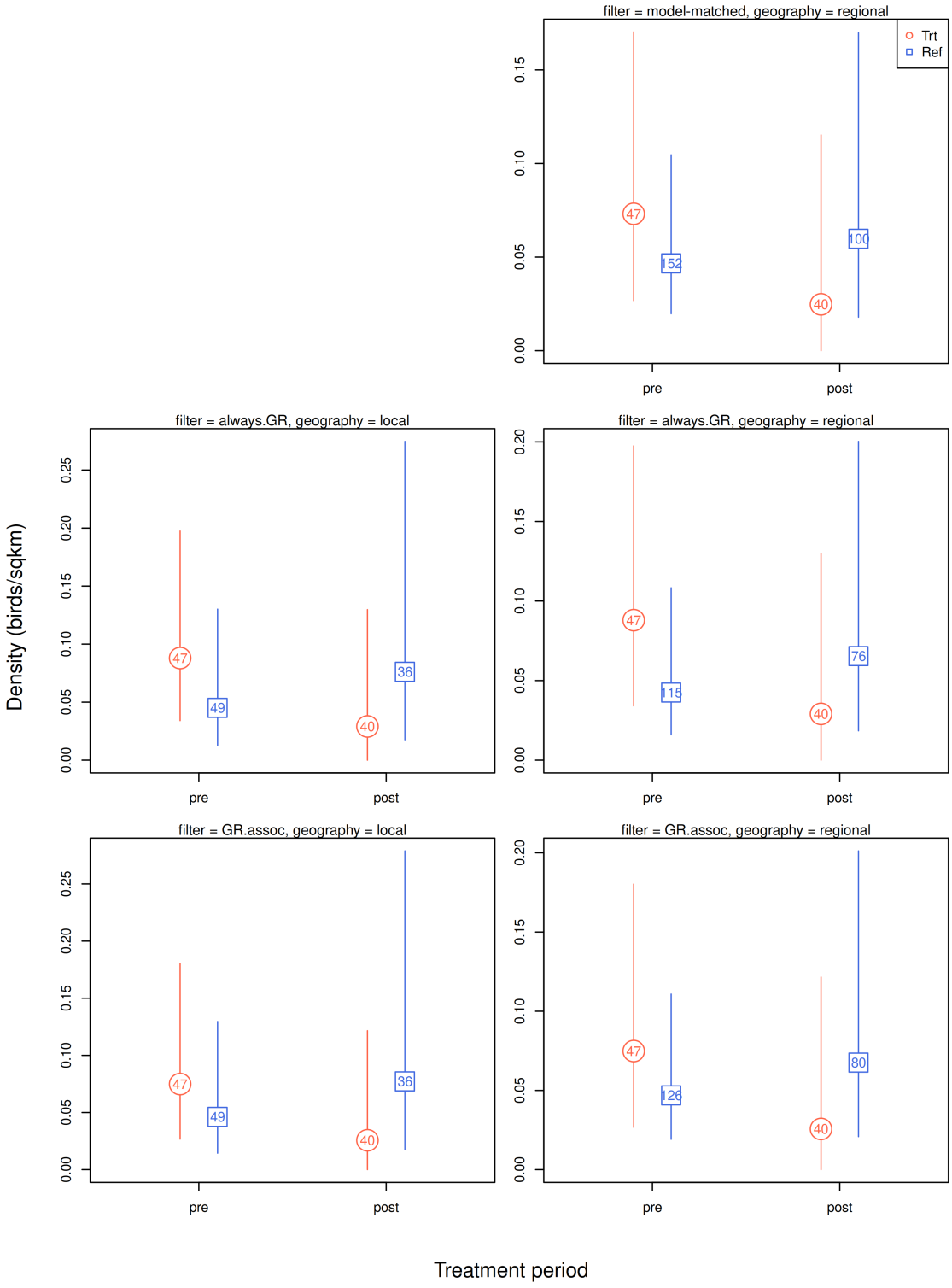


Figure D21. Population density estimates before (pre) versus after (post) initiation of grazing management for Northern Harrier.

Prairie Falcon

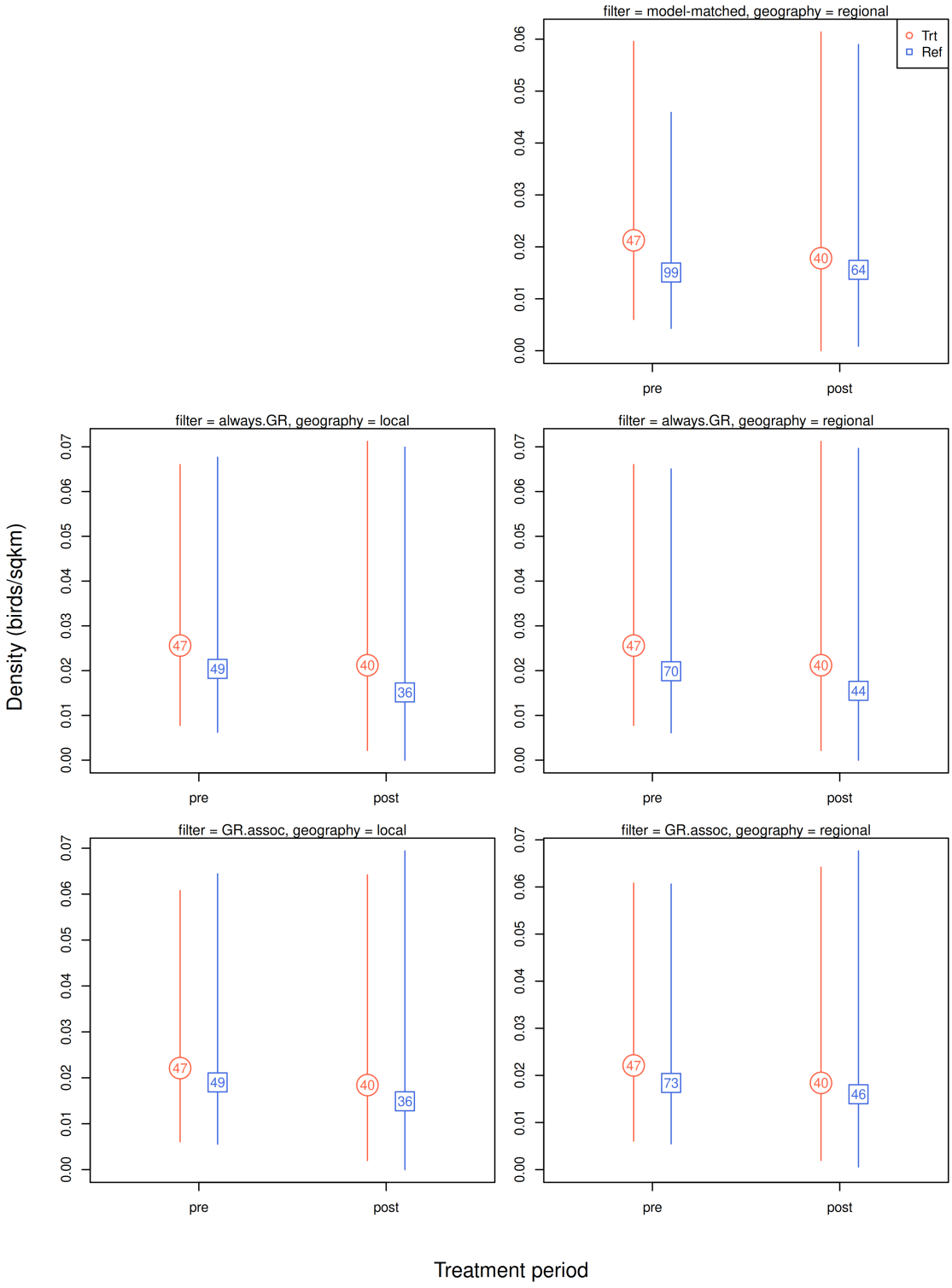


Figure D22. Population density estimates before (pre) versus after (post) initiation of grazing management for Prairie Falcon.

Red-tailed Hawk

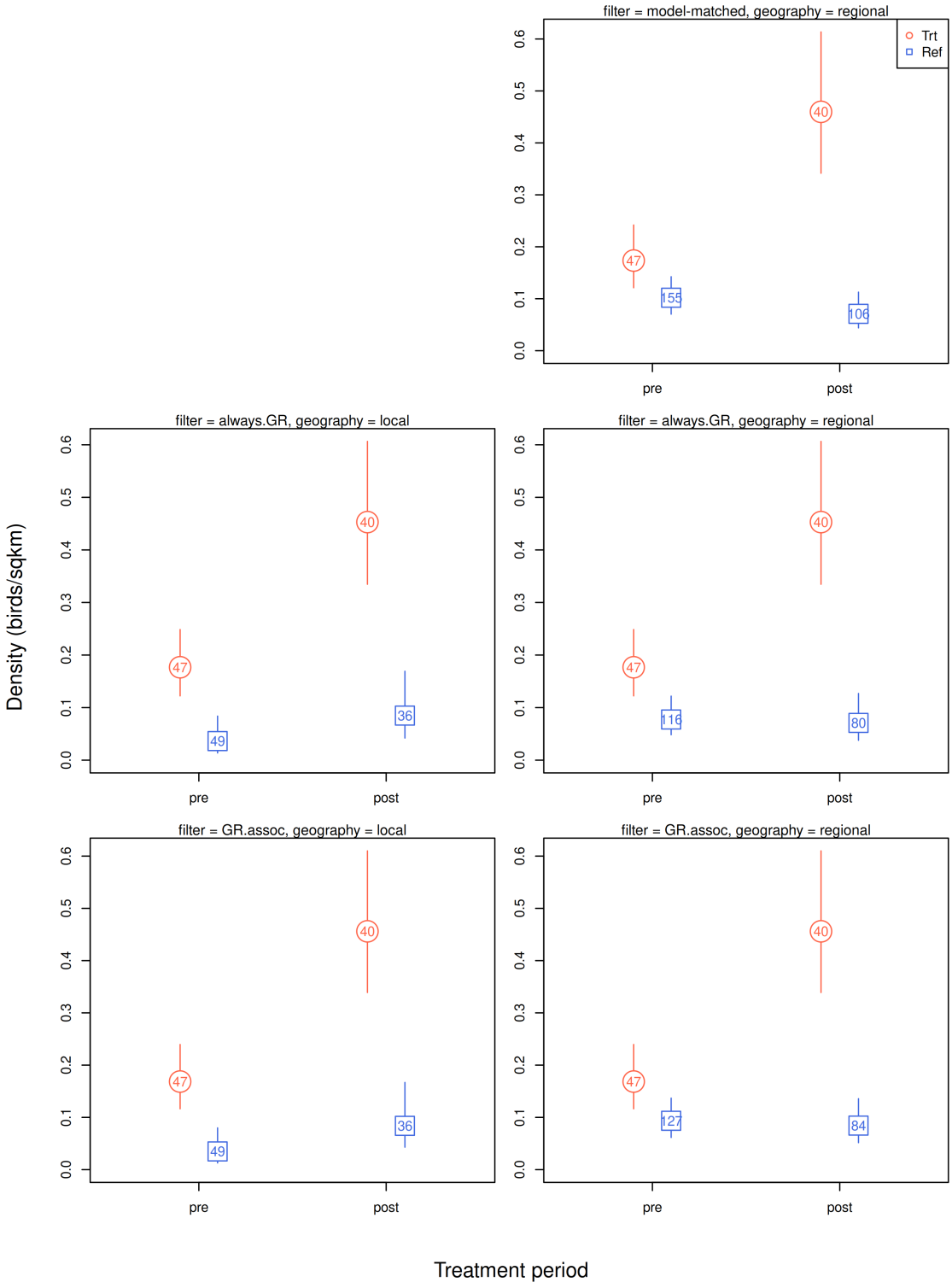


Figure D23. Population density estimates before (pre) versus after (post) initiation of grazing management for Red-tailed Hawk.

Red-winged Blackbird

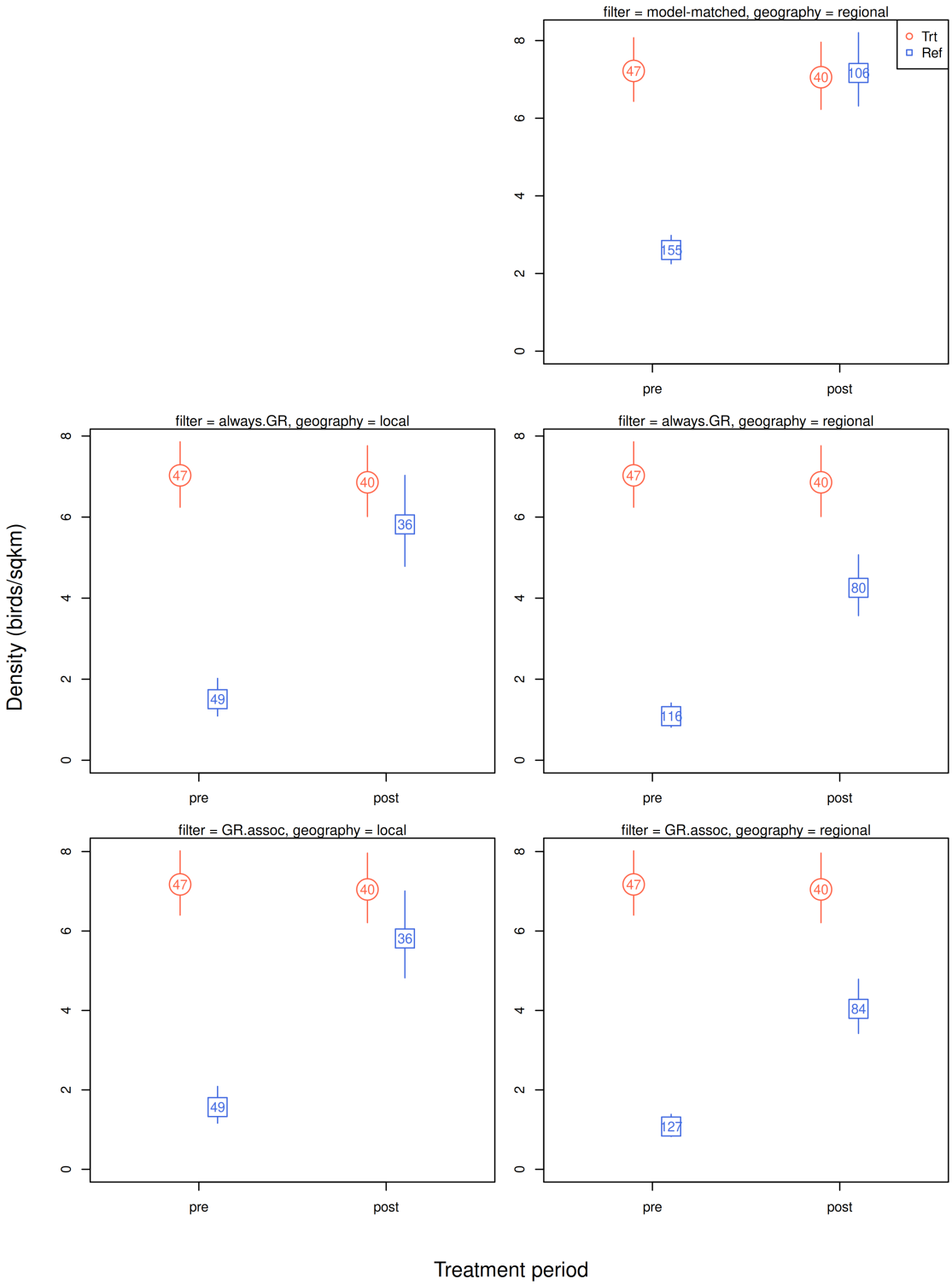


Figure D24. Population density estimates before (pre) versus after (post) initiation of grazing management for Red-winged Blackbird.

Say's Phoebe

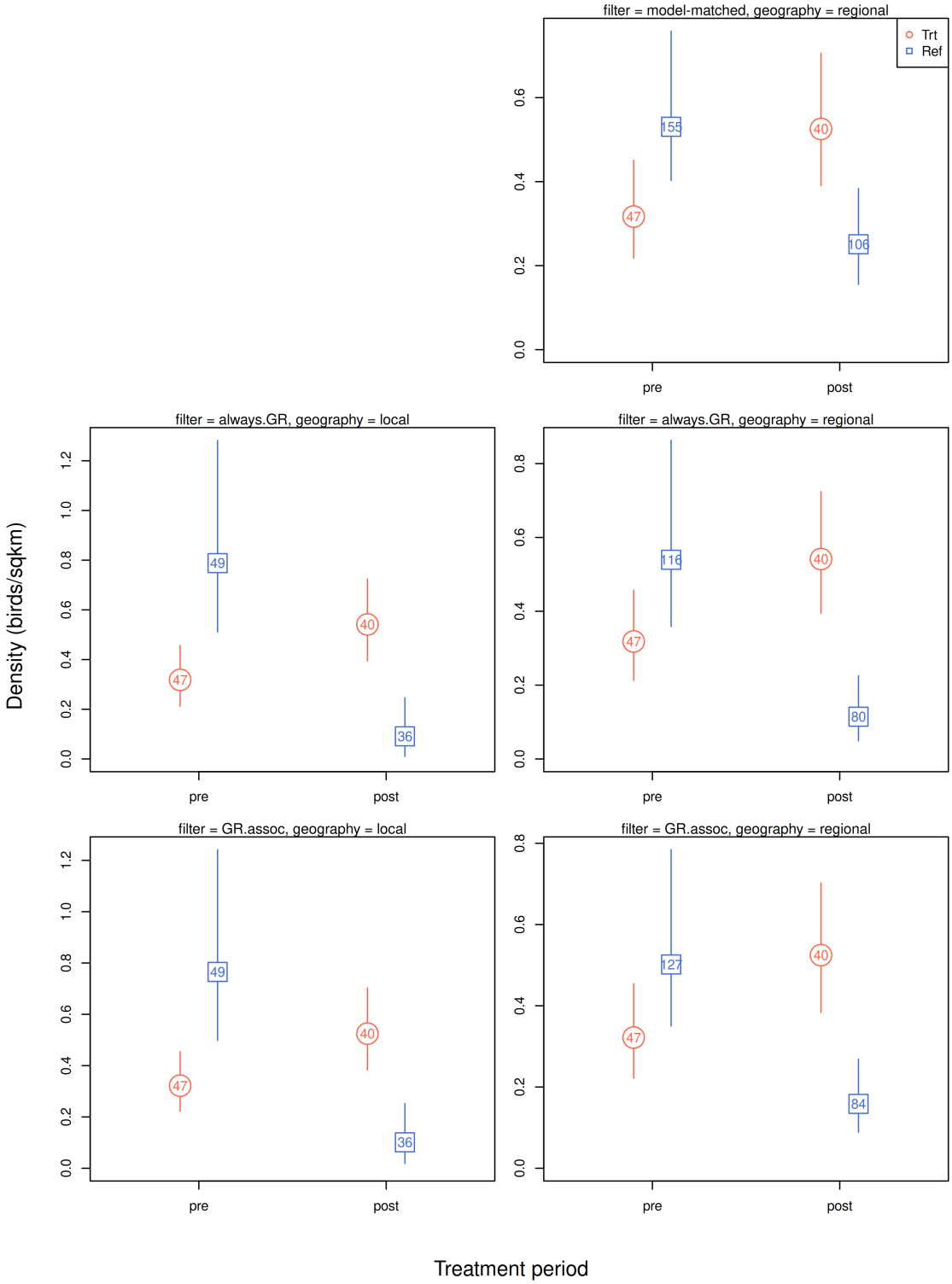


Figure D25. Population density estimates before (pre) versus after (post) initiation of grazing management for Say's Phoebe.

Savannah Sparrow

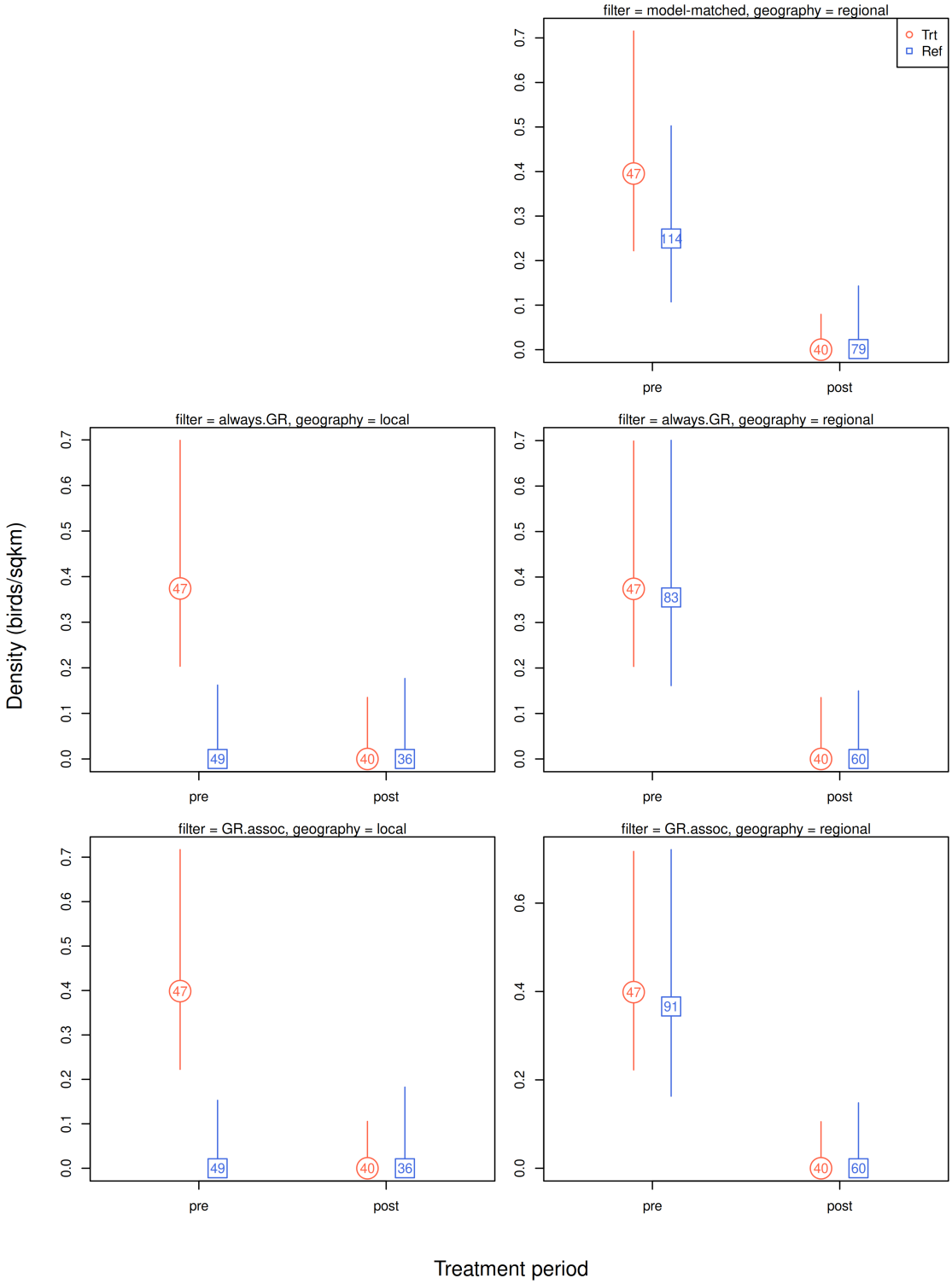


Figure D26. Population density estimates before (pre) versus after (post) initiation of grazing management for Savannah Sparrow.

Swainson's Hawk

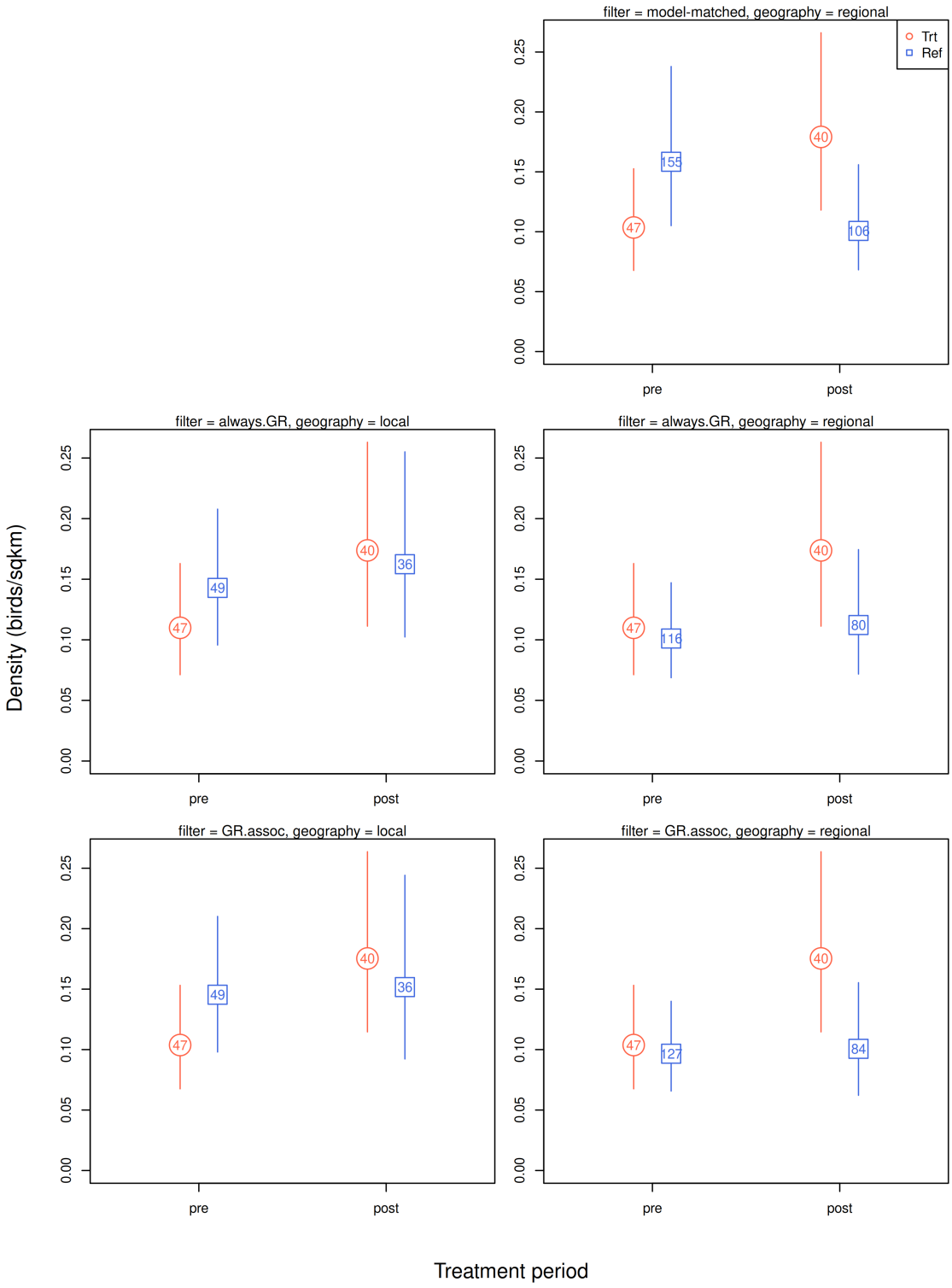


Figure D27. Population density estimates before (pre) versus after (post) initiation of grazing management for Swainson's Hawk.

Vesper Sparrow

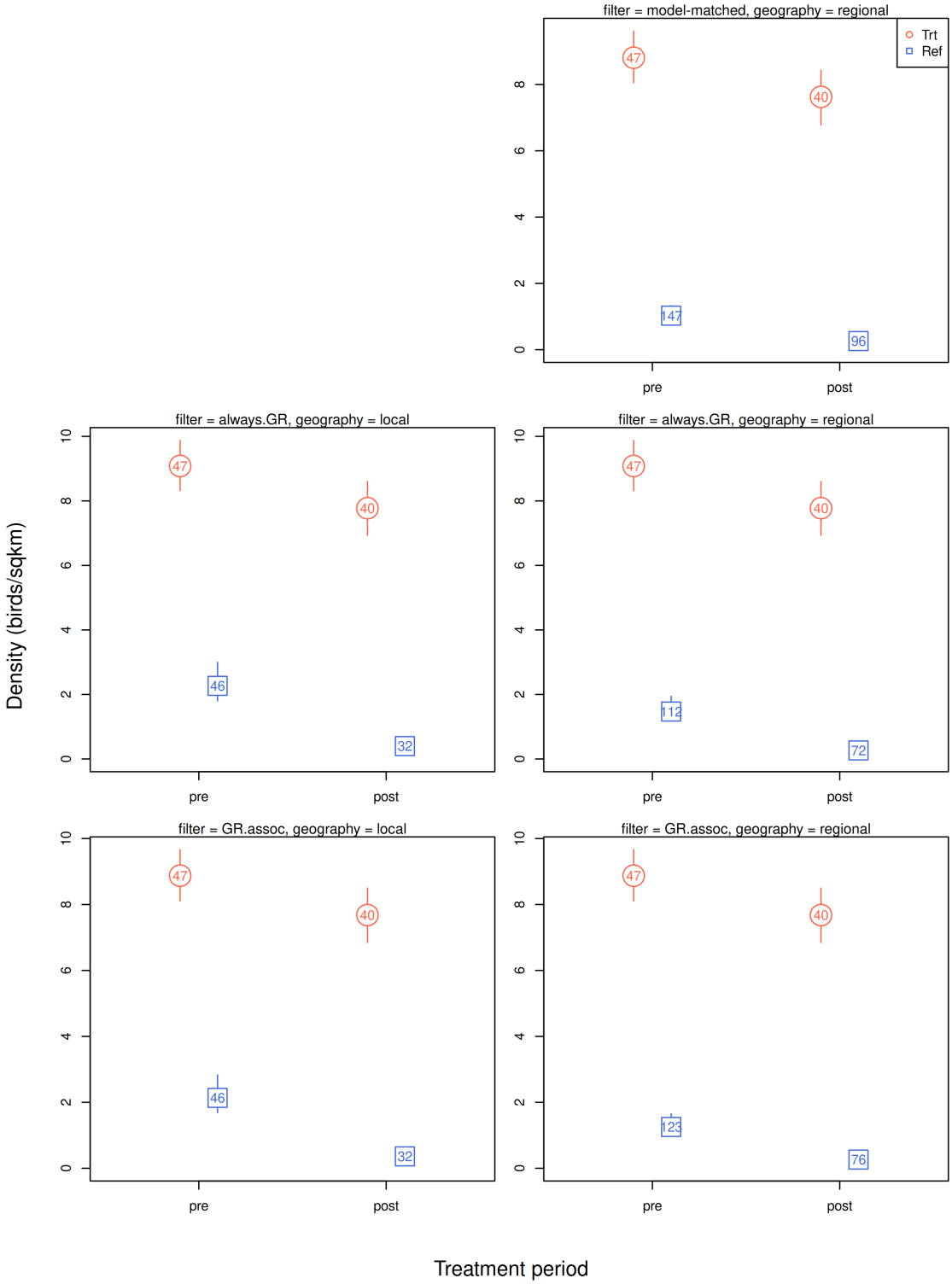


Figure D28. Population density estimates before (pre) versus after (post) initiation of grazing management for Vesper Sparrow.

Western Kingbird

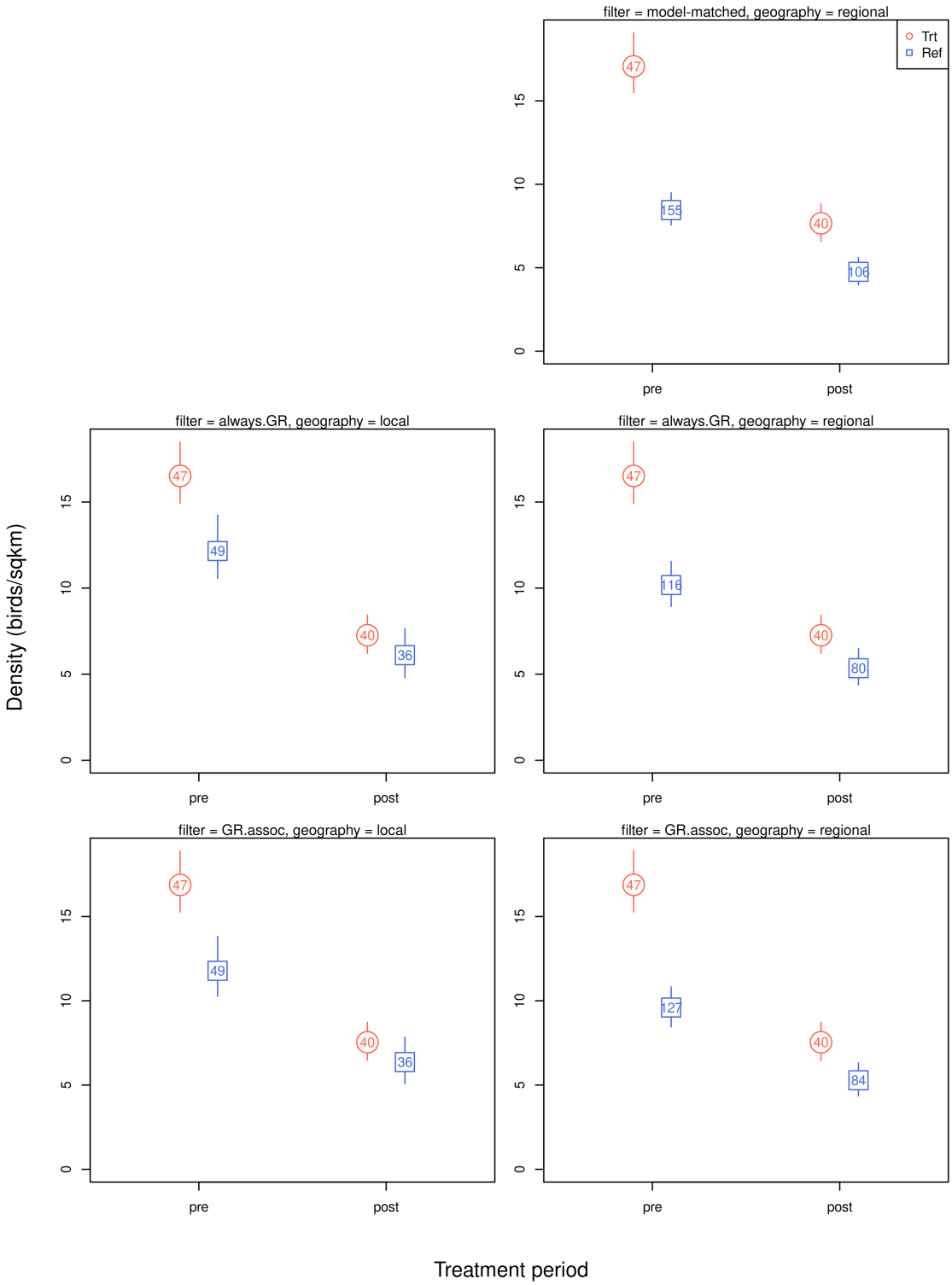


Figure D29. Population density estimates before (pre) versus after (post) initiation of grazing management for Western Kingbird.

Western Meadowlark

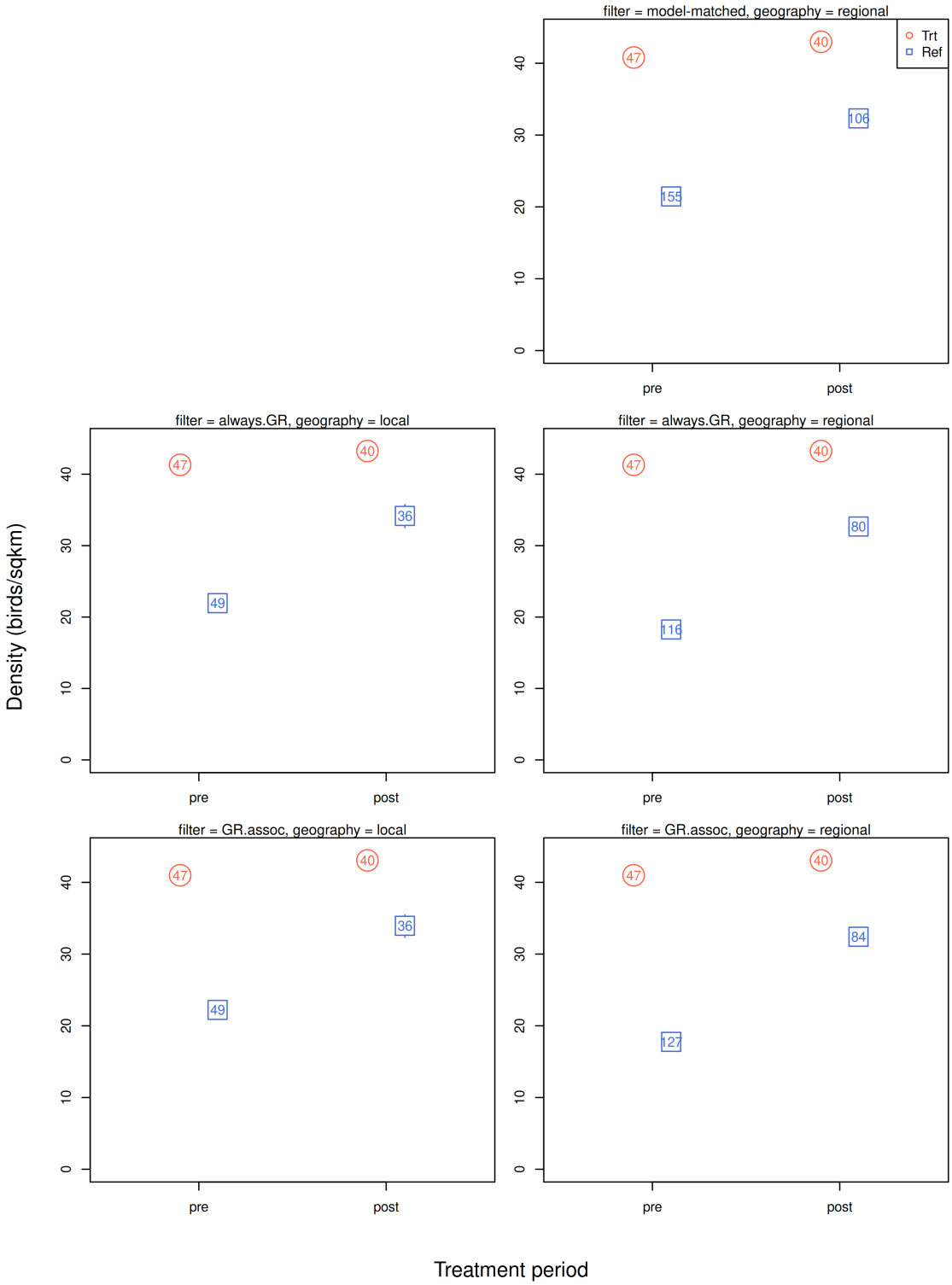


Figure D30. Population density estimates before (pre) versus after (post) initiation of grazing management for Western Meadowlark.

Wilson's Snipe

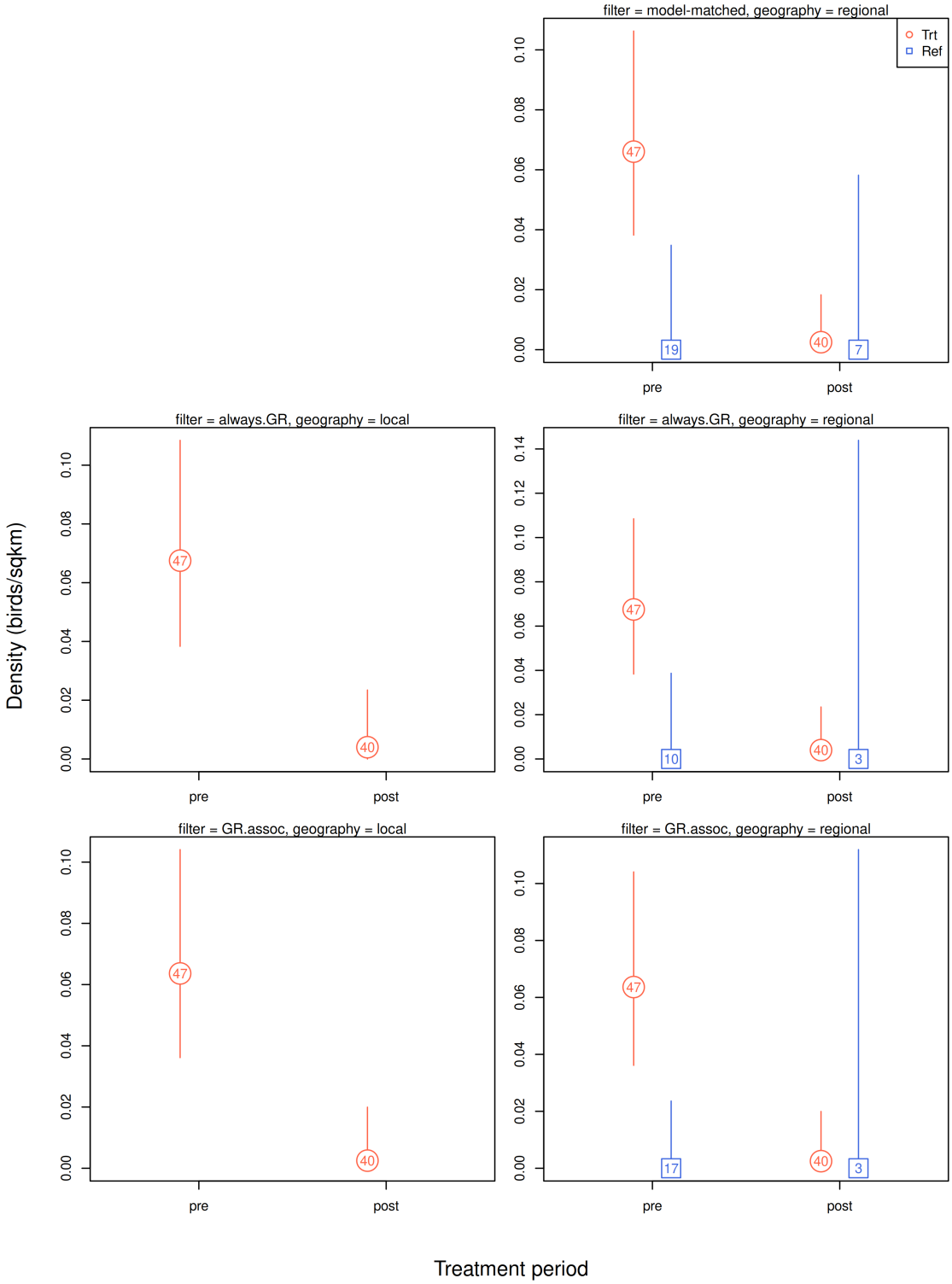


Figure D31. Population density estimates before (pre) versus after (post) initiation of grazing management for Wilson's Snipe.

Appendix E — Figures showing yearly Lowry Ranch and reference population density estimates before (2012–2014) and after (2024–2025) initiation of grazing management.

Each figure displays five panels corresponding to the reference sample comparisons summarized in Table 2 and Table 4. Panel headers indicate the grassland classification filter applied to the comparison ("model-matched," "always.GR" [Always grassland], or "GR.assoc" [Grassland associated]) and the geographic scope of the reference sample ("local" or "regional"). Within each panel, red circles (Trt) and blue squares (Ref) show estimated population densities (birds/sqkm) with 90% credible intervals for Lowry Ranch and reference samples, respectively, for each individual survey year. The dashed vertical line marks the boundary between the pre-management (2012–2014) and post-management (2024–2025) periods. The number printed inside each symbol gives the number of survey points contributing to that estimate, which for Lowry estimates was the same but differed for reference samples across species because only points within strata where the species was detected at least once over the course of the IMBCR program were included for analysis.

American Kestrel

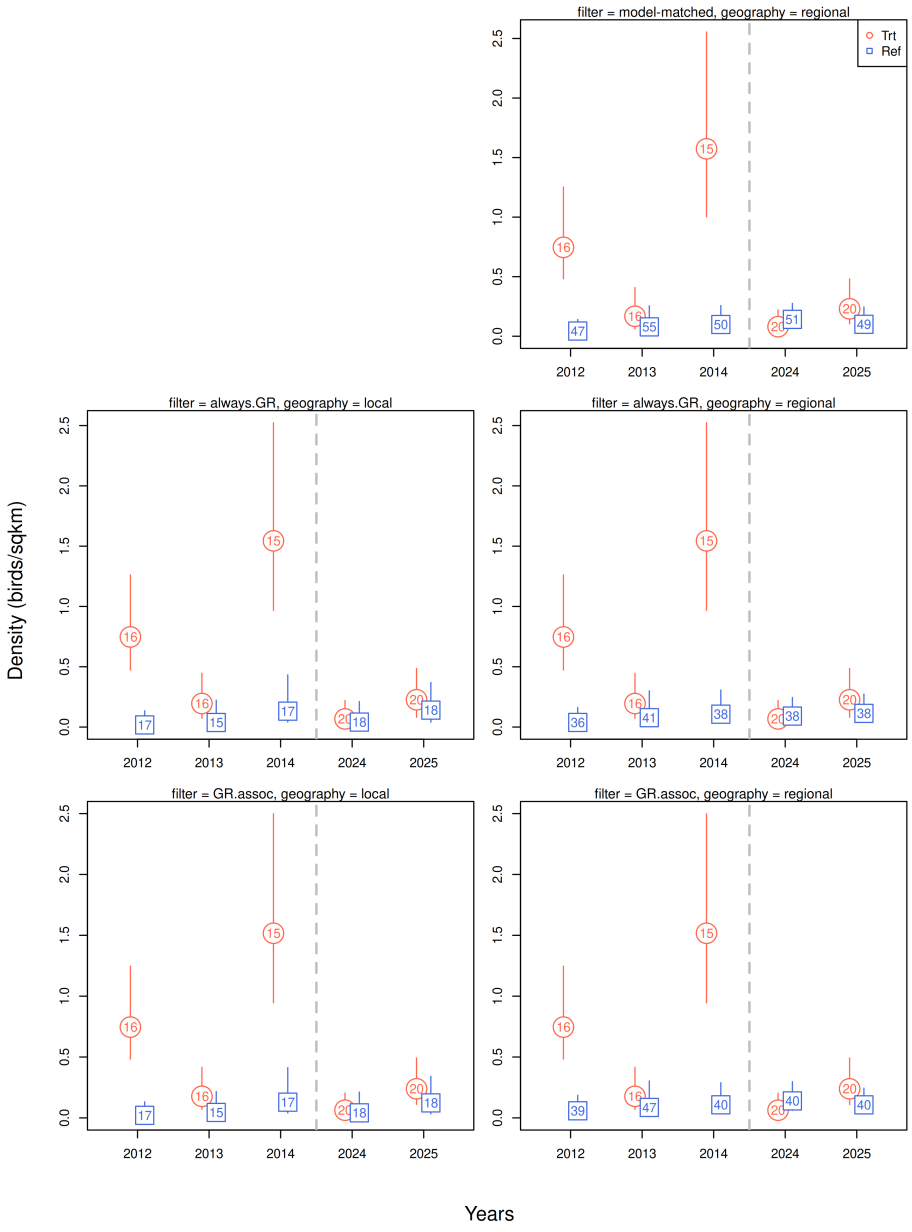


Figure E1. Yearly population density estimates before (pre) and after (post) initiation of grazing management for American Kestrel.

Barn Swallow

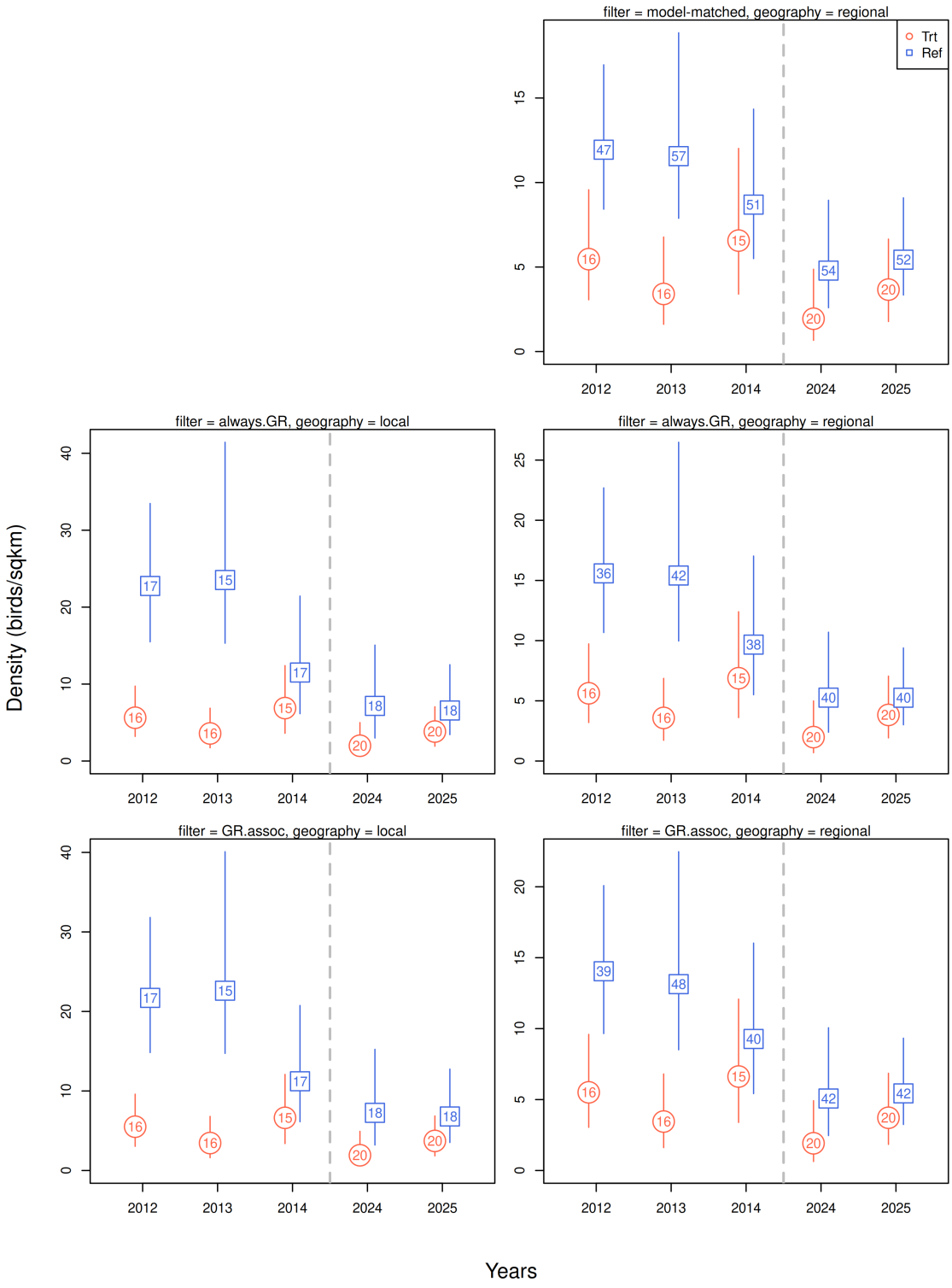


Figure E2. Yearly population density estimates before (pre) and after (post) initiation of grazing management for Barn Swallow.

Brown-headed Cowbird

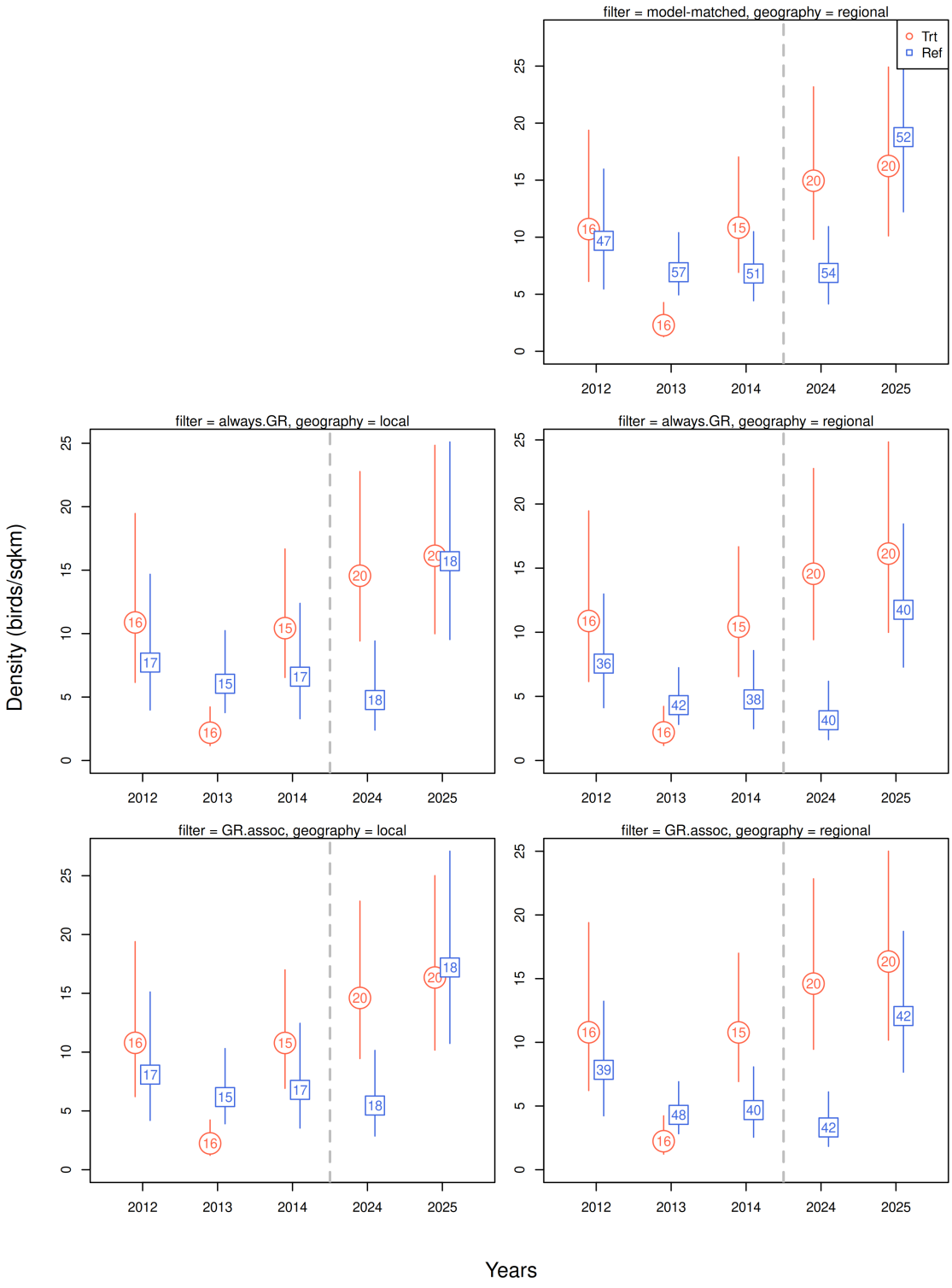


Figure E3. Yearly population density estimates before (pre) and after (post) initiation of grazing management for Brown-headed Cowbird.

Brewer's Blackbird

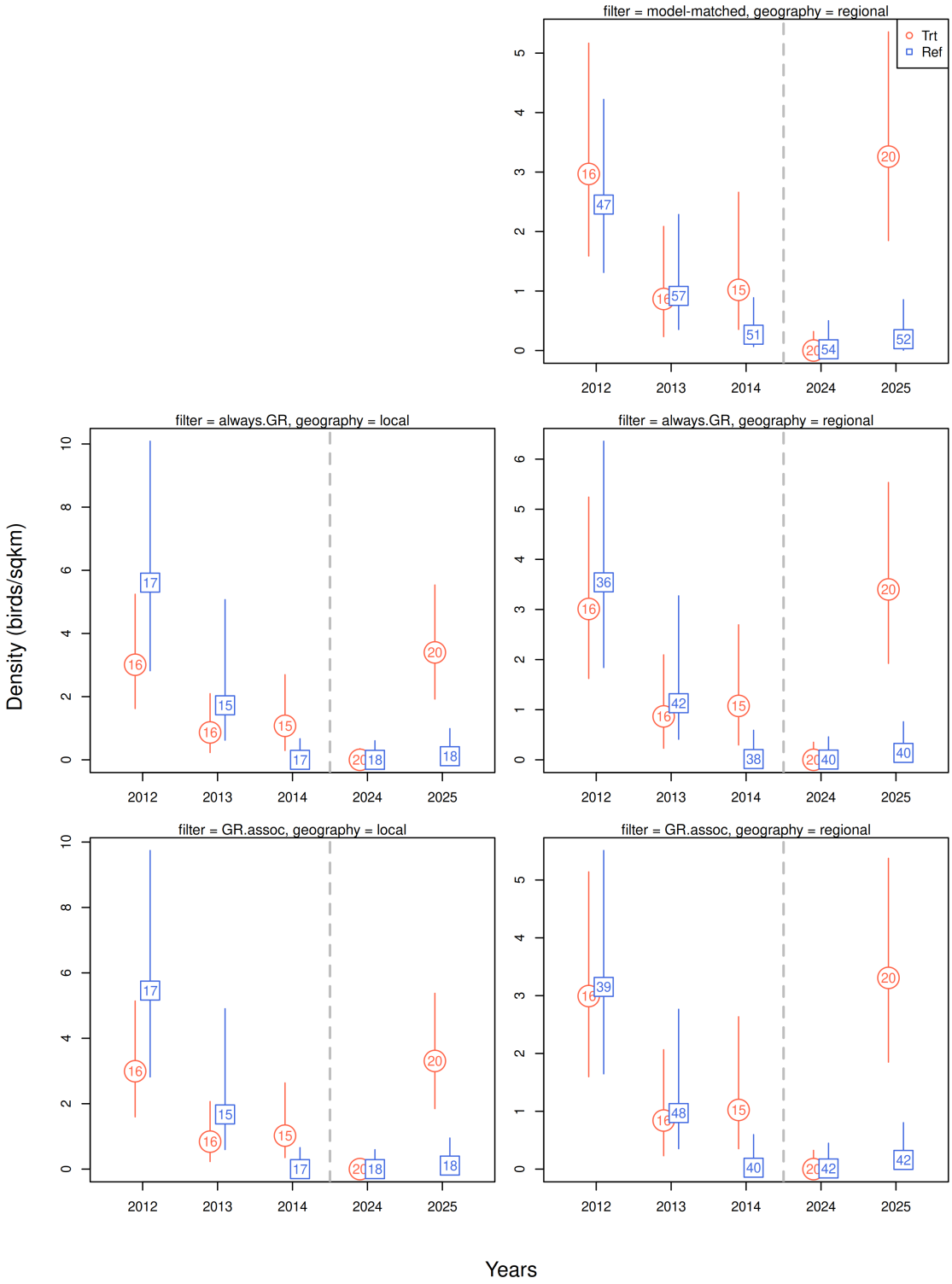


Figure E4. Yearly population density estimates before (pre) and after (post) initiation of grazing management for Brewer's Blackbird.

Burrowing Owl

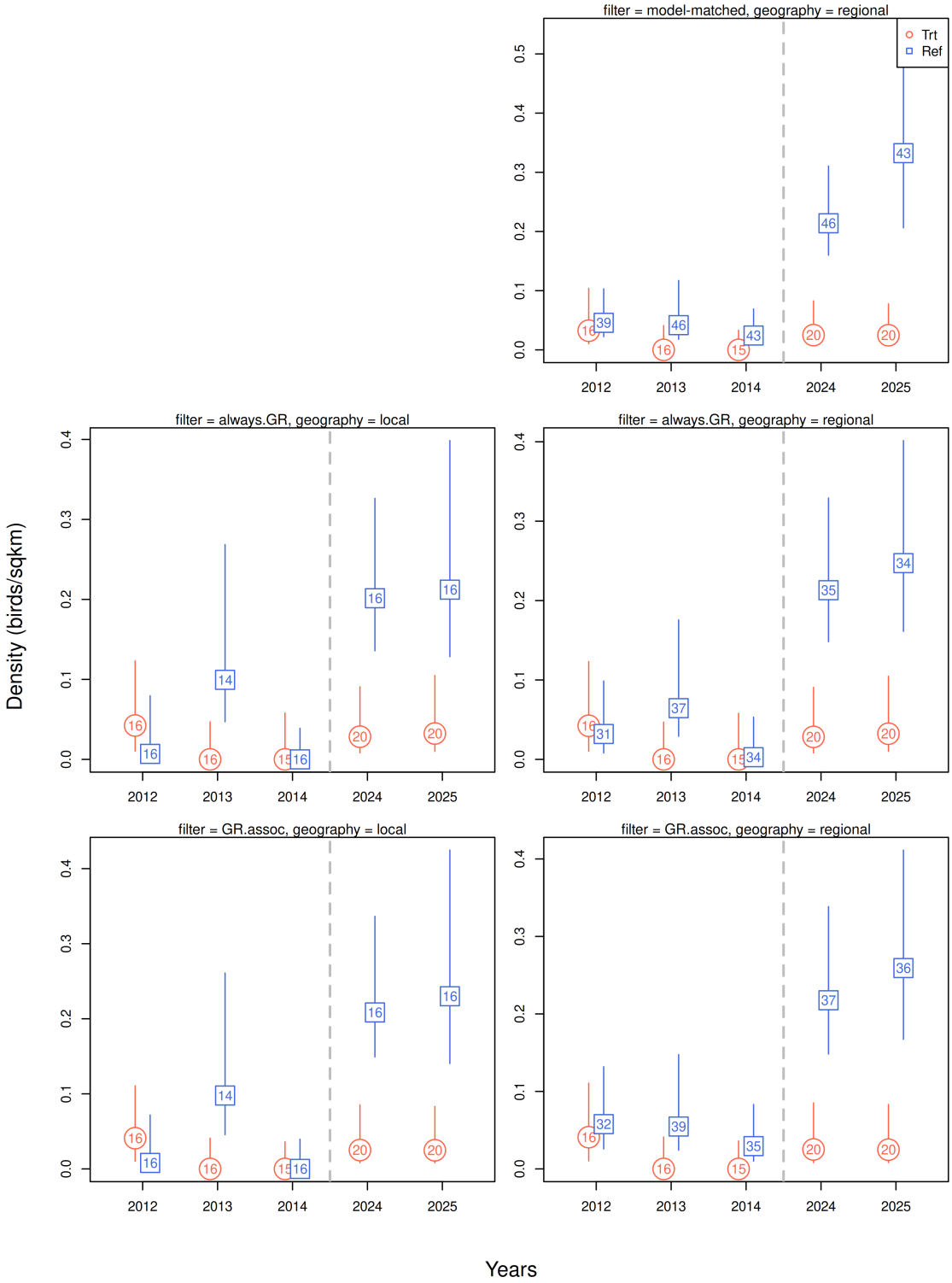


Figure E5. Yearly population density estimates before (pre) and after (post) initiation of grazing management for Burrowing Owl.

Cassin's Kingbird

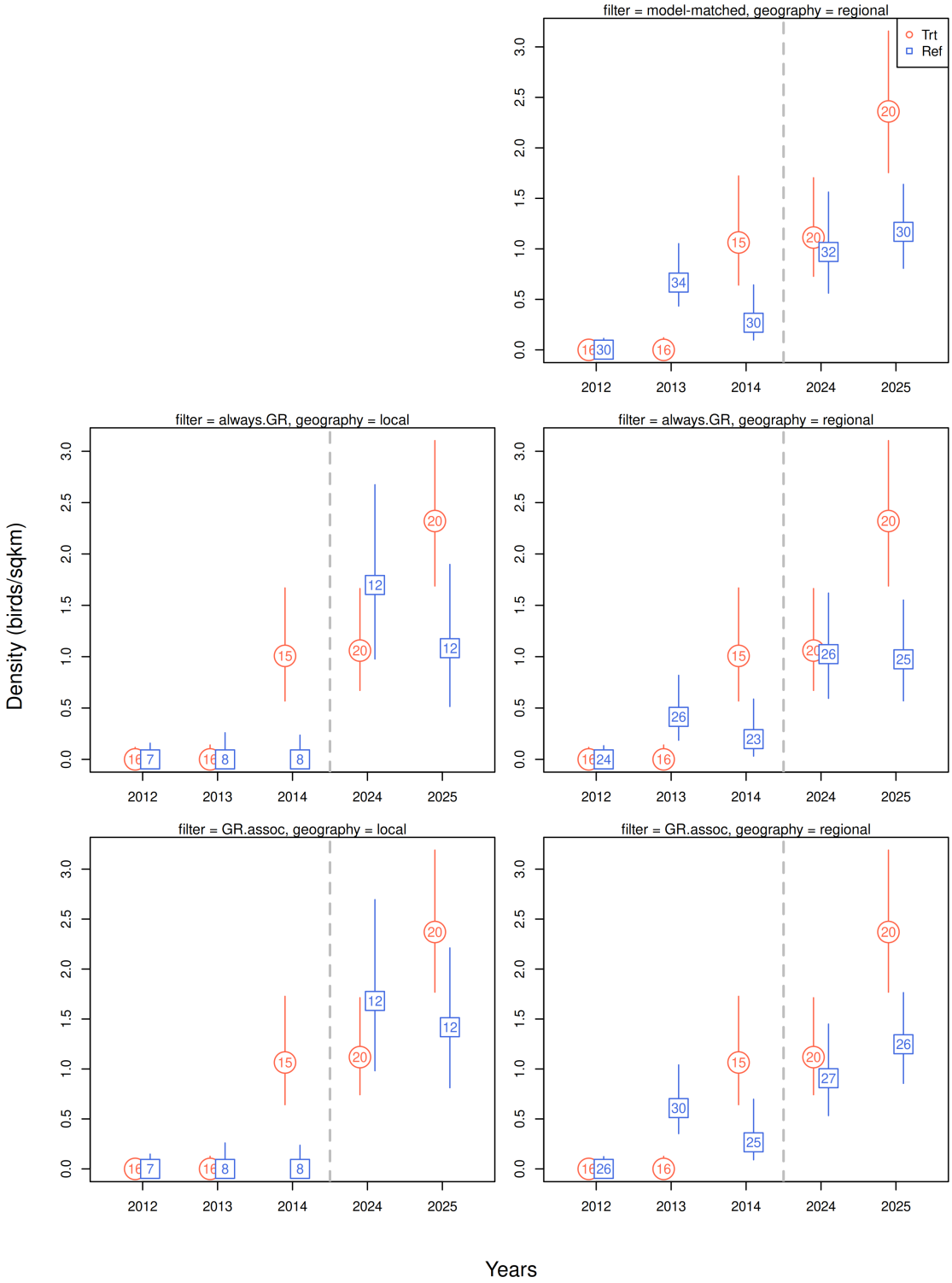


Figure E6. Yearly population density estimates before (pre) and after (post) initiation of grazing management for Cassin's Kingbird.

Cassin's Sparrow

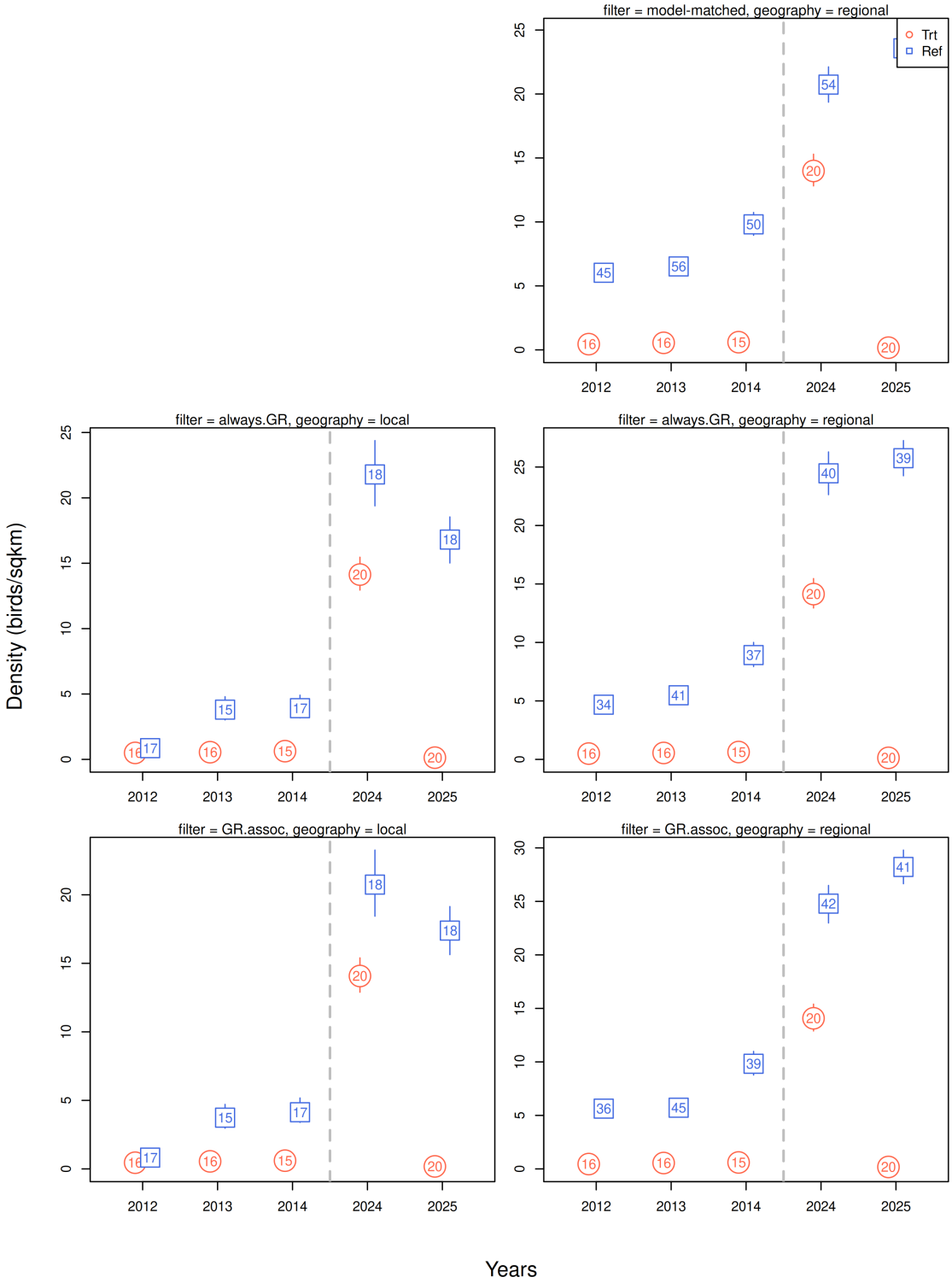


Figure E7. Yearly population density estimates before (pre) and after (post) initiation of grazing management for Cassin's Sparrow.

Cliff Swallow

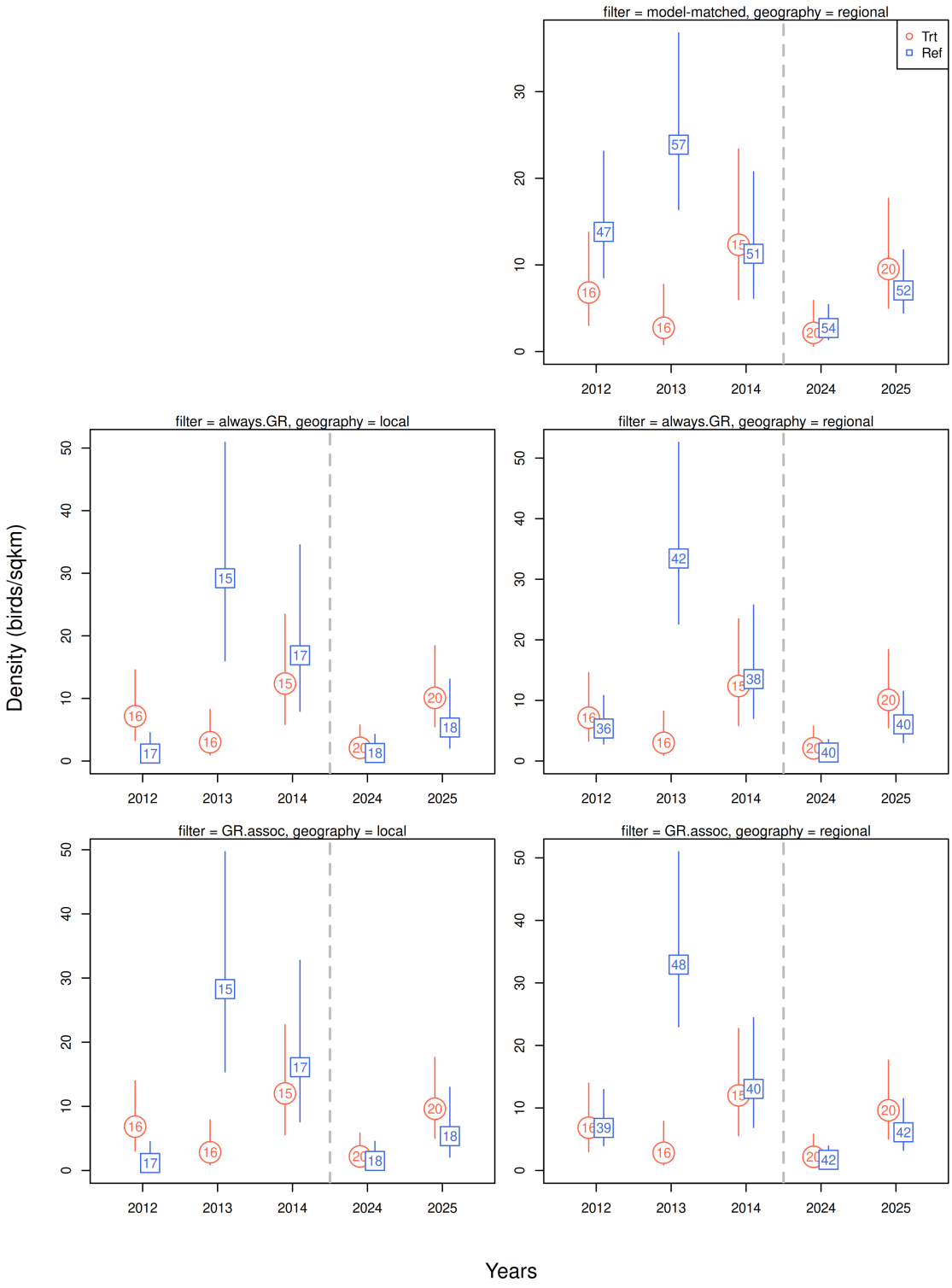


Figure E8. Yearly population density estimates before (pre) and after (post) initiation of grazing management for Cliff Swallow.

Common Nighthawk

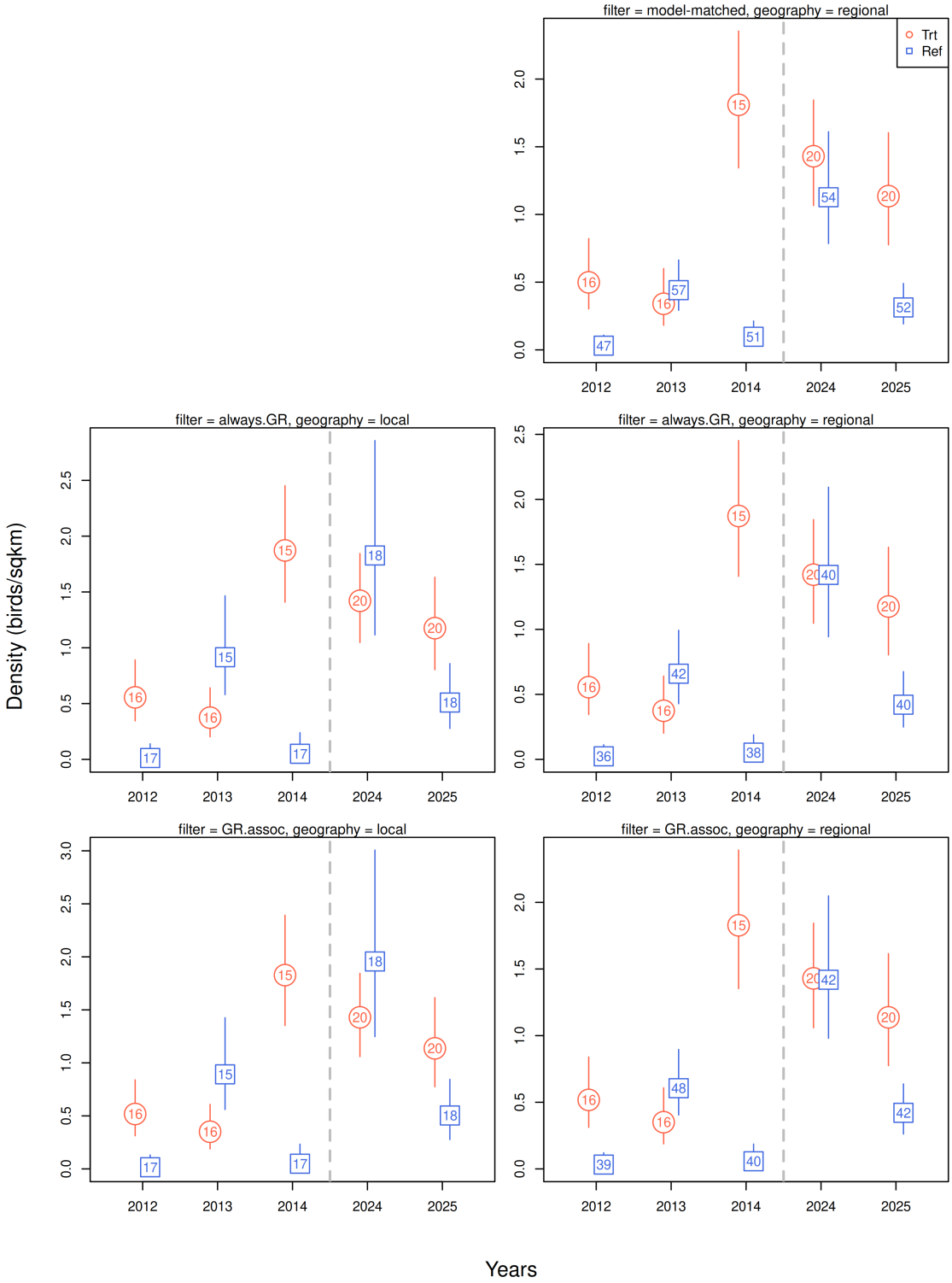


Figure E9. Yearly population density estimates before (pre) and after (post) initiation of grazing management for Common Nighthawk.

Dickcissel

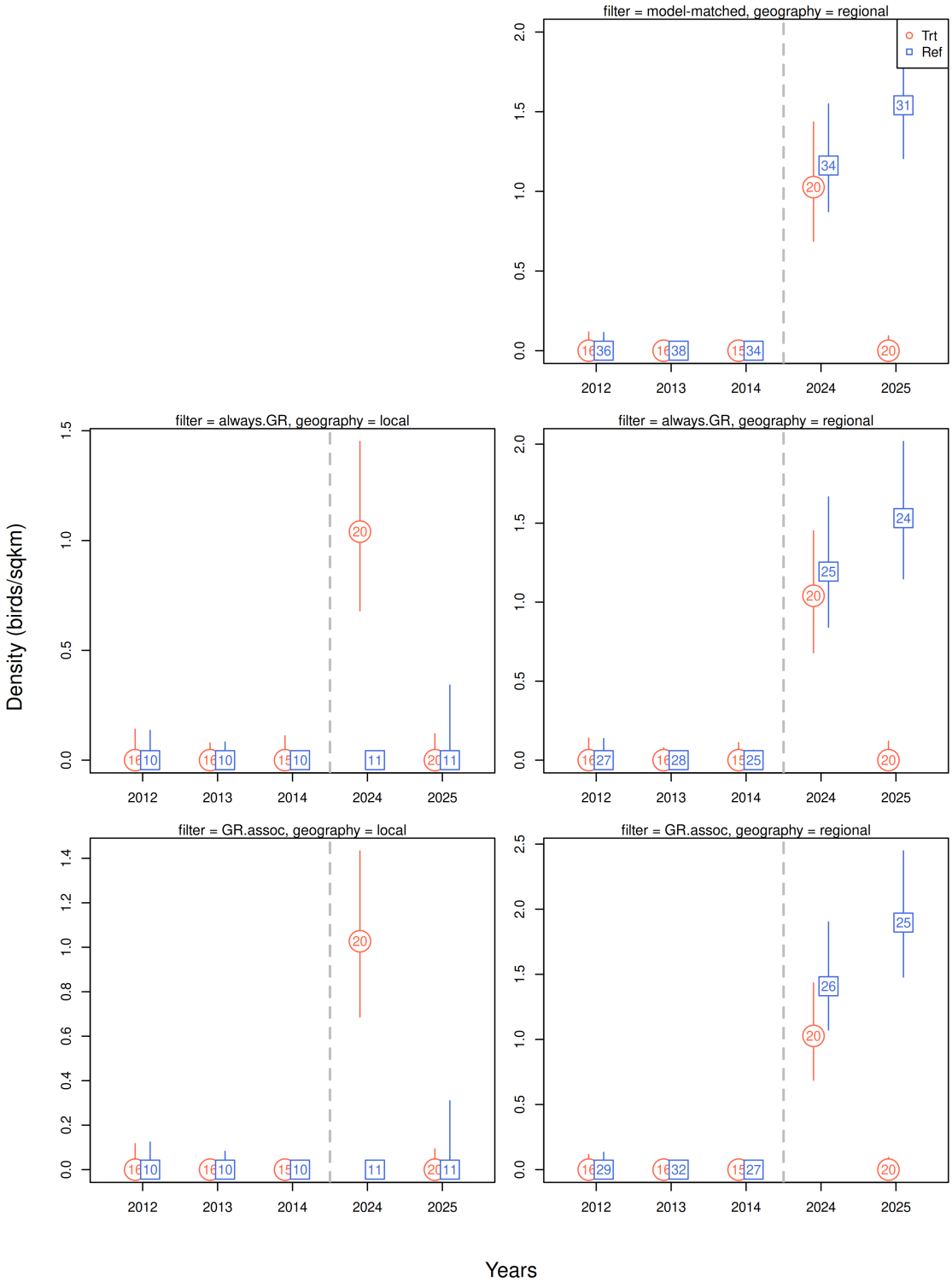


Figure E10. Yearly population density estimates before (pre) and after (post) initiation of grazing management for Dickcissel.

Eastern Kingbird

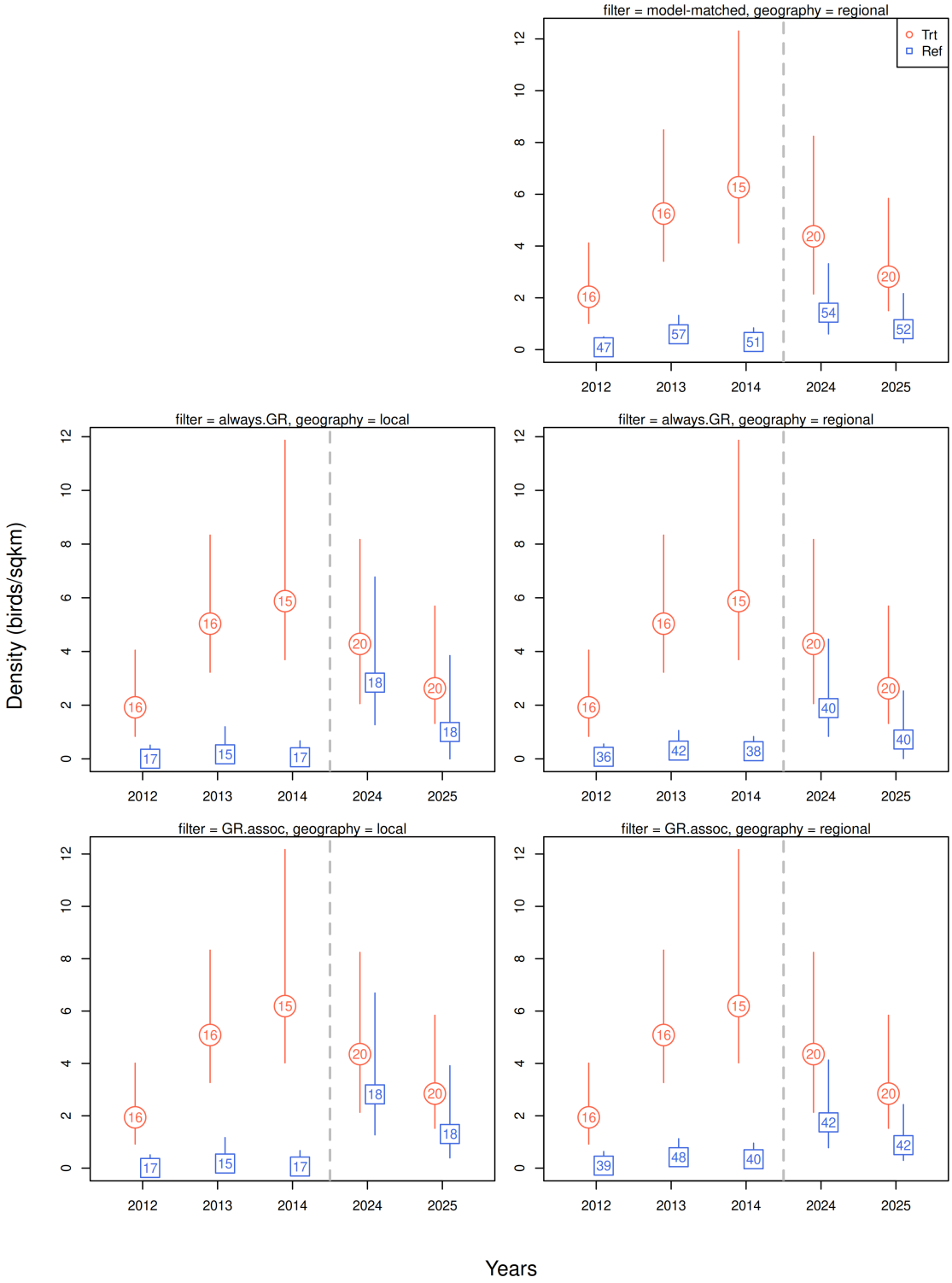


Figure E11. Yearly population density estimates before (pre) and after (post) initiation of grazing management for Eastern Kingbird.

Ferruginous Hawk

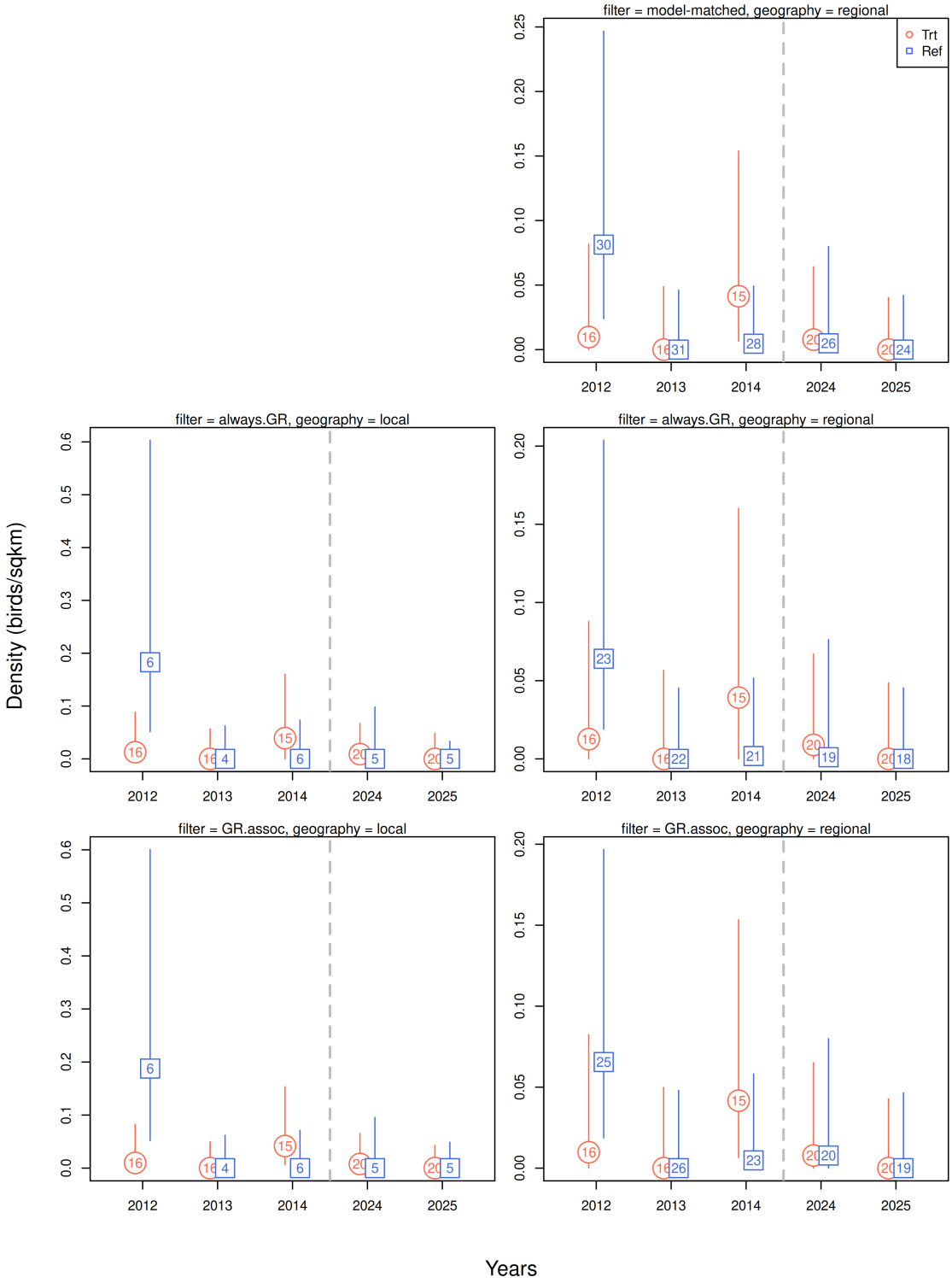


Figure E12. Yearly population density estimates before (pre) and after (post) initiation of grazing management for Ferruginous Hawk.

Grasshopper Sparrow

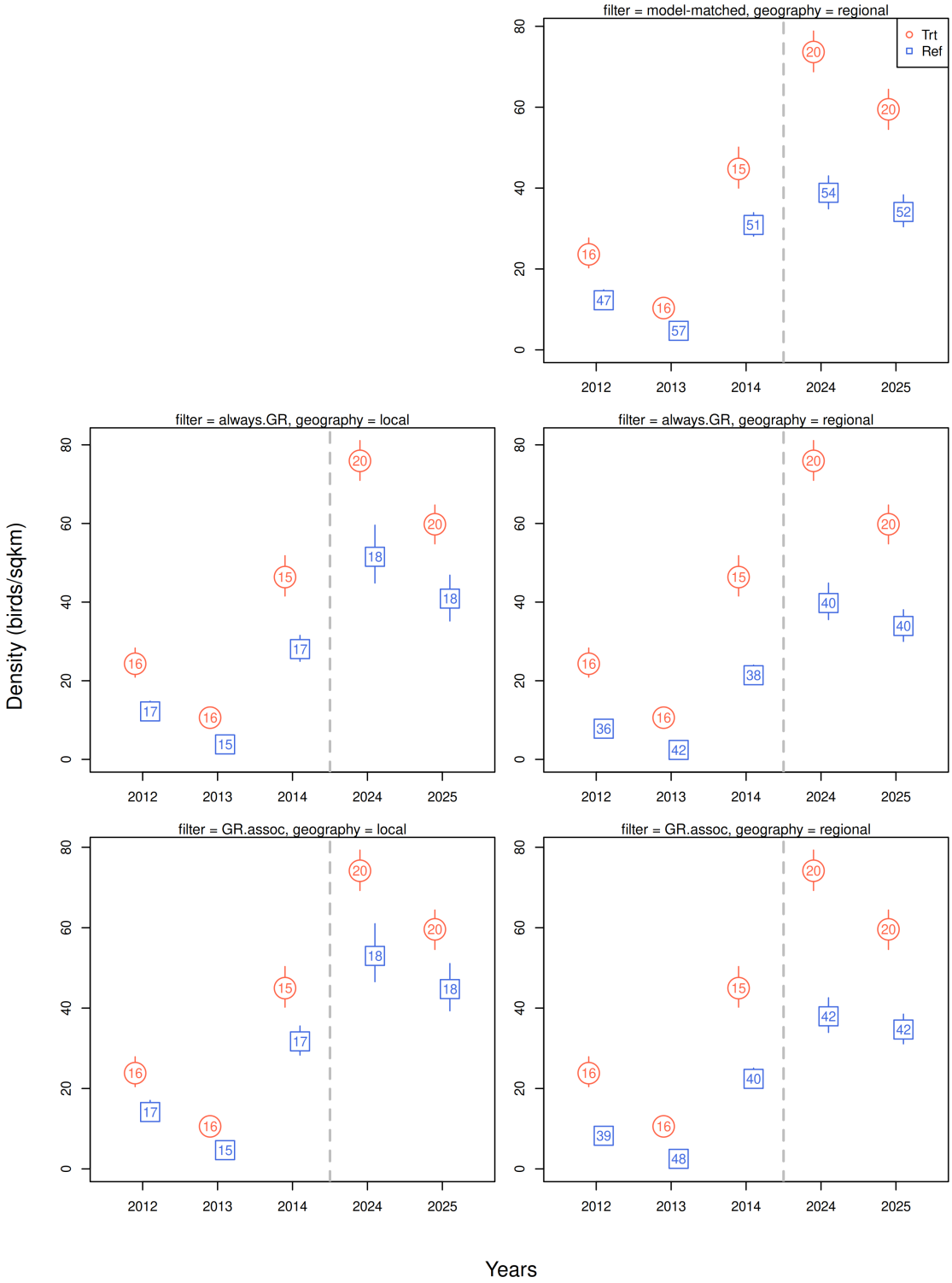


Figure E13. Yearly population density estimates before (pre) and after (post) initiation of grazing management for Grasshopper Sparrow.

Horned Lark

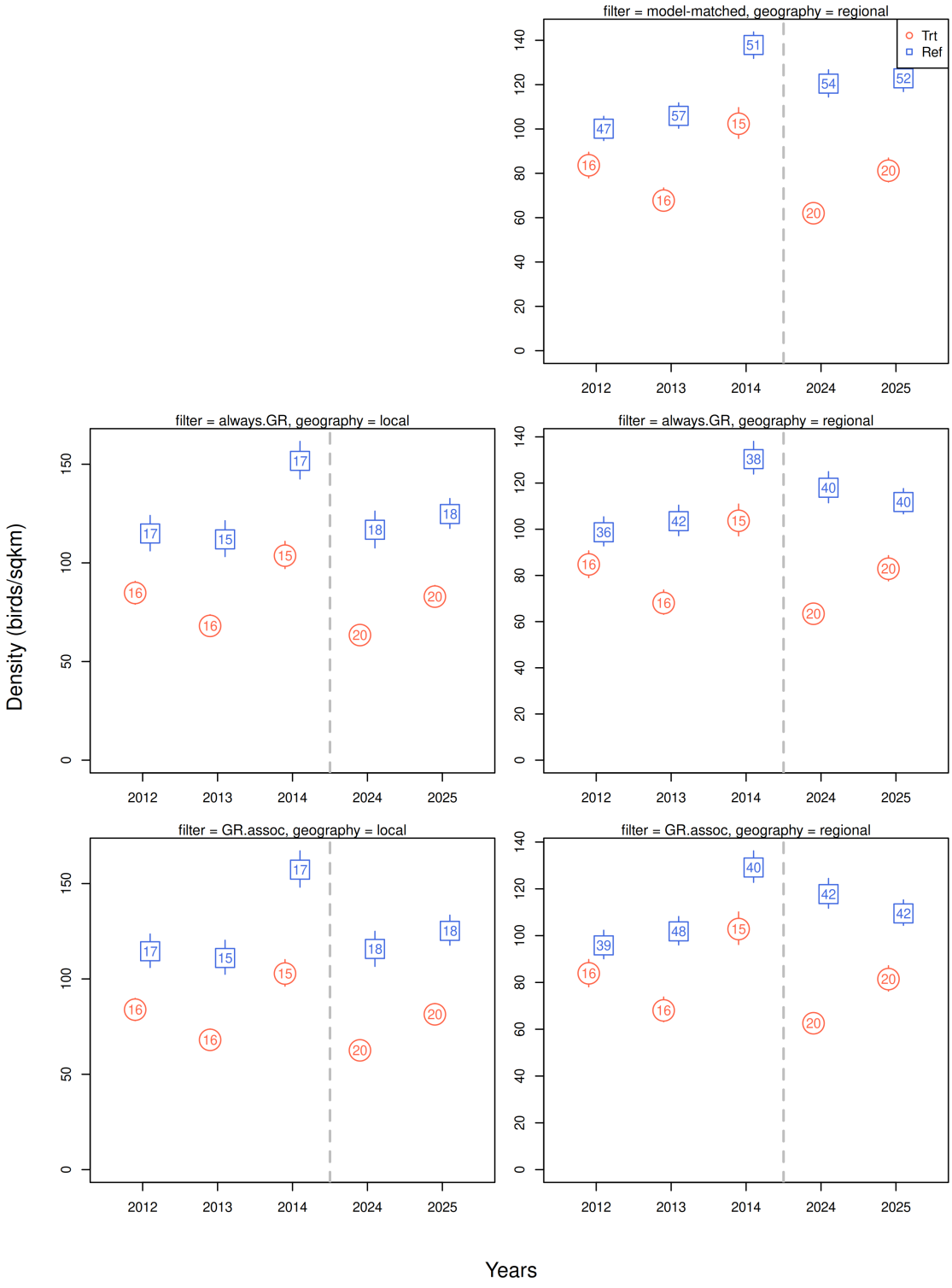


Figure E14. Yearly population density estimates before (pre) and after (post) initiation of grazing management for Horned Lark.

Killdeer

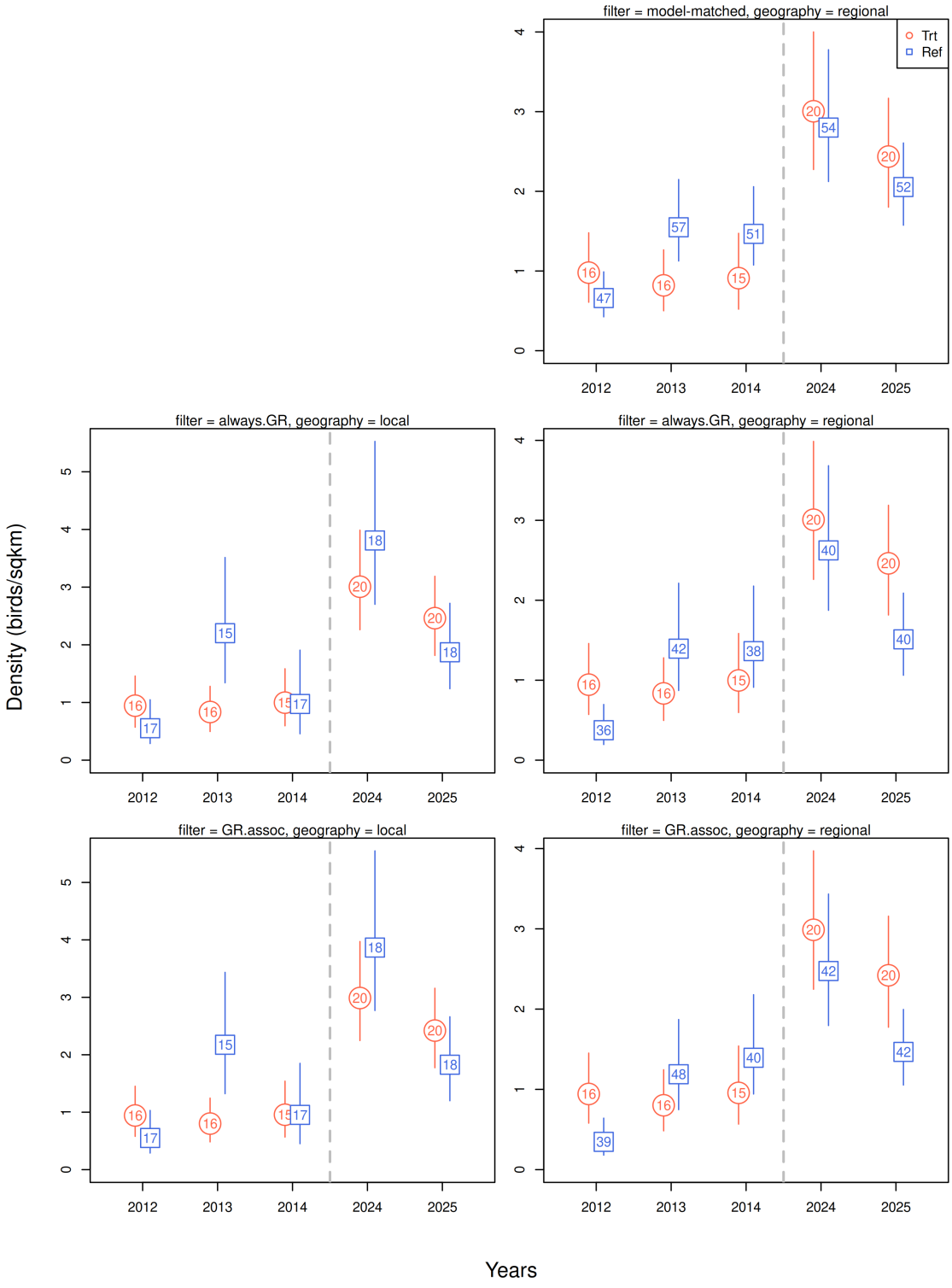


Figure E15. Yearly population density estimates before (pre) and after (post) initiation of grazing management for Killdeer.

Lark Bunting

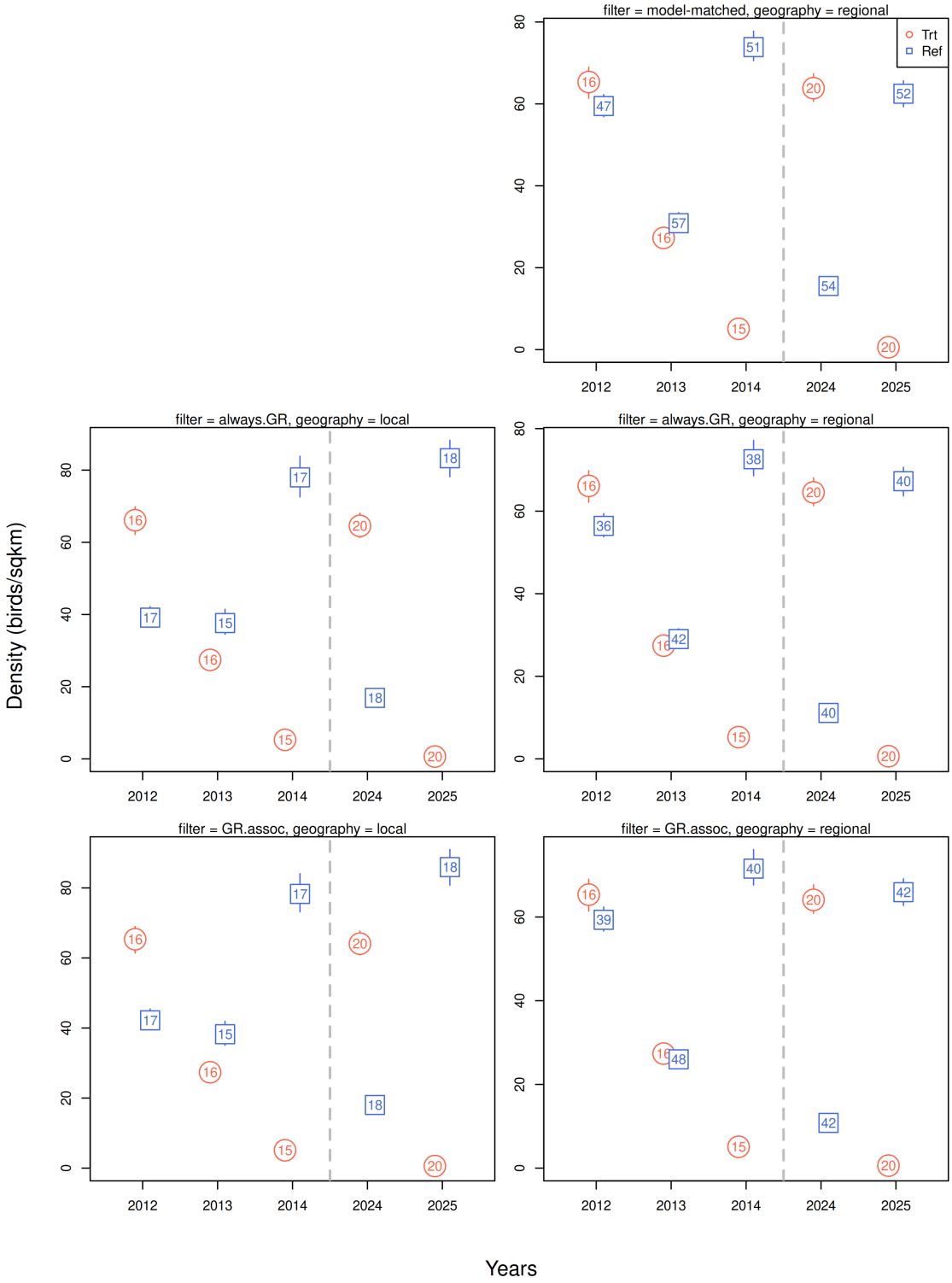


Figure E16. Yearly population density estimates before (pre) and after (post) initiation of grazing management for Lark Bunting.

Lark Sparrow

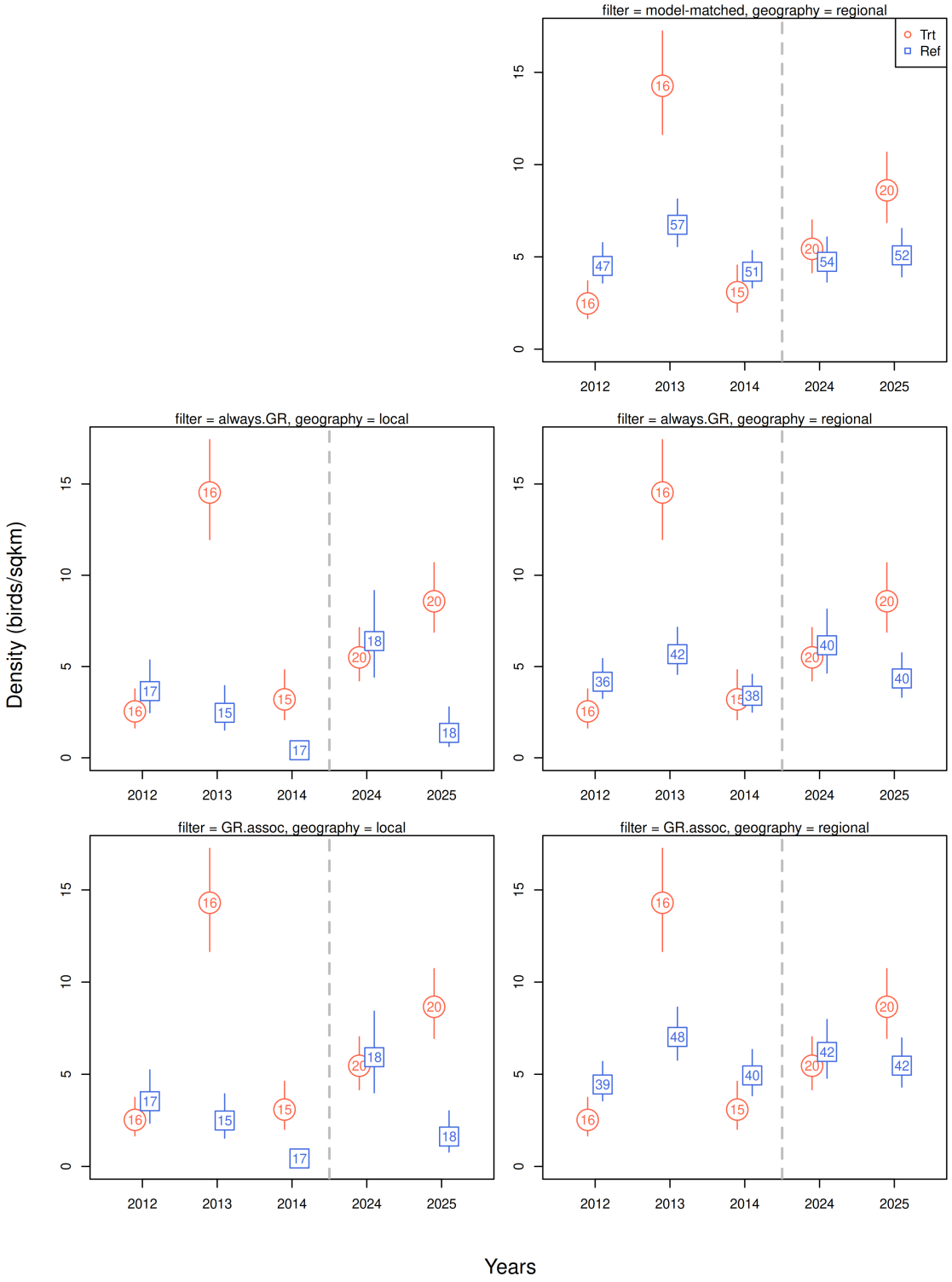


Figure E17. Yearly population density estimates before (pre) and after (post) initiation of grazing management for Lark Sparrow.

Loggerhead Shrike

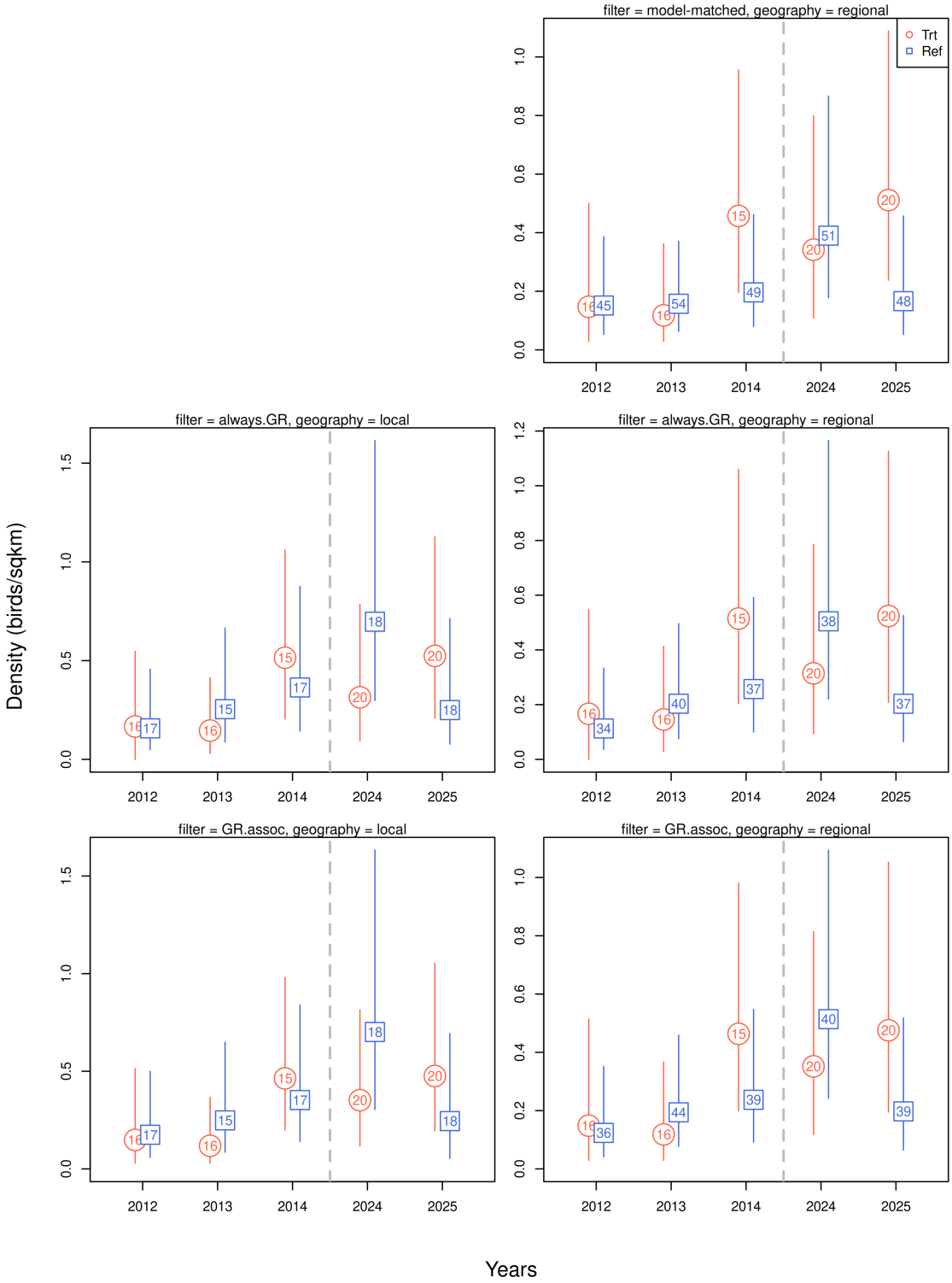


Figure E18. Yearly population density estimates before (pre) and after (post) initiation of grazing management for Loggerhead Shrike.

Mourning Dove

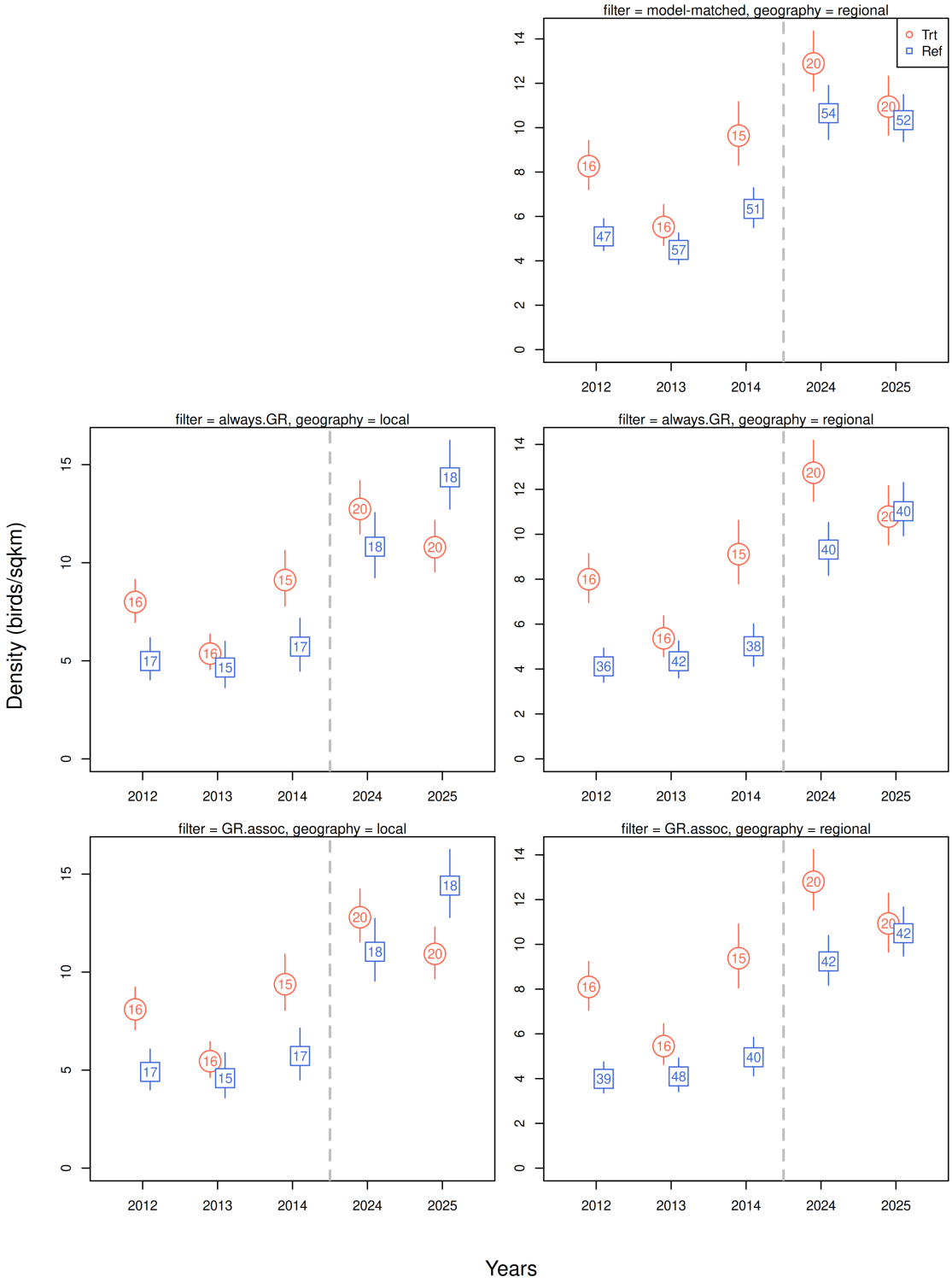


Figure E19. Yearly population density estimates before (pre) and after (post) initiation of grazing management for Mourning Dove.

Mountain Plover

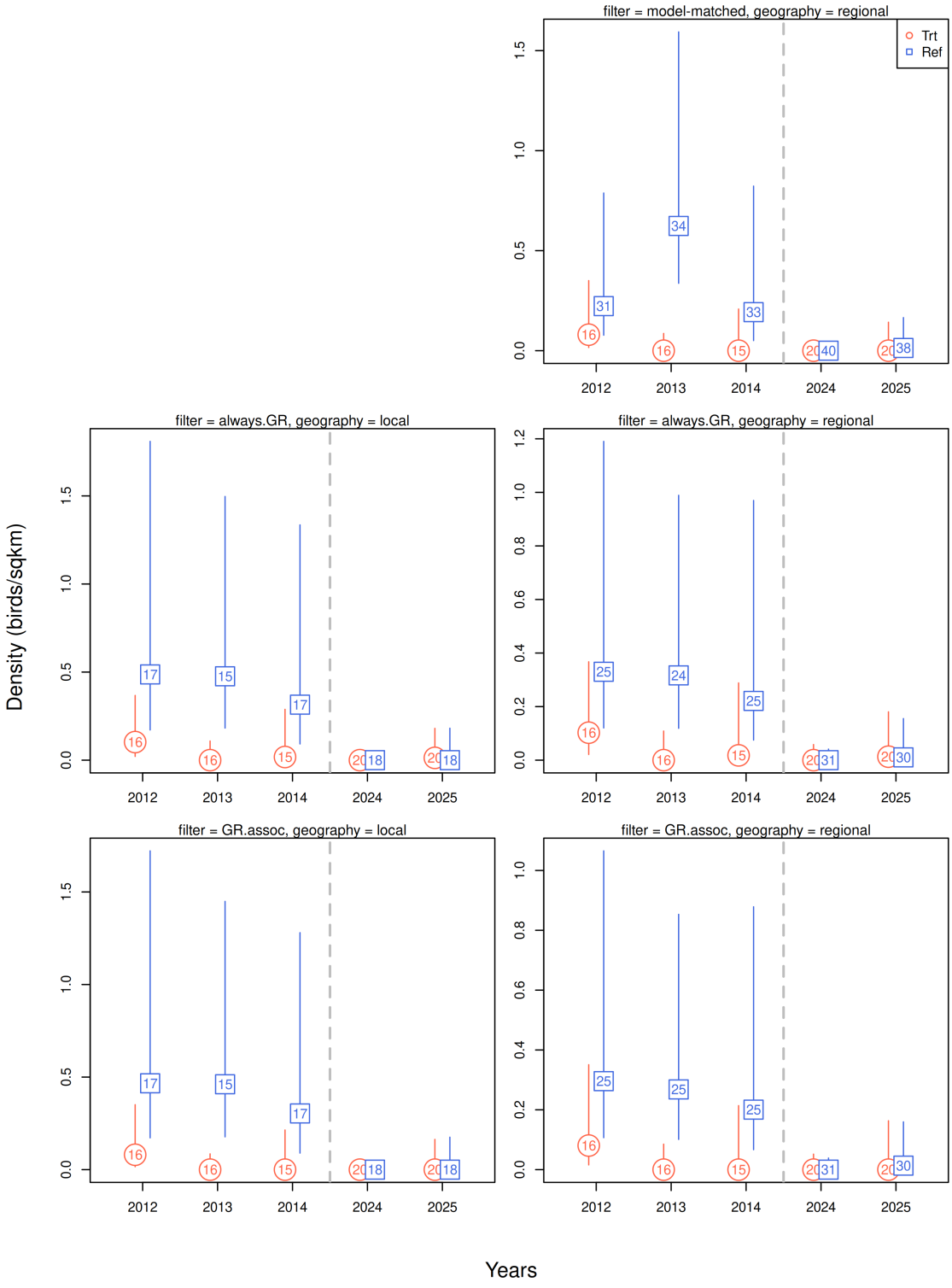


Figure E20. Yearly population density estimates before (pre) and after (post) initiation of grazing management for Mountain Plover.

Northern Harrier

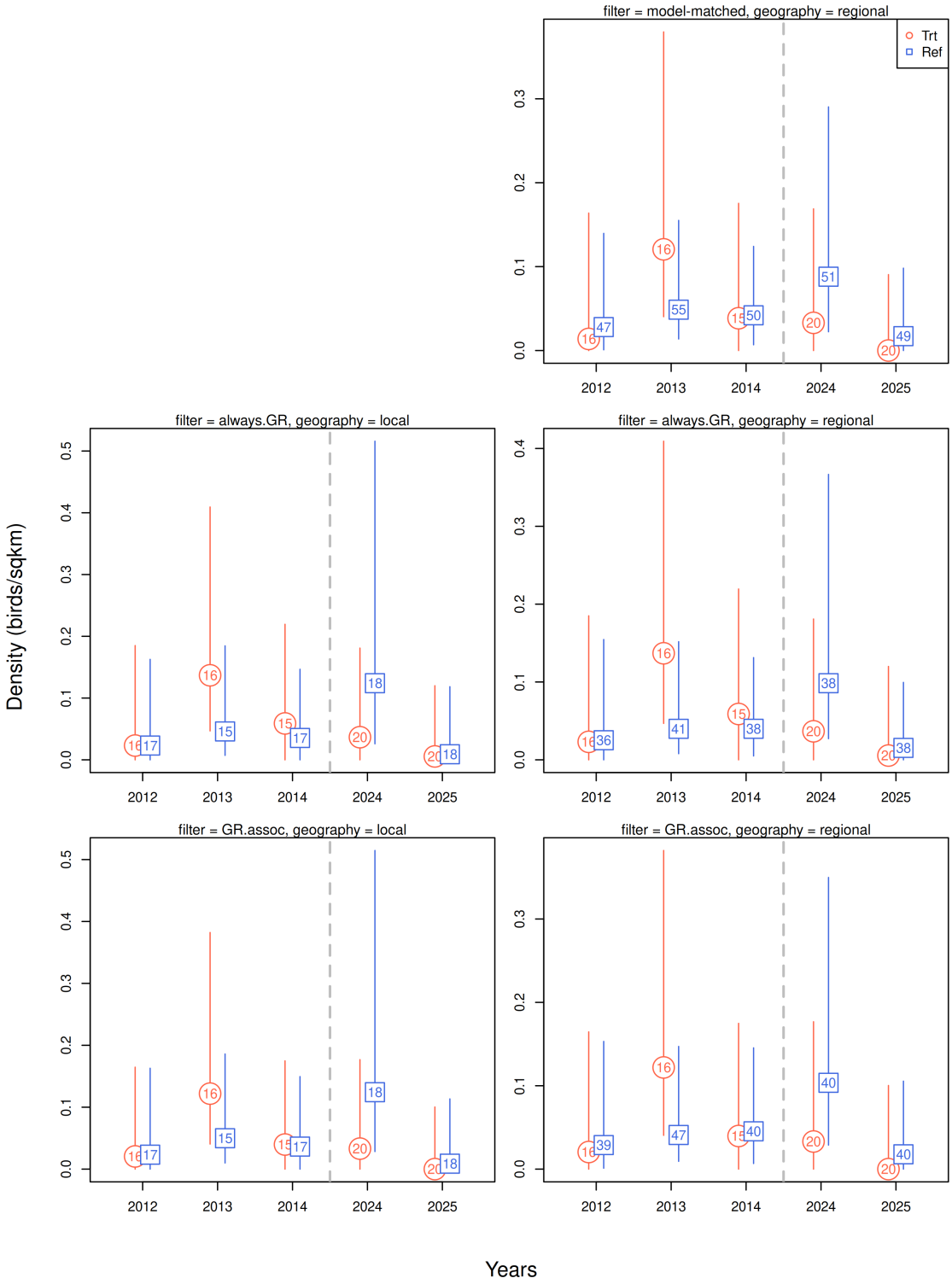


Figure E21. Yearly population density estimates before (pre) and after (post) initiation of grazing management for Northern Harrier.

Prairie Falcon

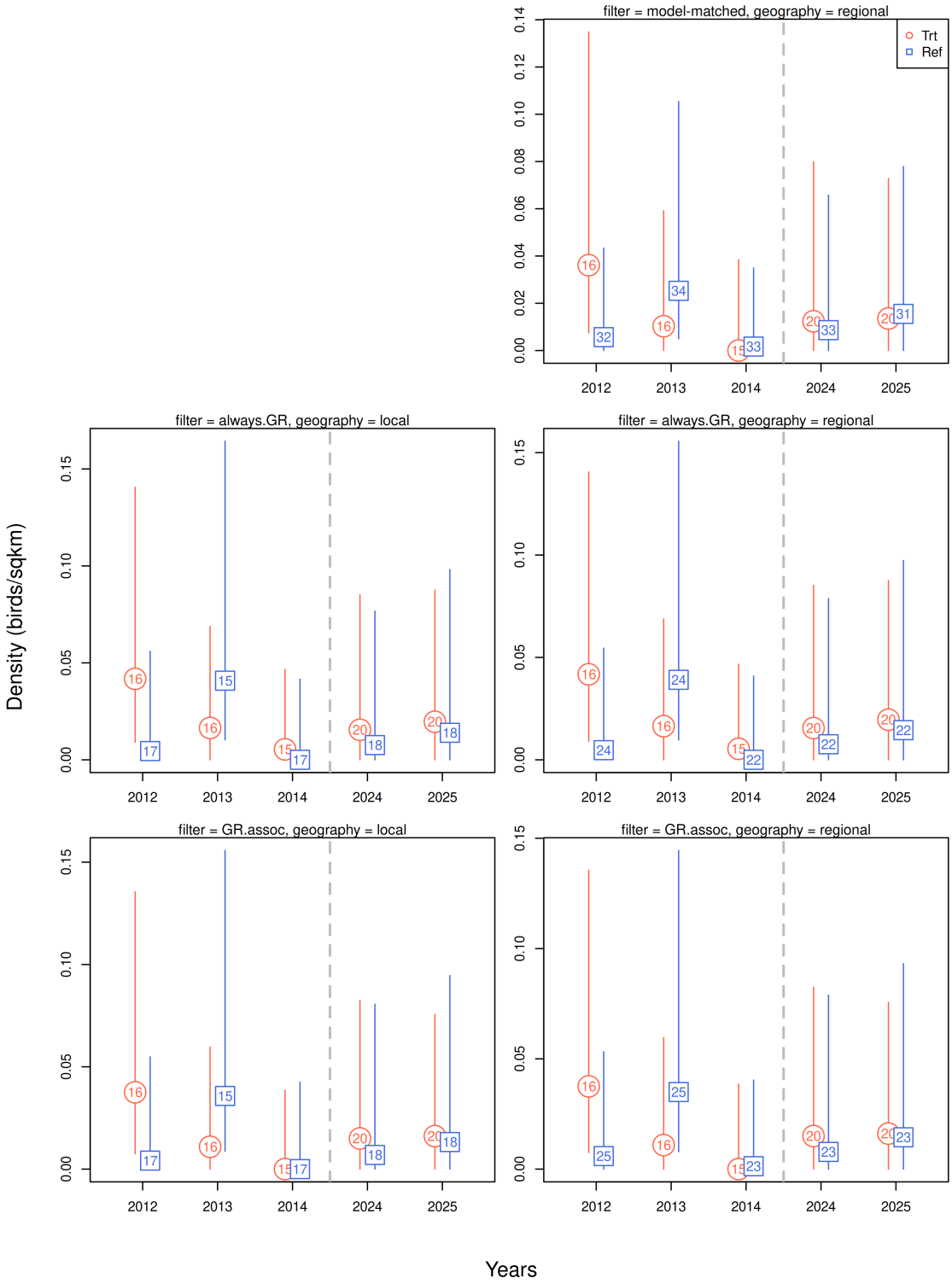


Figure E22. Yearly population density estimates before (pre) and after (post) initiation of grazing management for Prairie Falcon.

Red-tailed Hawk

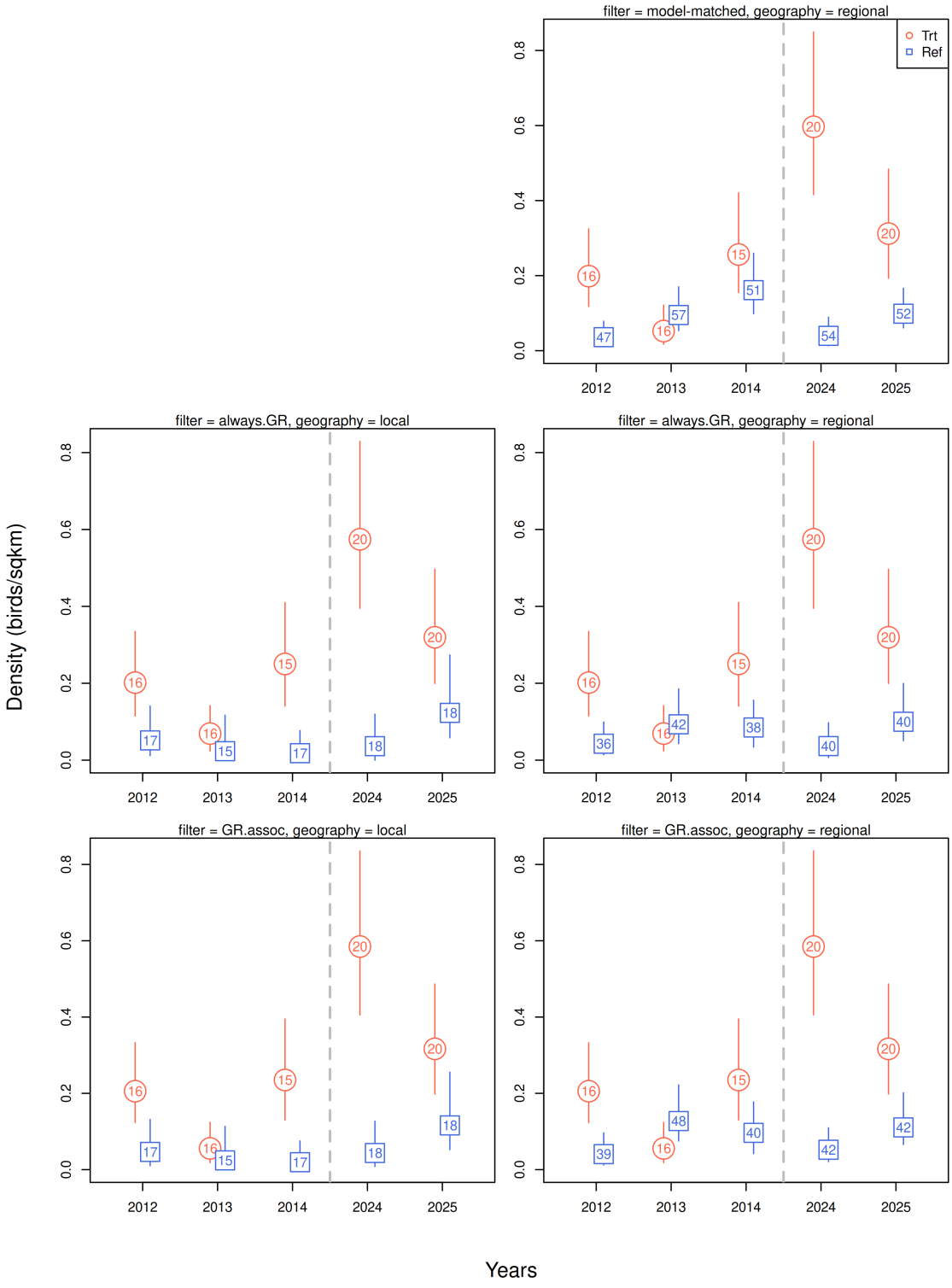


Figure E23. Yearly population density estimates before (pre) and after (post) initiation of grazing management for Red-tailed Hawk.

Red-winged Blackbird

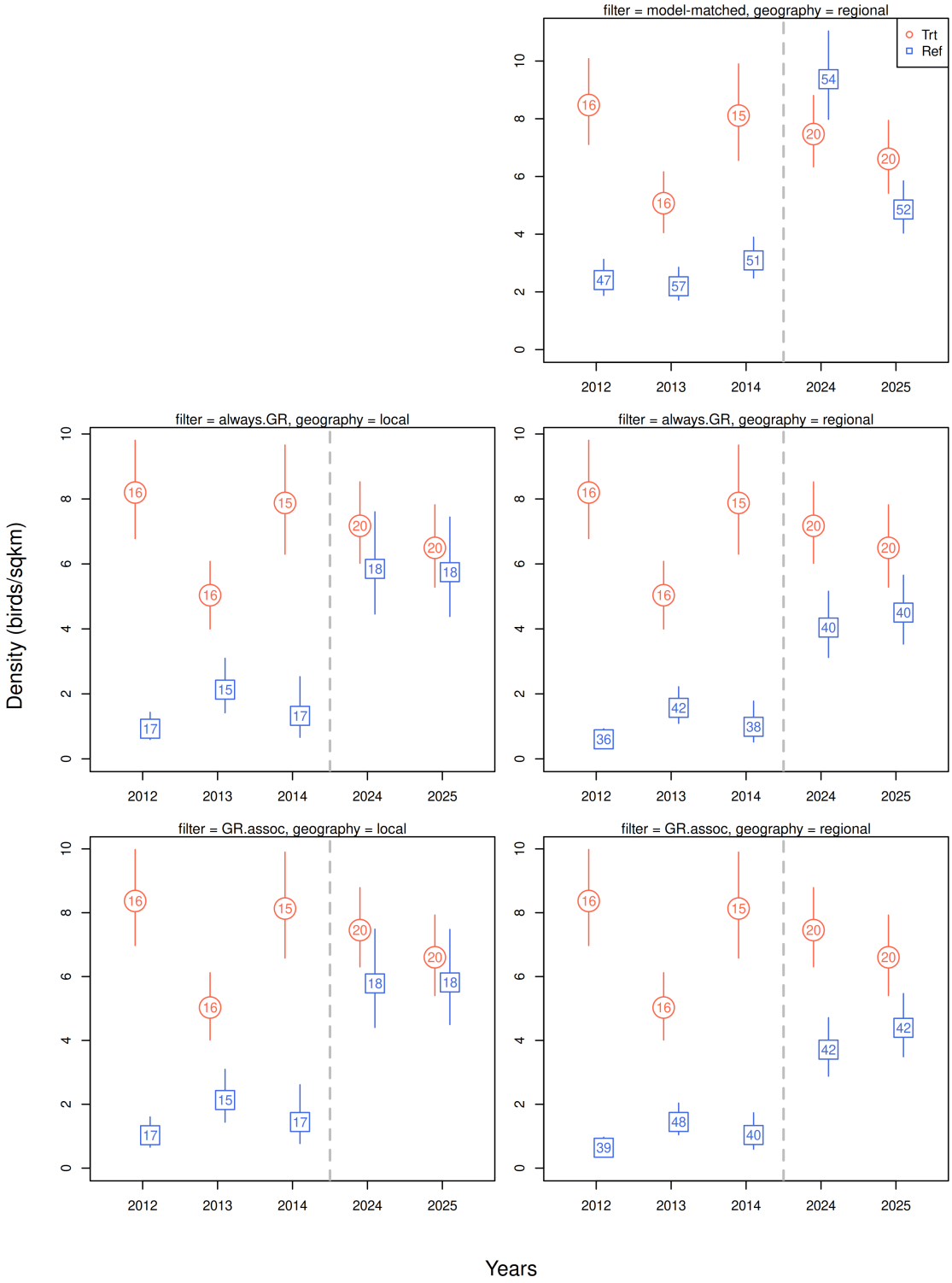


Figure E24. Yearly population density estimates before (pre) and after (post) initiation of grazing management for Red-winged Blackbird.

Say's Phoebe

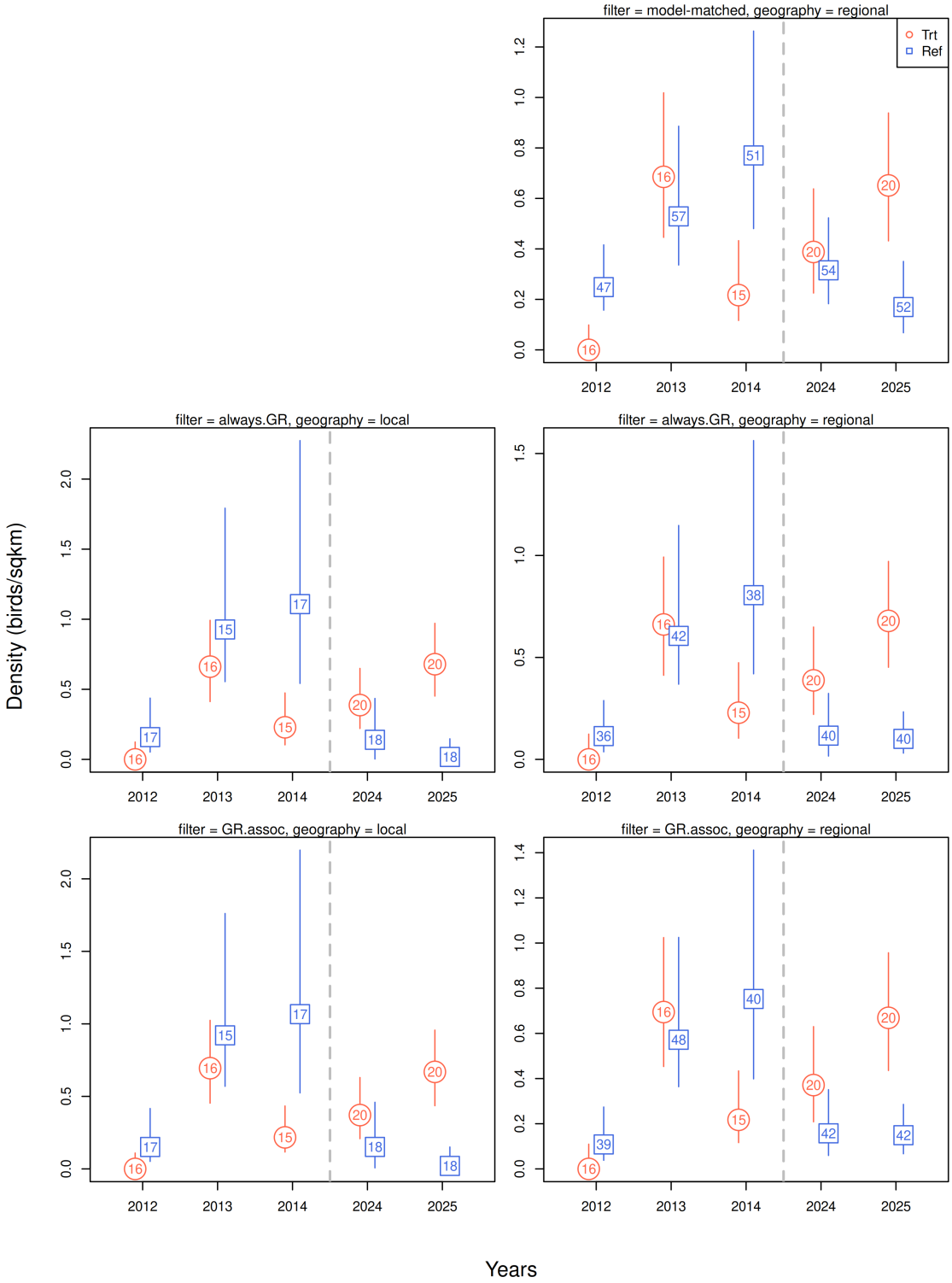


Figure E25. Yearly population density estimates before (pre) and after (post) initiation of grazing management for Say's Phoebe.

Savannah Sparrow

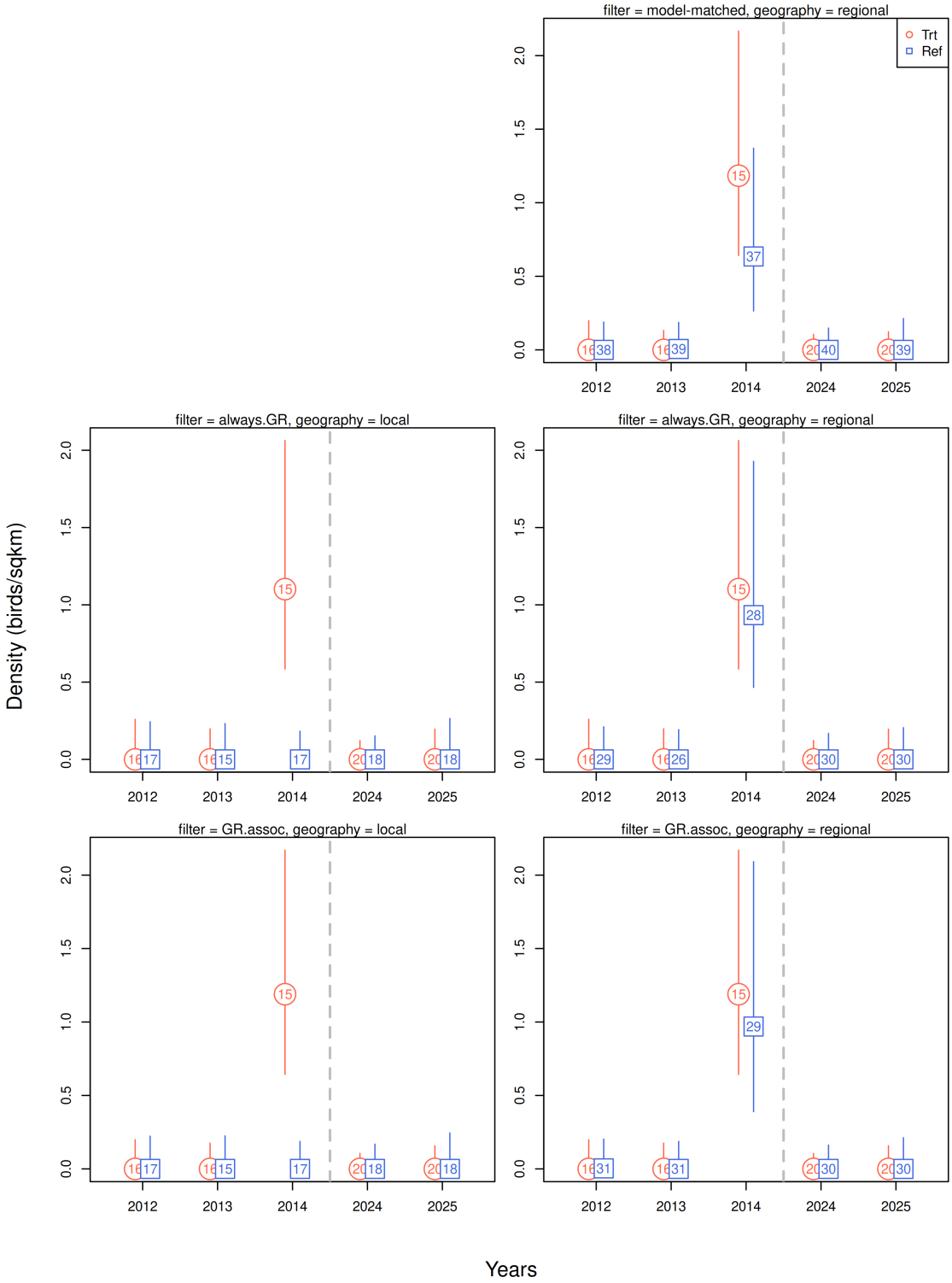


Figure E26. Yearly population density estimates before (pre) and after (post) initiation of grazing management for Savannah Sparrow.

Swainson's Hawk

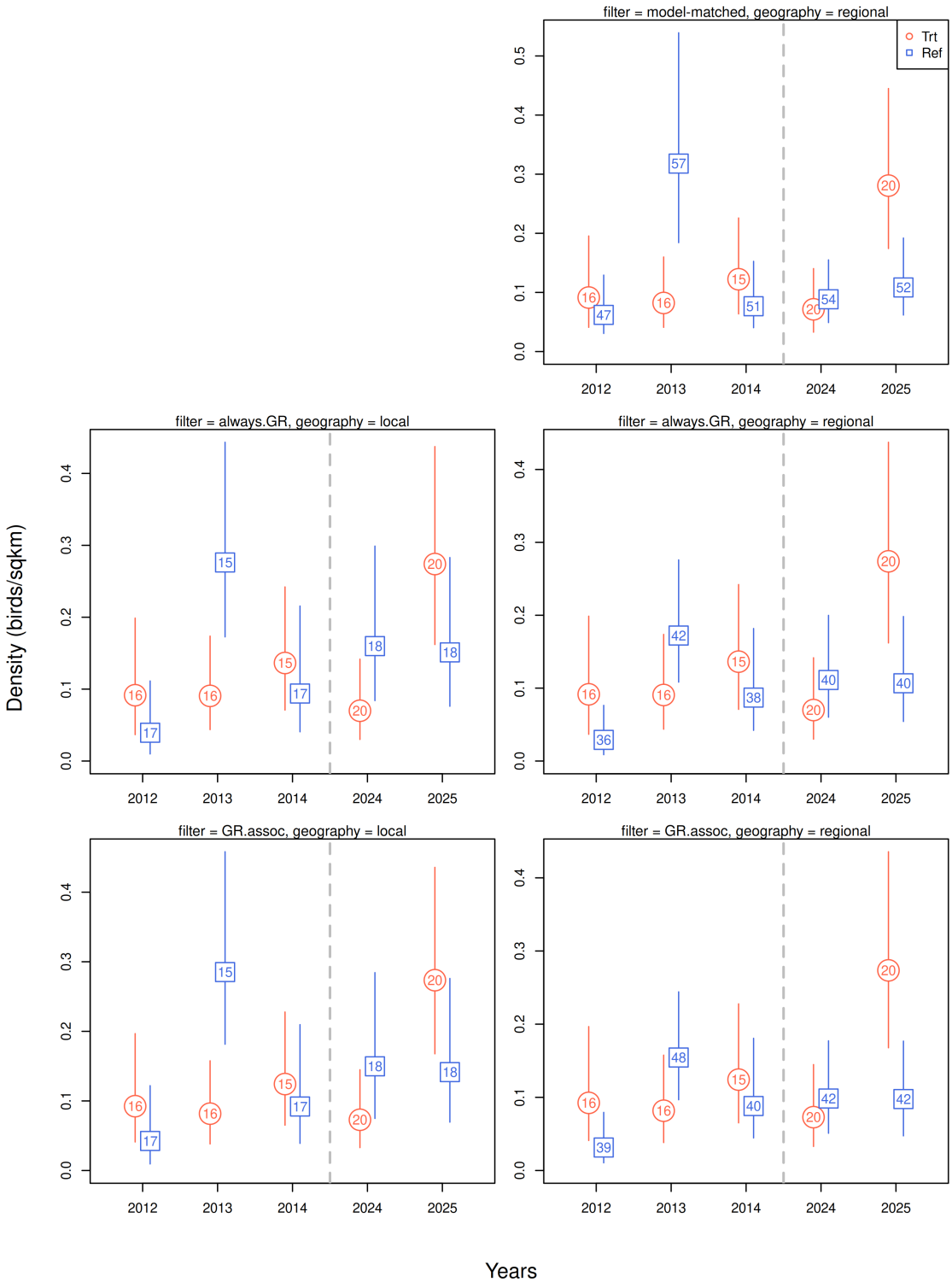


Figure E27. Yearly population density estimates before (pre) and after (post) initiation of grazing management for Swainson's Hawk.

Vesper Sparrow

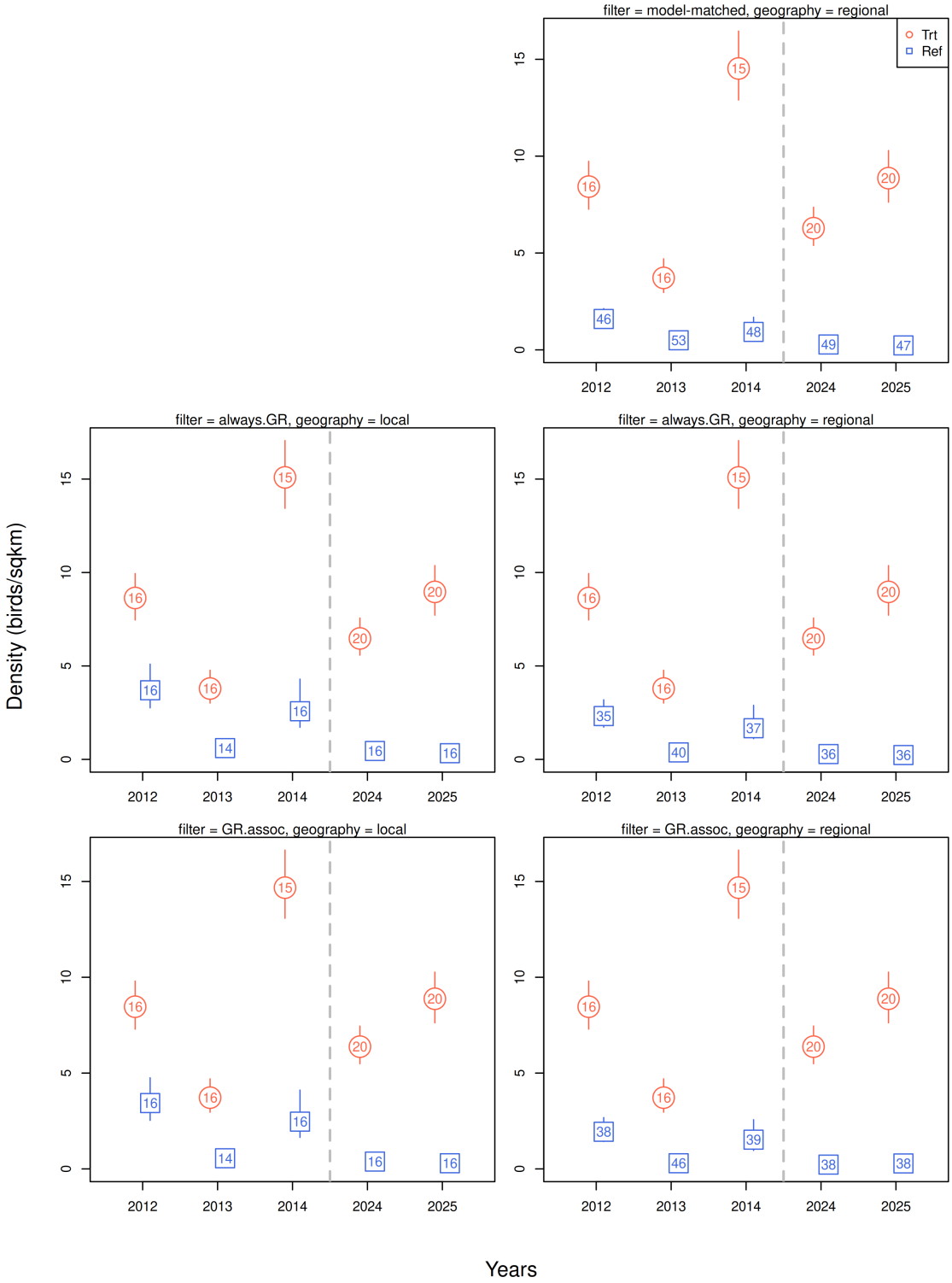


Figure E28. Yearly population density estimates before (pre) and after (post) initiation of grazing management for Vesper Sparrow.

Western Kingbird

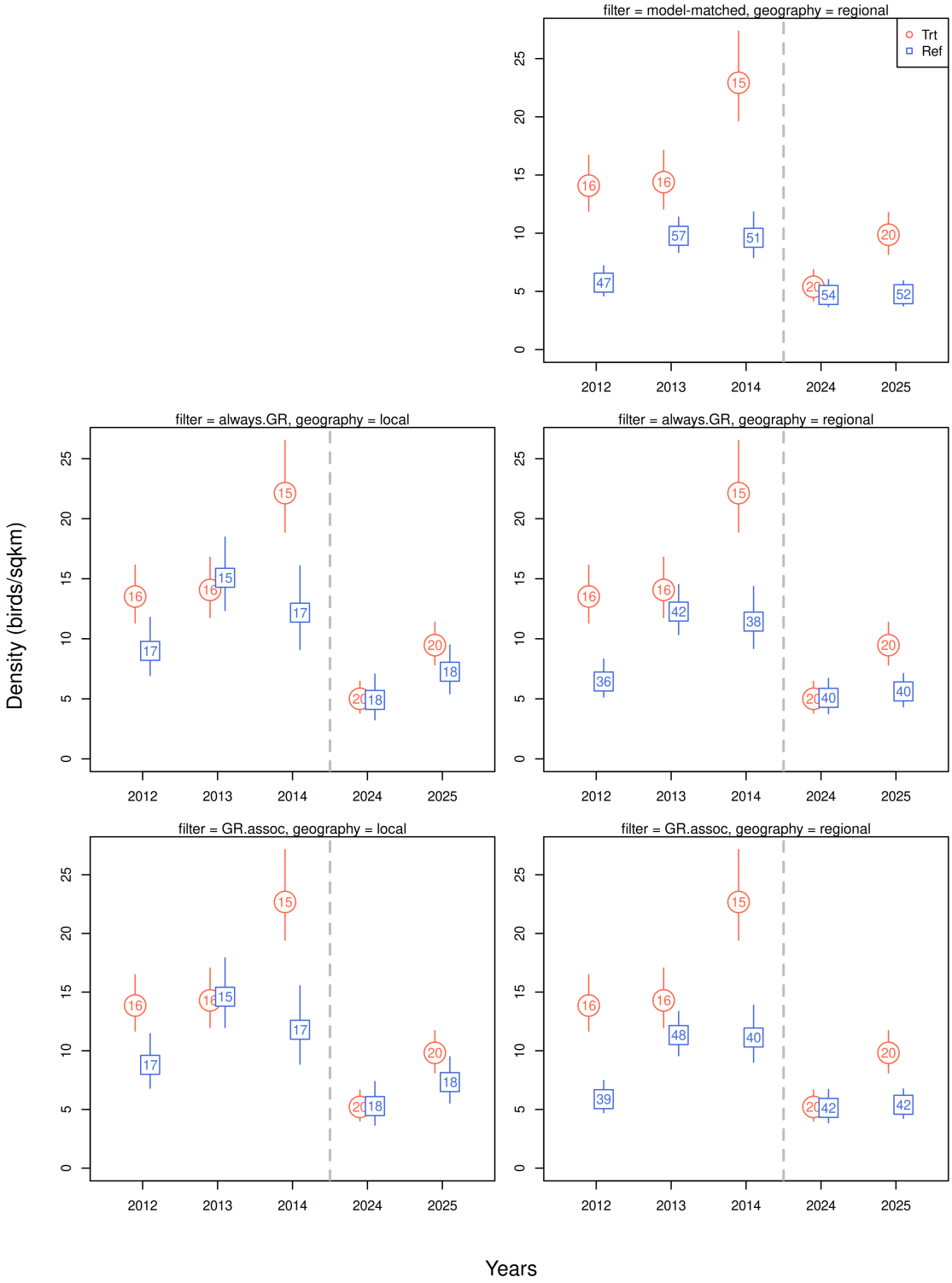


Figure E29. Yearly population density estimates before (pre) and after (post) initiation of grazing management for Western Kingbird.

Western Meadowlark

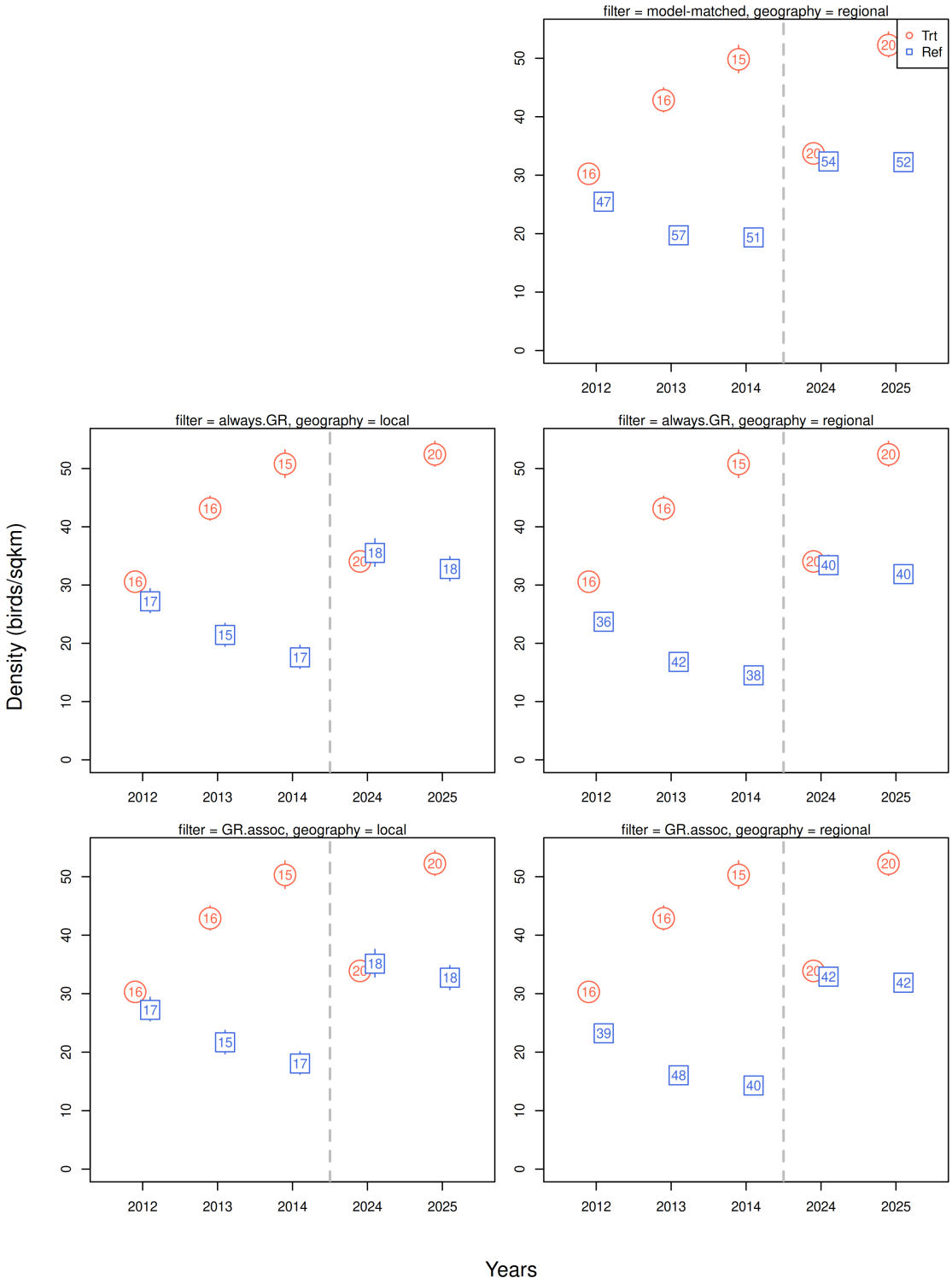


Figure E30. Yearly population density estimates before (pre) and after (post) initiation of grazing management for Western Meadowlark.

Wilson's Snipe

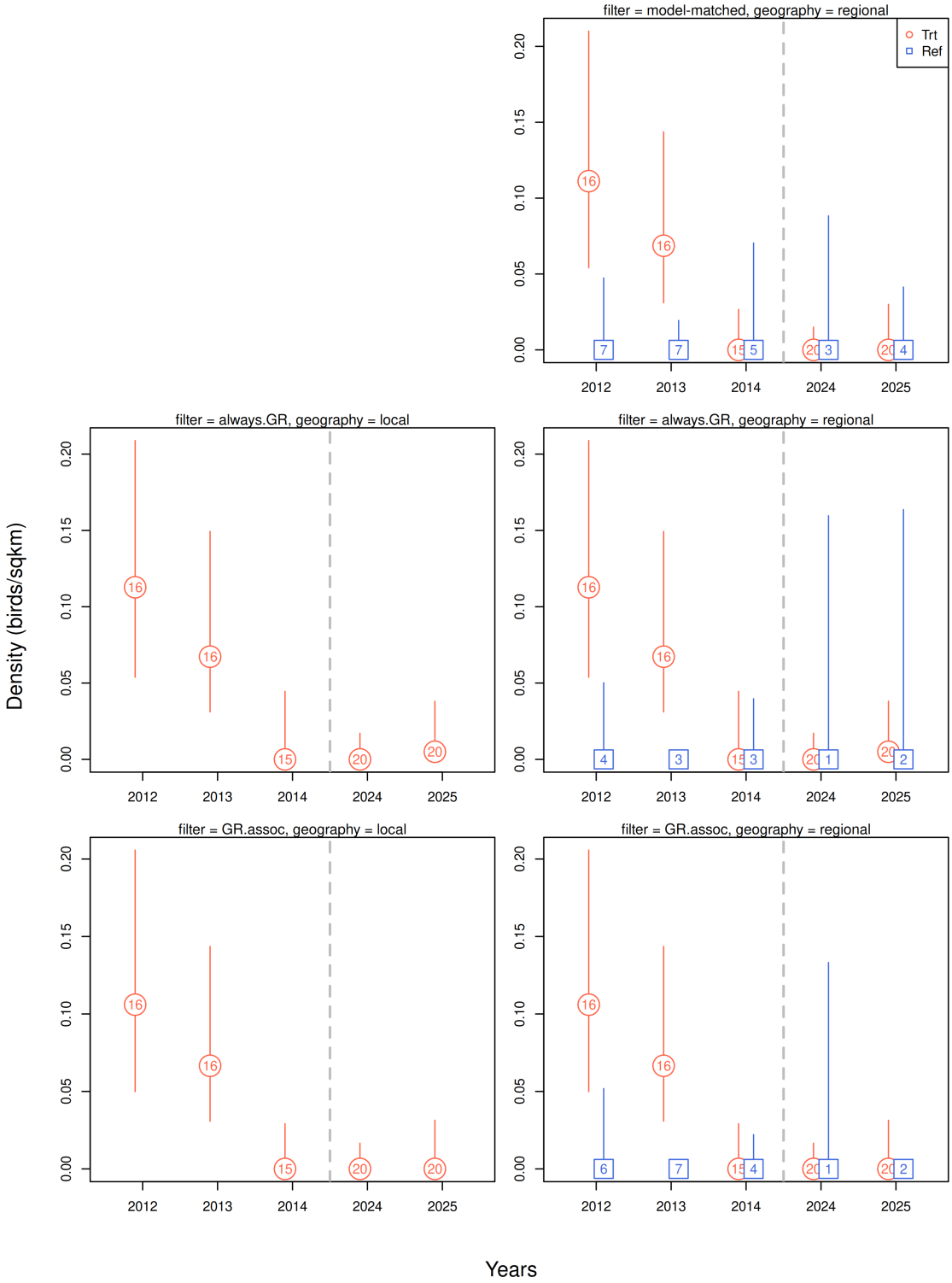


Figure E31. Yearly population density estimates before (pre) and after (post) initiation of grazing management for Wilson's Snipe.