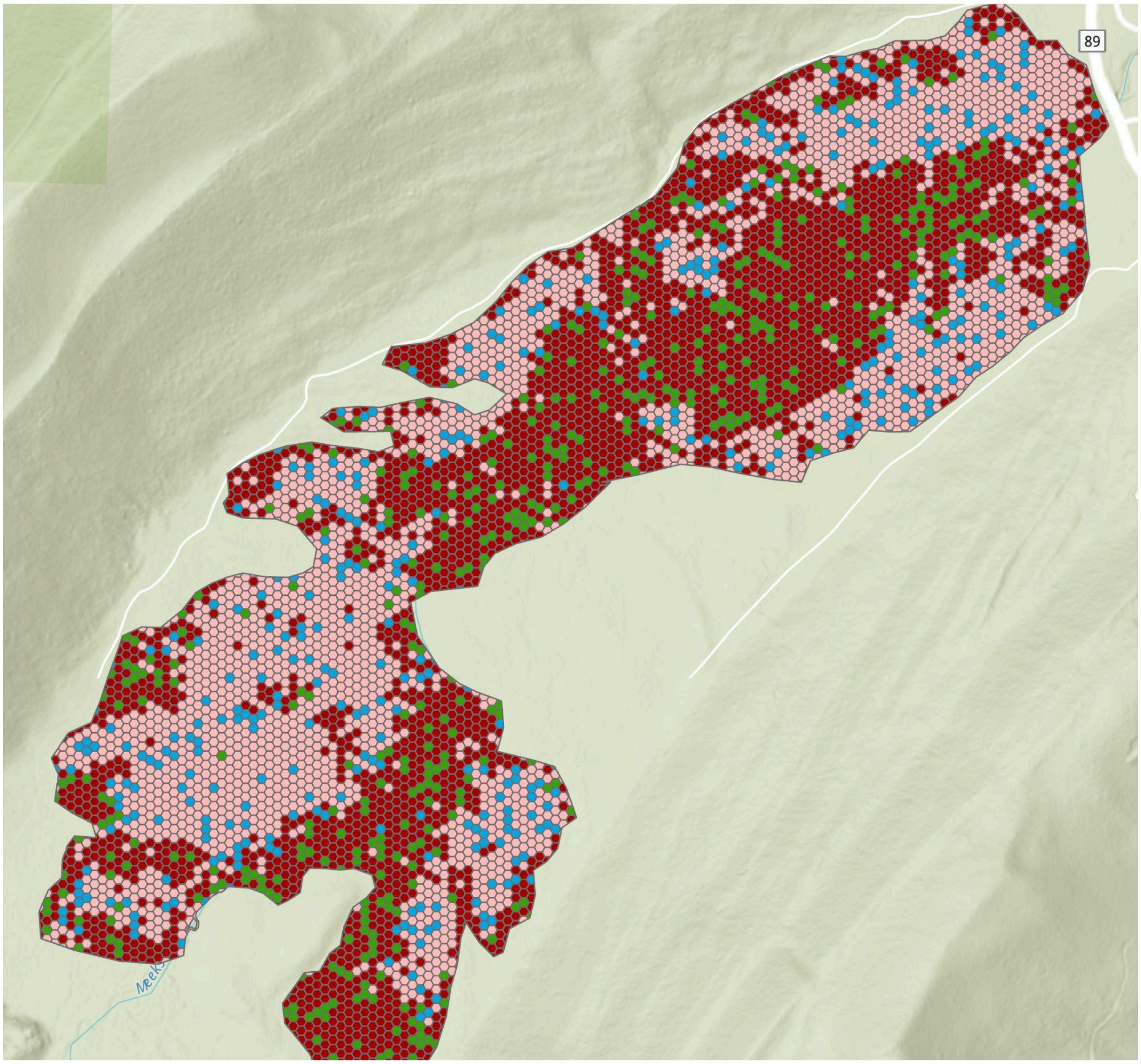
Evaluating Conifer Encroachment in Meeks Meadow SEZ Units
Lake Tahoe Basin (2009-2022)



Replicating a Geospatial Environmental Assessment

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Introduction

Meadow health is an important indicator of greater ecosystem function. In mountain watersheds like Lake Tahoe, these systems regulate water quality and groundwater storage, support diverse vegetation, and provide critical habitat. However, many montane meadows face rapid degradation due to the impacts 21st century land management and climate change; overlogging, fire suppression, grazing, and drought result in conifer encroachment, where conifer trees expand into areas historically dominated by meadow associates.

At early stages, meadow grasses will outcompete conifer seedlings when a healthy water table is present on the landscape. When a meadow's water table decreases, conifers (accustomed to dryer soils) are more readily able to compete with grasses. Once established, a conifer continues to drain the water table even further, and this meadow-degradation feedback loop continues. In the Lake Tahoe Basin, addressing conifer encroachment has become a key management priority because of its implications for watershed health, wildfire risk, and habitat restoration.

The Tahoe Regional Planning Agency (TRPA) monitors meadow condition through its Stream Environment Zone (SEZ) monitoring program, including indicators that assess ecological health in riparian and meadow ecosystems. One of these indicators uses historic meadow boundaries to gauge the presence of conifers with a grid-based analysis derived from lidar data. This indicator is now a standardized approach for tracking vegetation change across time and identifying restoration imperatives.

Meeks Meadow has been identified as a restoration priority on the western shore of Lake Tahoe in the Environmental Protection Program. Restoration efforts at this site focus on removing encroaching conifers and restoring meadow hydrology in order to improve ecosystem function and biodiversity. The objective of this study is to evaluate how conifer encroachment within Meeks Meadow has changed between 2009 and 2022 using methods consistent with the SEZ Baseline Condition Assessment. Specifically, this analysis reproduces the TRPA approach by identifying the presence of conifers within a 300 m² hexagonal grid using both a 2009 tree object dataset and canopy height models derived from 2022 lidar data. By comparing encroachment patterns across time, this study provides insight into the extent and spatial distribution of conifer expansion within Meeks Meadow and helps identify areas where restoration efforts may be most effective.

Methods

Study Area

This analysis evaluated four Stream Environment Zone (SEZ) assessment units in Meeks Meadow, located on the west shore of Lake Tahoe. The four assessment units analyzed in this study correspond to polygons classified as threshold year 2023 in the Tahoe Regional Planning Agency (TRPA) SEZ dataset. All spatial processing was conducted in ArcGIS Pro.

Data Sources

Two datasets were used to evaluate conifer encroachment. To assess 2009 meadow baseline conditions, the TRPA "Trees in Meadow" dataset derived from a 2009 lidar flight was used to reproduce original encroachment analyses. This data consists of points representing exact locations of lidar-derived tree objects, which includes tree height.

To assess 2022 meadow baseline conditions, more recent lidar data from the USGS 3DEP program (2022) were obtained through the National Map LidarExplorer portal. These data were compressed to LAZ files covering the Meeks Meadow study areas. Additional layers included TRPA SEZ Assessment Unit polygons and a basemap for spatial context.

2009 Conifer Encroachment Assessment

TRPA "Trees in Meadow" points were first filtered to exclude vegetation less than six meters tall, a necessary threshold to remove meadow associates such as alders and willows, and shrubs that can be characteristic of a healthy meadow. A hexagonal tessellation grid with a cell area of 300 square meters was generated across the meadow extent using the **Generate Tessellation tool**. This grid size and shape replicate the spatial sampling framework used by TRPA to quantify encroachment.

The filtered tree points were spatially joined to the hexagon grid with an intersect relationship. Hexagons containing at least one point from the filtered tree dataset were classified as ‘encroached’ with a value of 1, while hexagons containing no qualifying trees were classified as ‘non-encroached’ with a value of 0. The result was a binary classification where values of 1 were assigned red to indicate encroachment, and values of 0 were assigned green to indicate undisturbed meadow.

2022 Conifer Encroachment Assessment

Lidar data from 2022 was processed to generate a canopy height model. LAZ files were first converted into a LAS dataset using the **Convert LAS tool** in ArcGIS Pro. This dataset was used in the **LAS Dataset to Raster tool** to generate a Digital Surface Model (DSM) and Digital Terrain Model (DTM), where the DSM represents elevated surface features and DTM represents ground elevation.

A canopy height model was calculated by subtracting the DTM from the DSM using the **Raster Calculator tool**. The result is a raster displaying vegetation height above the ground. To avoid measuring healthy meadow associates and only identify established conifers, the canopy height raster was **reclassified** using the same six-meter threshold as 2009. Raster cells with a canopy below six meters were assigned a value of zero, while cells with canopy heights greater or equal to 6 meters were assigned a value of 1.

The **Zonal Statistics as Table tool** was then used to identify encroachment presence within each hexagon. Hexagons containing at least one raster cell with a canopy greater or equal to 6 meters were considered ‘encroached.’

Change Classification and Indicator Evaluation

Encroachment conditions from 2009 and 2022 were joined to classify change in conifer presence within each hexagon. Four categories were defined, where ‘no encroachment’ = (0 (conifers in 2009), 0 (conifers in 2022)), ‘conifer retreat' = (1,0), ‘new encroachment’ = (0,1) and ‘ongoing encroachment’ = (1,1). Percent encroachment was calculated for each SEZ assessment unit by dividing the number of encroached hexagons by the total number of hexagons within the unit.

These percentages were used to evaluate SEZ conifer encroachment indicator ratings using the criteria defined in the SEZ Baseline Condition Assessment. Maps and summary tables were generated to quantify changes between the two time periods.

Discussion of Results and Limitations

By replicating a grid-based approach using 300 m^2 hexagons and a six-meter canopy height threshold, the analysis identified both the spatial distribution of conifer presence and changes in encroachment over time.

The results indicate that conifer encroachment increased substantially across Meeks Meadow between 2009 and 2022. In 2009, conifer encroachment impacted 42.7 % to 56.6% of hexagons across the four SEZ units (*table 2*). By 2022, these values range from 80.8% to 84.8%, suggesting that a majority of hexagons across the meadow contained at least one tree greater than 6 meters tall. Figure 3 demonstrates encroachment rates in 2022, where all four assessment units experience a substantial increase in encroachment. Unit 2 exhibits the highest level of encroachment in 2022 (84.8%), while unit 3 experienced the most dramatic change, and greatest overall increase in encroachment, rising from 42.7% encroachment in 2009 to 84.8% in 2022.

To further illustrate the spatial dynamics of this expansion between 2009-2022, the grid analysis was symbolized to depict ongoing conifer encroachment, new encroachment, conifer retreat, and no encroachment (*figure 4*). Many hexagons experiencing encroachment in 2009 remained encroached in 2022, suggesting a persistent conifer presence across Meeks Meadow. Additionally, a substantial number of hexagons experienced new encroachment, validating how conifer encroachment has increased through time. Areas of conifer retreat were present, but limited, amounting to about 7-11% the hexagons in each study unit. Overall, this change analysis confirmed that conifer encroachment was persistent throughout the study period.

TRPA can use these findings to prioritize restoration and management efforts. Because 'new encroachment' represents areas where conifers have been recently established, these locations may represent priority zones, lest trees become more established and difficult to remove. Similarly, areas with ongoing encroachment indicate portions of the meadow where conifers are already well established, and may require intensive, yet meticulous intervention for such a sensitive riparian habitat. Identifying spatial clusters of encroachment status can help project managers prioritize treatments and allocate resources effectively.

While this analysis is useful at face-value, several methodological limitations should be considered before using this report to implement any changes in the Meeks Meadow Restoration Project. First, the methods used to identify conifers rely on a canopy height threshold of 6 meters instead of specific species identification. This threshold was designed to exclude shrubs, riparian vegetation, and other meadow associates like willows and alders, but it is not faultless; some non-conifers may grow above 6 meters, and young conifers below this threshold are neglected entirely. Thus, some areas classified as ‘no encroachment’ may actually be experiencing encroachment from conifer saplings/seedlings. Future analyses could bolster encroachment accuracy by incorporating additional lidar metrics such as canopy composition or integrating multispectral imagery to distinguish conifer foliage from other types.

Second, conifer count collection methods differed in 2009 and 2022. The 2009 encroachment assessment was derived from lidar-based tree object detection, while the 2022 analysis relied on a raster canopy height model from lidar point cloud data. Differences in sensor characteristics, point density, and processing methods may influence the quality of vegetation detection, introducing inconsistencies between the two datasets. For example, higher point densities in more contemporary lidar datasets may allow smaller canopy features to be more readily detected. This could increase the number of hexagons classified as ‘encroached.’

Third, a gridded hexagon framework does not consider the spatial nuance of a landscape, potentially leading to over-generalized conclusions. Each hexagon is classified as encroached if it contains one tree. Thus, areas with sparse vegetation might be falsely considered impacted to the same degree as areas experiencing severe conifer encroachment, simplifying complex spatial patterns.

Fourth, the 2009 dataset directly identified individual tree objects, but the 2022 analysis inferred conifer presence with canopy height values with raster cells. Raster canopy height models represent continuous vegetation surfaces rather than individual trees, which means that the 2022 analysis could slightly overestimate encroachment compared to the 2009 analysis, especially in areas where forest structure is complex, or in areas with other tall objects. However, the six meter threshold likely mitigated these effects.

Despite these limitations, the workflow presented is consistent and repeatable. The substantial increase in encroachment observed between 2009 and 2022 indicate that conifer expansion has been catalyzed throughout Meeks Meadow, highlighting the importance of ongoing restoration of meadow ecosystems in the Lake Tahoe Basin.

Conclusion

This analysis assessed changes in conifer encroachment within four Meeks Meadow Stream Environment (SEZ) assessment units between 2009 and 2022. Results suggest a substantial increase in encroachment throughout the study period. In 2009, percent encroachment ranged from 42.7%-56.6% across the four assessment units. By 2022, encroachment increased to 80.8%-84.8%, placing all units within the “D” rating category (71-100% encroachment) according to the SEZ indicator framework. The largest increase occurred in Unit 3, which rose from 42.7% to 84.4%, while Unit 2 exhibited the highest overall encroachment level in 2022 (84.8%). These findings signify the widespread expansion of conifers within Meeks Meadow, daylighting the importance of ongoing restoration efforts of meadow habitats in the Lake Tahoe Basin.

Figures and Tables

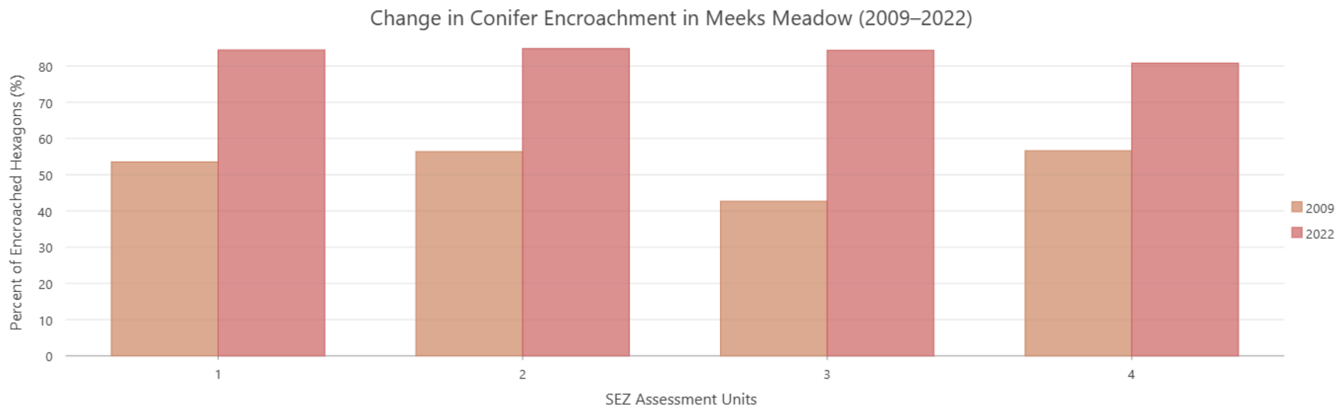
Table 1

Meeks Bay Meadow	No Encroachment	Conifer Retreat	New Encroachment	Ongoing Encroachment
Unit 1	168 (7.2%)	193 (8.3%)	911 (39.2%)	1050 (45.2%)
Unit 2	75 (6.1%)	112 (9.1%)	463 (37.6%)	583 (47.3%)
Unit 3	131 (8.1%)	121 (7.5%)	793 (49.2%)	567 (35.2%)
Unit 4	54 (8.4%)	69 (10.8%)	224 (34.9%)	294 (45.9%)
Total	428 (7.4%)	495 (8.5%)	2391 (41.1%)	2494 (43%)

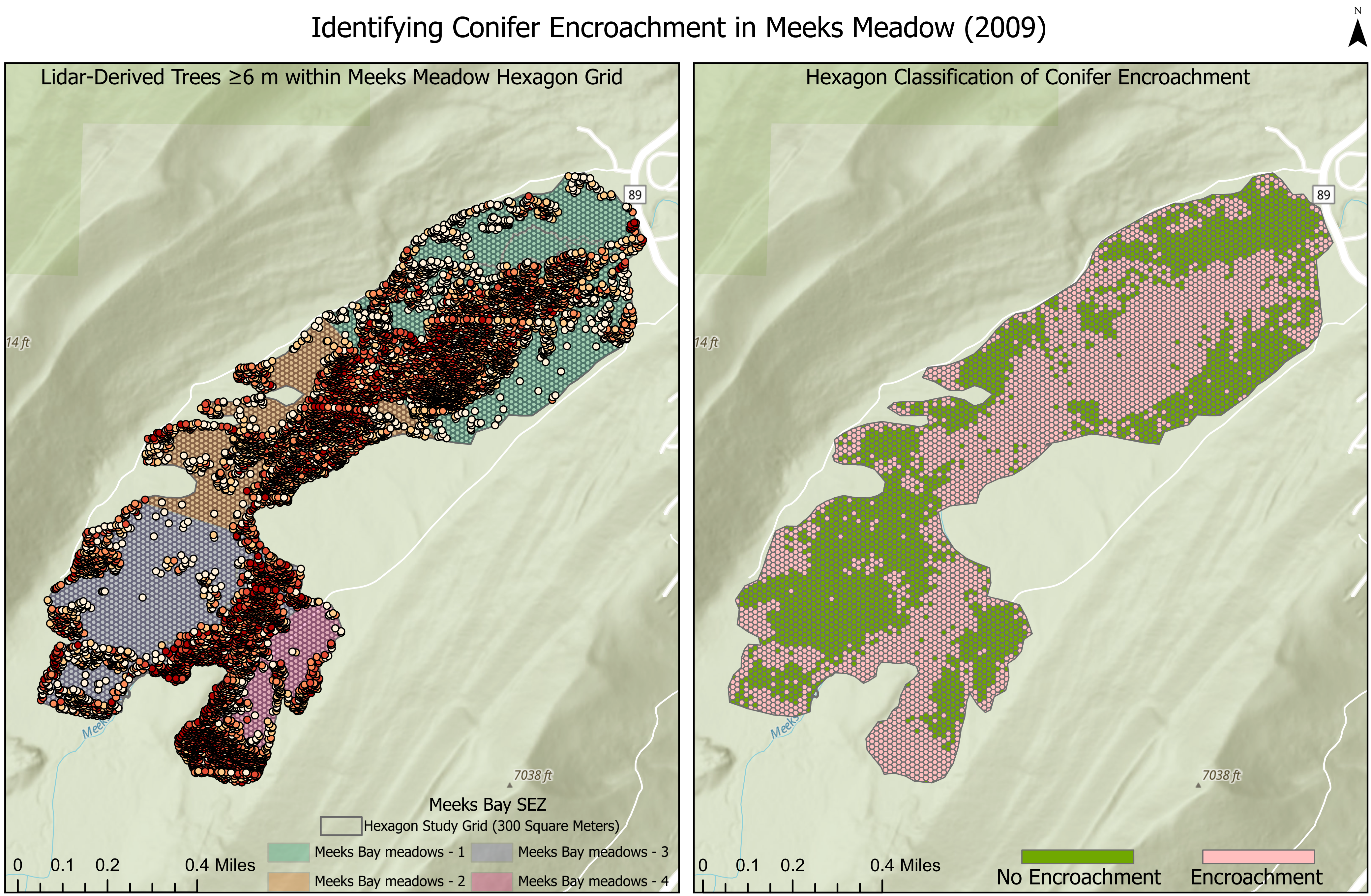
Table 2

Meeks Bay Meadow	2009 Percent Encroachment	2009 Indicator Rating	2022 Percent Encroachment	2022 Indicator Rating
Unit 1	53.5%	C	84.5%	D
Unit 2	56.4%	C	84.8%	D
Unit 3	42.7%	C	84.4%	D
Unit 4	56.6%	C	80.8%	D

Figure 1



Identifying Conifer Encroachment in Meeks Meadow (2009)



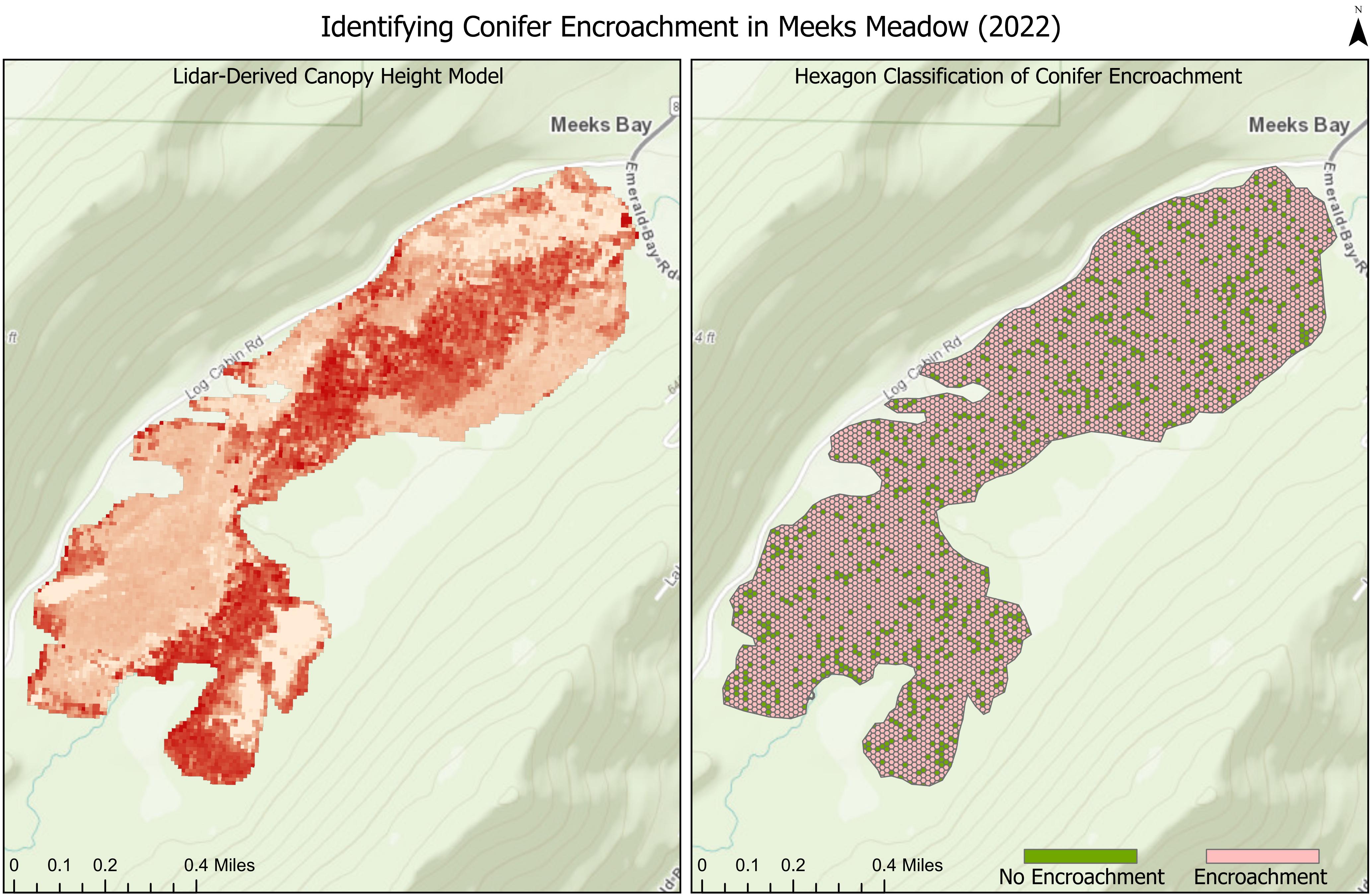
Trees Greater Than 6 Meters

Tree Height (Meters):

- 6.000000 - 11.240000
- 11.240001 - 16.680000
- 16.680001 - 21.760000
- 21.760001 - 26.770000
- 26.770001 - 46.169998

Data Sources: Tahoe Regional Planning Agency (TRPA) SEZ Assessment Units and Trees in Meadow dataset (2009); U.S. Geological Survey Lidar Program (2009); Esri World Topographic Basemap. Analysis and map by Liam Galleher, 2026.

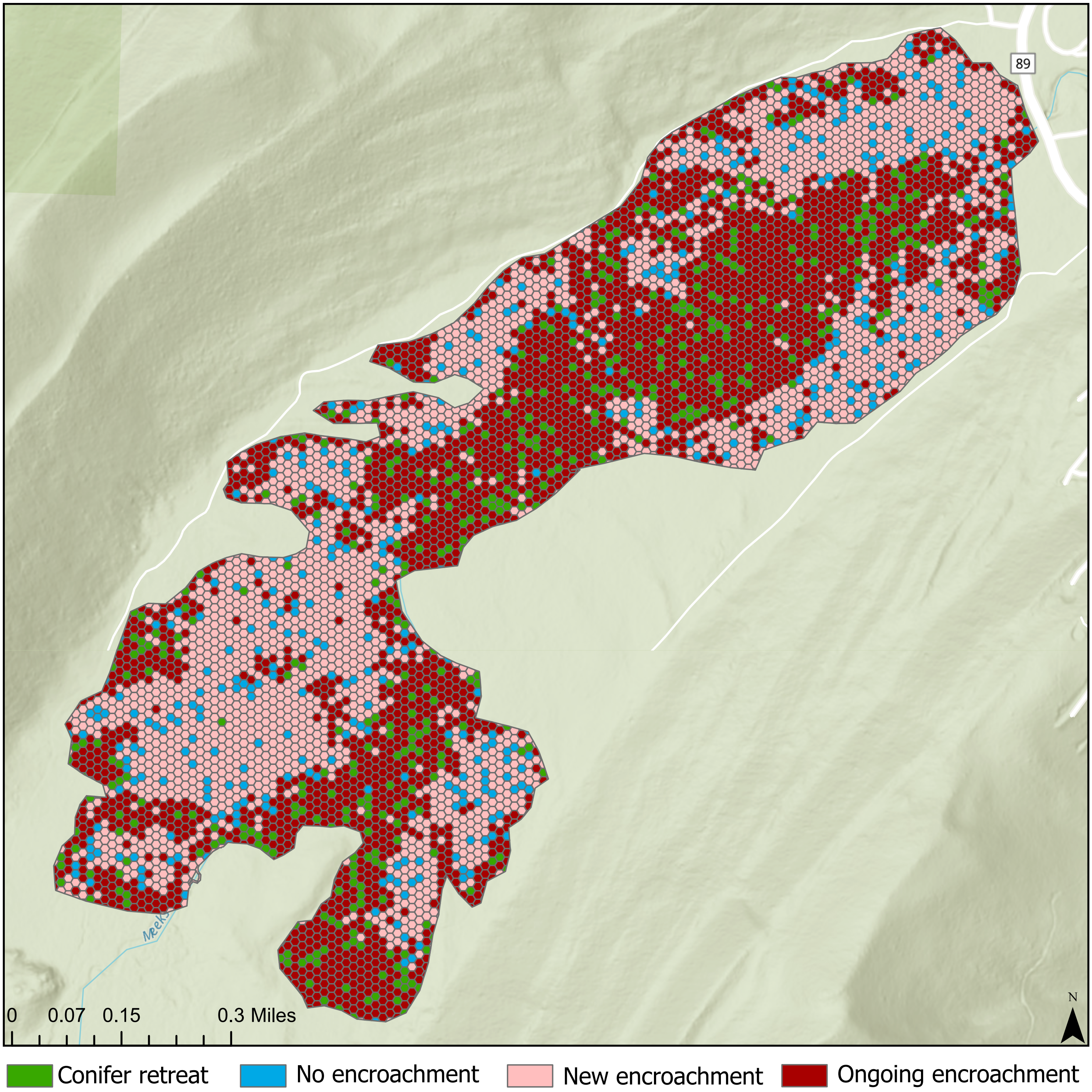
Identifying Conifer Encroachment in Meeks Meadow (2022)

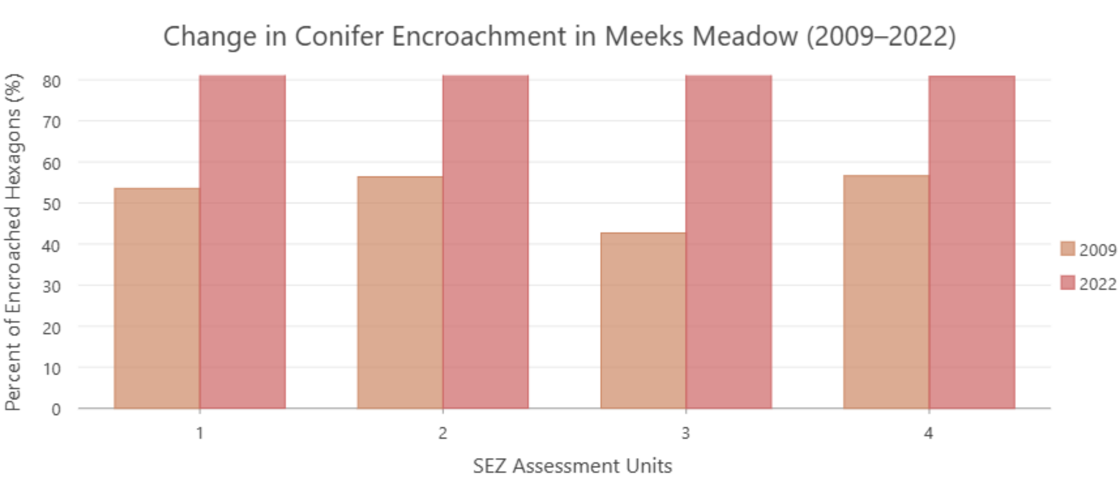


Data Sources: U.S. Geological Survey 3DEP Lidar Program (2022); Tahoe Regional Planning Agency (TRPA) SEZ Assessment Units. Basemap: Esri World Topographic Map. Map produced by Liam Galleher, 2026.

Change in Conifer Encroachment in Meeks Meadow SEZ Units (2009–2022)

Lake Tahoe, CA





Data Sources: Tahoe Regional Planning Agency (TRPA) Trees in Meadow dataset (2009) and SEZ Assessment Units; U.S. Geological Survey 3DEP Lidar data (2022). Basemap: Esri World Topographic Map. Map produced by Liam Galleher, 2026.

References

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