

# Long-Term Monitoring of High-Elevation White Pine Communities in Pacific West Region National Parks

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## Background

National Park Service Inventory and Monitoring (I&M) networks conduct long-term monitoring to provide park managers information on the status and trends in key biological and environmental attributes (Vital Signs). Here we present an overview of a collaborative approach to long-term monitoring of high-elevation white pine forest dynamics among three Pacific West Region I&M networks: Klamath (KLMN), Sierra Nevada (SIEN), and Upper Columbia Basin (UCBN). Whitebark pine (*Pinus albicaulis*) is monitored in five national parks: Lassen Volcanic and Crater Lake in the KLMN, and Yosemite, Sequoia, and Kings Canyon in the SIEN. Foxtail pine (*P. balfouriana*) is monitored in Sequoia and Kings Canyon, and limber pine (*P. flexilis*) is monitored in Craters of the Moon in the UCBN (Figure 1).

Previous but limited sampling efforts report relatively low levels of infection by the non-native pathogen, *Cronartium ribicola* (white pine blister rust). In the KLMN, up to 20 percent of whitebark pine trees were found to be rust infected during a 2000 survey (Murray and Rasmussen 2003). In 2009, the same general areas were surveyed again, and 25 percent of whitebark pine trees were rust infected; however 18 percent of the trees had cankers that were inactive, complicating current estimates of impact (KLMN unpublished report). Mountain pine beetle were largely responsible for a 5.4 percent decrease in whitebark pine since 2003 in the KLMN (Murray 2010). Several surveys report that less than 1 percent of sampled whitebark pine are rust infected in SIEN parks (Duriscoe and Duriscoe 2002; Maloney and others 2008; Das and Stephenson unpublished data). Rust was not found on foxtail or limber pine within plots in our parks; however, one infected foxtail pine was identified in Sequoia in 1995, and several infected limber pine trees were found in Craters of the Moon in 2006 (Duriscoe and Duriscoe 2002; McKinney and others submitted).

## Long-Term Monitoring Objectives

Determine the status and trends in the following:

- Tree species composition and structure.
- Tree species birth, death, and growth rates.

- Incidence of white pine blister rust and level of crown kill.
- Incidence of mountain pine beetle (*Dendroctonus ponderosae*).
- Incidence of dwarf mistletoe (*Arceuthobium* spp).
- Cone production of white pine species.

## Approach

Permanent macroplots are allocated to random locations using an equal-probability spatially-balanced approach by means of the Generalized Random Tessellation Stratified (GRTS) algorithm (Stevens and Olsen 2004). Two different macroplot sizes are employed in our protocol. KLMN uses a 20 m x 50 m macroplot (0.1 ha or 1,000 m<sup>2</sup>) and SIEN and UCBN use a 50 m x 50 m macroplot (0.25 ha or 2,500 m<sup>2</sup>) (Figure 2). The KLMN macroplot size was chosen to accommodate additional objectives related to other vegetation monitoring efforts. The SIEN and UCBN macroplot size choice was based on analysis results of pilot data collected in Network parks (Craters of the Moon, Yosemite, and Sequoia) in 2009 and 2010 that showed the lowest variation, and therefore greatest efficiency, in plots of 2,500 m<sup>2</sup> to 3,000 m<sup>2</sup> (Figure 3). Macroplots in all three networks are comprised of multiple 10 m x 50 m subplots, and data are collected by subplot to allow for comparisons among networks and with other white pine monitoring efforts. For example, the Greater Yellowstone I&M Network's whitebark pine protocol (GYWPMWG 2007) and the Whitebark Pine Ecosystem Foundation's monitoring methods (Tomback and others 2005) employ a 10 m x 50 m plot design. Hence the KLMN design incorporates two parallel 10 m x 50 m subplots and the SIEN and UCBN design incorporates five parallel 10 m x 50 m subplots.

A serially alternating panel design is used with a three-year rotation for re-surveying permanent plots (Table 1). Plot-level data are collected on slope, elevation, and aspect. Tree-level data are collected on status (live or dead), species name, diameter, height, cone production, rust infection (active cankers and indicators), crown kill, pine beetle infestation, and presence/absence of mistletoe infection. In the SIEN and UCBN, nine 3 m x 3 m regeneration plots are located within macroplots and data are collected on seedling

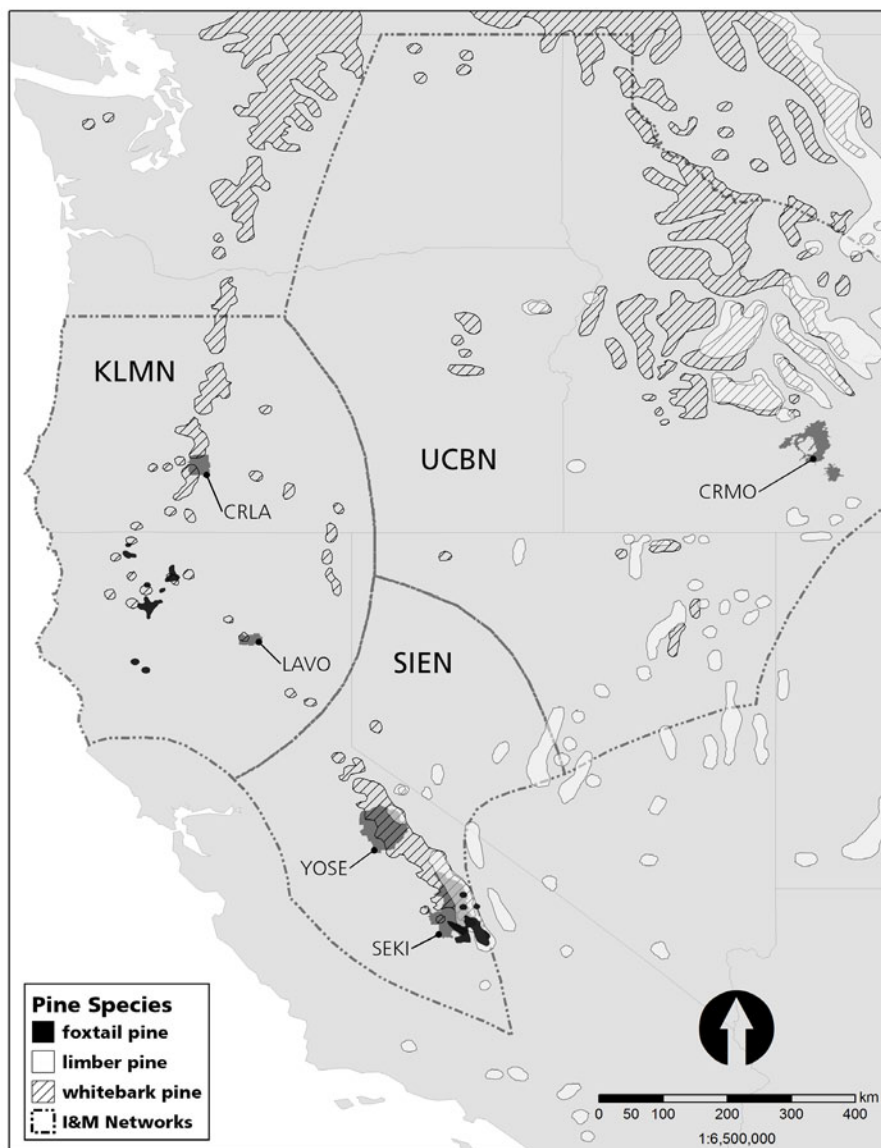


**Figure 1.** Distribution of whitebark pine, limber pine, and foxtail pine (from Little 1971), boundaries of the three Pacific West Region Networks, and National Park locations where the protocol is implemented. Network abbreviations: KLMN=Klamath, SIEN=Sierra Nevada, UCBN=Upper Columbia Basin. National Park unit abbreviations: CRLA=Crater Lake, LAVO=Lassen Volcanic, YOSE=Yosemite, SEKI=Sequoia and Kings Canyon, CRMO=Craters of the Moon.

counts by species and height class (20 to < 50 cm; 50 to < 100 cm; and 100 to < 137 cm) and averaged for plot-level values. By using a three-year rotation design, the project achieves a greater sample size with broader spatial extent for a given level of funding. The trade-offs are not knowing cone production, and year of seedling emergence, tree death, rust infection, beetle attack, and mistletoe infection during the two-year rest period.

## Analysis Methods

### Descriptive

Descriptive statistics include estimates of the proportion of trees and plots affected by blister rust, pine beetle, and mistletoe; the density of seedlings by height class; and the proportion and number of white pine trees producing cones. Stand tables are constructed displaying combinations of

species composition, diameter class, height class, tree status, and health status.

### Trend modeling

Within each network, temporal trends are analyzed in demographic (birth and death), reproductive (regeneration and cone production), growth (diameter and height), and infection (rust, beetle, mistletoe) rates. A linear mixed model developed by VanLeeuwen et al. (1999) and Piepho and Ogutu (2002) for correlated data is used to test the null hypothesis that the trend coefficient  $\beta_1$  is equal to zero ( $H_0: \beta_1 = 0$ ), with type I error ( $\alpha$ ) = 0.1. The model (equation 1) includes fixed effects, which contribute to the mean of the outcome of interest (park unit for example), and random effects, which contribute to the variance. Random effects estimate variation that can affect the ability to detect trend, such as site-to-site and year-to-year variation.

$$y_{ijk} = \mu + w_j \beta_i + a_{k(i)} + b_{j(i)} + \gamma_i + w_j t_{k(i)} + e_{j(i)} \quad (1)$$

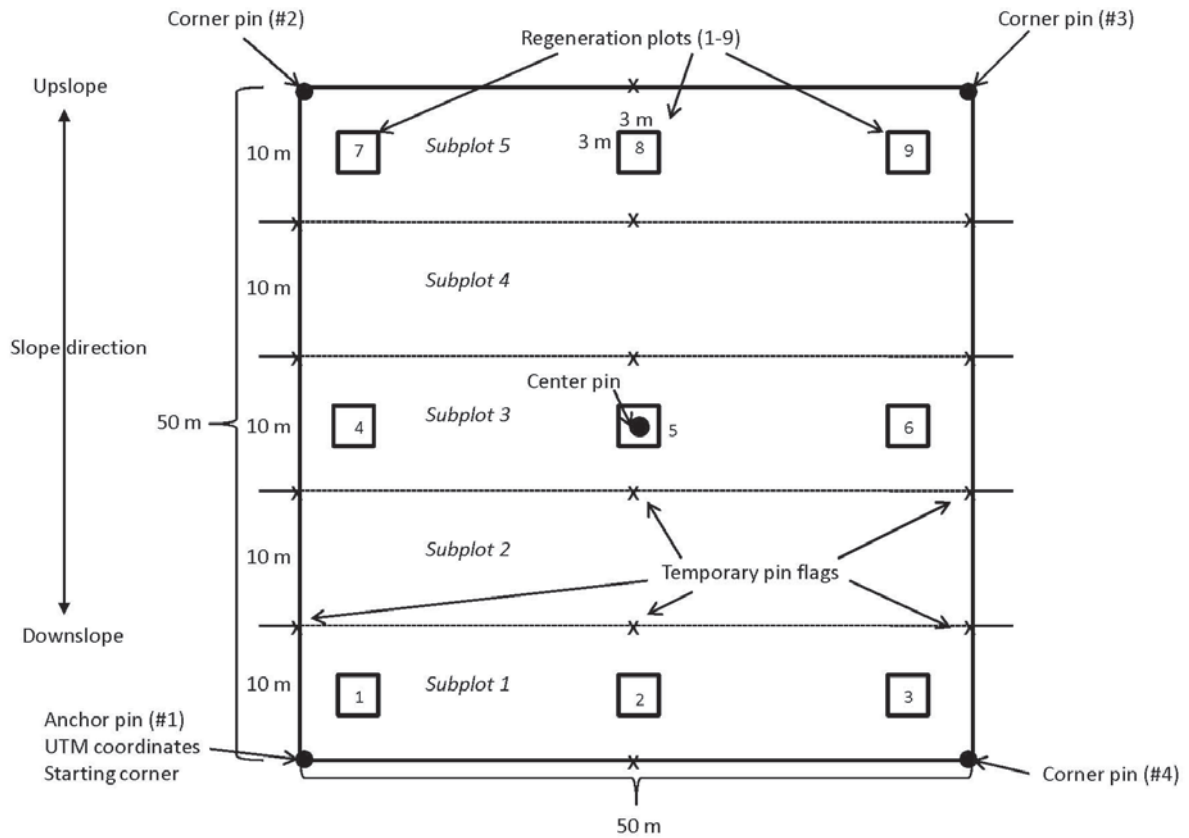


**Figure 2.** Layout of the 50 m x 50 m macroplot containing five 10 m x 50 m subplots, and nine 3 m x 3 m regeneration plots used in the Sierra Nevada and Upper Columbia Basin Networks. Regeneration plots are not permanently marked and are located 3 m in from the macroplot boundary lines.

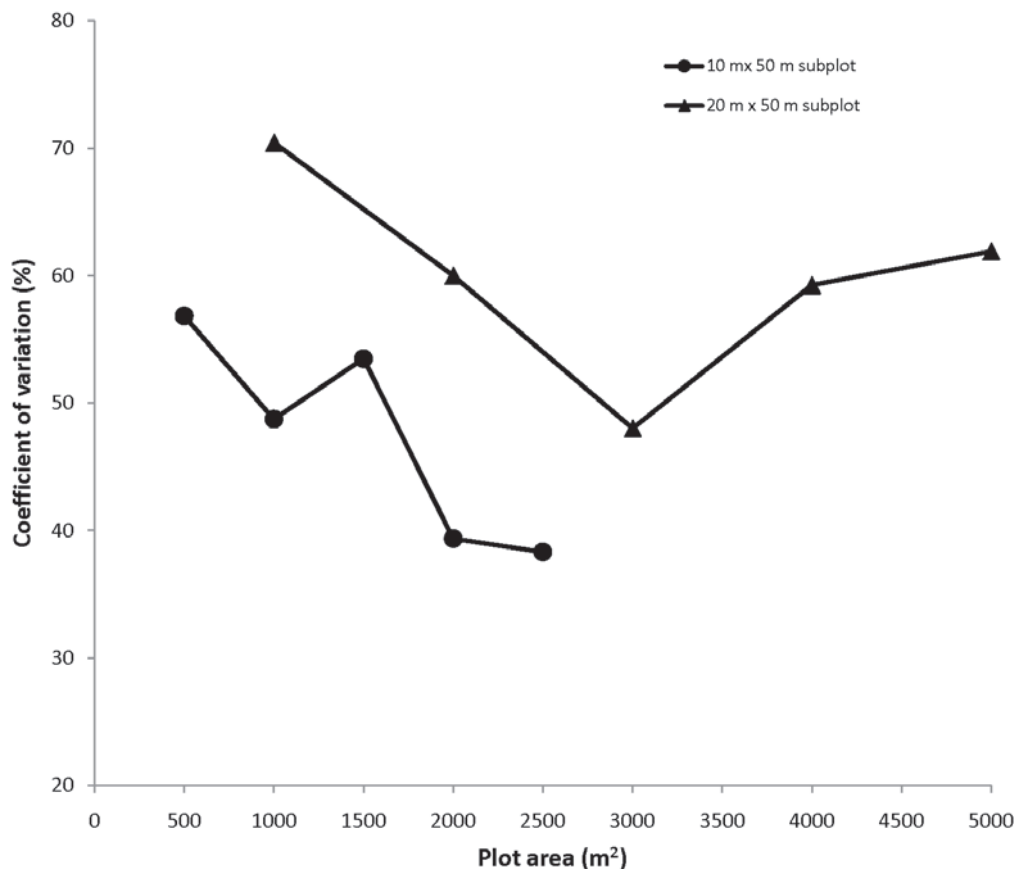


**Figure 3.** Variation in the total number of trees  $\geq 1.37$  m height as a function of plot area for two subplot sizes. The coefficient of variation is calculated as the sample standard deviation divided by the sample mean, multiplied by 100. Data were collected by laying out five consecutive subplots for each size. The 10 m x 50 m subplot (total area = 2,500 m<sup>2</sup>) was used in Yosemite National Park in whitebark pine habitat ( $n = 4$ ), and the 20 m x 50 m subplot (total area = 5,000 m<sup>2</sup>) was used in Craters of the Moon National Monument in limber pine habitat and in the Inyo National Forest in foxtail pine habitat ( $n = 9$ ).

where:

- $m_{a(i)}$  = the number of sites sampled in the  $i^{\text{th}}$  park;
- $m_{b(i)}$  = the number of years sampled in the  $i^{\text{th}}$  park;
- $m$  = the number of parks;
- $i = 1, \dots, 5$  indexes the five parks;
- $k = 1, \dots, m_i$  indexes the  $k^{\text{th}}$  site within the  $i^{\text{th}}$  park;
- $j = 1, \dots, m_{b(ki)}$  indexes the  $j^{\text{th}}$  survey year of the  $k^{\text{th}}$  site in the  $i^{\text{th}}$  park;
- $\mu$  = fixed intercept of the linear time trend;
- $w_j$  = is a constant representing the  $j^{\text{th}}$  year (covariate) which is centered such that the year of least variation occurs at  $w_j = 0$ ;
- $\beta_i$  = fixed linear slope of the  $i^{\text{th}}$  park;
- $a_{k(i)}$  = the random intercept of the  $k^{\text{th}}$  site in the  $i^{\text{th}}$  park, assumed independent and identically distributed as  $N(0, \sigma_{a(i)}^2)$ ;
- $b_{j(i)}$  = random effect of the  $j^{\text{th}}$  year in the  $i^{\text{th}}$  park, assumed independent and identically distributed as  $N(0, \sigma_{b(i)}^2)$ ;
- $\gamma_i$  = fixed effect of the  $i^{\text{th}}$  park;
- $t_{k(i)}$  = random slope of the  $k^{\text{th}}$  site in the  $i^{\text{th}}$  park in the  $i^{\text{th}}$  network, assumed independent and identically distributed as  $N(0, \sigma_{t(ik)}^2)$ ; and
- $e_{j(ik)}$  = unexplained error, assumed independent and identically distributed as  $N(0, \sigma_{e(ij)}^2)$ .

### Regional analyses

Mixed linear models are used to estimate trends in the response variables across the three networks. Comparisons of

rates of change among the networks are made using  $F$ -tests to test for differences in slope and intercept coefficients. Descriptive statistics are compared among the networks using standard uni- and multivariate approaches.

## Application

Blister rust and mountain pine beetle occurrence within several of the network parks, coupled with projections of increased temperature and decreased precipitation in the region, portend future declines in white pine communities, underscoring the need for broad-scale collaborative monitoring. Our joint efforts will provide comparable data on rust infection rates and tree damage, pine beetle outbreaks, and tree mortality across a large region with diverse forest types. Collaborative monitoring will also create opportunities to share information to better understand the effects of modern stressors on the dynamics of high-elevation forest ecosystems, and add to our knowledge of blister rust spread and epidemiology. This information can help park managers adapt to anticipated short- and long-term changes in ecosystem structure and function. Annual reports will be published through the NPS Natural Resources Technical Report series and served through NPS websites. Resource briefs will be produced and updated each year to provide a quick overview on the status of high-elevation white pine communities in each park. The first trend analyses will occur at the end of nine years (three panel rotations), and subsequently after each three-year panel rotation, ultimately resulting in more in-depth reports for the NPS technical report series and manuscripts for peer-reviewed publication.

**Table 1.** Revisit design for monitoring white pine species in a) the Klamath Network, b) the Sierra Nevada Network, and c) the Upper Columbia Basin Network. LAVO=Lassen Volcanic, CRLA=Crater Lake.

a. This panel design is followed for whitebark pine in the Klamath Network. Each third year is an off (or rest) year yielding a total  $n = 50$  unique plots.

|                   | Year |      |      |      |      |      |      |      |      |      |      |      |      |
|-------------------|------|------|------|------|------|------|------|------|------|------|------|------|------|
|                   | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 |
| LAVO ( $n = 25$ ) | x    |      |      | x    |      |      | x    |      |      | x    |      |      | x    |
| CRLA ( $n = 25$ ) |      | x    |      |      | x    |      |      | x    |      |      | x    |      |      |

b. This panel design is followed for whitebark pine in Yosemite and for whitebark and foxtail pine each in Sequoia-Kings Canyon for a total SIEN  $n = 144$  unique plots.

| Panel          | Year |      |      |      |      |      |      |      |      |      |      |      |      |
|----------------|------|------|------|------|------|------|------|------|------|------|------|------|------|
|                | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 |
| 1 ( $n = 16$ ) | x    |      |      | x    |      |      | x    |      |      | x    |      |      | x    |
| 2 ( $n = 16$ ) |      | x    |      |      | x    |      |      | x    |      |      | x    |      |      |
| 3 ( $n = 16$ ) |      |      | x    |      |      | x    |      |      | x    |      |      | x    |      |

c. This panel design is followed for limber pine in Craters of the Moon for a total UCBN  $n = 90$  unique plots.

| Panel          | Year |      |      |      |      |      |      |      |      |      |      |      |      |
|----------------|------|------|------|------|------|------|------|------|------|------|------|------|------|
|                | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 |
| 1 ( $n = 30$ ) | x    |      |      | x    |      |      | x    |      |      | x    |      |      | x    |
| 2 ( $n = 30$ ) |      | x    |      |      | x    |      |      | x    |      |      | x    |      |      |
| 3 ( $n = 30$ ) |      |      | x    |      |      | x    |      |      | x    |      |      | x    |      |

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## Literature Cited

- Duriscoe, D. M., and C. S. Duriscoe. 2002. Survey and monitoring of white pine blister rust in Sequoia and Kings Canyon National Parks: Final report on 1995-1999 survey and monitoring plot network. Science and Natural Resources Management Division Sequoia and Kings Canyon National Parks, Three Rivers, CA.
- Greater Yellowstone Whitebark Pine Monitoring Working Group (GYWPMWG). 2007. Interagency whitebark pine monitoring protocol for the Greater Yellowstone Ecosystem, v 1.00. Greater Yellowstone Coordinating Committee, Bozeman, MT.
- Little, E. L., Jr. 1971. Conifers and important hardwoods. Volume 1 of Atlas of United States trees. U.S. Department of Agriculture Miscellaneous Publication 1146.
- Maloney, P., J. Dunlap, D. Burton, D. Davis, D. Duriscoe, J. Pickett, R. Smith, and J. Kliejunas. 2008. White Pine Blister Rust in the High Elevation White Pines of California: A Forest Health Assessment for Long-Term Monitoring. USDA Forest Service, Forest Health Protection. Internal Draft Report. Pages 64.
- McKinney, S. T., T. Rodhouse, L. Chow, G. Dicus, L. Garrett, K. Irvine, D. Sarr, and L. A. H. Starcevich. [Submitted September 2010]. Monitoring white pine (*Pinus albicaulis*, *P. balfouriana*, *P. flexilis*) community dynamics in the Pacific West Region: Klamath, Sierra Nevada, and Upper Columbia Basin Networks. Natural Resource Report NPS/PWR/NRR-2011/XXX. National Park Service, Fort Collins, CO.
- Murray, M. P.; Rasmussen, M. C. 2003. Non-native blister rust disease on whitebark pine at Crater Lake National Park. Northwest Science. 77: 87-91.
- Murray, M. P. 2010. Will whitebark pine not fade away? Insight from Crater Lake National Park (2003-2009). Park Science. 27(2): 64-67.
- Piepho, H. P.; Ogutu, J. O. 2002. A simple mixed model for trend analysis in wildlife populations. Journal of Agricultural, Biological, and Environmental Statistics. 7(3): 350-360.
- Stevens, D. L.; Olsen, A. R. 2004. Spatially balanced sampling of natural resources. Journal of the American Statistical Association. 99: 262-278.
- Tomback, D. F.; Keane, R. E.; McCaughey, W. W.; Smith, C. 2005. Methods for surveying and monitoring whitebark pine for blister rust infection and damage. Whitebark Pine Ecosystem Foundation, Missoula, MT.
- VanLeeuwen, D. M.; Birkes, D. S.; Seely, J. F. 1999. Balance and orthogonality in designs for mixed classification models. The Annals of Statistics. 27(6): 1927-1947.

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