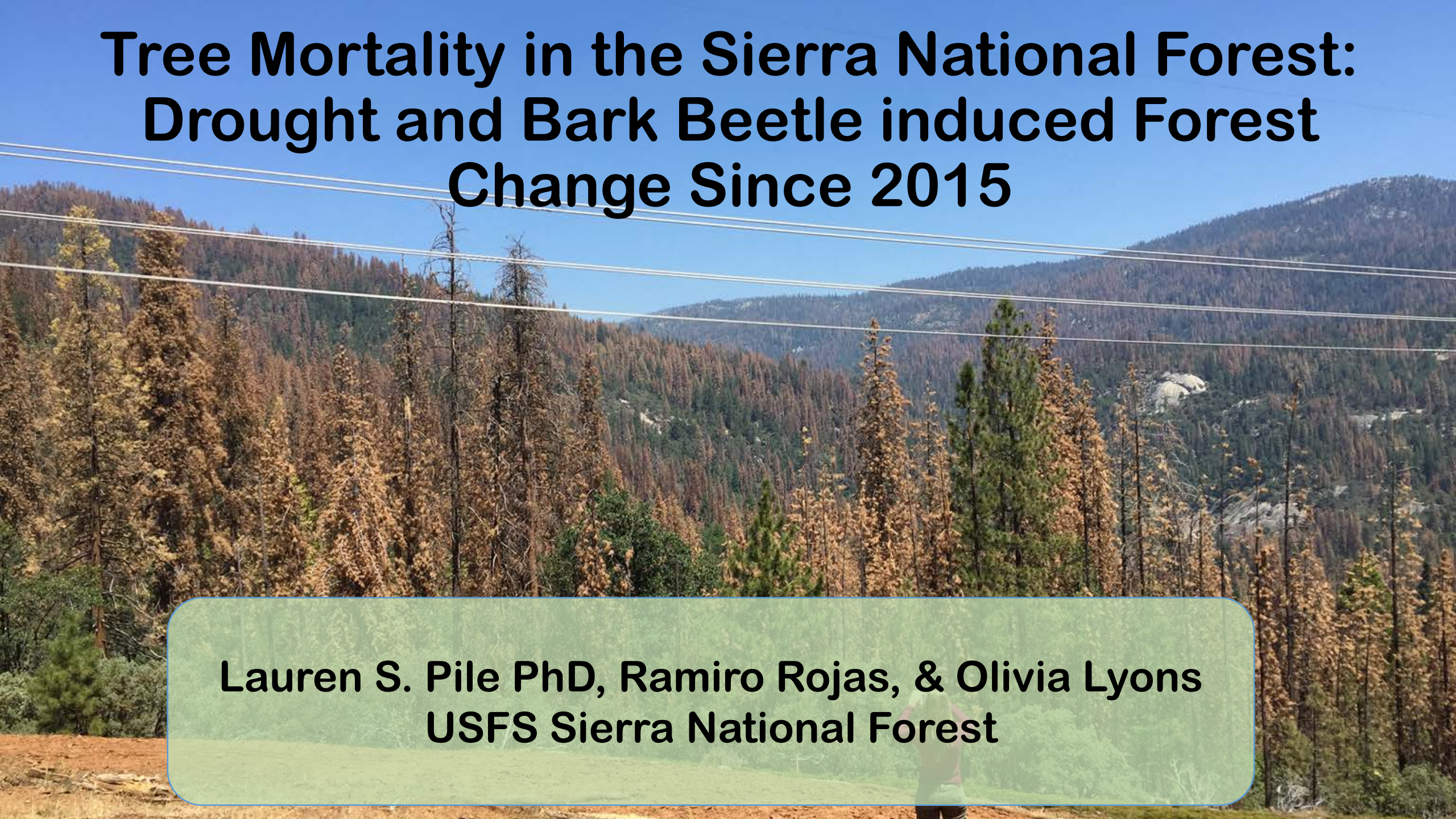
Tree Mortality in the Sierra National Forest: Drought and Bark Beetle induced Forest Change Since 2015



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Data Collection

- Repeated measurements were taken across 255 plots and recorded 1699 individual trees
- The plots were established in SPRING 2015 and resampled in FALL 2015 and SUMMER 2016

- By using a repeated measurement design approach of the same individual this allows for the comparison of species survivorship across time periods – providing valuable insights into the trends of tree mortality and can guide future forest management

Mortality Plot Locations

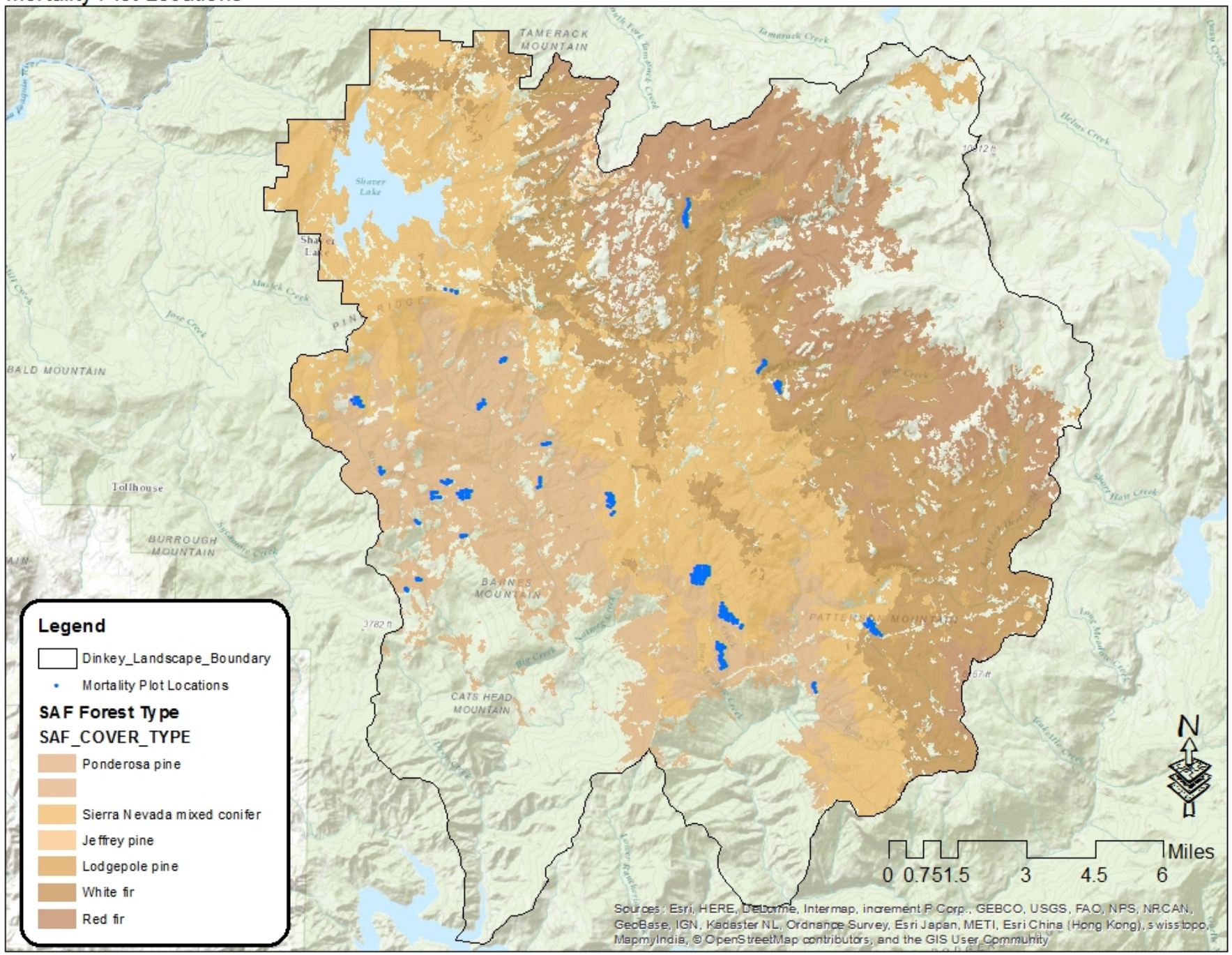


Figure:
This figure shows the percent survivorship of trees larger than 10 inches in DBH as measured in Spring 2015, Summer 2015, and Summer 2016

Note:

1. **The dramatic reduction in sugar and ponderosa pines in 2015**
2. **The reduction in incense cedar and white fir from 2015 to 2016**

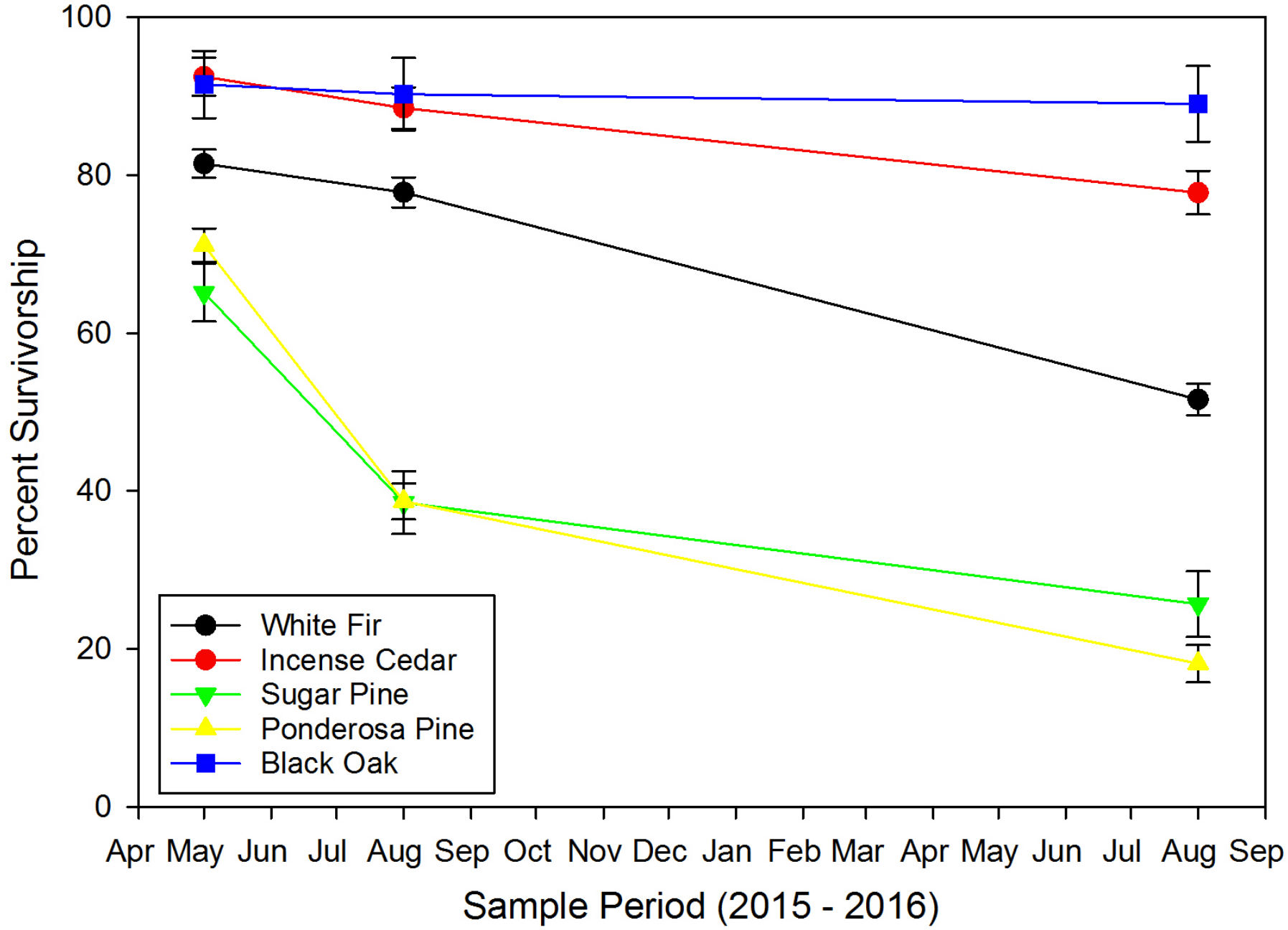


Figure:
This figure shows the density of surviving trees larger than 10 inches in DBH as measured in Spring 2015, Summer 2015, and Summer 2016

Note:

1. **The reduction in sugar and ponderosa pines in 2015**
2. **The reduction in incense cedar and white fir from 2015 to 2016**

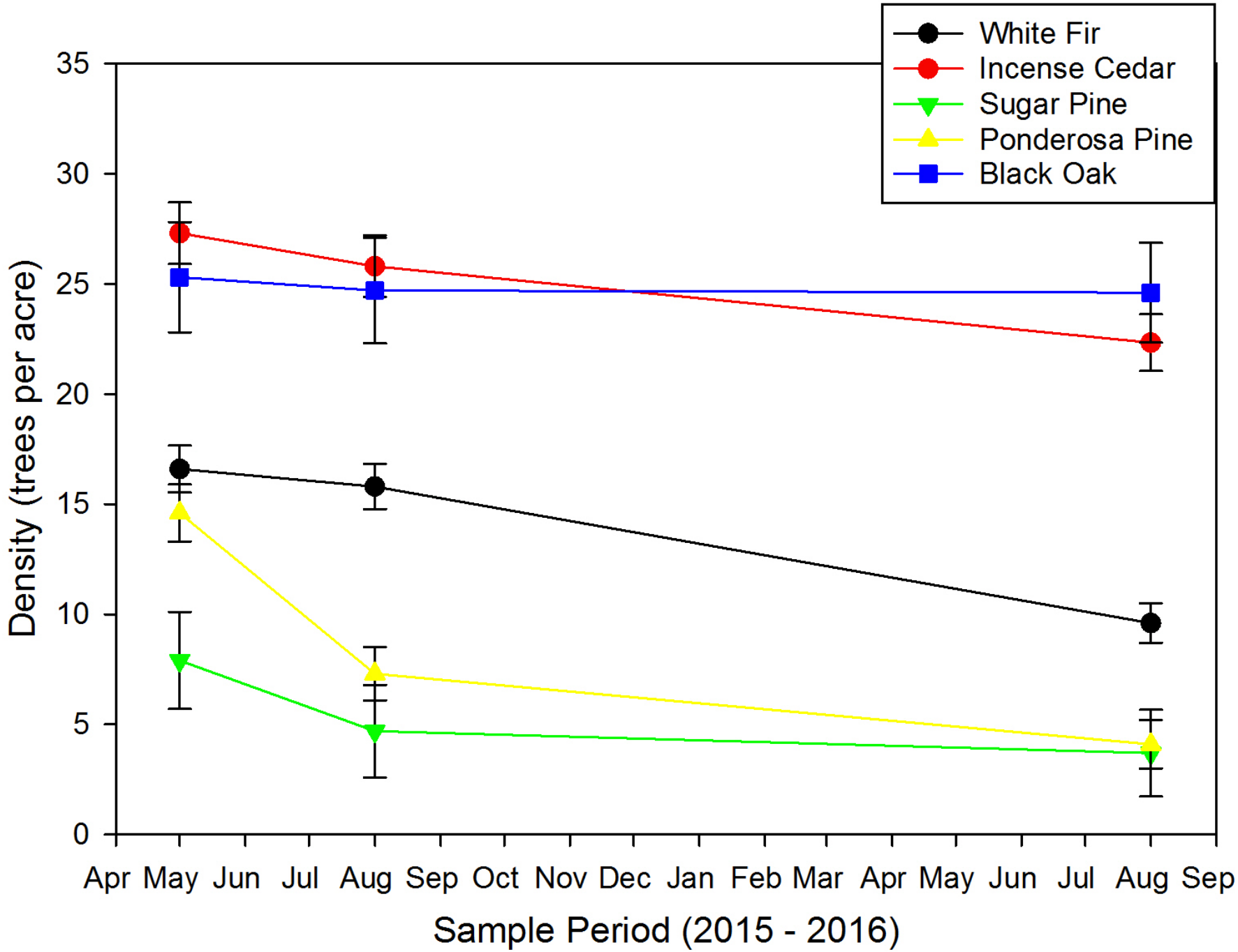


Figure:
This figure shows the basal area of surviving trees larger than 10 inches in DBH as measured in Spring 2015, Summer 2015, and Summer 2016 by SAF Forest Type

Note:

1. **Basal area of red fir, incense cedar, and black oak remain relatively stable**
2. **Reduction in basal area in 2015 of ponderosa pine and sugar pine**
3. **Reduction of basal area of white fir in 2016**

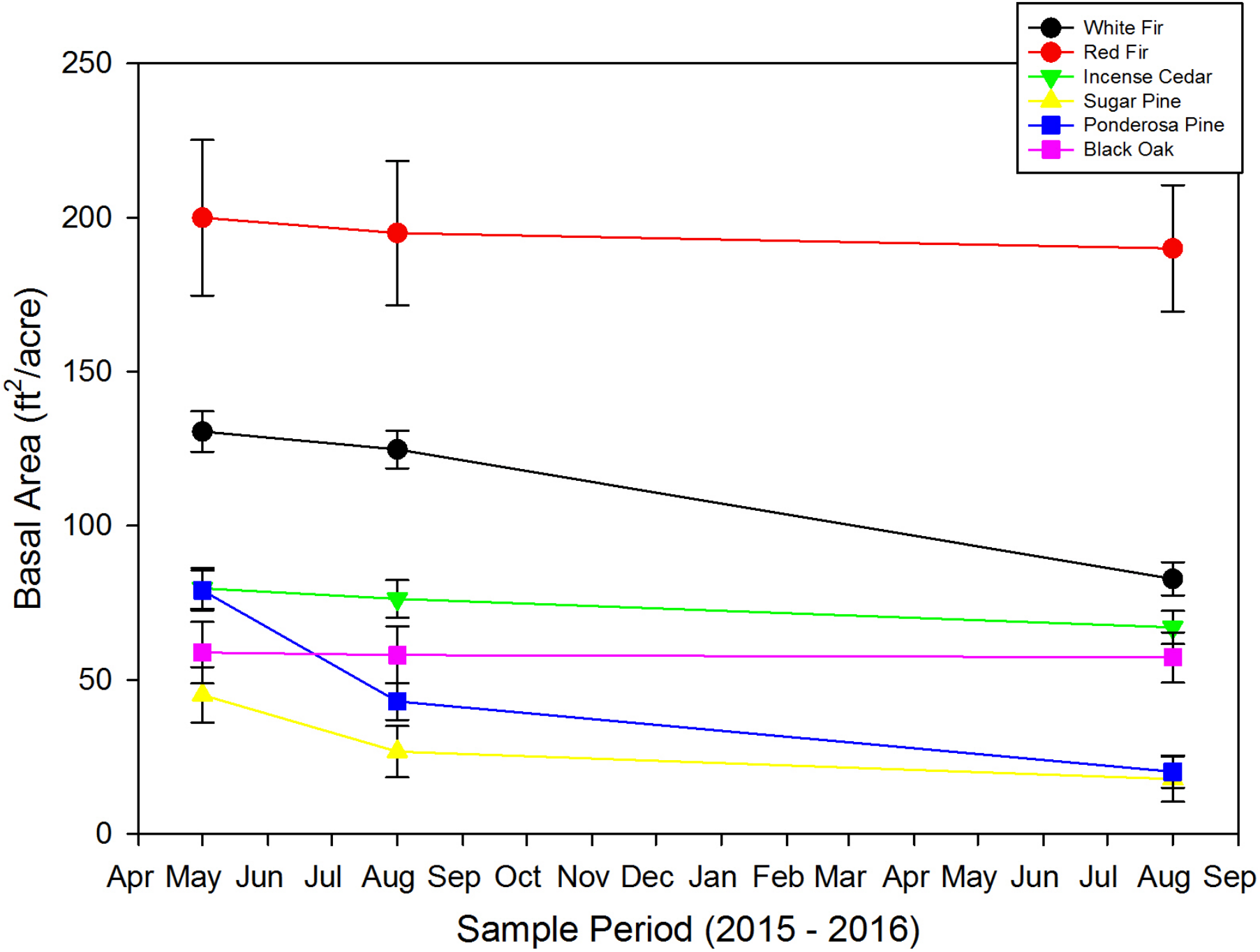
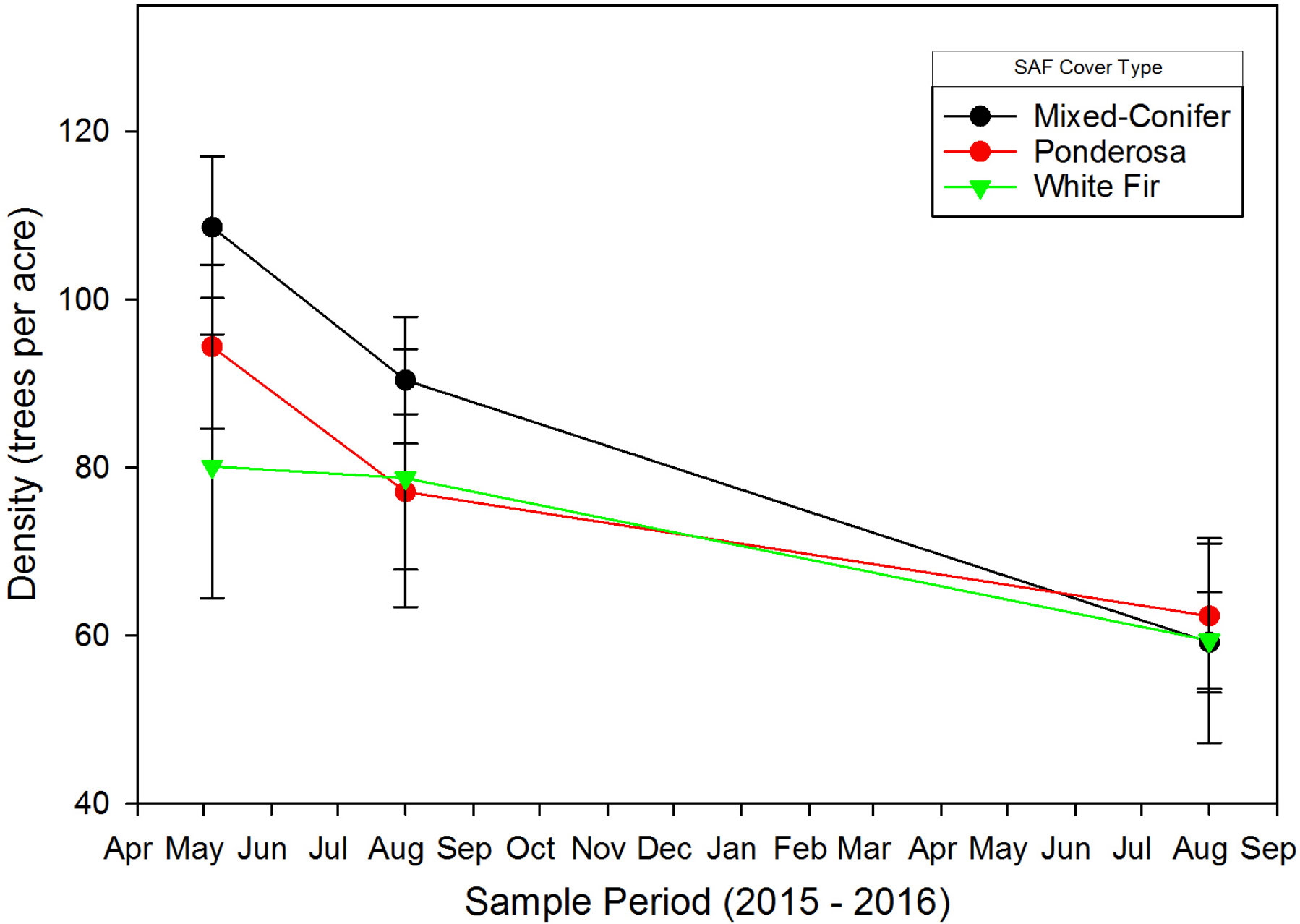


Figure:
This figure shows the density of surviving trees larger than 10 inches in DBH as measured in Spring 2015, Summer 2015, and Summer 2016 by SAF Forest Type

Note:

1. **Mixed-Conifer forest type is reduced from 115 in 2015 to 60 trees per acre greater than 10 inches by 2016**
2. **Ponderosa and White Fir forest types have approximately 50 trees per acre over 10 inches in 2016**



Management note

- Low survivorship in ponderosa pine plots reflects the obvious change in forest structure. Average pine stands have less than 50 trees per acre over 10 inches DBH. Five trees per acre in pine species.

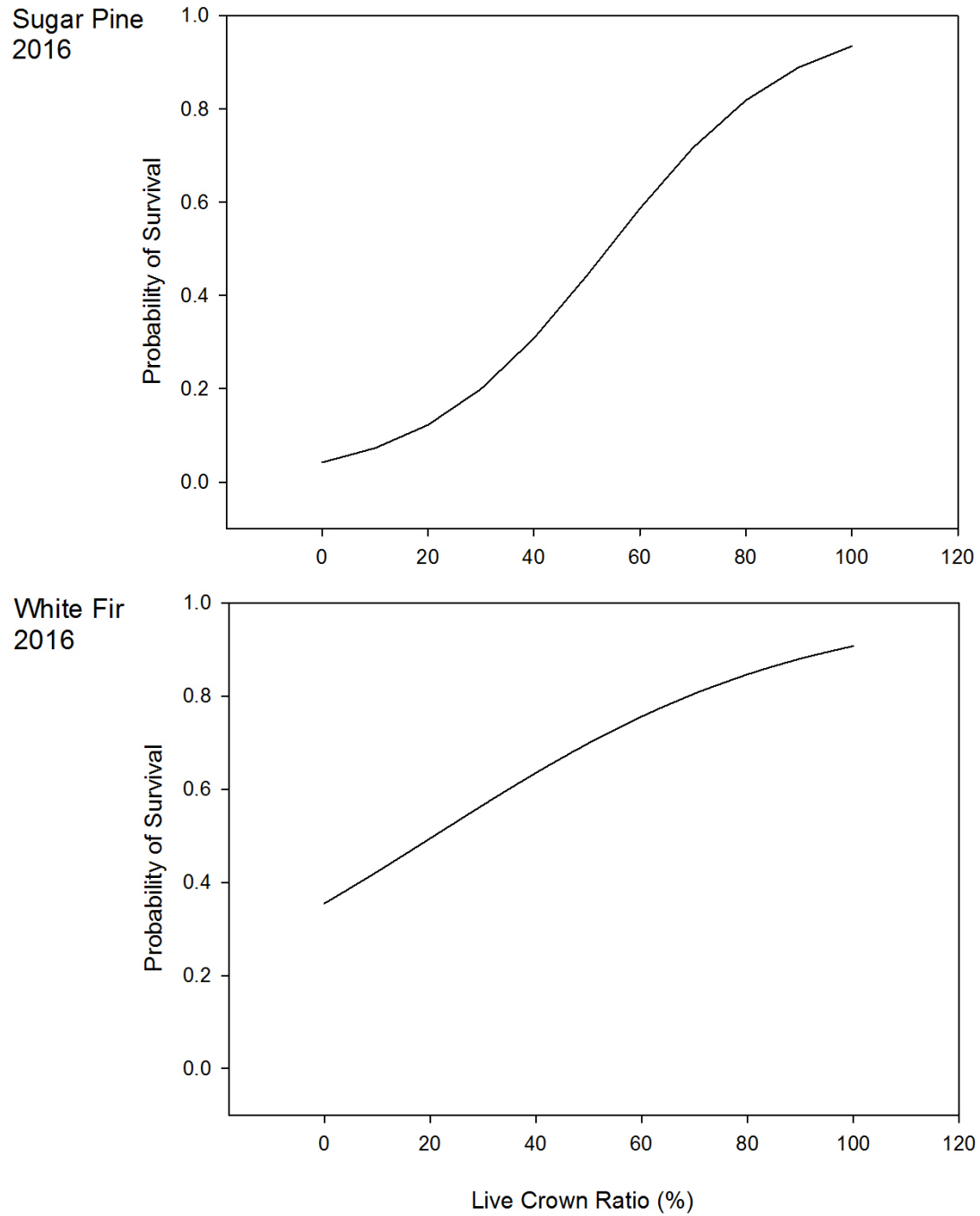
- Remaining forest structures are dominated by white fir, black oak and incense cedar. Only scattered by pines with no pines in many stands.

- Reforestation actions to regenerate pine are needed to set stands on a restoration trajectory.

Figure:
This figure shows the probability of survival by species as a factor of live crown ratio. Live crown ratio (the proportion of the tree that supports green foliage) was significant in determining the probability of survivorship for sugar pine and white fir in 2016.

Note:

1. **The larger the live crown ratio the higher the survivorship**
2. **Sugar pine – at a live crown ratio of 50% there will be an estimated 50% survival**
3. **White fir – at a live crown ratio of 50% there will be an estimated 65% survival**



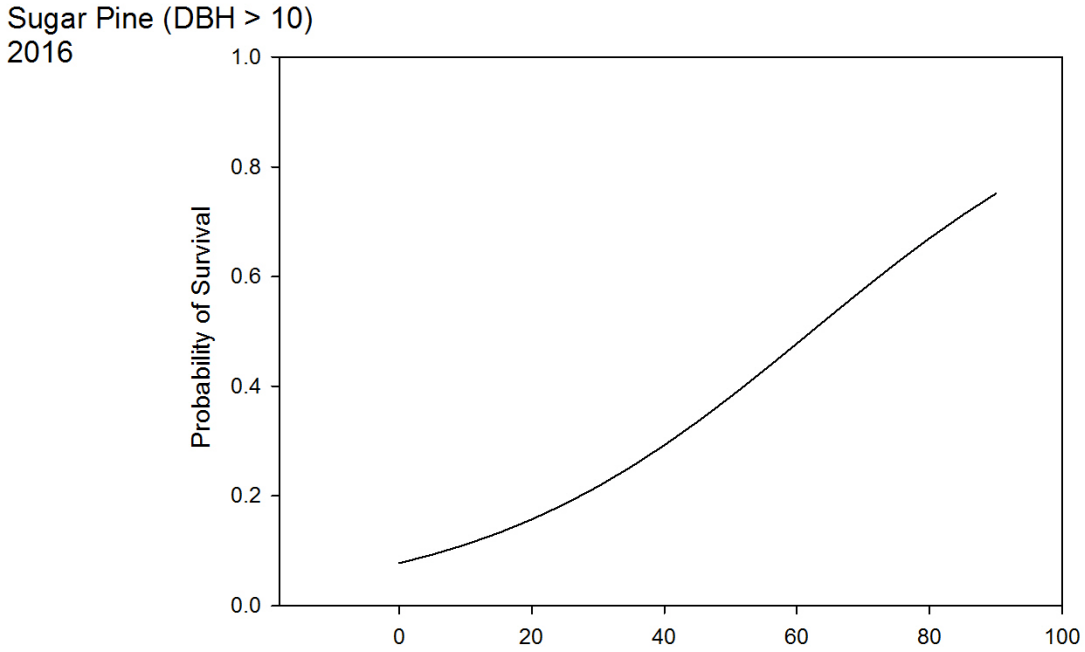
Management note

- Live crown ratio can be manipulated by tree density or stocking
- Reduced forest densities will increase live crown ratios by providing more growing space (consider the difference between an open grown tree and a tree in a dense forest)
- However, thinning must occur prior to a threshold in live crown ratio – thinning past this threshold will not increase the live crown ratio (thinning when the crown is reduced to 30% will not cause the tree to increase in crown ratio)

Figure:
This figure shows the probability of survival by species as a factor Diameter Class for individuals greater than 10 inches. Diameter was significant in determining the probability of survivorship for sugar pine in 2016 and ponderosa pine in 2015.

Note:

1. **Sugar pine – individuals with a larger diameter had a greater probability of survival in 2016 than those that had a smaller diameter.**
2. **Ponderosa Pine - individuals with a larger diameter had a greater probability of survival in 2015 than those that had a smaller diameter but this was not the case by 2016.**



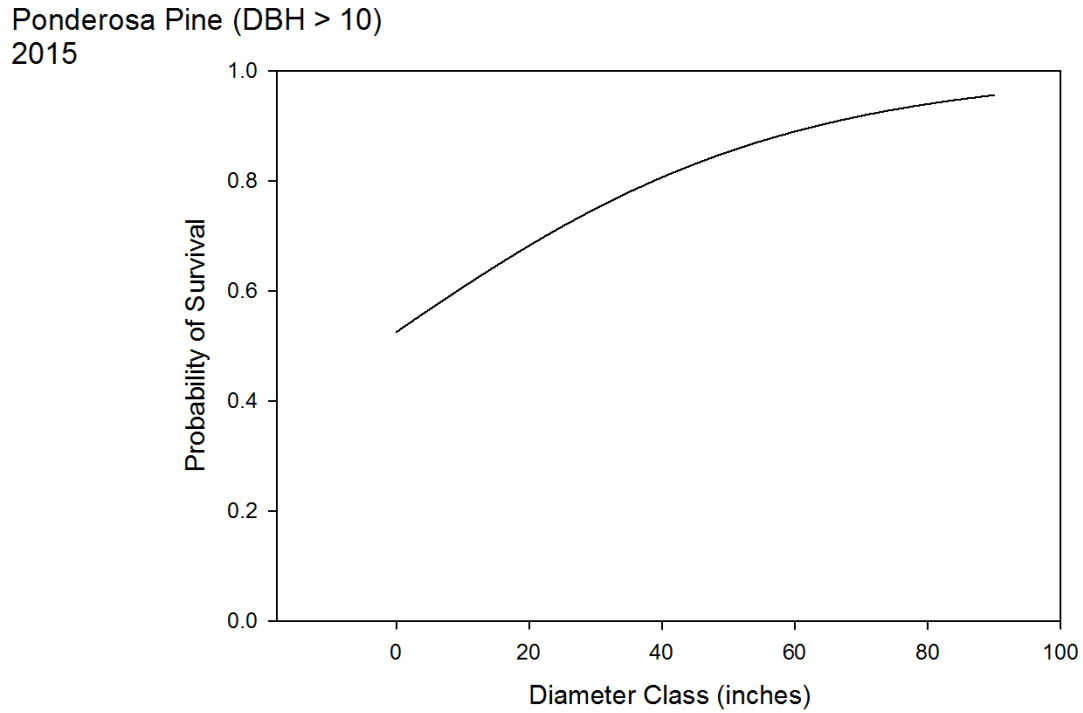
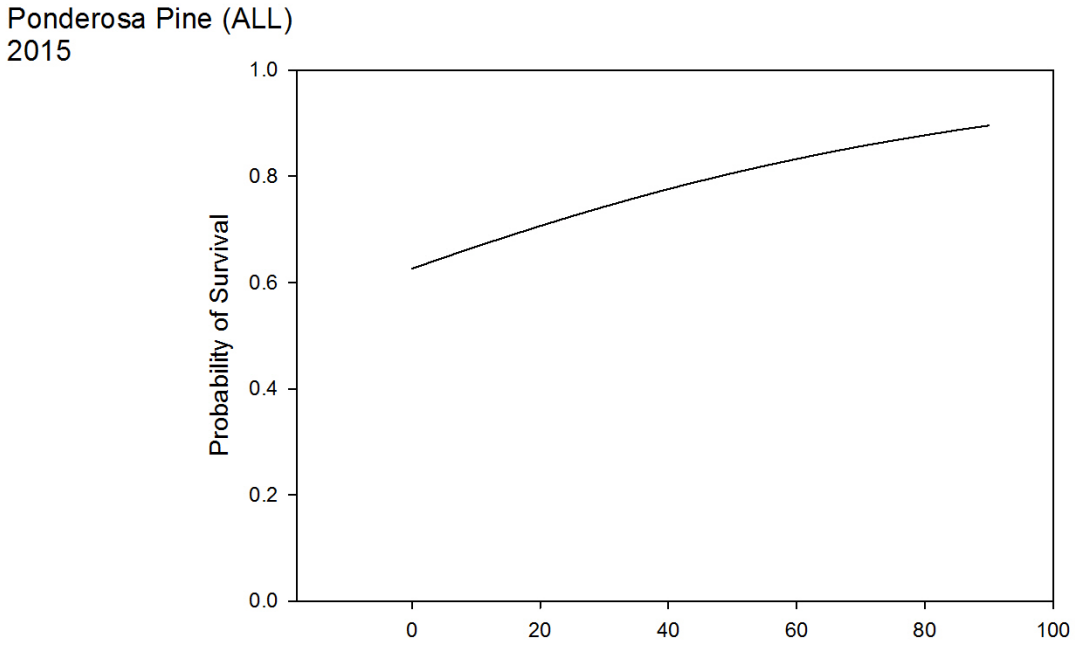
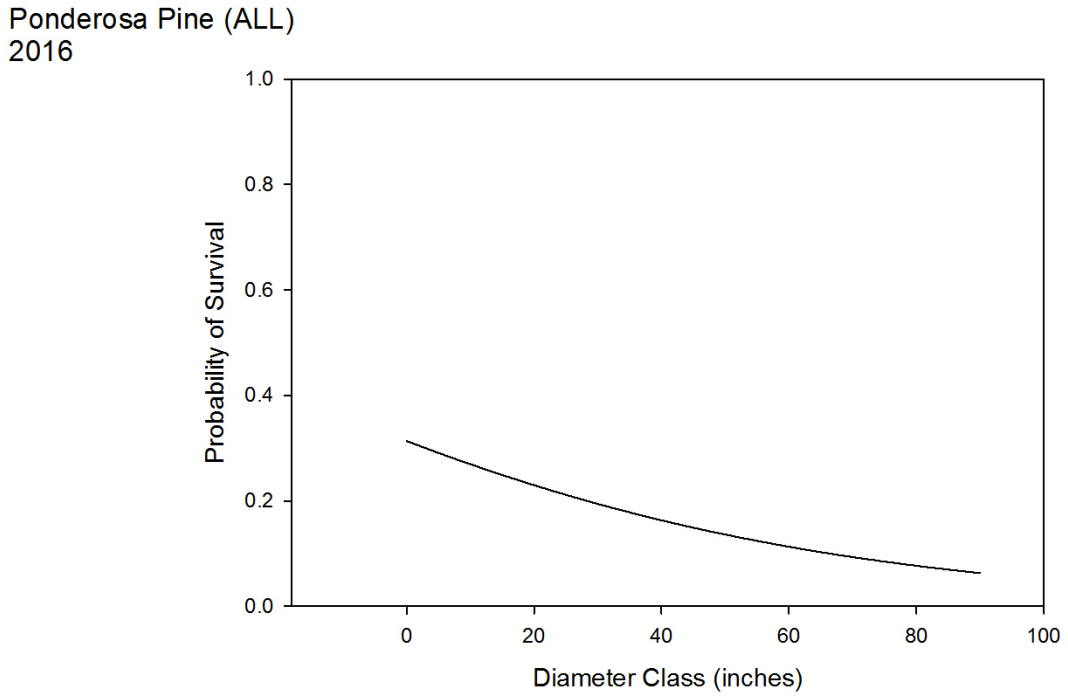


Figure:
This figure shows the probability of survival by species as a factor Diameter Class for all individuals (greater than 1 inch DBH). Diameter class was significant for determining survival in 2015 and 2016 but the result is very different.

Note:

1. **2015 – as diameter of ponderosa pine increased so did survivorship→ this may reflect natural thinning and mortality due to drought effects**
2. **2016 – as diameter of ponderosa pine increase survivorship decreased → this reflects the increasing beetle population**
3. **Also 2016 – survivorship across all diameter classes is low**





Management note

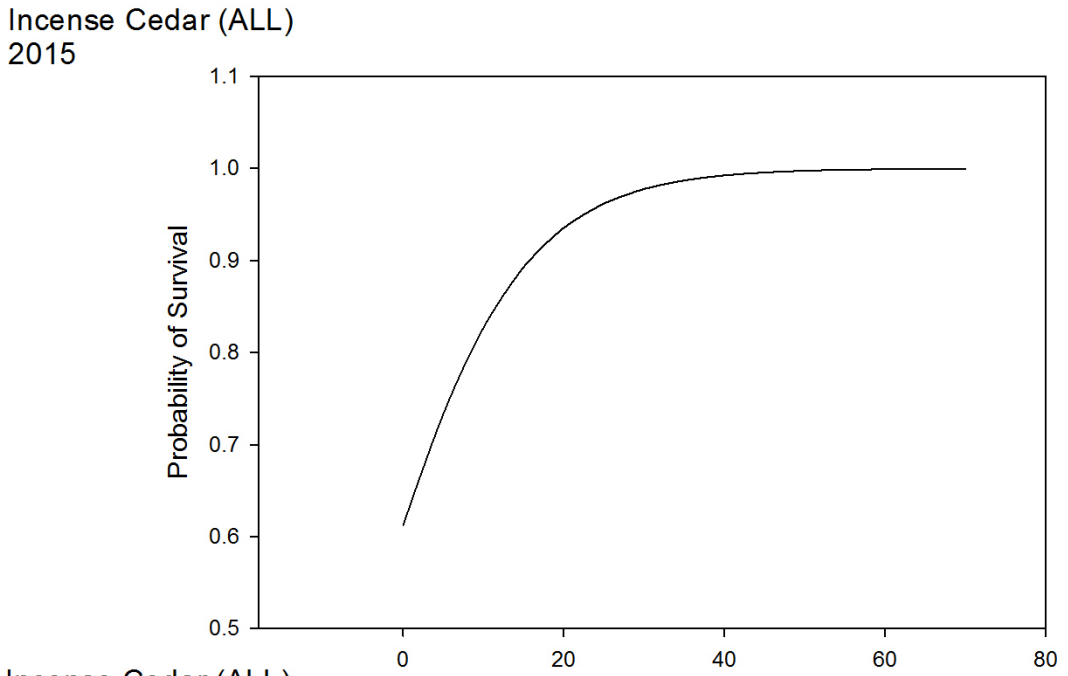
- In moderate drought represented by conditions in early 2015 – stand management that promotes large individual trees could increased survivorship.
- However in extreme droughts representative of conditions in 2016- Variable structures that contain both large and small trees result in more survivors. creating multi-aged stands may increase resilience and survivorship.

- During extreme drought, prescriptions that promote openings for new trees or retain small trees are likely to recover soonest.

Figure:
This figure shows the probability of survival for incense cedar by Diameter Class (all individuals). Diameter was significant in determining the probability of survivorship for incense cedar in 2015 and in 2016, although the slope of the curve for survivorship was different.

Note:

1. **2015 – survivorship was greatly reduced for individuals less than 20 inches but was high and remained level over 20 inches**
2. **2016 – survivorship was much more gradual with increasing diameter**



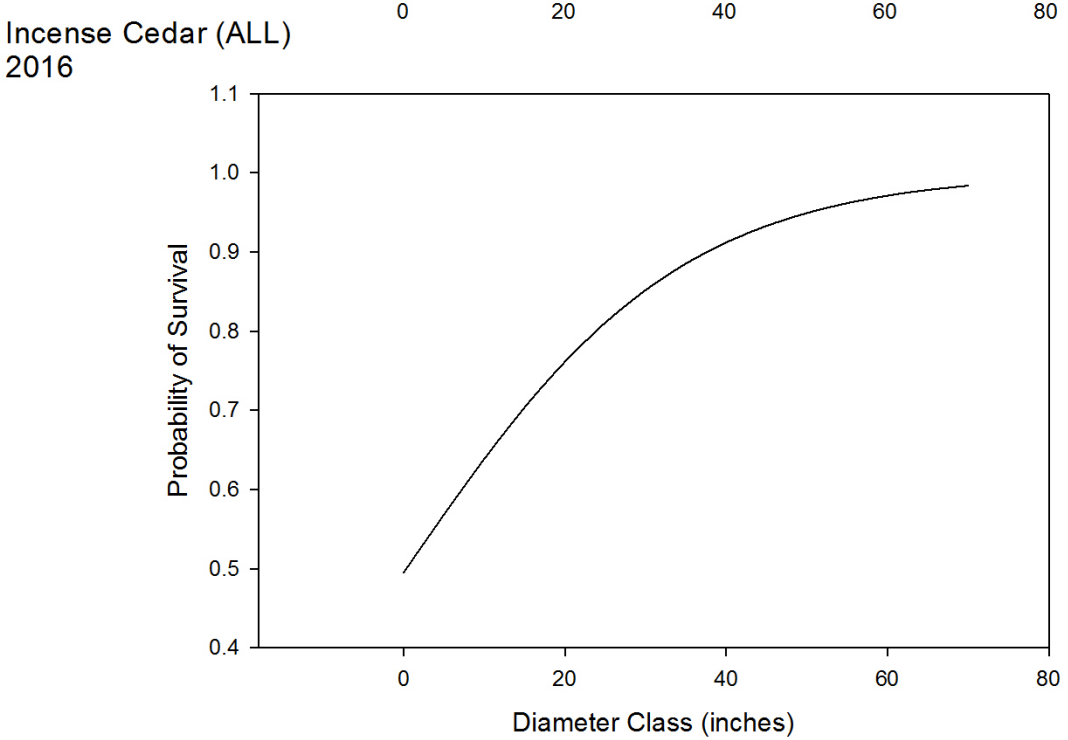
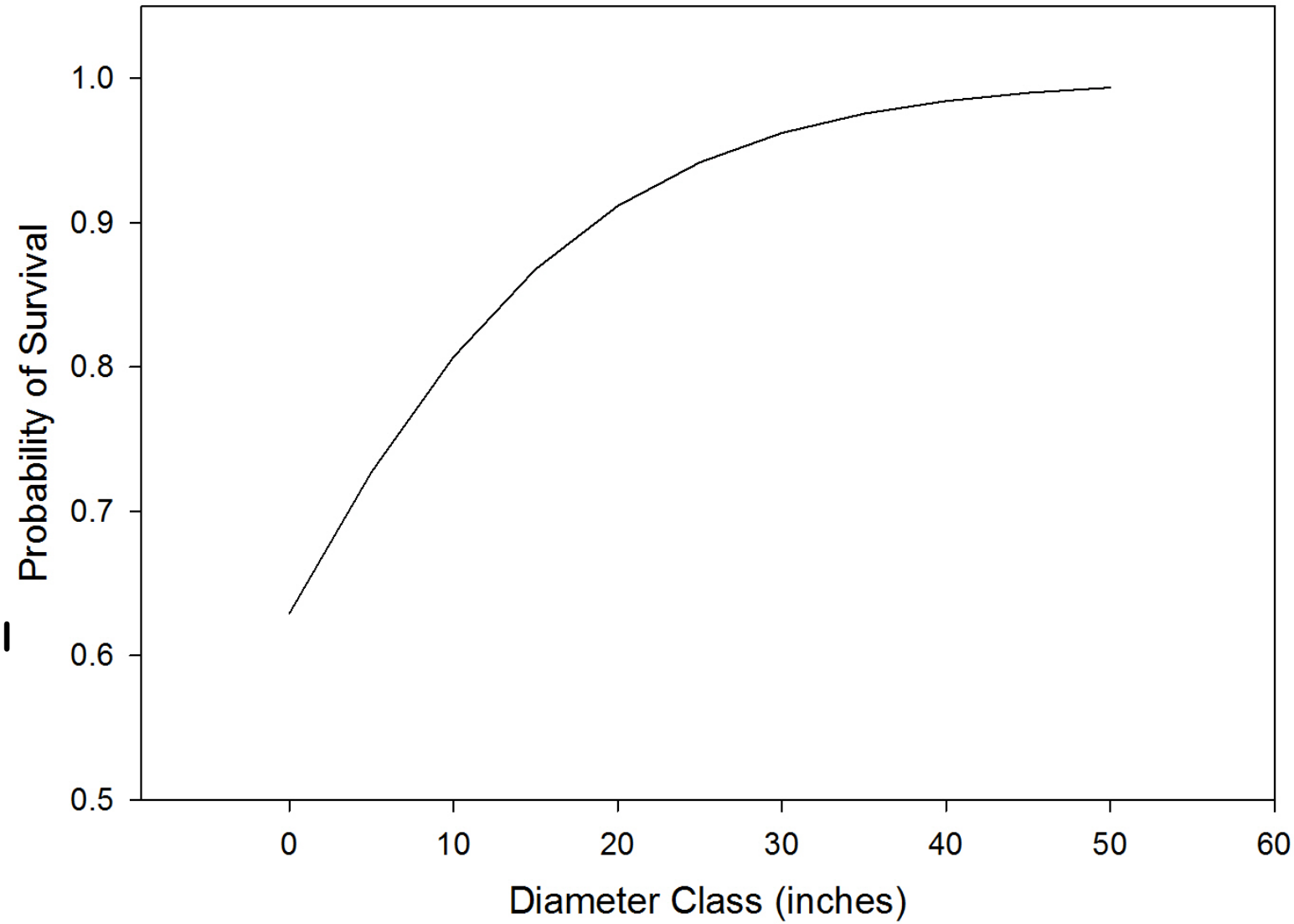


Figure:
This figure shows the probability of survival by black oak as a factor Diameter Class (all individuals). Diameter was significant in determining the probability of survivorship for black oak in 2016.

Note:

1. **Larger individuals of black oak may have greater capabilities for survival during drought – such as larger, more developed root systems**



Management note

- High incense cedar survivorship will shift stand composition in unique ways. Incense cedar is typically intermediate in dominance. It is unclear if these understory trees will persist.

- Poor understory (incense cedar less than 20 inches DBH) survival is likely driven by poor crown and root development. Sudden release of understory incense cedar may be resulting in the decline of smaller trees.

- Prescriptions that retain incense cedar with larger diameters and larger live crowns have a higher probability of successful tree develop.

Figure:
This figure shows the percent survivorship by diameter class (5 inch intervals) for white fir across the three sample periods.

Note:

1. **Spring and Summer 2015 had little reduction in survivorship across the diameter classes**
2. **Reduction was more dramatic across the smaller diameter classes in 2016 with some stability in the larger diameter classes**

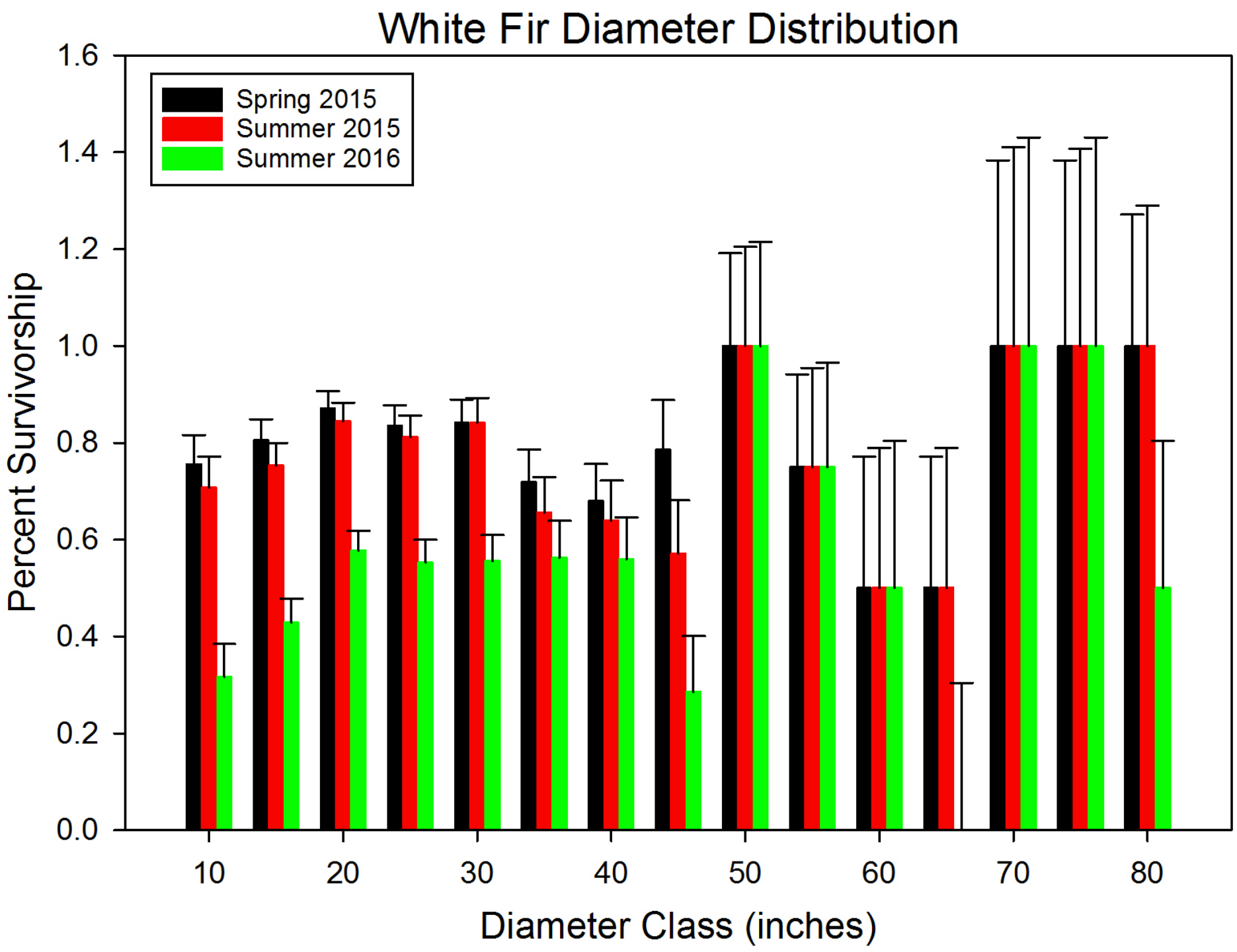


Figure:
This figure shows the percent survivorship by diameter class (5 inch intervals) for incense cedar across the three sample periods.

Note:

1. **Spring and Summer 2015 had little reduction in survivorship across the diameter classes**
2. **Some reduction in smaller diameter classes in 2016**

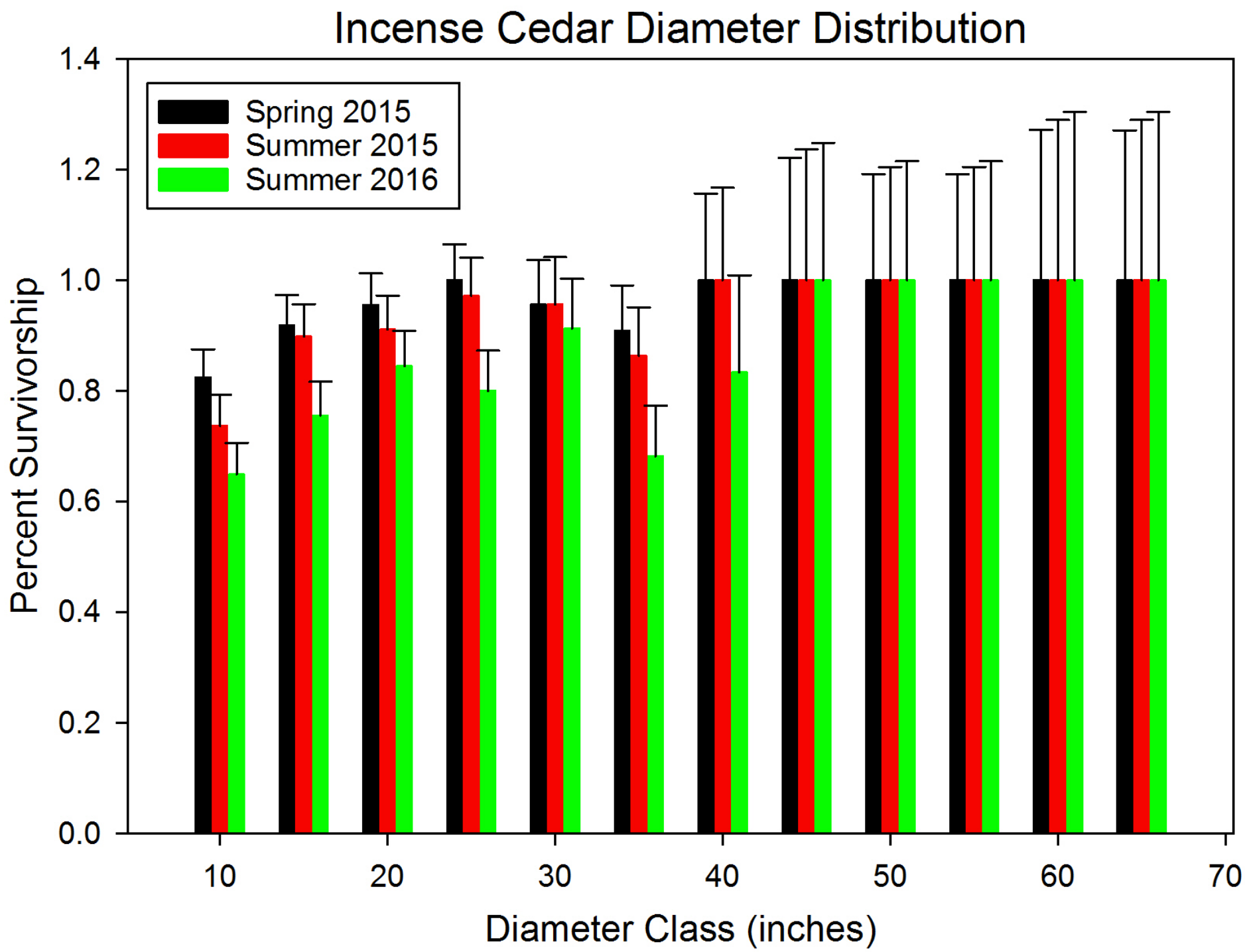


Figure:
This figure shows the percent survivorship by diameter class (5 inch intervals) for sugar pine across the three sample periods.

Note:

1. **Reduction across all diameters in summer 2015**
2. **Additional reductions across all diameters in 2016**

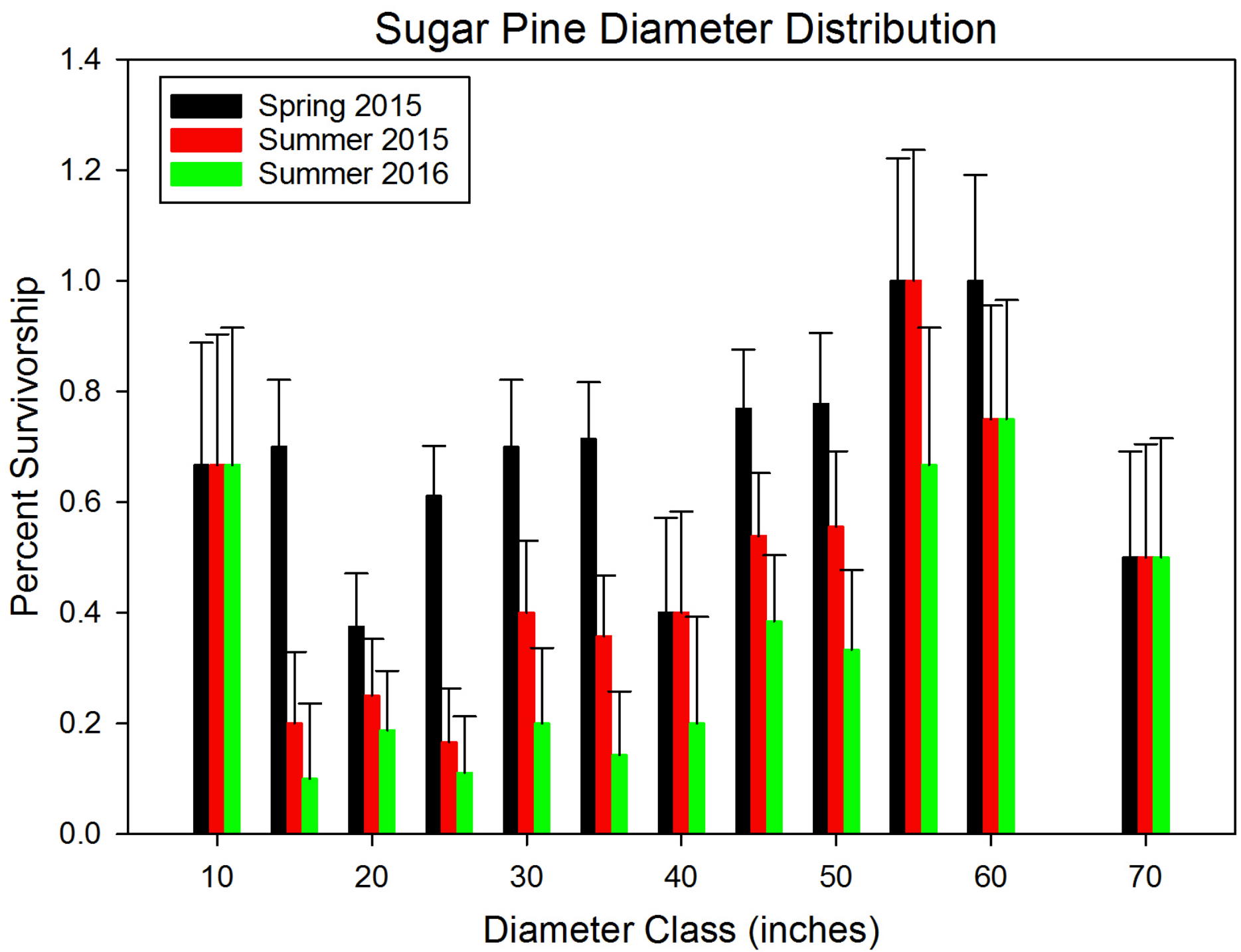
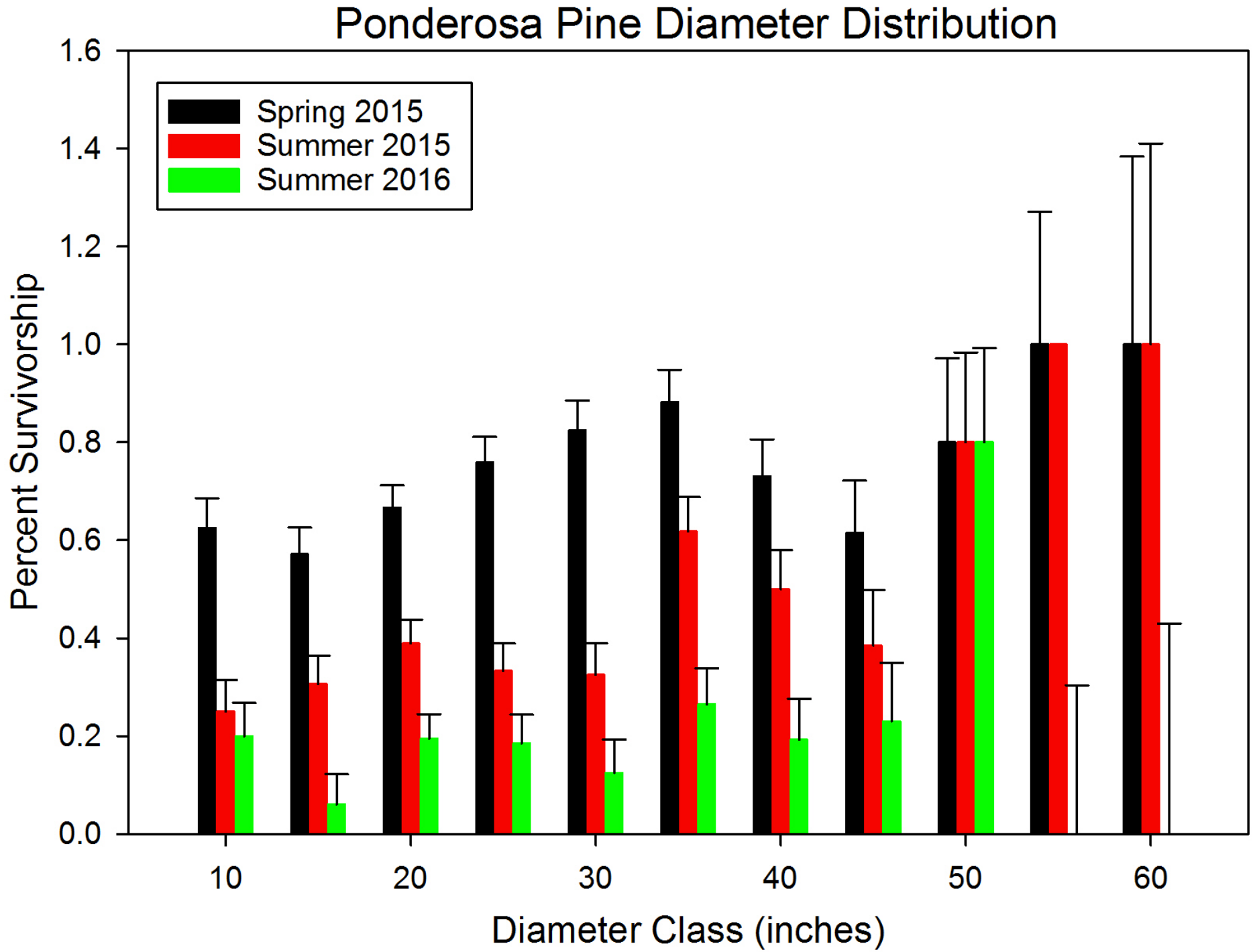


Figure:
This figure shows the percent survivorship by diameter class (5 inch intervals) for ponderosa pine across the three sample periods.

Note:
1. **Reduction across all diameters in summer 2015**
2. **Additional reductions across all diameters in 2016**



Management note

- The dramatic loss of ponderosa pine and sugar pine creates conditions that limit the potential for natural pine regeneration
  - Few large trees or none
  - Unlike fires no bare mineral soil is created.

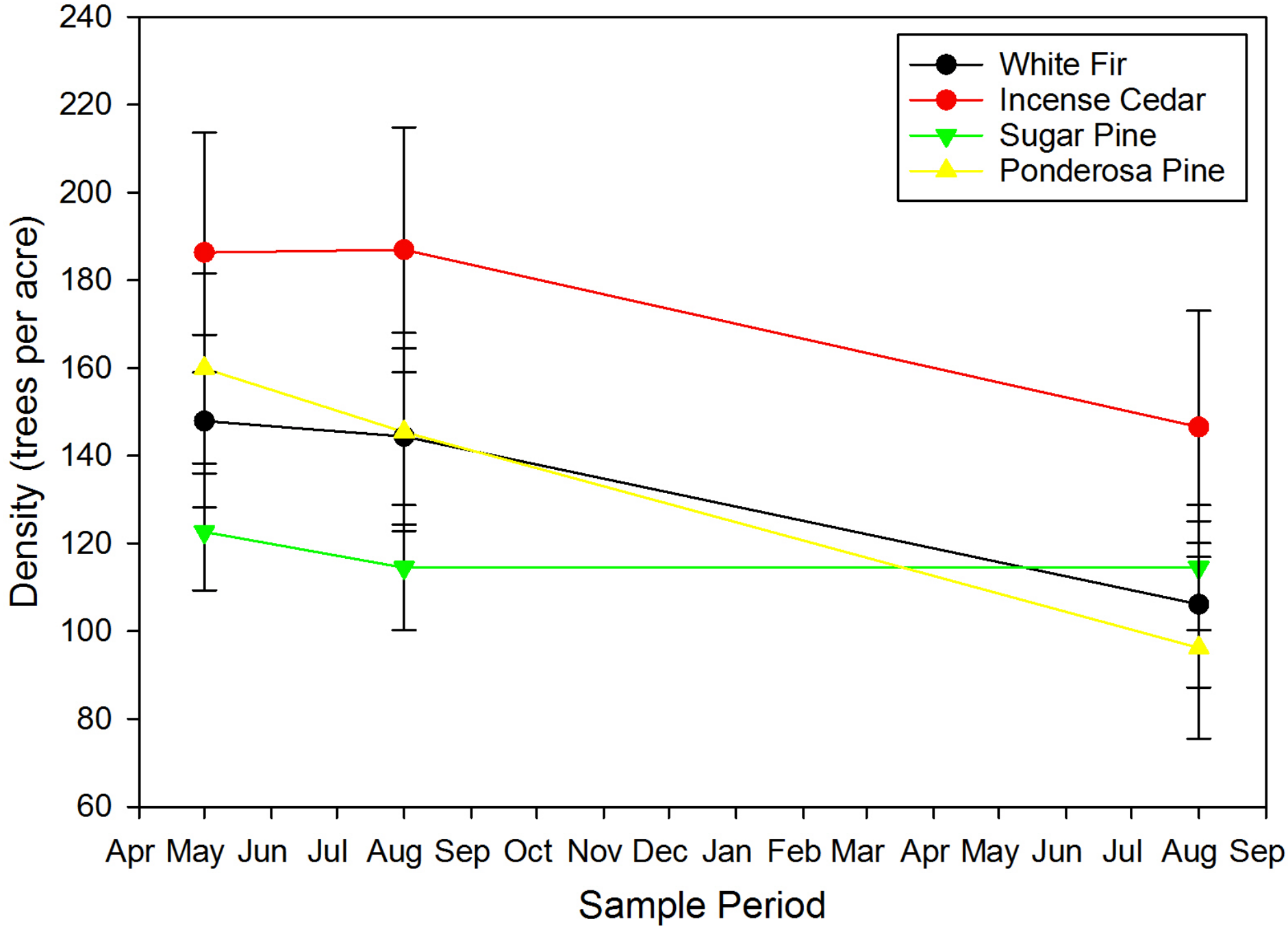
- Reforestation efforts are necessary to create conditions for pine regeneration.

- Current conditions create opportunities to maintain black oak crowns and increase mast.

Figure:
This figure shows sapling density (trees less than 10 inches)

Note:

1. **Although there is a reduction through time in sapling density, the reduction is not different between the species**
2. **In 2016, on average, there is 115 sugar pine and 96 ponderosa pine saplings per acre**
3. **In 2016, 36% of ponderosa pine less than 10 inches have live crown ratios > 30%**



Management note

- Surviving understory trees may provide opportunities to accelerate restoration of forest structure.

- However, careful selection of understory trees with sufficient live crown (>30%) and potential for future growth will be necessary.

- Increasing growth of understory survivors is complicated by the high volume of dead overstory. In particular overstory removal greater than 15 mbf is problematic and often results in the loss understory. (Average dead volume per acre for pine dominated stands is 21 thousand board feet per acre)

Results Summary

- Ponderosa and sugar pine had significant mortality in 2015 and mortality continued in 2016 (< 25% survivorship).
- White fir and incense cedar mortality has occurred since the summer of 2015, with greatest mortality in trees less than 20 inches.
- 2016 mortality has resulted in the greatest mortality in the mixed-conifer forest type
- Live crown ratio (controlled through stand density) and larger tree size are strong predictors of survivorship for all species during moderate drought experience in early 2015.
- however, in extreme drought with high bark beetle populations, experienced in late 2015 and early 2016, smaller ponderosa pine maintain greater probability of survivorship.

Management Summary

- Management systems that maintain a range of size classes and create heterogeneity provide the greatest potential survivorship during moderate and extreme drought.

- Stand prescriptions that maintain low relative tree density and subsequent high live crown ratio provide for the greatest survivorship.

- Post mortality structures that retain survivors with live crown ratios above 30% provide opportunities to accelerate objectives to restore forest structure.

Management Considerations

- Bare mineral soil is necessary to achieve pine regeneration
- Removal of dead overstory trees in excess of 15 thousand board feet per acre can result in the loss of surviving understory. Follow recommendations for directional felling and identification of skid trails to enhance post harvest survivorship.
- Low pine survival creates opportunities for the rapid increase of shrubs and noxious weeds.

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