

**Regression-based Age Estimates of Yellow Pine Saplings,
Jefferson National Forest, Virginia**

A Senior Honors Thesis

The University of Tennessee- Knoxville

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August 2005

Acknowledgements

This thesis is for all of the little saplings out there. I owe more thanks to Georgina DeWeese Wight than I can put words onto paper. Not only was it her idea for me to write this paper, but she also guided me along in this endeavor. I am grateful for the opportunity to write a thesis while still an undergraduate and partake in all that comes along with it. I am glad I was put under Georgina's wing; otherwise I might have failed miserably. Also, I owe a great deal of thanks to her husband, Jason Wight, for his expertise in computer software and SAS. Dr. Henri Grissino-Mayer was instrumental in this work. He guided me through unfailingly to see that I not only become a better student, but also a better researcher and geographer. I cannot leave out all of the people whom I annoyed with many questions, and yet they all answered so graciously: Daniel Lewis, Evan Larson, Saskia van de Gevel, Justin Hart, Will Fontez, Anna Compton, and Charles Lafon. Of course, I also thank the people who made my work possible through grant funding, the US Joint Fire Science Program.

Abstract

For studies interested in determining the age structure of a forest stand, node counting is often used for trees too small to extract an increment core. However, node counting of yellow pine (e.g. Table Mountain pine (*Pinus pungens* Lamb.) and Virginia pine (*Pinus virginiana* Mill.)) saplings has yet to be proven as a reliable method for estimating age. The most common method currently used involves removing an entire cross-section from the sapling, thereby killing the tree. This method can be detrimental in areas where Table Mountain pine stands are now in decline. If node counting proves an accurate method for determining sapling age, then harvesting of saplings would no longer be necessary. This study evaluates the effectiveness of node counting on yellow pines as a means of estimating ages of pine saplings. At Griffith Knob, located in the Jefferson National Forest, Virginia, branch nodes on 130 yellow pine saplings were counted to estimate age in the field, then harvested and aged by ring counts. We found that a single node counted in the field approximates 1.2 yrs of actual age. Age can be estimated in the field using the following equation: estimated age = 0.7178 (nodes) + 7.3488. Our method of estimating ages of pine saplings suggests counting branch nodes on saplings in the field is a viable method for estimating actual age.

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Introduction

To determine the age structure of a forest stand, node counting can be used for trees too small to extract an increment core. Determining the age of saplings is important because they are an indicator of regeneration within a species and can provide information on the stability of a population over time (Williams and Johnson 1990). Previous methods for determining sapling ages involved harvesting (taking a cross-section) saplings. A reliable method to estimate age based on node counting of yellow pine (*e.g.* Table Mountain pine (*Pinus pungens* Lamb), Virginia pine (*Pinus virginiana* P. Mill), and Pitch pine (*Pinus rigida* Mill.)) saplings will reduce the need for destructive sampling of yellow pine saplings.

Previous studies of age structure on Table Mountain pine in southwestern Virginia revealed a bimodal age distribution with a major peak in mature trees and smaller peaks within the seedlings (Williams and Johnson 1990). Age structures of disturbance-dependent conifers are often reflections of large scale disturbance (*i.e.* fire, logging, *etc.*) (*e.g.* Ross *et al.*, 1982; Christiansen and Peet, 1984; Clark, 1986) that are bimodal or polymodal (Williams and Johnson, 1990). Shade intolerant and disturbance-dependent trees generally depict the type of age distribution that displays a convex or bell-shaped distribution, representative of a declining population with low recruitment (Williams and Johnson, 1990; *e.g.*, Auclair and Cottam, 1971; Harcombe and Marks, 1978). However, Table Mountain pine reflects the former, bimodal distribution due to reflecting pulses of recruitment (Williams and Johnson, 1990; *e.g.*, Ross *et al.*, 1982; Christenson and Peet, 1984; Clark, 1986). Gaps within age distribution models indicate that either populations of Table Mountain pine are not regenerating or recruitment is

sporadic (Williams and Johnson, 1990). Similar observations of gaps in the establishment of yellow pines have been observed in other forests in North Dakota and southeast Texas (Johnson *et al.*, 1976; Harcombe and Marks, 1978; Williams and Johnson, 1990).

Poor recruitment of shade-intolerant species, such as yellow pines, is caused by shade tolerant competitors overtaking the forest overstory, understory, and shrub layers or a forest's canopy (Harcombe and Marks, 1978; Williams and Johnson, 1990). Besides competition, low seedling survival rates may also be attributed to summer drought, inadequate seed rain, seed predation, and poor seedbed conditions (Eyre, 1938; McQuilken, 1940; Bramble and Goddard, 1942; Chrosciewicz, 1974; Williams and Johnson, 1990).

Yellow pines, named so for their yellowish bark and pollen (Fralish and Franklin, 2002), are an important component of the mixed oak-pine forest common on dry and rocky terrain in the highlands of the southeastern US. Table Mountain and Virginia pine serve as facilitators for post-fire recovery and erosion control on extreme sites and also increase landscape diversity in Appalachian forests (Williams, 1998). Many southern Appalachian wildlife species depend upon pioneer and mid-seral pine-oak forests for habitat or food (Sutherland *et al.*, 1995), such as the northern pine snake (*Pituophis melanoleucus* Burch), the slender glass lizard (*Ophisaurus attenuatus*) (Sutherland *et al.*, 1995), turkey (*Meleagris gallopavo*), deer (*Odocoileus virginianus* Boddaert), grouse (*Bonasa umbellus* Linnaeus), and the scarlet tanager (*Piranga olivacea* Gmelin).

Relationship with disturbance

Table Mountain pine cones are serotinous, remaining closed at maturity and opening when the required amount of heat dissolve the resins that tightly bind the cone scales (McIntyre, 1929; Zobel, 1969; Barden, 1979; Williams, 1998). Once the cones open, the seeds are dispersed. Cones can open during periods of high temperatures, but establishment is hindered due to competition from hardwood and poor seedbed conditions (Sutherland *et al.*, 1995). Pines retain their low branches (or ladder fuel) as a mechanism to generate a low intensity fire into a hot crown fire (Fralish and Franklin, 2002). Moreover, fire-adapted communities where fire has been excluded are more likely to experience future fires that are catastrophic and highly destructive (Mutch, 1970; Sutherland *et al.*, 1995).

Both human-initiated and lightning fires have historically maintained xeric species, such as Table Mountain pine, endemic to Appalachia (Sutherland *et al.*, 1995). Periods of increased disturbance, both anthropogenic and natural, have allowed for the expansion of yellow pine populations into more mesic areas (Harmon, 1982). Since fire suppression began in the 1930s, yellow pine dominance on xeric sites has declined (Sarvis, 1993 a, b; Williams, 1998).

Researchers studying the effects of fire suppression in Appalachian forests believe that yellow pine species are not regenerating as they have in the past (Sutherland *et al.*, 1995; Waldrop *et al.*, 2002). Ridgetop pine communities are entering later seral stages and ultimately disappearing due to decades of fire suppression (Outcalt, 2002). Competition with shade-tolerant hardwoods due to fire exclusion, combined with low

seed rain and poor seedbed conditions, restricts the ability of Table Mountain pine to persist in some locations (Williams and Johnson, 1990; Zobel, 1969; Williams, 1989).

Medium-high to high intensity fires eliminate an adequate amount of the overstory which provides optimal establishment conditions for seedlings (Outcalt, 2002). Multiple lower intensity fires contribute by reducing duff and preserving mineral soil (Outcalt, 2002). Duff depth can be as high as 15–20 cm when fires are intermittent, with depth enhanced by the slow decomposition rates common in southern Appalachian forests (Robichaud and Waldrop, 1994; Sutherland *et al.*, 1995). Seedlings only successfully establish in areas with a thin duff layer (<4 cm) (Williams and Johnson, 1992). Prior to a fire, these areas are also more open than the surrounding areas (Williams and Johnson, 1992) due to the inability of seedling roots to reach mineral soil through the heavy duff layer (Robichaud and Waldrop, 1994; Sutherland *et al.*, 1995).

Ice storms are a main contributor in clearing areas of duff at these open sites (Robichaud and Waldrop, 1994; Sutherland *et al.*, 1995). Damage from an ice storm is usually localized, and depends on factors that include topography and microclimate (Boerner *et al.*, 1988; Williams and Johnson, 1990). However, ice storms cannot be relied on as an adequate source for maintaining pine stands, as they contribute only to the creation of canopy gaps (Williams, 1998; Sutherland *et al.*, 1995). The death of a single canopy tree is more frequent in a yellow pine community than the removal of an entire canopy by an ice storm (Boerner *et al.*, 1988; Williams and Johnson, 1990). Needles may suffer from extensive ice damage, but are able to repair in the spring with resistance to future ice storms (Fralish and Franklin, 2002). The thick curtain layer on the epidermis also protects needles from winter desiccation from the blowing wind and ice crystals.

Because pines are more susceptible than oaks to glaze-induced stem breakage and mortality, ice storms can also increase succession by converting pine to oaks (Whitney and Johnson, 1984; Williams, 1998).

Conifers can endure in low temperatures due to the protection of overwintering buds and living xylem (Fralish and Franklin, 2002). Tracheids within the stem resist the formation of air bubbles, or cavitation. Cavitation causes the liquid column to break and then a large amount pressure is needed to pull up water (Fralish and Franklin, 2002).

Maintenance of Table Mountain pine is questionable under the current disturbance regime due to the aggressive regeneration of gap exploiting woody species, such as oaks (*Quercus* Spp.), black gum (*Nyssa sylvatica* Marsh), and sassafras (*Sassafras albidum* Nutt.) (Williams and Johnson, 1990), coupled with fire repression. Older populations of Table Mountain pine are likely the result of seed trees that survived heavy logging and fires at the turn of the century (Williams and Johnson, 1990). Seed trees can regenerate populations via the seed tree regeneration hypothesis (Feret, 1974), which is supported by the significant differences in isozyme frequencies and morphological characteristics among Table Mountain pine populations. This is probably due to the founder effect from a small amount of seed trees (Williams and Johnson, 1990).

Fire, extended droughts, and assault by the southern pine beetle (*Dendroctonus frontalis* Zimmerman) form a triad of a cycle that further drives the successional dynamics of yellow pine forests (Barden and Woods, 1976; Kuykendall, 1978; White, 1987; Smith, 1991; Williams, 1998). Forest stands may become more susceptible to fires and increased fire intensity due to drought and southern pine beetle outbreaks (Williams,

1998). Conditions for the spread and development of high-intensity fires are increased by periods of low humidity with tinder dry fuel and occasional summer droughts (Barden and Woods, 1976; Williams, 1998).

Southern pine beetle attacks may become facilitated by drought (Mattson and Haak, 1987; Williams, 1998), when forests are more vulnerable to adult southern pine beetles seeking to feed on phloem. Widespread mortality due to the beetle increases horizontal and vertical fuels in yellow pine forests (Nicholas and White, 1984; Williams, 1998). This increases the possibility for high-intensity fires under the right conditions for fuel moisture and proper ignition (Williams (1998). Pine stands do not regenerate from beetle attacks due to the lack of exposed mineral soil, which would have been provided by fire (SAMAB, 1996; Gray, 2001). The holes created by the southern pine beetle permit the blue-stain fungus (*Ceratocystis minor*) to enter pine trees (Williams, 1998), which blocks xylem vessels, leading to eventually failure of the internal water transport. The closing of water transport, combined with vascular tissue damage, leads to tree mortality.

Other forest processes that cause decline

Pathogens such as the gypsy moth (*Lymantria dispar* L.) pose a threat to some yellow pines by affecting regeneration and maintenance of some yellow pines (most notably Table Mountain pine and pitch pine) in the southern and central Appalachians. Pines are defoliated by instars of the moth, even though the gypsy moth larvae prefer to feed on leaves of oaks and other hardwoods (Rossiter, 1987; Williams, 1998). The effects of the gypsy moth could potentially be similar to those caused by the southern

pine beetle, resulting in a shifting dominance towards hardwoods that are more durable to defoliation. However, this is less likely because the gypsy moth larvae prefer oaks and other hardwoods than feeding on foliage, their mortality could offset loss of pines (especially when other stressors are already applied, such as years of drought) (Rossiter, 1987; Williams, 1998).

The Table Mountain pine cone worm (*Dioryctria yatesi* Mutuura & Munroe), a cone-boring insect (USDA, 1990; Gray, 2001), is another harmful agent attributing to the demise of Table Mountain pines. Other agents include *Phaeulus schweinitzii* (causes butt and root rot) and *Phellinus pini* (causes heart rot) (USDA, 1990; Gray, 2001).

Air pollution is also a stressor on forests in southern Appalachia (Bormann, 1990; Williams, 1998). Laboratory tests have given some insight for effects on Pitch pine (Scherzer and McClenahan, 1989), a species shown to be susceptible to damage by ozone and sulfur dioxide. Furthermore, northeastern states have observed an elevated mortality and growth decline in this species (Whiton, 1987; McClenahan and McCarthy, 1990; Bormann, 1990; Williams, 1998). Future declines in yellow pine forest stands could be due to the stress of air pollution, either alone or in combination with other stress factors, such as drought or invasive species (Bormann, 1990; Williams, 1998).

Trends in pine forest regeneration

Past and present anthropogenic and natural disturbances that effect the distribution and growth of yellow pines in southern Appalachia can be conceptualized in a three phase model based on changes in land use and forest management (Williams, 1998). In Phase I, the pre-settlement phase, pine forests are constrained to xeric sites and

rock outcrops, (Whittaker, 1956; Williams, 1998). Extended drought fuels high-intensity fires that helps spread pines throughout the landscape. Abundance in pines is centered on an equilibrium based on the availability of xeric pine regeneration foci (Williams, 1998). Fires caused by lightning shaped the vegetation of the southeast for thousands of years before human settlement (Komarek, 1974; Buckner and Turrill, 1999). However, lightning strikes only resulted in low intensity, irregular burns, generally limited in location to ridge-tops and small areas (SAMAB, 1996). The extent and influence of Native American burning is unknown, but their fires would have influenced the abundance of pines prior to European settlement (Guffey, 1977; Chapman *et al.*, 1982; Harmon, 1982; De Vivo, 1991; Williams, 1998).

Phase II involves European settlement, especially in the later 19th century and early 20th century, when pine forests reached the expansion stage and increased in abundance. This expansion occurred because of widespread clearing and burning that enabled yellow pine forests to spread from the xeric, regeneration foci sites into more mesic areas (Williams, 1998). The early settlers burned the forests of southern Appalachia to clear the land and improve blueberry production (Otto, 1989; Sarvis, 1993a; Williams, 1998). The extent of this burning is largely unknown and the intensities of these fires were generally low, surface fires (Ayles and Ashe, 1905; Harmon, 1982; Harmon *et al.*, 1983; Williams, 1990). The impact on abundance and distribution of pines these early settlers had on southern Appalachia is probably little considering the low value of timber, the inaccessibility of most pine forest stands, and the apparent prevalence of low intensity fires (Williams, 1998). However, increasing population pressures eventually spread from the localized, human impacts in the valleys to

cultivation, grazing, and forest harvesting on steep hillsides and other marginal lands (Otto, 1989; Sarvis, 1993a; Williams, 1998).

Logging also played a significant role in the southern Appalachian Mountain landscape, although pines were of secondary importance commercially (Ayres and Ashe, 1905; Frothingham, 1931; Williams, 1992; Williams, 1998). The era of heavy, industrial logging occurred between the 1890s to the 1920s in southern Appalachia (Sarvis, 1993a; Williams, 1998). Sargent (1884) noted in 1880 that the forest cover of southwestern Virginia was extensive, yet located on inaccessible ridges (Williams and Johnson, 1990). By the turn of the century, Wilson (1902) described a landscape scarred by the logging industry.

Fuel for wide-spread, intense fires was provided by abundant logging slash (Ayres and Ashe, 1905; Frothingham, 1931; Williams, 1998) and railroads. These intense fires, of anthropogenic origins, aided in the spread of yellow pine forests. Many current Ridge and Valley forests established during this time of heavy cutting and frequent fires before the 1930s (Ross *et al.*, 1982; Williams and Johnson, 1990).

The final phase (Phase III) is the decline phase, in which the acreage of pine (*i.e.* Table Mountain-pitch pine forests) dwindled during the mid-20th century (White, 1987; Williams, 1991; Williams, 1998). During this era, pine stands became reproductively stagnant because of changes in land use and fire suppression (White, 1987; Williams, 1991; Williams, 1998). Following a timber boom in the southern Appalachians, federal and state agencies organized a massive fire suppression program beginning in the 1930s (Sarvis, 1993a, 1993b; Williams, 1998). One of the goals of this program was to

regenerate desirable species in the previously plundered forests that had been logged to exhaustion.

Fires were seen as a setback and thus eliminated from the formula with all accidental fires (natural and anthropogenic) being suppressed. For example, Table Mountain pine and other yellow pines burned in the Great Smoky Mountains and the Ridge and Valley Province of Virginia on average once every 10 to 12 years from the mid- 1800s to about 1940 (Harmon, 1982; Sutherland *et al.*, 1995). Sometime during the 1940s, the highly successful fire suppression program eradicated fire from Appalachian yellow pine stands. The result of this program in southern Appalachia was a near absence of yellow pine regeneration, which increased the stand dominance of hardwoods and other shade tolerant species (Harmon, 1982; Williams and Johnson, 1990; Sutherland *et al.*, 1995; Williams, 1998). This caused a shift in forest stand dominance from pines to oaks (particularly chestnut oak (*Quercus prinus* Lamb.) and hickories (*Carya* spp.)), while yellow pines withdrew to isolated xeric sites. This natural and anthropogenic disturbance has led to various magnitudes of a wave-like pattern of expansion and retreat in the general trend of pine abundance (Williams, 1998).

Curiously, little research has been conducted on yellow pine successional trends in stands until recently. The stimulus for the present scientific research of pine forests in southern Appalachia focuses on the decline in abundance of these forests (Harmon, 1982; White, 1987; Williams, 1991; Williams, 1998). Because harvesting saplings only further jeopardizes the ability of pine to regenerate within an area, our research was conducted in three small, 50x20 m plots to minimize the potential impact on yellow pine in the Jefferson National Forest of southwestern Virginia.

Research objectives

The objective of my research was to analytically evaluate the estimated age of pine saplings and to develop models to estimate sapling age from field-derived node counts. If there is a correlation between field-based node counts and laboratory-based ring counts, then the linear relationship can be used to develop an equation to determine the ages of saplings in the field rather than having to harvest them for ring counting. Additionally, this research should demonstrate the need for more extensive disturbance-induced procedures for maintaining yellow pine in southeastern Appalachia. This research can also be used to test results from Williams and Johnson's (1990) study of the age distribution of Table Mountain pine saplings/seedlings within a pine-oak forest on Brush Mountain, Virginia.

Biogeography of Forests in Southern Appalachia

A unique collection of southern, northern, and endemic plant species collectively make up the composition of southern Appalachian pine forests (Williams, 1998). There are four geographically-unique species of pine that co-exist (Little, 1970; Williams, 1998): white pine (*Pinus strobus* L.), Virginia pine, pitch pine, and Table Mountain pine. All are classified as pioneer species because they only establish after disturbances (USDA Forest Service, 1965; Buckner and Turrill, 1999). Pine-dominated forests form a patchy composition on the southern Appalachian landscape because they are restricted by soils, topographic locations, and other features (Whittaker, 1956; Racine, 1966; Zobel, 1969; Williams, 1998). They often occur on steep ridges as physiognomically diverse patches within a matrix of hardwoods (White, 1987; Williams and Johnson, 1990).

Understory composition depends mostly on fire frequency and intensity (Williams, 1998). Small tree and shrub strata are often well developed in areas that have not been disturbed for long intervals (Williams and Johnson, 1990; Groeschl *et al.*, 1992; Williams, 1998). For example, Williams and Johnson (1990) found 16 species of small trees (stems ≥ 2.5 cm dbh, < 10 cm dbh) within a Table Mountain pine and Pitch pine community in southwestern Virginia (Williams, 1998). Black gum, chestnut oak, scarlet oak (*Quercus coccinea* Menchh), American chestnut (*Castanea dentate* Marsh), and sassafras made up the majority of the understory, while pines were notably absent. Their study site had been free of fire for over 60 years (Sutherland *et al.*, 1995; Williams, 1998).

At least ten species of shrubs inhabit Table Mountain pine and other yellow pine forests, and can form a continuous shrub layer. They include four ericaceous species: mountain laurel (*Kalmia latifolia* Lamb.), blueberry (*Vaccinium pallidum* Ait.), huckleberry (*Gaylussaccia baccata* Wengen.), and bear huckleberry (*Gaylussaccia ursine* Curtis.). Well-developed ericaceous shrub layers combined with a sparsely canopied yellow pine communities form pine heaths (Cain, 1931; Whittaker, 1956, 1979; Williams, 1998). High elevation pine heaths can cover 60%–90% of yellow pine forest understory, while shrub cover in successional stands ranges from 30%–40% (Whittaker, 1956; Williams and Johnson, 1990; Williams, 1998).

The ground stratum in yellow pine communities is often sparse and poorly developed, covering only 5%–20% of the ground (Whittaker, 1956; Williams, 1998). Species that make up the ground stratum include: mayflower (*Epigaea repens* L.), galax (*Galax aphylla* non L.), teaberry (*Gaultheria procumbens* L.), spotted evergreen

(*Chimaphila maculate* L.), and bracken fern (*Pteridium aquilinum* Kuhn.). Many species in the ground strata and shrub layer are evergreen, an adaptation to nutrient poor, dry soils that aids in increasing nutrient-use efficiency (Monk, 1966; Williams, 1998).

Yellow pines

Appalachian Mountain peaks and ridges have an elevational replacement of species with Table Mountain pine at the highest sites (760–1400+ m above sea level (ASL)), pitch pine at intermediary sites (700–980 m ASL), and Virginia pine at the lowest elevations (15–760 m ASL) (Whittaker, 1956; Zobel, 1969). Yellow pines are prevalent on the upper slopes on southwest aspects (Buckner and Turrill, 1999), which are drier and have a higher transpiration rate. Xeric sites facilitate fires that burn more frequently and with higher intensity if permitted by the fuel load.

When fire is integrated on a regular basis (pre-fire suppression era), the forest structure would consist of pure hardwoods on the foot slopes, then transitioning into mixed pine-hardwoods on mid-slopes, and into pure yellow pine stands on the upper slopes (Buckner and Turrill, 1999). Most of southern Appalachia seral stages can be maintained by this gradation of communities, which maximizes biodiversity and landscape heterogeneity. However, two vegetative types can occur on southwest-facing slopes when variations in fire frequency occur (Bucker and Turrill, 1999). The first variation happens when intense fires occur at long decadal intervals. Under this variation, yellow pine stands can be maintained, transitioning downslope into pine-hardwood communities which are more mesic than their counterparts farther downslope (Bucker and Turrill, 1999). The second variation occurs when fires burn more

frequently, but at less intensity due to the declining fuel load. The community is stabilized by the fires and open, grassy stands develop. This would result, if continued for long periods, into open, grassy balds (Bucker and Turrill, 1999).

Table Mountain pine and Virginia pine of the eastern United States are shade intolerant and thrive on mildly acidic, thin soils with pH levels of 6.1 to 6.5 (Virginia Tech, 2005 Forestry Dept.). The evergreenness of conifers stores nutrients, which is an effective adaptation to endure a low soil nutrient regime (Fralish and Franklin, 2002). The cuticle layer in the needles acts as barrier for water loss so that yellow pines can thrive in areas of droughty sites. Areas with degraded or eroded soil or high evaporation rates (*i.e.* where there is openness or windiness) are ideal for regeneration because of the retention of nutrients and low transportation rate (Fralish and Franklin, 2002).

Like other conifers, yellow pines have low rates of carbon gain per unit of leaf area, however they exhibit a greater leaf area index (Richardson, 2000). Conifer wood is soft and lower in strength than hardwoods due to cell structure (Fralish and Franklin, 2002). Tracheids, which are long cells, comprise most the composition of gymnosperm wood (xylem). Throughout the xylem, resin canals are interspersed because of spaces created after the maturity of the stem (Kramer and Kozlowski, 1979; Fralish and Franklin, 2002). Lack of shade reduces seed germination and seed survival, as does heavy shading (Outcalt, 2002). Thirty percent shading has the highest success rate for seedling establishment, however 30% may be insufficient without the mulching effect of duff in order to avoid moisture deficit (Outcalt, 2002).

Although many species of yellow pine exist, this research concentrates only on Table Mountain pine, Virginia pine, and pitch pine which dominate our study area. Note:

Pitch pine is within the study area, but not within the microplots. Saplings from site A are all Table Mountain pine, while sites C and D have a few Virginia pine. Both of these yellow pines exhibit bimodal or polymodal age distributions and sizes due to recruitment pulses within the forest stand lifespan (Whittaker, 1956; Barden, 1977, 1988; Ross *et al.*, 1982; Williams and Johnson, 1990; Williams, 1998). The future of the abundance and distribution of these forests depend upon active management and restoration, the presence of invasive species, and the force of forest decline contributors (Williams, 1998).

Table Mountain pine is associated with the *Pinus* subsection *Australes* (the southern pines) (North Carolina State University, 2005). It is also referred to as hickory pine, poverty pine, mountain pine, or prickly pine (Sutherland *et al.*, 1995). Leaves occur in bundles of two per fascicle, which are twisted and 3 to 6 cm in length (Fralish and Franklin, 2002).

Table Mountain pine can be identified by their ovoid cones, which are three inches long and dark reddish-brown (Virginia Tech, 2005). Cones are mostly serotinous throughout much of the species' range (McIntyre, 1929; Zobel, 1969; Barden, 1979; Sutherland *et al.*, 1995). These heavy, stalkless cones are supported by an irregular crown on this small to medium sized tree (>10 cm dbh) (NCSU, 2005), with a height of 13 m (Fralish and Franklin, 2002). Cones appear in clusters of three to four. Table Mountain pine cones are sessile and persistent, and mature in the fall (Virginia Tech, 2005). Even though the cones open partially at maturity, they can remain attached for many years (North Carolina State University, 2005). Male cones mature and release pollen in late April to early May. Female cones mature and partly open in autumn of the second season, steadily releasing seeds.

Many cones may open soon after maturing on southerly and easterly exposures, but only at certain temperatures. However, in closed stands on western and northern exposures, cones are only serotinous. Closed cones can remain on a tree for 5–25 years, while the seeds remain viable for 9 or more years. Cones can remain closed for up to 25 years, but their seed viability declines after five years (Barden 1979; Williams, 1998). A study by Gray (2001) noted that cones over 10 years of age, collected in the winter, have the highest number of seeds. More importantly, those seeds were considered to be the most viable (Gray, 2001). Trees 10 years old or younger had seeds that were less viable, even though these trees had numerous seeds.

The seeds are dull black to gray in color, 6 mm long, with a wing of 19–25 mm long (NCSU, 2005). Compared to other *Pinus* species, Table Mountain pine seeds are medium to heavy in weight, and are thus not adapted to wind dispersal (McIntyre, 1929; Zobel, 1969; Barden, 1979; Sutherland *et al.*, 1995). The seeds have adapted to regenerate *in situ* and to dry conditions. Site disturbance, light, and heat are needed for Table Mountain pine seed regeneration (Della-Bianca, 1990; NCSU, 2005).

Unfortunately, Table Mountain pine has the lowest thermal threshold (ca. 30°C) required to open its cones than any other serotinous conifer (McIntyre, 1929; Williams, 1998). Therefore, seed fall can occur at any point in time throughout the year in the absence of fire during warm temperatures (Williams and Johnson, 1992; Williams, 1998). They are fire-dependent, requiring fires that occur at frequent intervals for optimal regeneration and maintenance (Williams, 1998). Moreover, Table Mountain pine may be nonsuccessional and self-maintaining on extreme sites that have exposed ridgetops,

granite domes, and rock outcrops, even with the lack of exogenous disturbances (Zobel, 1969; Barden, 1977, 1978; Williams, 1998).

Certain yellow pines (*i.e.* Pitch pine) have also adapted to reproduce vegetatively from basal sprouts after a fire (Zobel, 1969; Sutherland *et al.*, 1995). The vascular tissue of Table Mountain pine is insulated by its thick bark from low intensity surface fires (Ledig and Little, 1979; Harmon, 1984; Williams, 1998). The species has adapted to frequent ground fires by establishing a deep rooting habit, pitch production to seal off wounds, and self-pruning limbs (Zobel, 1969; Sutherland *et al.*, 1995).

Summer drought plays a significant role in seedling and sapling mortality (Ledig and Little, 1979; Williams and Johnson, 1992; Williams, 1998), while older, well-established trees have a higher tolerance for drought (McIntyre and Schnur, 1936; Barden, 1988; Williams, 1989, Williams, 1998). Drought tolerance is a major factor in the species' adaptation to open, xeric sites (Williams, 1998). During certain years, low recruitment can be attributed to drought. Barden (1988) noted low recruitment on a granite dome in North Carolina that was associated with rain-free intervals greater than two weeks in length during the growing season (Williams, 1998).

Table Mountain pine trees can live up to 200 years in the absence of stand-replacing disturbances (Zobel, 1969). Forests dominated by this pine usually occur on xeric ridgetops and southwest-facing slopes (Williams, 1998). Populations fare better on exposed ridgetops, which usually have sparse pine canopies (Barden, 1977, 1988; Williams and Johnson, 1990). Stands on mid-elevational slopes and ridges have a basal area ranging from 20 to 30 m² ha⁻¹ (Harmon, 1984; Williams and Johnson, 1990;

Groeschl *et al.*, 1992; Williams, 1998). Granitic domes or rock outcrops have significantly less basal area (Barden, 1977; Abrams and Orwig, 1995; Williams, 1998).

Table Mountain pine occurs solely in the Appalachian Mountains, ranging from southern Pennsylvania to northeast Georgia and east Tennessee (NCSU, 2005). Scattered patches of forests, however, do exist on the eastern fringe of the Appalachian Plateau Province and on the monadnocks and river bluffs of the western Piedmont Province (Zobel, 1969; Seischab and Bernard, 1991; Williams, 1998). Unlike other species of yellow pine, such as pitch pine, Table Mountain pine is absent in the northern portions of the Ridge and Valley Province (*i.e.* the Shawangunk Mountains of southeastern New York and the Kittatiny Mountains of northwestern New Jersey) (Zobel, 1969). The Southern Appalachian Assessment recognizes Table Mountain pine as one of 31 rare communities due to a shifting of species dominance by oaks and hickories (SAMAB, 1996). Southern Appalachia's Table Mountain pine abundance and distribution trends have been one of expansion followed by retreat, initiated by natural and anthropogenic disturbances (Williams, 1998).

Virginia pine is associated with the *Pinus* subsection *Contortae*, the fire pines (NCSU, 2005). The species prefers low elevation mountain slopes, plateaus, and ridges on the western fringe of the southeastern and mid-Atlantic Coastal Plain and Piedmont Provinces (Society of American Foresters, 1926; Frothingham, 1931; Whittaker, 1956; Fowells, 1965; Clebsch, 1989, Williams, 1998). Cones are 3.8 to 6.3 cm long, conical in shape, and red-brown scales (Virginia Tech, 2005). They are sessile and persistent, maturing from September to November. The winter months act as a dispersal time, unless the cones stay closed, which can occur for months or years (USDA Forest Service,

1980). Leaves are twisted and 3 to 7 cm in length, occurring two per fascicle (Fralish and Franklin, 2002). These small (15-23 m) to medium (> 36.5 m) sized trees develop flat tops with their meager shape (USDA Forest Service, 1980). Height can reach 20 m (Fralish and Franklin, 2002). Flowers and seeds may form from 5–50 years of age, depending on stand density as trees grow older (USDA Forest Service, 1980).

Also referred to as scrub pine (Richardson, 2000), Virginia pine is the most abundant conifer of all the minor species of southern pines (USDA Forest Service, 1980). The species is capable of growing well on impoverished or disturbed sites (Virginia Tech, 2005). This pine can survive long, dry spells better than other pines, but growth is slow during these periods (USDA Forest Service, 1980). The preferred growing areas are on clay or sandy loams that are fair to well drained, at elevations of 30-7620 m (USDA Forest Service, 1980). Unlike Table Mountain pine, it can regenerate after logging or clear cutting, and they do not require fire to open up their cones (USDA Forest Service, 1980). Virginia pine thrives best in humid ranges that receive 890–1400 mm of annual precipitation (Carter and Snow, 1990).

Seedlings are shade intolerant and under a full crown cover, can die within a year from only receiving partial shade (USDA Forest Service, 1980). Older pines of 50 years or more can fall victim to heart rot, as many stands already have (USDA Forest Service, 1980). This can prove detrimental to wildlife (*e.g.* bobwhites (*Colinus virginianus*), mice (*Muridae*), rabbits (*Sylvilagus*), and deer), that feed on the stem tissue of young trees, browse on foliage, or nest within the trees (Virginia Tech, 2005).

Pitch pine is associated with the *Pinus* subsection *Australes* (the southern pines) (North Carolina State University, 2005). The twisted, stiff, yellowish-green needles are 6

to 14 cm long and occur in bundles of three per fascicle (Fralish and Franklin, 2002). Leaves frequently produce from dormant holes within the bole. Sprouts develop after the bole is killed via fire (Fralish and Franklin, 2002). It has the ability of sprouting from the base of a stump when burned or cut back when young (Virginia Department of Forestry, 2005). The monoecious male flowers are cylindrical, red to yellow, appearing in large clusters at branch tips (Virginia Tech, 2005). Female flowers are yellow to red, with small, curved scales. Cones are light brown and ovoid, 5-10 cm long (Virginia Tech, 2005). Pitch pine cones can remain persistent for many years and mature in the fall. Bark develops into thick flat plates of a reddish-brown hue (Virginia Tech, 2005). The wood is soft and brittle and is often used for lumber and fuel (Virginia Department of Forestry, 2005).

This medium size tree (30 m in height) grows at about 1,070 m elevation (Virginia Department of Forestry, 2005). Pitch pines grow in xeric sites, with sandy to loamy soils (Fralish and Franklin, 2002). It is suited to develop on dry ridges and slopes, cold swamps, and at the bottom of mountains (Virginia Department of Forestry, 2005). Habitat ranges from Georgia and South Carolina to New York and Maine (Fralish and Franklin, 2002).

Methods

Site description

Griffith Knob (37°1'N, 81°13'W) is located within the Jefferson National Forest between Little Walker and Brushy Mountains in Bland County, Virginia, adjacent to Mill Creek Valley (USDA, 1997). The study site was located on the western face of Griffith

Knob. The Ridge and Valley topography is characterized by gentle rolling valleys, underlain with Cambrian and Ordovician limestone and shales, with high, narrow ridges of Silurian sandstone (Hoffman, 1969; Williams and Johnson, 1990).

Soils on these sites are thin, acidic, and nutrient poor Typic, Unbric, or Lithic Dystrochrepts that are well drained and shallow on mid- and upper- slopes (Ferret *et al.*, 1979; Schafale and Weakley, 1990; Williams and Johnson, 1992; Williams, 1998). The soils are low in nutrients, organic matter, highly permeable, and highly acidic (Ferret *et al.*, 1979; Cregar *et al.*, 1985; Williams and Johnson, 1990).

Table Mountain pine, chestnut oak, scarlet oak, red maple (*Acer rubrum* L.), black oak (*Quercus velutina* L.), and Virginia pine constitute the overstory (Table 1). The midstory is dominated by blackgum, Virginia pine, and Table Mountain pine. The understory is dominated by bear oak (*Quercus ilicifolia* Wangenh.) and mountain laurel, with a thick cover of blueberry.

The climate of southwestern Virginia is a highly seasonal region with summer months (June–August) being the wettest and warmest, and autumn months (September–November) being the driest (Sutherland *et al.*, 1995). The average annual precipitation is 900 mm, distributed evenly throughout the year (Ruffner and Blair, 1987; Williams and Johnson, 1990). The average annual temperature is 12°C.

Field Methods

A 50 x 20 m plot was placed on each of three adjacent ridges on Griffith Knob, Jefferson National Forest, Virginia, in May of 2004. Saplings were classified as having stems < 5 cm dbh or being over 50 cm high. Before harvesting with a handsaw, all Table

Mountain and Virginia pine saplings were aged by counting their branch nodes. All pine saplings in the microplot were then cut as close to ground level as possible to ensure the maximum number of rings was obtained. All saplings were labeled according to site name, plot identification, and sapling number (*e.g.* GKA 501).

Nodes are where the tree-stem and branches connect, or where long shoots or branch whorls are attached to the stem (Kozlowski and Pallardy, 1997). In-between two nodes on a stem is the internodal area, which estimates growth rate (Fralish and Franklin, 2002). The expansion of internodes depends upon the availability of food and hormonal growth regulators (Kozlowski and Pallardy, 1997). Age can often be estimated on trees less than 25 years old by counting the whorls (Fralish and Franklin, 2002).

Laboratory Methods

The sections from all saplings were frozen for 48 hours in a deep freezer at -40°C to kill any insects, pathogens, and mold. The sections were cut to a thickness of 5 cm. Sanding the sections involved using progressively finer sandpaper (80, 120, 180, 240, and 320 grit) to enhance the clarity of all tree rings on the small cross sections.

Tree rings are growth layers caused by a single yearly flush of development (Fritts, 1976). I counted all tree rings in each section, beginning with the outer most ring (2004) until the pith was reached. Each century year was marked with three dots, each half century year with two dots, and each decade year with one dot (Stokes and Smiley, 1968). The year of the pith was marked on the sapling and recorded. A binocular stereozoom boom-arm microscope (7–35X continuous zoom) was used for an enhanced view of the rings to ensure accuracy in crossdating. Crossdating is the comparison of

similar tree rings within different trees, and the selection of the exact temporal placement for all tree rings (Douglass, 1947).

By comparing the node counts taken in the field with the age estimates, via the use of SAS, a linear equation was found. In addition, all 130 saplings were sorted by age in increasing values. Three age classes were assigned by using the equal interval method. Age class 1 includes ages 7–19, age class 2 includes ages 20–27, age class 3 includes ages 28–66. Then each age class was analyzed separately.

Results

Griffith Knob sites A, C, and D contained varied levels in the number of saplings and in their ring counts. For example, sites A and D are similar because they both contain between 60 and 55 saplings with the mean age estimate of 21.7 years for site A and 24.0 years for site D, while site C had only 15 saplings with a mean age of 54.7 years. The *age* and *year* of each sample denotes the number of rings minus the time of harvesting the saplings in the spring of 2004. Thus, an estimated age is acquired. The *difference* between the age and the node count is listed in positive and negative numbers (Tables 2, 3, and 4). Negative numbers represent where the node count was greater than the age estimate. The differences for site A (Appendix 1) and site D (Appendix 3) are relatively narrow, while differences for site C (Appendix 2) exhibit a broader range.

GKA has an age range of 8 to 45 years, with a mean average of 21.7 years. The age class for this microsite is widely dispersed (Figure 1), with age class 1 and 2 showing the highest levels of regeneration and signs of recent disturbance. Abundant saplings suggest a prospective mature Table Mountain pine stand in the future.

The linear relationship for site GKA (Figure 2) correlates well in showing the age estimate to node comparison ($r^2 = 0.44$). The linear equation is $y = 0.55x + 11.05$. The relationship does not become stronger or weaker at any age, but exhibits a tight clustering about the regression line, with increasing age not playing a major role.

Samples from site GKC have an age range from 38 to 66 years, with a mean of 54.7 years. Only one age class (class 3) subsists within this microplot (Figure 3), indicating a forest stand with little, but older regeneration. The GKC site does contain a higher number of oak saplings, but not of pines, which suggest a site with few, if any, recent disturbances that would help initiate pine regrowth. The GKC site displays data that show a strong linear relationship (Figure 4) of $y = 0.26x + 39.43$, $r^2 = 0.37$.

Samples from site GKD have an age range of 7 to 56 years, with a mean average of 24.0 years. Age classes are almost evenly spread out between age class 1, 2, and 3 (Figure 6), which suggests that this site is healthy with an abundant number of saplings that could result in mixed age growth of future forest stands. The age classes also indicate that disturbances have occurred regularly. The samples from GKD display linearity, with some older samples extending outward from the regression line (Figure 7). The linear equation is $y = 0.67x + 6.43$ and the r-square value for site GKD is 0.64, the highest for all sites.

Comparing the age with node counts for all three sites (Figure 8) displays a strong linear function. The r-squared is 0.76, while the calibration equation is $y = 0.7178x + 7.3488$. A formula can be applied from this equation as: *estimated age* = 0.7178 (*nodes*) + 7.3488. Notice how after 40 years the relationship becomes less distinct and more erratic.

By breaking down the data via age class rather than study site, more meaningful linear equations and correlations can be found (Figures 9, 10, and 11). Age class I has an r-square value of 0.27 and an equation of $y = 0.3342x + 9.5891$. Age class II has a very similar r-square value of 0.27 and an equation of $y = 0.1414x + 20.339$. Age class III has the highest r-square value of 0.58 and an equation of $y = 0.5481x + 17.767$.

Regression models (via use of SAS) depict age estimates and nodes as linear for all age classes. Age serves as the dependent variable and nodes as the independent variable. The overall r-square value of 0.76 shows an excellent relationship between the two variables.

Discussion

The relationship between sapling age and node count can be determined by comparing node counts taken in the field to the actual ring counts from those same saplings. By using the formula, $estimated\ age = 0.7178 (nodes) + 7.3488$, dendrochronologists and forest scientists can estimate the age of pine saplings without having to harvest them. For example, a sapling in the field is counted as having 23 nodes. The formula would be applied as :

$$estimated\ age = 0.7178 (23) + 7.3488$$

$$estimated\ age = 16.5094 + 7.3488$$

$$estimated\ age = 23.85\ years\ old$$

Thus, the estimated age for a sapling with 23 nodes is 24 years. This method strongly agrees with the linear values and r-square results for each age class. The overall r-square value for all age classes of 0.76 suggesting a high correlation with ring counts and nodes.

These results corroborate with Williams and Johnson (1990) who analyzed Table Mountain pine sapling/seedling age estimates. They also found no significant difference between harvested saplings (stems <2.5 cm dbh) aged by bud scars and that of annual rings (paired t-test, $p > 0.01$, $n = 60$).

A few limitations exist in applying my formula that must be considered. First, not all nodes can be seen in the field. Nodes can blend in with other nodes or become unobservable with tree width growth. Second, older saplings will be more inaccurate than younger ones due to the ring count and nodes having a large difference, because of self-pruning. We conclude that node counting to estimate ages of yellow pines is less reliable for trees with more than 40 nodes. Third, our research only applies to yellow pines, as this method has not been applied to other tree species in our study area. Harvesting of saplings must be carefully considered because poor regeneration may limit the number of saplings available for analysis.

Yellow pines may continue to decline relative to oaks (especially scarlet and chestnut, common climax species on dry sites) in overstory composition without the aid of fire for regeneration (Smith and Linnartz, 1980; Williams and Johnson, 1990). Because Table Mountain pine and Virginia pine are poor competitors that need open, scarified seedbeds for seedling establishment (Bramble and Goddard, 1942; Ledig and Little, 1979; Williams and Johnson, 1992; Williams, 1998), they face replacement by oaks and other shade tolerant hardwoods, and small shrubs. Fires increase the soil pH levels, which yellow pines thrive upon, because of the release of mineral bases into the soluble ash (Buckner and Turrill, 1999). Groeschl *et al.* (1991) noticed that, after low intensity burns, the total carbon and nitrogen levels increased in the upper 10 cm of

mineral soil in a yellow pine community in Shenandoah National Park, Virginia. They also noticed in burn areas an increase in mineral soil inorganic nitrogen levels, which are conducive to increased plant intake (Buckner and Turrill, 1999).

Death in young pines by desiccation can occur because moisture can be out of reach of young pine seedlings due to heavy leaf litter accumulation that forms an impervious isolating obstruction (Williams *et al.*, 1990). Yellow pine seedling and saplings typically develop poorly under the forest canopy due to suppression (Little and Somes, 1964; Williams and Johnson, 1990). Releasing saplings of suppression is often unsuccessful, plus regeneration may be limited. White (1987) noted that the greatest threat to southern Appalachian pine was the integrity and maintenance is fire suppression.

Pine seed germination and seedling establishment are the most advantageous when high intensity fires destroy competing vegetation, while consuming leaf litter and exposing mineral soil as it removes allelopathic compounds from the soil (Williams, 1998). Serotinous cones are opened in these fires. Also, site quality degrades under high intensity fires, which lowers soil fertility and moisture retention, creating sites that are more adaptable for growth of pines than for hardwoods (Groeschl *et al.*, 1993). However, Williams and Johnson (1992) suggest that post-fire duff depth did not differ with fire intensity and regeneration may not require consumption of the entire forest floor (see also Sutherland *et al.*, 1995). Another option would be to burn the logging slash, which would help facilitate regeneration from the seedfall of serotinous cones (Wilson, 1902; Frothingham, 1931; Smith and Linnartz, 1980; Williams and Johnson, 1990).

Land managers would be advised to initiate intense, small-scale burning to clear the forest floor, leaving the mineral soil exposed and eradicating hardwood competitors

(Buckner and Turrill, 1999). Yellow pines will be able to regenerate and restore their populations on a localized scale. This process might have to be repeated on a five to seven year cycle if the yellow pine stands prior to burning were depleted. A pulse-reset disturbance regime (Reiners, 1979; Williams and Johnson, 1990) that integrates fire at frequent intervals will assist in the maintenance of yellow pines. Although, in order to reestablish a landscape-scale mosaic, watershed scale burning would need to take place (Buckner and Turrill, 1999). This would create a site-dependent gradient of pines to pine-oaks to oak stands created by burning the watershed from the bottom (oak dominance) and allowing the fire to run upslope. Southern pine beetles also play an important role in accelerating the successional shift from pine to oak dominance, which are facilitated by the continued lack of suitable conditions (i.e. duff litter) to regenerate pine and the increased oak regenerating process (Kuykendall, 1978; Smith, 1991; Williams, 1998).

Because more large, vigorous trees survive after fires than small trees (Harmon, 1984), recruitment and maturity of seedlings are vital to maintain pine populations. The absence or presence of disturbances, especially fires, plays a pivotal role in pine regeneration (Zobel, 1969). That Table Mountain pine and Virginia pine can regenerate at all under the current forest conditions is phenomenal. Not only do they need fire to clear out the overstory and understory, duff, and to open their cones, but they also need plentiful light and few competitors. The future of yellow pine is yet to be determined. That is why it is vital to use the equation: $estimated\ age = 0.7178 (nodes) + 7.3488$ instead of harvesting saplings.

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Appendix

Table 1: Numbers of saplings inventoried within sites GKA, GKC, and GKD on Griffith Knob, Jefferson National Forest, Virginia. A dash indicates that no saplings were present within that microplot.

Scientific Name	Common Name	GKA	GKC	GKD
<i>Acer rubrum</i>	red maple	4	1	2
<i>Carya glabra</i>	pignut hickory	--	--	1
<i>Nyssa sylvatica</i>	black gum	5	--	--
<i>Pinus Pungens</i>	Table Mountain pine	61	15	52
<i>P. virginiana</i>	Virginia pine	--	4	7
<i>P. strobus</i>	white pine	1	14	3
<i>Quercus alba</i>	white oak	4	2	1
<i>Q. coccinea</i>	scarlet oak	40	28	25
<i>Q. rubra</i>	northern red oak	2	3	1
<i>Q. velutina</i>	black oak	3	--	2
<i>Q. prinus</i>	chestnut oak	4	--	--
<i>Robinia pseudoacacia</i>	black locust	--	2	1
<i>Tsuga canadensis</i>	eastern hemlock	--	1	2

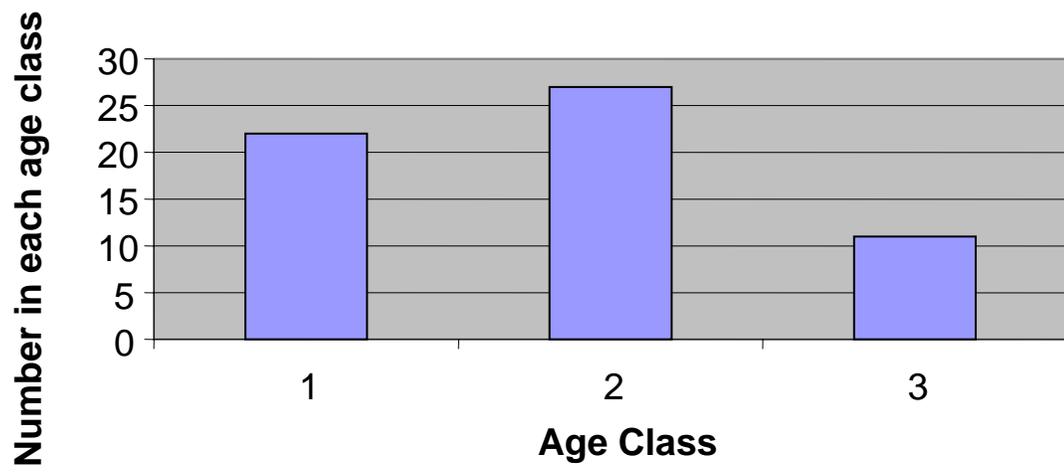


Figure 1: GKA Age Class

GKA Age and Node Comparison

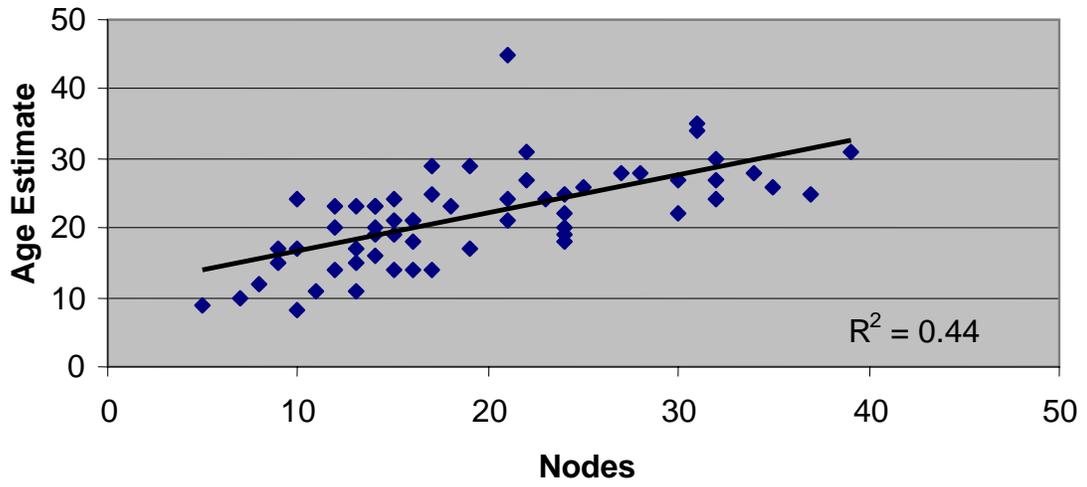


Figure 2: Comparison of estimated age and node counts, site GKA

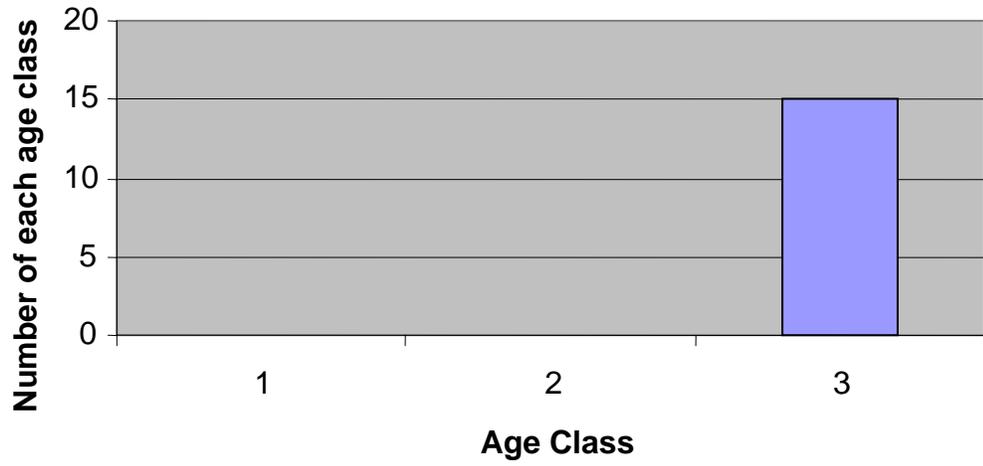


Figure 3: GKC Age Class

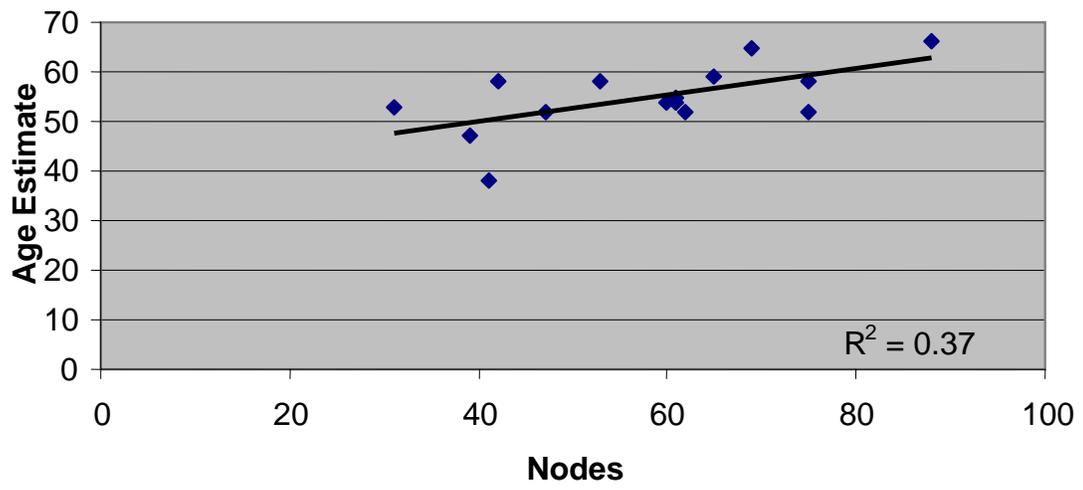


Figure 4: Comparison of estimated age and node counts, site GKC

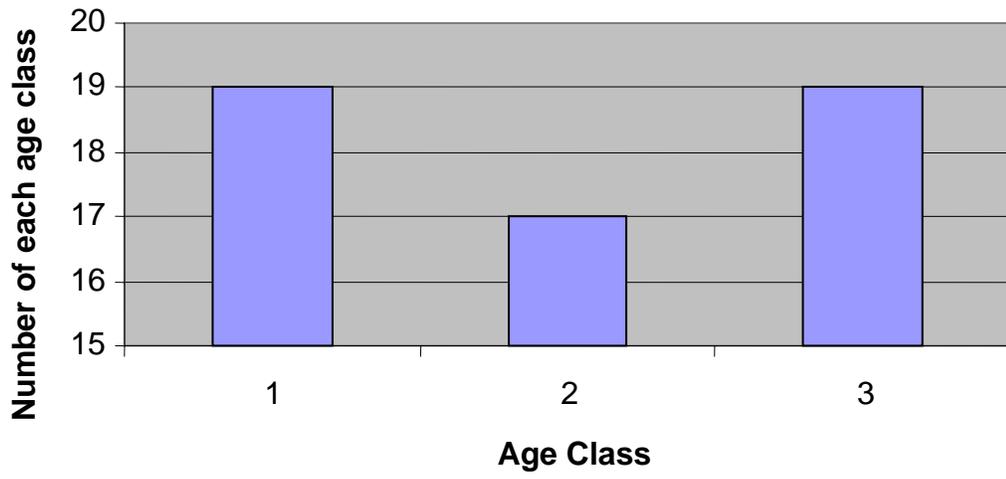


Figure 6: Age Classes for site GKD

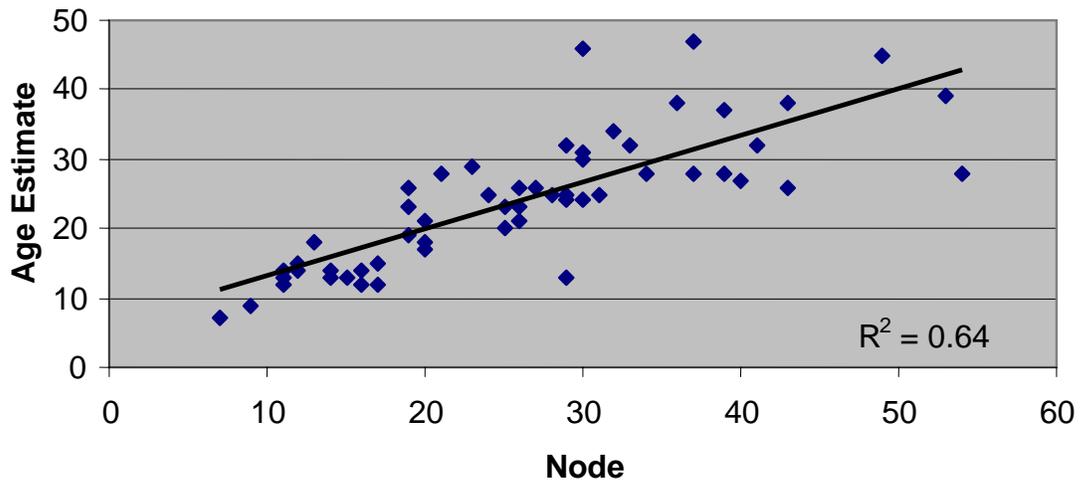


Figure 7: Comparison of established age and node counts, site GKD

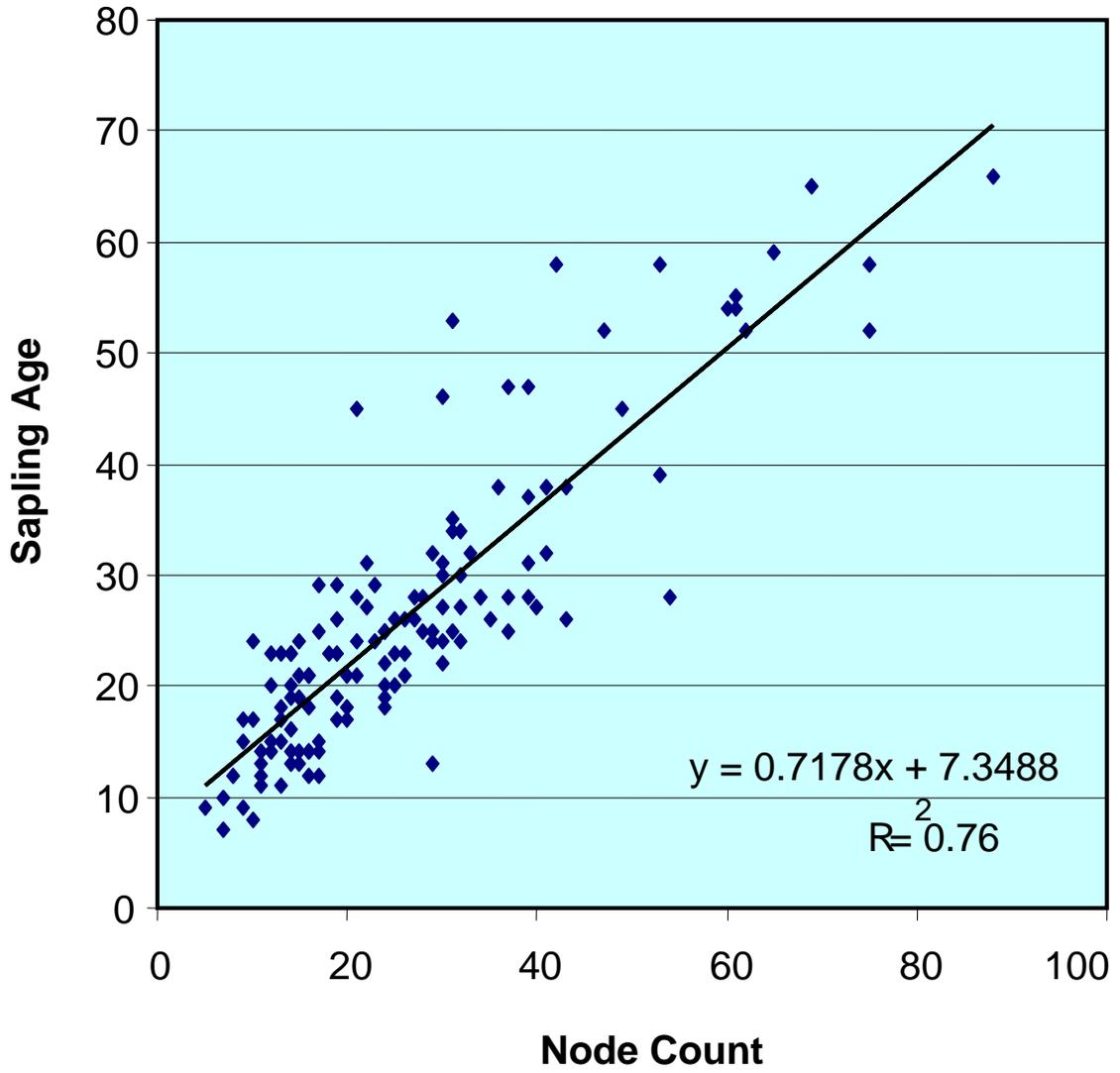


Figure 8: Age compared to nodes, all samples from three sites

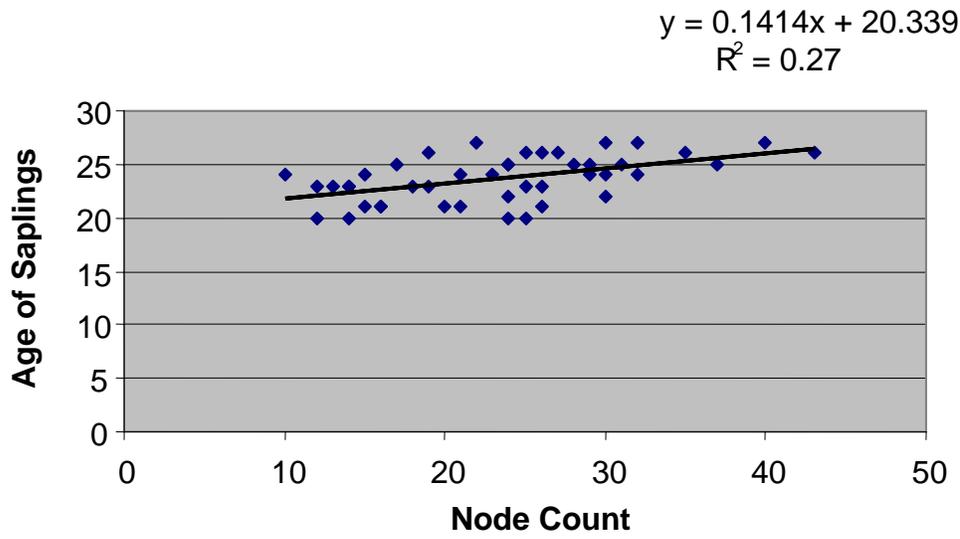


Figure 9: Age Class I, all three site

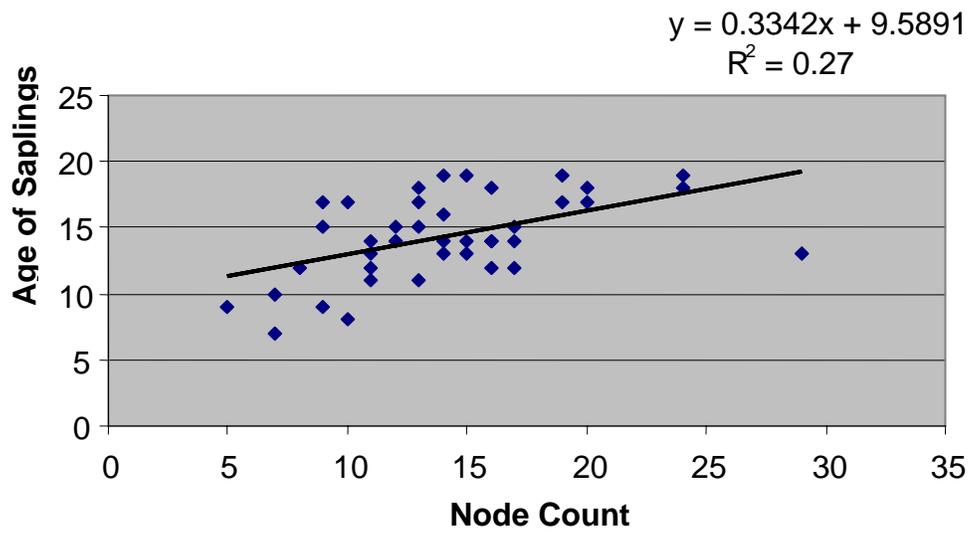


Figure 10: Age Class II, all three sites

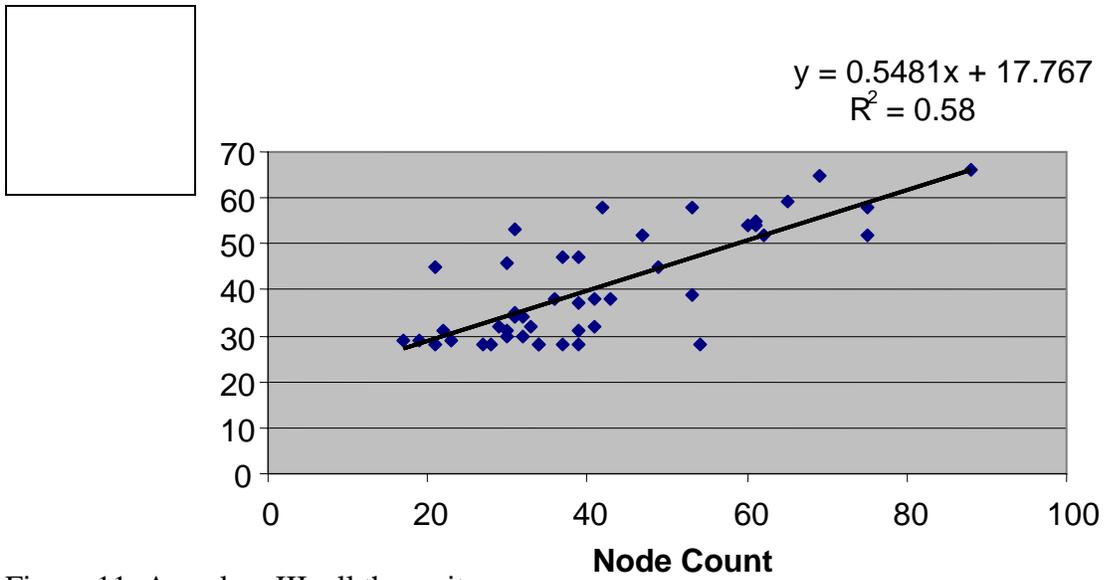


Figure 11: Age class III, all three sites

A-1: Griffith Knob site A

Site	I.D.	Year	Age	Nodes	Difference
GKA	501	1975	29	17	12
GKA	502	1973	31	39	-8
GKA	503	1981	23	14	9
GKA	504	1978	26	35	-9
GKA	505	1978	26	25	1
GKA	506	1981	23	18	-3
GKA	507	1979	25	37	-8
GKA	508	1980	24	21	3
GKA	509	1985	19	15	4
GKA	510	1995	9	5	4
GKA	511	1986	18	16	2
GKA	512	1981	23	12	11
GKA	513	1977	27	32	-5
GKA	514	1980	24	32	-8
GKA	515	1992	12	8	4
GKA	516	1976	28	28	0
GKA	517	1976	28	34	-6
GKA	518	1980	24	23	1
GKA	519	1990	14	12	2
GKA	520	1993	11	13	-2
GKA	521	1990	14	17	-3
GKA	522	1976	28	27	1
GKA	523	1994	10	7	3
GKA	524	1959	45	21	24
GKA	525	1986	18	24	-6
GKA	526	1969	35	31	4
GKA	528	1977	27	22	5
GKA	529	1981	23	13	10
GKA	530	1975	29	19	10
GKA	531	1983	21	15	6
GKA	532	1987	17	10	7
GKA	533	1979	25	24	1
GKA	534	1979	25	17	8
GKA	535	1983	21	16	5
GKA	536	1990	14	15	-1
GKA	537	1974	30	32	-2
GKA	538	1987	17	9	8
GKA	539	1985	19	14	5
GKA	540	1987	17	13	4
GKA	541	1980	24	10	14
GKA	542	1973	31	22	9
GKA	543	1989	15	9	6

GKA	544	1987	17	19	-2
GKA	545	1993	11	11	0
GKA	546	1983	21	21	0
GKA	547	1980	24	15	9
GKA	548	1996	8	10	-2
GKA	549	1989	15	13	2
GKA	550	1983	21	16	5
GKA	551	1982	22	24	-2
GKA	552	1988	16	14	2
GKA	553	1984	20	12	8
GKA	554	1984	20	14	6
GKA	555	1985	19	24	-5
GKA	556	1990	14	16	-2
GKA	557	1984	20	24	-4
GKA	558	1982	22	30	-8
GKA	559	1977	27	30	-3
GKA	560	1981	23	14	9
GKA	561	1970	34	31	3

Note that GKA 527 was eliminated from analysis due to inability of age estimating it. Its value of none made it difficult to obtain correct results. Thus, it was eliminated from all data

A-2: Griffith Knob site C

Site	I.D.	Year	Age	Nodes	Difference
GKC	501	1966	38	41	-3
GKC	502	1951	53	31	22
GKC	503	1946	58	53	5
GKC	504	1952	52	47	5
GKC	505	1952	52	75	-23
GKC	506	1957	47	39	8
GKC	507	1945	59	65	-6
GKC	508	1946	58	75	-17
GKC	509	1950	54	60	-6
GKC	510	1939	65	69	-4
GKC	511	1950	54	61	-7
GKC	512	1946	58	42	16
GKC	513	1952	52	62	-10
GKC	514	1949	55	61	-6
GKC	515	1938	66	88	-22

A-3: Griffith Knob site D

Site	I.D.	Year	Age	Nodes	Difference
GKD	501	1989	15	17	-2
GKD	502	1997	7	7	0
GKD	503	1991	13	11	2
GKD	504	1974	30	30	0
GKD	505	1983	21	26	-5
GKD	506	1976	28	34	-6
GKD	507	1976	28	54	-26
GKD	508	1991	13	14	-1
GKD	509	1990	14	14	0
GKD	510	1995	9	9	0
GKD	511	1991	13	29	16
GKD	512	1992	12	16	-4
GKD	513	1991	13	15	-2
GKD	514	1990	14	16	-2
GKD	515	1987	17	20	-3
GKD	516	1992	12	11	1
GKD	517	1978	26	26	0
GKD	518	1989	15	12	3
GKD	519	1979	25	24	1
GKD	520	1972	32	41	-9
GKD	521	1980	24	30	-6
GKD	522	1986	18	20	-2
GKD	523	1977	27	40	-13
GKD	524	1972	32	33	-1
GKD	525	1972	32	29	3
GKD	526	1980	24	29	-5
GKD	527	1978	26	27	-1
GKD	528	1976	28	39	-11
GKD	529	1978	26	43	-17
GKD	530	1976	28	21	7
GKD	531	1981	23	26	-3
GKD	532	1990	14	11	3
GKD	533	1984	20	25	-5
GKD	534	1992	12	17	-5
GKD	535	1981	23	19	4
GKD	536	1959	45	49	-4
GKD	537	1981	23	25	-2
GKD	538	1990	14	12	2
GKD	539	1966	38	43	-15
GKD	540	1978	26	19	7
GKD	541	1986	18	13	5

GKD	542	1979	25	31	-6
GKD	543	1957	47	37	10
GKD	544	1976	28	37	-9
GKD	545	1979	25	28	-3
GKD	546	1966	38	36	2
GKD	547	1970	34	32	2
GKD	548	1975	29	23	6
GKD	549	1965	39	53	-14
GKD	550	1979	25	29	-4
GKD	551	1967	37	39	-2
GKD	552	1985	19	19	0
GKD	553	1973	31	30	1
GKD	554	1983	21	20	1
GKD	555	1958	46	30	16