AProject Report
On
Dendrochronology and its application in the age assessment of *Abies spectabilis* from Uttarakhand western Himalaya

Submitted in partial fulfilment of the requirement for the award of the degree of
Master of Science

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Finally I am thanking for providing me this opportunity to undertake postgraduate studies in this institute…..

Condidate

Mohd Ajmal Khan

DECLARATION

This is certify that project entitled **"Dendrochronology and its application in the age assessment of *Abies spectabilis* from Uttarakhand western Himalaya"** is my work that it has not been submitted for any degree or examination in any other university, complete references. And that all the sources I have used or quoted have been indicated and acknowledged by complete references.

The work was done under the guidance of Dr. Parminder Singh Ranhotra (Scientist BSIP) Lucknow.

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-: Introduction:-

Background of Dendrochronology:-

Dendrochronology is the study of annual tree ring growth. Yearly ring growth is related to both external resources and conditions in the tree. External factors include water, temperature, light, carbon dioxide, oxygen and soil minerals, which affect temperature, water availability, and carbon building materials within trees. Therefore the availability of resources for growth depends on climate, site, and stand conditions as well as genetics. One aspect of dendrochronology, dendroclimatology, relates differences in yearly growth to climatic factors in order to improve understanding of the past, present, and future relationship between climate and tree growth.

In India tree-ring analysis has a vast scope for c1imatic studies. Due to its latitudinal and altitudinal ranges a variety of micro-c1imates and in consequence a diversity of forest types from tropical to alpine have to be taken into account (Champion & Seth 1968). Since long many tree species of these forests are known to produce annual rings (Gamble 1902), but systematic dendroc1imatic studies have only been performed since the end of the 1970s (Pant 1979; Pant & Borgaonkar 1984; Ramesh et al. 1985, 1986; Pant et al. 1992, 1995; Bhattacharyya et al. 1988, 1992a, b; Bhattacharyya & Yadav 1990, 1992, 1996; Yadav & Bhattacharyya 1992; Borgaonkar et al. 1994, 1999). In this paper dendroc1imatic reconstructions for both Himalayan and tropical forest sites of India will be discussed.

Missing rings and False rings :-

Complication may arise when some rings are missing or there are some extra rings in the tree-ring cores from the location where a core was taken. Abrupt changes in climate, soil conditions, forest dynamics, etc. can produce condition when a tree is not able to produce a full growth layer completely around the stem; or a tree is able to produce extra ring in the same year. These missing and false rings can easily be detected during the process of cross dating several specimens.

:-Review of literature:-

Global warming influences the vegetation diversity and natural upper tree line shift to higher elevations due to increase in air and soil temperatures (Holtmeier 2009; Körner 2012; Paulsen & Körner 2014). Natural tree line has advanced at some places in the Himalayan regions (Dube *et al*. 2003; Gaire *et al*. 2014; Shrestha *et al*. 2014; Tiwari *et al*. 2017; Yadava *et al*. 2017) and other parts on the Earth (Gehrig-Fasel *et al*. 2007; Kullman & Oberg 2009; Lloyd *et al*. 2003; Moen *et al*. 2004; Moiseev & Shiyatov 2003). Earth has witnessed an unprecedented warming trend during the 20th century (Briffa *et al.* 1995; IPCC 2013; Jones & Moberg 2003; Mann *et al.* 1999; Pant & Rupakumar 1997) responsible for changes in vegetation diversity and tree line shifts. Himalayan region is highly vulnerable to climate change (Xu *et al*. 2009) and also characterized with variety of forest types and growth form (Holtmeier 2009; Schickhoff 2005; Shi & Wu 2013). Most of these forest types are poorly investigated in terms of their health, growth and tree-line shift to climate change (Holtmeier & Broll 2007; Schickhoff *et al*. 2015). We need to generate more data on age stand structure at local species level to improve our understanding of forest health and controlling factors. For the present study we have selected *Abies spectabilis,* an important constituent of upper temperate to subalpine forests in Himalaya extending from Afghanistan to the eastern parts of India (Sahni 1990). This study from the Indian western Himalaya has the following objectives

:-Objectives:-

- To calculate the age of fir trees
- To develop the age-girth stand structure of fir forest

-: Materials & Methods:-

Study area -

I received the tree-ring cores of *Abies spectabilis* (silver fir) for the study during my dissertation. The samples were collected in October 2022 from silver fir trees growing on the slopes between ~3100 and ~3500 m asl at the Pakhwa locality in the Kumaon region of western Himalayas (Figure 1). The Pakhwa locality can be reached by 9 km of mule trek from the Khati village, which is 70 kms from Bageshwar towenship in Uttarakhand.

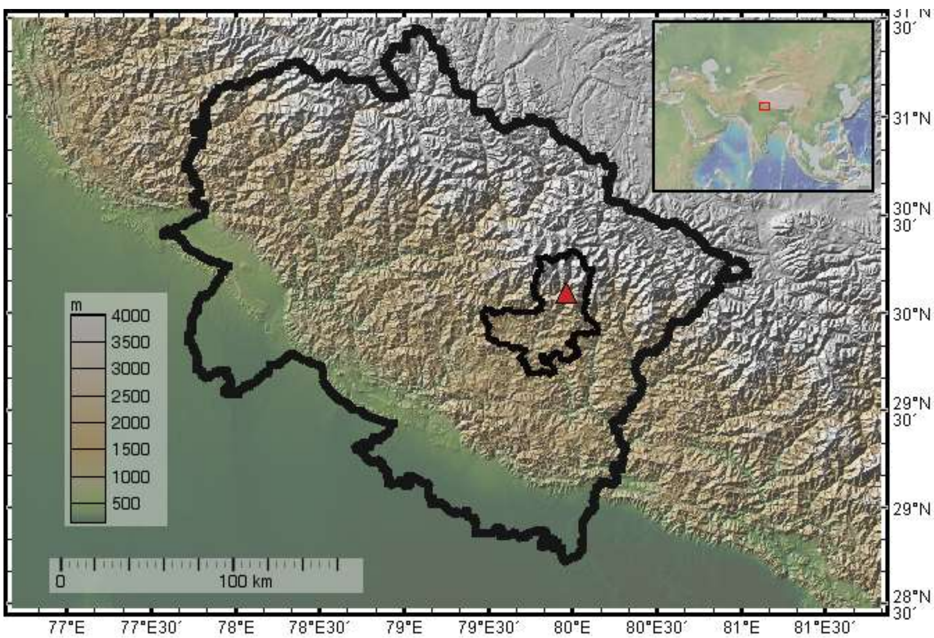


Figure 1. Digital elevation map of Uttarakhand showing the s**tudy area Pakhwa in the Kumaun region of Uttarakhand State, western Himalayas. Red triangle shows the sampling site.**

Climate of the area

Warmest month being July with mean temperature of 12.56 ± 1.23 °C (Fig.S1). Annual precipitation is 2400±430mm, of which 89.5% comes through Indian summer monsoon (ISM) during June-September. Snow cover, largely due to westerlies, lasts for 85 ± 22.7 days yr^{-1} during winter months. However, for developing the tree growth climate relationship, the required long term measured climate data are not available for the area. The gridded data for the area from Climatic Research Unit (CRU) of the University of East Anglia [CRU-TSv.3.22; (05x05degree) grid, available athttp://www.cru.uea.ac.uk/cru/data/hrg/)] for the period 1901-2020 CE (Harris *et al.* 2014) have therefore been used for the dendrochronological studies.

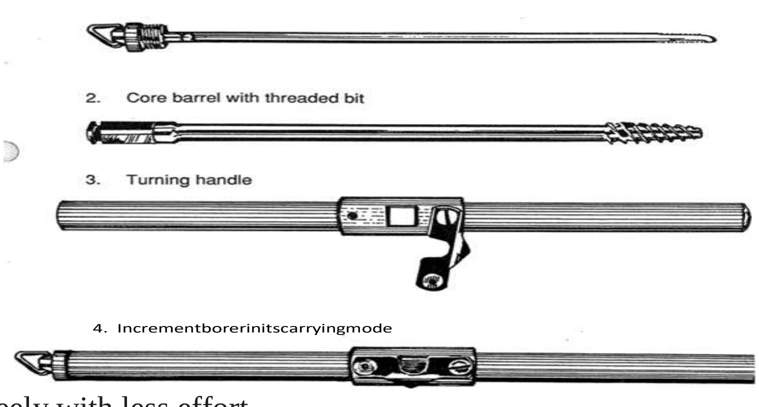
-: Sample collection in field:-

Increment borer -

An increment borer is the most important instrument in a Dendrochronologists' toolbox. It is essential for extracting a core of wood from tree, logs, poles or any other type of timber. Most of the increment borers have Teflon coated bits. This coating helps reduce friction, protects against rust and keeps the bit cleaner and extends the life of the bit. Nearly all increment borers are made in Sweden and Finland. An increment borer is a precision instrument and should be handled at one end; the tip of which is finely chiseled to cut wood as it goes through a tree. The hollow opening of the barrel starts as small opening at the cutting tip and then increases diameter towards the handle. This structure of the corer barrel provides enough space for the borer's extracting from within the borer barrel. iii. The handle is used to transport the extractor and borer, as well as to turn the borer in and out of the tree.

Tree coring Protocol:

Only with practice can one become good at coring trees. Otherwise, one will experience lots of trouble like jammed cutting tips, missed pith, broken cores and even injuring oneself. Trees that are growing on leveled ground can be cored formal most any direction but those growing on a slope should be cored parallel to the slope's contour. The location where to core a tree will ultimately depend on the goals of the study, or the investigators use of the resulting tree ring information. Here are the basic steps to take before coring or a decayed portion of a tree. A rot pocket is often identified when there is sudden change in boring resistance; all of a



sudden the borer turns freely with less effort.

Fig. 2 Anatomy of increment borer (Jozsa,1988).

1- Before coring a tree, apply beeswax to the core barrel. This will make penetration and removal of the borer bit easier by making the borer smooth and helping to reduce the degree of friction to which the borer will twist under strain.

2- Never bore into the rotten center core barrel from the wood as the threaded bit will not have solid wood to hold and push against to reverse coring direction of borer.

The goal is to bore directly towards the pith, however sometimes the pith is not in the geometric center of the tree. This is often the case with leaning trees, trees growing on a slope and tree species (gymnosperm and angiosperm tree species).

3.1 Avoid branch whorls and obvious wounds -

It is very difficult to core through branch knots due to their hardness and the resulting cores contain confusing twisted and pinched ring patterns due to the interference of the branches. Usually there are some marks on the outside of a tree that are evidence of branch stub sand wounds made behind the bark. The same is true for the area nearest obvious wounds where the tree has tried to close the wound with reaction wood.

3.2 Coring position -

Once you have selected the tree for coring, and determined a suitable location

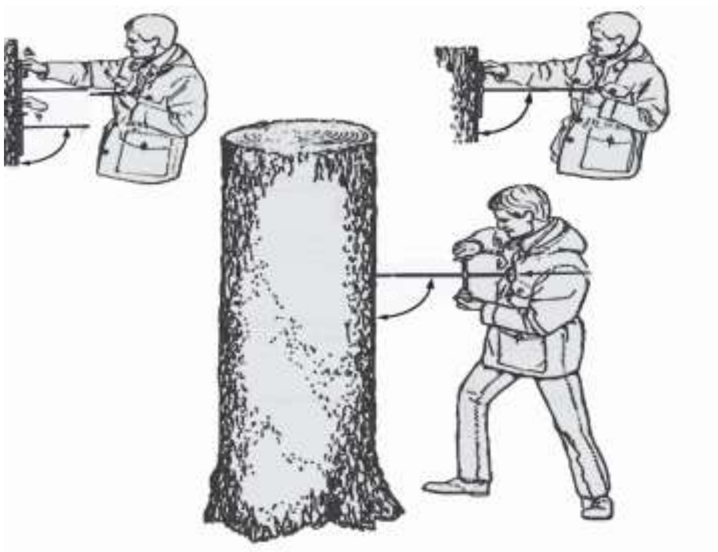


Fig. 3 Tree coring position (Jozsa,1988).

on the stem to take the sample, find a secured ground position and place the borer barrel 90-degree to the tree trunk (Fig.3). All you need to do now is to steadily spin the borer into the tree, maintaining the 90-degree with tree trunk and directing borer towards the pith position.

3.3 When to push and how hard -

At the start, the most common approach is to hold the borer near the center of the handle with one hand and while pushing with the palm of your hand, slowly turn the cutting tip clock wise into the tree. The other hand may be used to steady the bit to prevent it from wobbling and to maintain a 90-degree angle with the stem. Once the bit has penetrated about 2 cm into wood of the tree, and the cutting threads are completely in the wood, pushing the borer is no longer required except clock wise rotation.

The height at which one cores is dependent on the objectives of the study, and the use of the tree-ring in formation recovered. If the study is interested in finding the total age of a tree, or if the objective is to obtain the longest record of tree ring growth, then coring height position is to be closed to the root collar of the tree.

If the objective is to convert the radial increments obtain from a tree into some volume by use of a volumetric conversion table then sampling at breast height (1.37 meter) is preferable. This is especially true if measures of incremental growth are to be converted to volumes, and the volumetric conversion tables used are based on breast height measurements.

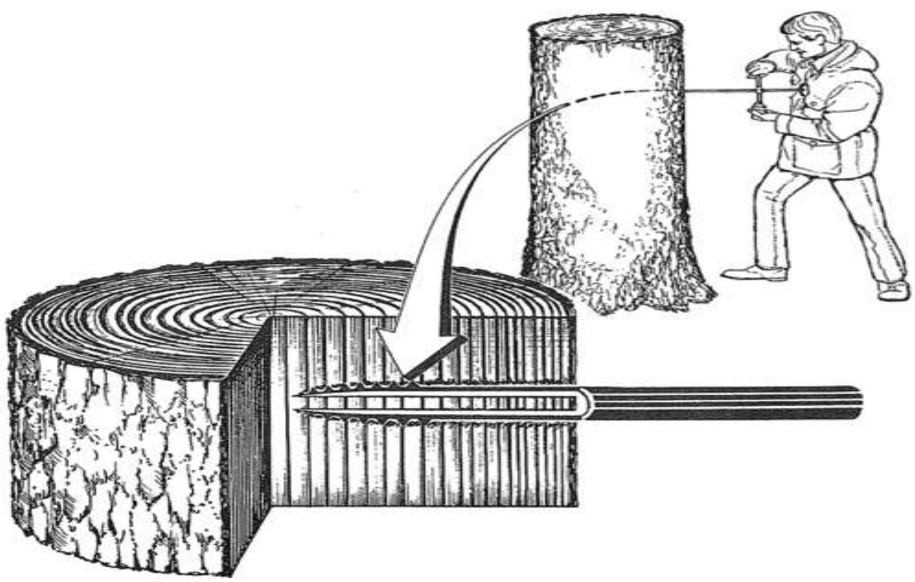


Fig.4 Coring position and barrel orientation (Jozsa, 1988).

There are instances when one might core at other heights along the stem depending on the research questions, but most commonly we suggest coring at height that is comfortable and safe for the working conditions in the field.

3.1 Where to keep core extractor spoon while coring -

It is best to place extractor spoon into a furrow in the bark of the tree at slightly above your eye level. Gently slip the extractor spoon tip into a crack in the bark letting the serrated tip of the extractor to hold the extractor in place. This prevents misplacing the extractor and more importantly accidentally stepping on or bending the extractor.

3.2 Removing the core -

Insert extractor spoon like this"∩"into the borer from the handle end, so that it slides between the core and the metal sides of the borer. Once the spoon has been inserted the full length, the borer is given a half turn counter-clockwise to break the core from the tree and also to turn the spoon like this "U". The core is then withdrawn from the tree by pulling the extractor out of the corer.

3.3 Handling the Core -

Cores are fragile so handle them very carefully. Before pulling the spoon and the core out from the borer, be ready with a plastic straw or paper straw to capture the core. After inserting and securing the core, close the opening ends of the straw and label the straw with the necessary ID code. ID code should have information like: site name, species, core serial number, and collection date.

Testing for decayed wood inside tree :-

It is not uncommon to come across rotten wood with in trees, especially in old trees. The presence of hollow and rotten wood in trees can sometimes be determined by striking a blow to the tree and listening for a resonating sound. The presence of hollow inside the tree sounds like a drum. Another way of detection while boring is by the sudden change in boring resistance and sound. In decayed wood, the increment borer turns easily with very less effort. Conversely, asudden increase in resistance means that the borer has hit a branch stub/knot; do not force it further, take the borer out and try another location on the tree.

3.1 What to do with struck borer -

Obtain core samples as quickly as possible. It is best to remove the bit almost all the way out of the tree even before examining the sample. This will reduce the possibility of the bit becoming stuck or locked in the tree. If a borer is struck, first try pulling while continuously twisting counter-clockwise (Fig. 6). If pulling and twisting do not work, then loop a rope around the borer's handle and the adjacent tree directly behind the borer. Twisting the looped rope in a clockwise direction causes the rope to shorten thus pulling the borer backward. The goal is to put enough reverse-pull on the borer to engage the threads in some solid wood so the threads can push the borer backwards. This is dangerous because a tight loop will produce lot of reverse pull on the borer. Keep in mind that the only thing holding the borer handle on the core barrel is the small keeper (clip/locker) on the handle which, if not in good condition or fastened tightly, may slip off causing he handle to fly backwards in the direction of the rope' sanchor.

Fig.5 Removing a struck borer (Jozsa,1988).

Coring a small diameter tree -

If you are taking bark-to-bark cores (one core through a tree), special precaution must be taken to ensure that the threaded cutting tip does not come out fully on other side of the tree. If this does happen, it gets extremely difficult to withdraw the borer from the tree as the borer's threads have no wood to push back against. When extracting your core from the borer be aware that the extractor spoon may push all or some of the core out of the borer. Before inserting the extractor spoon, push the core back into the borer away from the cutting tip(bit), with a small piece of wood to prevent breaking or loosing your sample. Then, holding the core in place with your stick inside the borer, insert the extractor spoon and remove the core.

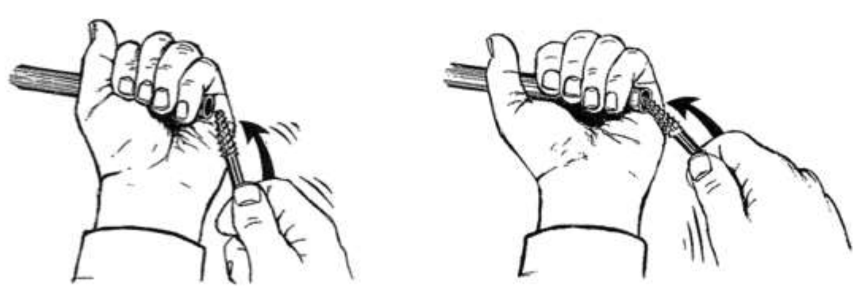
Coring a large diameter tree -

The greater the diameter of the tree, the longer the length of the borer is required to reach the pith. When using long borers, bear in mind that increment borers are not designed to with standing bending stress (up-down-left-right). One trick to coring large trees is to start by taking the first core with a short borer (16inches). If the short core comes out complete put it in a straw and take a second core, in the same hole, with a longer borer. This step may be repeated with progressively longer borers until one is satisfied with the result. Be certain to label your cores correctly so you can properly reassemble the complete core in the lab.

Footnote: *Be aware of any changes in resistance when boring largetrees. Also, be sure not to bend a long borer when coring. Increment borers are built to withstand a lot of twisting force but not to stand bending stress.*

Putting the borer back into the handle -

Be cautious while putting the borer back into the handle. If you are careless, it can cause



serious damage to the cutting tip and you may not be able to use the tool again. Hold the handle near the opening with one hand and with your other hand gently insert the spiraled bit into the handle without touching the metal edge of the handle (Fig.7). One must always prevent the cutting tip of the borer from touching anything other than wood.

Fig.6 Method of placing core barrel back into the handle (Jozsa,1988)

How to dislodge jammed tips -

Never use the extractor spoon or any metal items to clear a jammed tip. Often a small twig can dislodge jammed tips. It is advisable to carry wooden chopsticks so you won't have to search for something suitable that fits inside the jammed tips (Fig. 8).

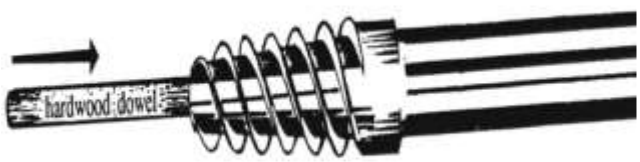


Fig.7 Sharpening the cutting tips

5.1 Mounting the Core :-

Cores are small and fragile so it is necessary to mount them before any surfacing works. If the cores are still moist, they should be dried for a few days before mounting, so that they will not shrink and pull a part in the mount as they dry. When core shave dried, glue is applied in the groove of the wooden core mount to hold the cores securely in place. You cannot mount the core haphazardly because if the core's fiber direction is improperly positioned then the annual rings will not be distinct (Fig.11). Once a core is properly placed in its core mount, secure the core to the mount tightly with string or tape to prevent the core from bending until the glue dries. There is another technique to mount cores, especially for species which have faint fibers. In this case, hold the core at both ends and rotate slowly. You will see light reflection on the sides of the core, mount he reflective surfaces facing sideways.

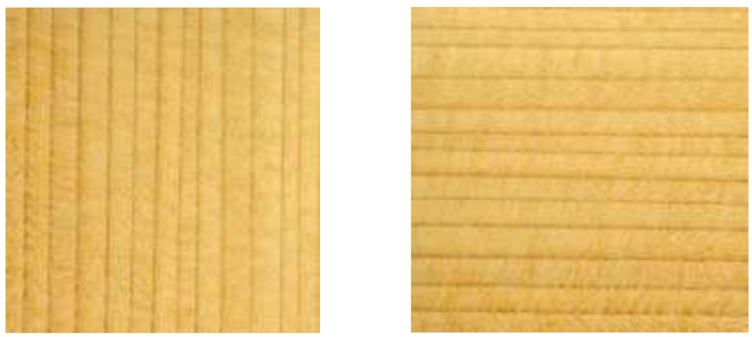


Fig.8 Fiber orientation in relation to properly positioned cores (left), and improperly positioned cores (right) in core mounts.

5.2 Labeling the core mount -

At the time of core removal from its straw, copy the ID from straw and write it on the core mount. The identifying label should also be recorded in the inventory log sheet (e.g,ID:RP12540105A). Here, the represent Research plot;1254 is the plot number, 01 identifies the species; and last two digits refers to tree number"05"and'A'referstothe first core.

5.3 Surfacing the Core -

After the glue is set and the string or tape is removed, the cross-sectional surface of the core is sanded by a series of progressively finer sandpapers. Depending on the density of the wood, the initial paper may be as coarse as 80to120grit. Once2/3rd soft he protruding core surface has been sanded away by this first paper, a suitable progression of finer papers is used to polish the surface (e.g., 280, 320, 420, 600). Continue sanding with the same grit until you see no further improvement in the wood. Only when there is no further improvements in the appearance of the wood, a finer grit of sand paper may be used.

Care must be taken not to sand away too much of the core with the first two papers, and to produce a polished surface that is flat, or parallel to the core mount. After sanding, a buffer is used to clean up the dust from specimens. Keep in mind that the sanding procedure is a violent step, one must be certain that the core is adequately glued into its core mount , otherwise it may be broken during this step.

Processing and dating of samples :-

The extracted cores were air dried and then mounted in the wooden frames. The upper surfaces of the core were cut by sharp edge razor blade and polished with coarse and fine grade sand papers to enhance the surface resolution of cells of annual rings, which is to make ring boundaries distinctly visible under microscope. Rings of each core were counted under the stereo zoom microscope (Leica) and each ring was assigned a calendar year through cross dating.

Cross Dating –

Using a stereomicroscope, count the rings in each samples starting from the bark toward the pith. If the sample was taken from a living tree, at or near the end of the growing season, then the date of the outer most ring near the bark will be the year the sample was taken. Working from this date, count backwards one year for every visible ring. Mark the wood sample with a sharp pencil at every tenth ring. There should be one mark for each decade (e.g. 1970, 1980, 1990). There should be two marks for every half century (e.g.1950,1850).There should be three marks for every century(e.g.2000,1900…). After counting, assign a calendar year for every half century and full century with a start with assign a calendar year for every half century and full century with a start with the most recent and then continue to wards the pith.

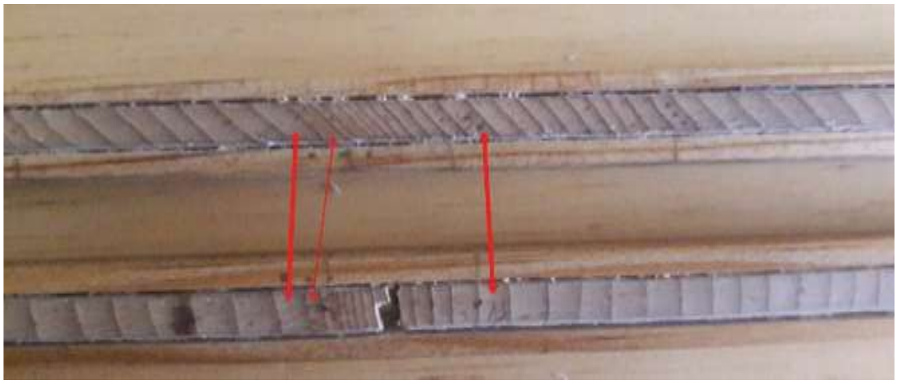


Fig. 9 Cross dating two samples of Tsuga demosain Bhutan (Source: Yeshey Khandu, 2016)

The matching of ring-width pattern among wood samples is known as cross dating. It would be simple if all trees in a given area contained the same pattern of wide and narrow rings but in most cases they do not. Similar tree ring patterns exist in varying degrees between trees growing under similar climatic conditions (Fig. 12). This is because atmospheric circulation, rainfall patterns, and mountain ranges divide the earth's surface into numerous "macroclimatic" sites. Within these climatic macro sites, the annual meteorological conditions vary uniformly on a relative scale and one may consider each area to have homogenous climate. Due to this, the ring patterns throughout a macroclimate zone will be relatively similar even though individual tree' sab solute growth rates, within the same climatic zone may differ.

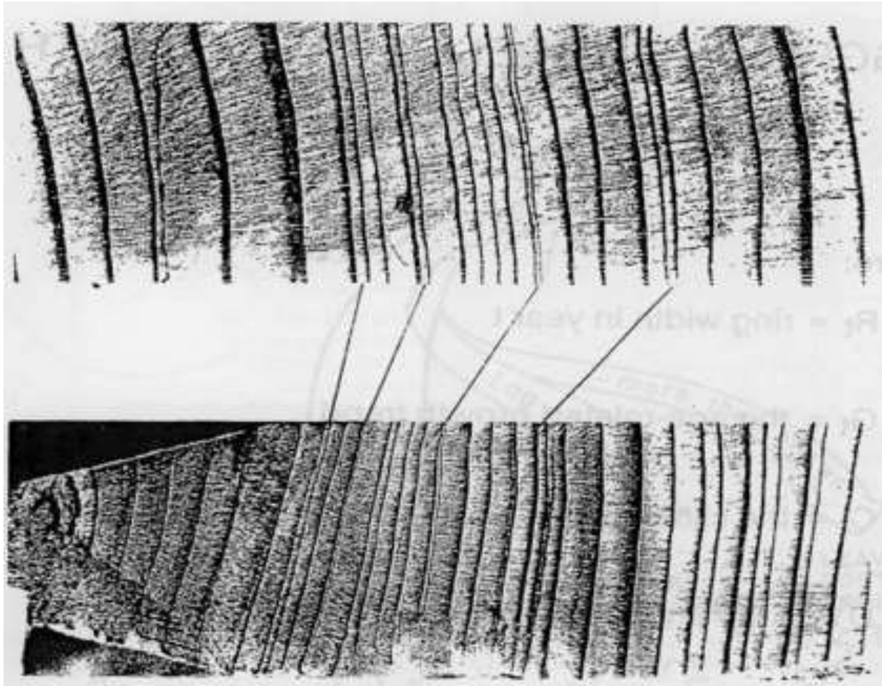


Fig. 10 Cross dating and the identification of common ring-width patterns between core samples (Stokes and Smiley, 1968).

Marking dates for rings –

As mentioned in chapter 6 it is essential to mark every tenth ring of as ample. This will serve as reference/pointer mark. If you do not, then it may irritate you when you lose count especially in old trees. Some people mark the rings with a pin (Fig.14)

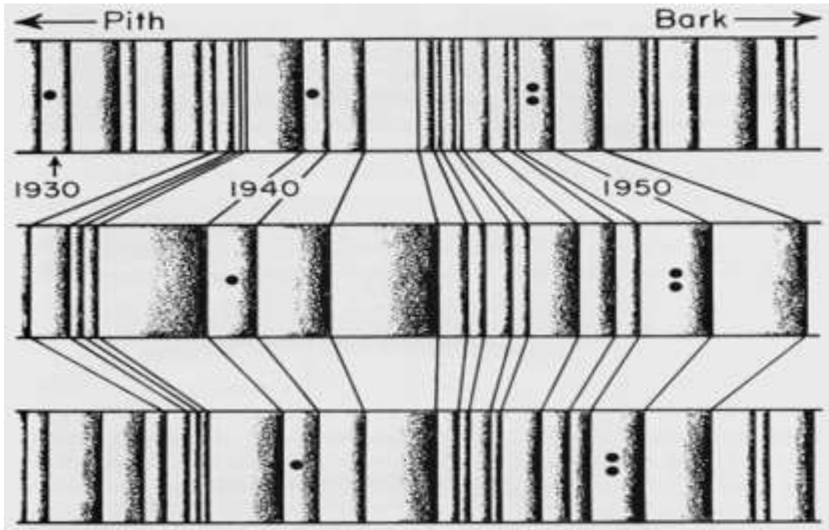


Fig. 11 A systematic way of counting and marking year (Stokes and Smiley, 1968).

False rings or Double rings :-

Another complication that arises in the process of cross dating is the occasional presence of false or double rings in a specimen. There are several ways of detecting false rings. The last late wood cells of a false ring are not clearly delineated but rather diffused because the late wood seems to turn back into early wood before the final late wood is formed at the end of the growing season.

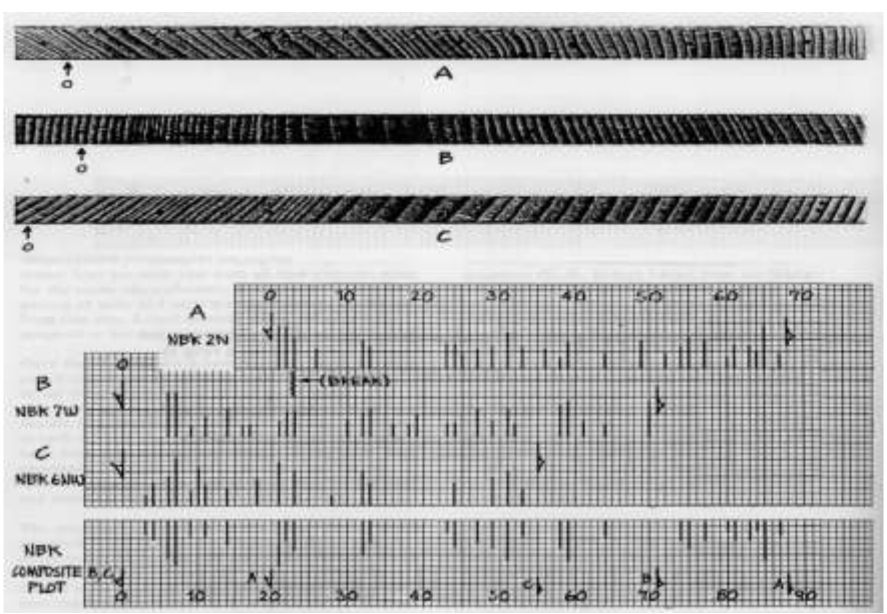
In some conifer species, resin ducts are common in the late wood, one can see that false late wood terminates at a duct, while true late wood surrounds the duct in corporating it into the annual ring. Some species like cypress and junipers have ring series in which it is often impossible to distinguish between true and false rings. When these methods of identification fail, false rings can sometimes

Skeleton plot -

The skeleton plot technique is used as an aid for chronologically relating a group of specimens to each other by pattern matching, and for determining exact calendar year/dates for individual rings in a sample. A skeleton plot is drawn on a strip of graph paper and labeled with the specimen number. A zero is placed at the extreme left of the paper. It is a plot drawn with vertical bars in which the length of each bar is inversely related to the width of the ring noted. In a skeleton plot a narrower ring gets a longer bar height and wider ring width gets shorter bar height. Locally average rings gets no marks on the graph. On a skeleton plot one may also note the position of peculiar wood anatomical features like false rings and partial rings. These help guide the matching of distinctive ring patterns between samples.

6.1. Composite skeleton plot –

After each specimen in a group has been skeleton plotted, all plots can be compared at one time. When this is done, similarities in their ring patterns can be noted and matched so the similar patterns are lined up one under the other. When this matching has been correctly done, all of the rings formed in the same year will fall on the same vertical line. When all of the specimens have been lined up, a piece of graph paper is placed at the bottom and then composite is made by ploting the average length of all lines that are present in each year as



shown in Fig.15.

Fig.12 Skeleton plot (Stokes and Smiley, 1968).

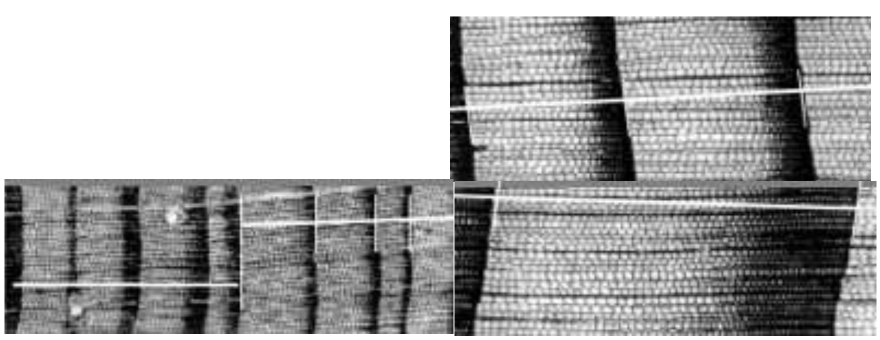
Measuring Samples -

Since the invention of computers and the application of micro-chip circuitry, tree-ring measuring systems have become very accurate and affordable. Today's most precise measuring systems incorporate linear encoders that can measure ring-widths to the nearest0.001mm.However,the single most important advice one can give to the no vice regarding tree-ring measurement is, be consistent.

6.2 Measuring Tree-Rings-

Individual rings are measured by moving the samples on the sliding stage under a stereoscope setup with cross hair in one ocular. Measurements are recorded in the micro computer and subsequently on a magnetic disc by pressing a remote switch when the cross hair is lined upon the ring boundaries of successive rings.

A ring-width is measured from the edge of the first cell of early wood to the edge of the last cell of late wood (Fig.16). The goal of measuring a ring is to take the path that most approaches a perfect radial path. In some cases, particularly with cores, the perfect radial path is difficult o determine, or the point where to begin and end a measurement is not clear. In either case, consistently using the same criteria will improve results



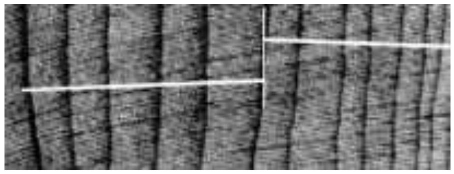


Fig.13 Ring-width measurement technique (Photo:P.Krusic).

Tree ring Measuring System:-

Basic components of a modern Tree-ring measuring system (Fig.17).

1) A Computer set with measuring software program installed, suchasJ2X,Tellorvaor TSAPwin.
2) Linear measuring stage with Digital Read-Out(DRO)
3) Stereomicroscope with cross-hair reticle, boom stand, and illuminator.

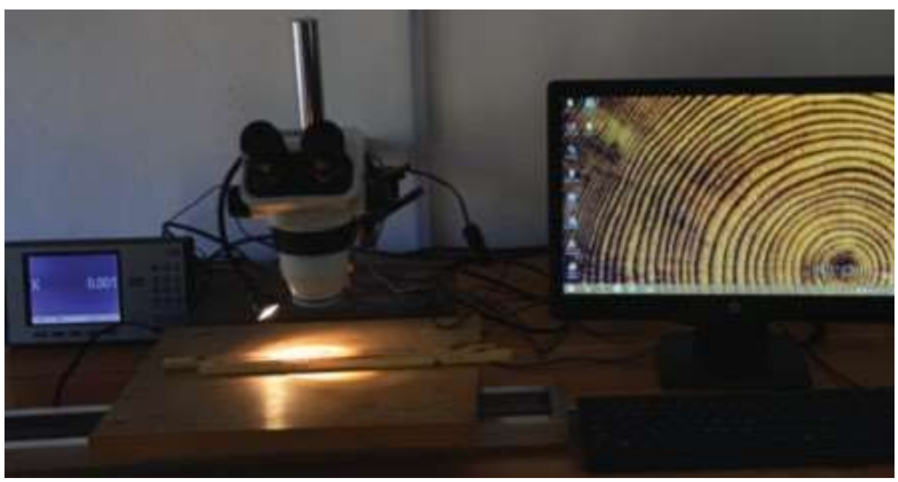


Fig.14 A complete measuring micro meter stage

7.2 Measuringprogram J2X –

The Following steps will help you to operate the measuring system .For detail description of the J2X measuring program and operator's instructions go to first, switch on the DRO/Display. The string "SFE 1.01" will print out on the display panel. Press "DISPLAY ON" which will change the string to the 0.000(Fig. 18).

Fig.15 J2X measuring program operator

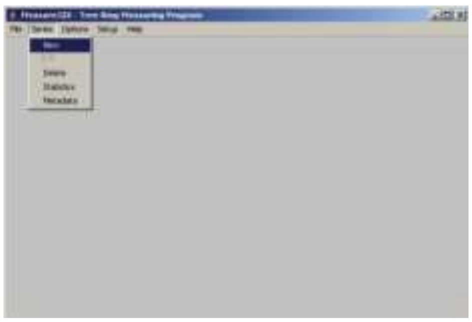
1. Open the program, then click **Setup** from the menu bar and check that the program settings are correctly initialized. If not, then you have to configure the program settings as shown in the Fig. 19.

The example provided here conforms with the system used for making this document. Depending on the configuration of components that make up your system, the settings may be different. To choose the proper settings for your system see the J2X Users. Guide web

document downloadable from the Voortech website.

Fig.16 Measuring program setup

1. In **Series** menu bar, click on "New" and enter a maximum 8character ID for the specimen, and the start year of the first measurement as shown



in(Fig 20).

Fig.17 Input series ID with start year, sample ID should not be more than 8 digit

Once you have entered the core ID and initial year, click on "OK" and then Fig.21 should be the next screen. Use the "Mode" button to change the direction of measurement. There are four choices, "APP-Fix LYOG" (Append-Fix, Last Year of Growth)permits the user to measure samples from the bark to the pith. APP-Fix LYOG mode decrements the start year by one after every measurement. APP-Fix FYOG (Append Fix, First Year of Growth) is the opposite measuring mode, where with each successive measurement the start year is incremented by one(e.g., measuring from pith to bark). The other two modes, Ins-Fix FYOG and Ins-Fix LYOG, are modes used to insert values post-measurement, Once the appropriate mode is selected, zero out the display and click "Measure". Then, to send the display value to the program presses the "print" button on the remote switch as shown in the (Fig22). Be sure to set the initial value to zero (0.0) before making your first measurement (fig.21).

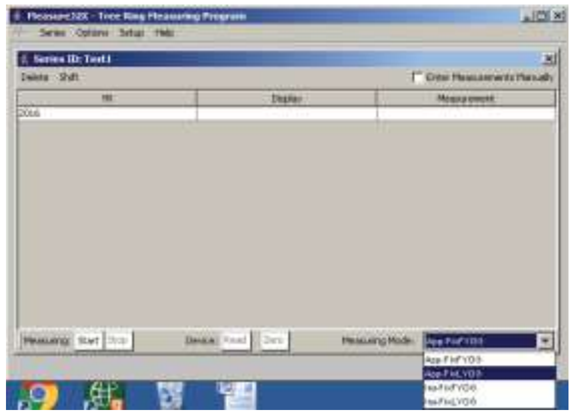
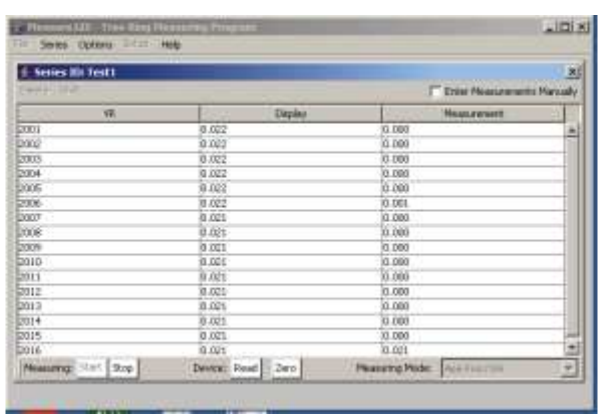


Fig.18 Measuring mode should be App-fix Last Year of Growth if measurement is taken from bark towards pith.

Fig.19 Initial value should be set to zero before beginning measurement

Place the specimen that you want to measure on the stage sample table and be sure to set the initial value to zero. If you are measuring from bark to pith, align the center of the cross-hair with the edge of the late wood of the last ring and rotate the dial/crank till the same point on the cross-hair



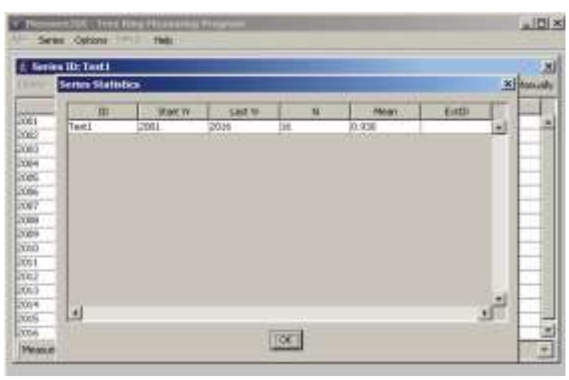
reaches the edge of the early wood in the same ring. Now press the“print” button to send the measured ring width to the measuring program **Fig.20.**

Fig.20 Example of measurement from 2016 to 2001

Continue till you have measured all the rings in the specimen. To save the measured specimen, click “Done” and CLOSE the measuring window. Then open the **file** tab and save your measurements in a new file with any name you want. That is the procedure for measurement and saving the first specimen. For there of the specimens, you repeat the same steps, how ever remember to save the data in the same file. Each time you save new data to the same file the program flashes a warning (Fig.24).Each time the program saves data it rewrites all the data that was already in the file and the new data just measured is appended to the end. This re-writing and saving habit has changed with older versions of the program, so check J2X Measurement users manual before use.

Sometimes, while measuring a ring width, you might press the print button twice instead of once or make some mistake in measuring. When that happens, click “Done”, highlight the bad measurement and delete it by pressing the delete button. To continue the measurement, click the “measure” button and position your sample at the proper place. Press “OK”. Reset your measurement to zero (0.0) by pressing in the remote switch “zero button” and then the “print” button. Now, you are ready for measuring again.

If you want to see how many samples you have measured: open the **Series** tab and go to



the “Statistics” (Fig. 25). Here you may select “records” to edit and/or delete.

Fig.21 The summary of measurements from start to end year.

After you have completed all measuring, the file is saved as a simple text file in your designated folder.

Result & Discussion

Growth dynamics and shift rate :-

To understand the growth dynamics and altitudinal shift rate of fir, various relationship models were developed amongst the tree diameter at breast height (DBH), tree age and their altitudes. DBH of each tree was calculated dividing the measured GBH (circumference) by

the value of pie (3.14). Each tree sampled for cores was assigned an age following the standard method of annual ring counts, cross dating and necessary corrections (Camarero & Gutierrez 2004; Gaire *et al*.2014; Speer 2010). Complete cores of around 120 trees having the length from bark to pith were taken to develop the DBH and age relationship model.

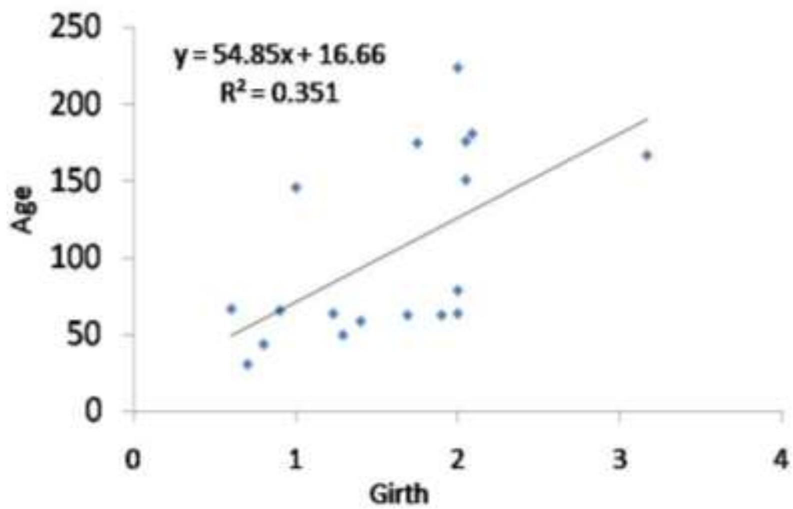


Fig 22. Girth at breast height and Age relationship of *Abies spectabilis* from Pakhwa, Uttarakhand.

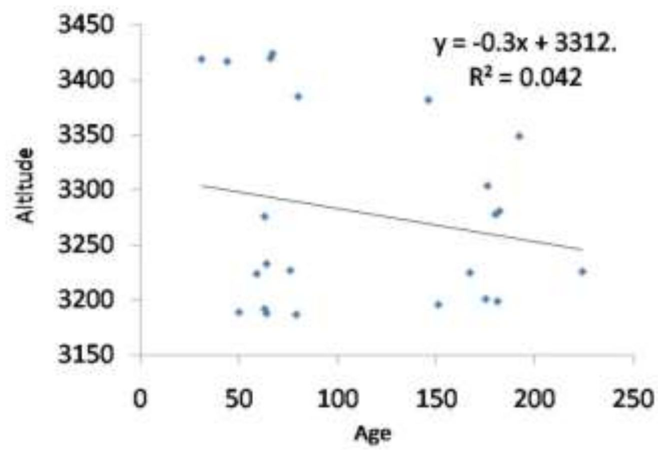


Fig23. Age and growth altitude relationship of *Abies spectabilis* growing in the Pakhwa area, Uttarakhand.

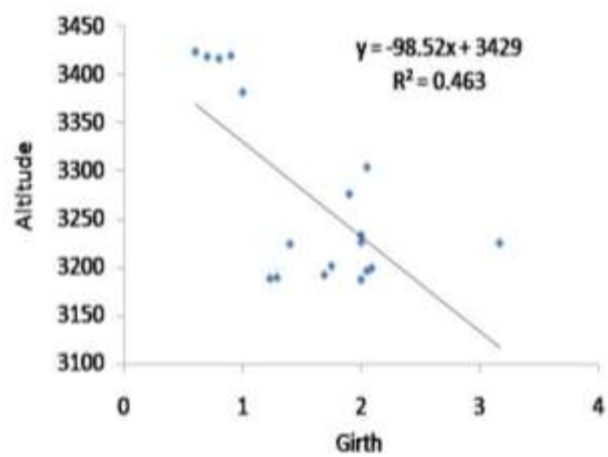


Fig.24 Girth at breast height and altitude relationship of *Abies spectabilis* from Pakhwa, Uttarakhand.

To correct the age for the core extraction height, a decade was added to the counted age of each tree (Gaire *etal*. 2011). Some trees with their GBHover2meterswerefoundtoberottenandpithlengthcores were not available. Considering the variation in growth distribution of *A. spectabilis* above and below 3100m asl altitude, the DBH-age relationship model has also been tested separately for the trees growing above and below the 3100m asl respectively (Figs. S2–S3) . This allowed assessing the stand structure and growth variability of *A.spectabilis* at different elevational levels. The DBH and age regression models were used to estimate the near approximate age of rotten and uncored trees with measured GBH. The girth class and age distribution, and the growth rate dynamics of this conifer has been analyzed by establishing the relationships between DBH and altitude, and age and altitude of the trees using linear regression model (Figs.5and6). Temporal advancement or shift rate of fir to higher elevation has been approximated following the standard calculation (Gamache & Payette 2005; followed by Gaire *etal*.2014; Tiwari *etal*.2017 and others) by dividing the difference between the altitudes of uppermost individual and oldest individual with the difference between the age of oldest individual and uppermost individual. Also, to understand the establishment year of *A.spectabilis* at different altitudinal transects and to know the temporal variations in the shift rates, the same were calculated separately by dividing altitudinal transects into 100 and 200m bands(Fig. 6).

Upper limit and age stand structure of Abies spectabilis

Along the altitudinal transect of Pakhwa area, *Abies spectabilis* forms the upper limit at ~3425 m asl with ±5 meters of altitudinal variation which might be due to local factors. To analyze the stand structure, various correlation analyses were performed among stage, DBH and altitude and they showed significant correlation values. Correlation between DBH and age was positively significant (r = 0.64, $P < 0.05$) with 35% variability explained by girth (Fig. 22). This showed that less aged trees have lower girth.

All along the altitudinal gradient, girth ranged from 0.6 to 3.17 m, with lower girth trees in higher elevations. The correlation between girth and altitude was found significantly negative ($r=-0.72$, $P < 0.01$), indicating decrease in girth size of trees with the increase in altitude, but explaining 46% variability in girth by altitude (Fig. 24).

The correlation analysis between altitude and age showed insignificant negative correlation ($r=-0.2$, $P<0.05$) with 5% variability (Fig. 23), indicating the mixture of younger and older trees at higher elevations.

The presence of trees younger than 100 years within the forest stand near ecotone limit indicates subsequent infilling of forest and also explains the growth behavior of fir trees in relation to increasing temperature of winter months during the last century. Evidences of no regeneration above the present fir limit and the presence of few seedlings within the upper ecotone limit could be related to mixed response to climate and other local factors at this site. In spite of rapid warming silver fir tree line inTungnath area has not shown upslope advance. It seems that the positive effect of warming in tree growt his nullified by water stress resulting from increased evapotranspiration. *Abiess pectabilis*, climate-growth relationship, tree line shift, tree ring width, Uttarakhand, Western Himalaya.

-:**Conclusion:-**

Our study indicates that climate as well as other local factors have significant role in the growth and tree line dynamics of *Abies spectabilis* at the study area for past two years. This study thus justifies the importance of area specific control on tree growth response that can have vital relevance in assessing tree growth dynamics and predictions in regional aspects. At this site fir reached its present upper ecotone limit by the early 20th Amongst several factors, winter warming could have played an important role for the high growth and advancement of fir to upper elevations. The occurrence of fir trees younger than 100 years within the forest ecotone limit might be the result of observed increasing trend in the winter temperature during the 20th century. The increased land use pressure for last few decades might also have played a significant role in the stability of fir ecotone limit and could be reasoned for poor regeneration. Recent year regeneration of fir by the presence of few seedlings near the ecotone limit could indicate regeneration and advancement of fir in the Tungnath area. But the continued land use might also play role in tree line dynamics and thus needs future monitoring on the overall survival and growth of fir in relation to climate and other factors

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