Altitudinal Variation in Phenology, Seedling Characteristics & Natural Regeneration of *Abies pindrow* Spach

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Thesis

Submitted to

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Dedicated

to my beloved Parents

Sher-e-Kashmir
University of Agricultural Sciences and Technology of Kashmir
Faculty of Forestry, Benhama, Ganderbal

Certificate – I

This is to certify that the thesis entitled, **"Altitudinal Variation in Phenology, Seedling Characteristics & Natural Regeneration of *Abies pindrow*Spach"** submitted in partial fulfilment of the requirements for the award of the degree of **Doctor of Philosophy in Forestry**, to the **Faculty of Forestry, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir** is a record of bonafide research work carried out by **Mr. Hiilal Ahmad Bhat (Regd. No. 2011-373-D)** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.

It is further certified that information received during the course of investigation has duly been acknowledged.

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Certificate – II

We, the members of the Advisory Committee of **Mr. Hiilal Ahmad Bhat (Regd. No. 2011-373-D),** a candidate for the degree of **Doctor of Philosophy in Forestry** have gone through the manuscript of the thesis entitled, **"Altitudinal Variation in Phenology, Seedling Characteristics & Natural Regeneration of *Abies pindrow*Spach"** and recommend that it may be submitted by the student in partial fulfilment of the requirements for the award of the degree.

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Certificate – III

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ABSTRACT

In Jammu and Kashmir, the important conifer forest forming tree species include deodar *(Cedrus deodara),* kail (*Pinus wallichiana*), fir (*Abies pindrow*), and chir (*Pinus roxiburghii*). These species have been placed under tremendous pressure due to increasing fuel wood and timber demands. Besides this, the natural causes which had significantly contributed to their vulnerability to man induced degradational activities include raw humus on forest floor, low germinative capacity of seeds and infrequent good seed years and thus need human intervention aimed at identification of best seed source, development of maturity indices, improvement in germinability, production of quality seedlings and identification of regeneration constraints for their sustainability. Silver fir an important tree is distributed over a wide altitudinal belt and has been taken as a model tree species for investigating all these aspects along the altitudinal gradient under the title "Altitudinal Variation in Phenology, Seedling Characteristics & Natural Regeneration of *Abiespindrow*" were carried out with the following objectives:

1. To study the phenological characteristics of *Abies pindrow* at different altitudes
2. To study maturity of cone, seed and germination behavior of seeds in response to chilling for overcoming dormancy

3. To study regeneration status of *Abies pindrow* at different altitudes

For taking phenological characteristics, twenty phenotypically superior trees replicated thrice were selected at each altitudinal strata randomly 100 m apart to have genetic diversity. The morphometric phenology varied sharply from lower altitudes to higher altitudes. Maximum tree height (31.60 m), basal area (1186.86 cm^2) and dbh (38.90 cm) recorded at lower altitude (2300-2600 m) in Sind forest division was followed by lower altitude of Tangmarg Forest Division and decreased progressively as we moved towards higher altitudes. Highly significant difference in basal area was recorded in both the forest divisions among the altitudinal stratas. The highest crown length (22.95 m) and crown spread (4.06m) was recorded in Sindh forest division and Tangmarg forest division respectively at middle altitudes (2,600-2,900 m). The phenological studies revealed that male and female cones appeared in the month of April at lower (2,300-2,600 m) and middle (2,600-2,900 m) altitudes whereas at upper altitude (>2,900 m) male and female cones were observed during early May. The leaf renewal started from April at lower (2,300-2,600 m) and middle altitude (2,600-2,900 m) whereas at upper altitude (>2,900 m) new flush of leaves appeared during early-May thereby indicating influence of altitude on leaf renewal.

For cone and seed maturation 40 cones were harvested fortnightly from July onwards till their maturation at each altitudinal strata of the selected forest division. Maturity indices study for *Abies pindrow* revealed that prominent changes occur in cone and seed color towards maturity. Cones mature in late-September at lower (2,300-2,600 m) and middle altitudes (2,600-2,900 m) whereas at upper altitude (>2900 m) cone maturity is attained in early-October as revealed by cone color change from deep purple to chocolate with purple scale edges towards maturity. The seed color changed from deep pink to deep chocolate just before dispersal. Seeds dispersal commenced in the month of October at lower (2,300-2,600 m) and middle altitudes (2,600-2,900 m) whereas at upper altitudes (>2,900 m) most of the cones dispersed in the month of November though the dispersal started during late- October. The cone weight increased for the first four collections and then started declining from 15th August onwards as the collection progressed. The maximum cone weight (87.18 g) and cone length (12.00 cm) at maturity were recorded in Tangmarg forest division at lower altitude. Progressive decrease in cone weight and cone length was recorded from lower altitudes to higher in Tangmarg forest division. The cone weight and cone length decreased from 87.18g to 69.36 g and 12.00 cm to 10.50 cm respectively. In Sindh forest division, middle altitude recorded the maximum cone weight (82.48 g) and cone length (11.65 cm) at maturity. Mean fresh weight of seeds increased throughout the collection period. In Tangmarg forest division, the seed weight at lower altitude increased from 37.36 g/1000 to79.47 g/1000 from first July to 15th October. In Sind forest division, the maximum seed weight (75.38 g/1000) at maturity was recorded at middle altitude (2,600-2,900 m). The moisture content of seeds decreased while seed germination per cent, viability per cent and seed dimensions recorded the increasing trend as the collection progressed. At maturity the seed moisture oscillated between 15.35 and 11.08 %. In Tangmarg forest division, lower altitude (2,300-2,600 m) recorded maximum values for germination percent (40.25) and viability percent (52.75) at maturity. In Sind forest division, middle altitude proved superior and recorded higher values for seed germination (37.25%) and seed viability (48.25%) at maturity.

The seeds collected from different altitudes were subjected to different levels of moist chilling duration on maturation at a temperature of 3 ± 1^{o}C. Two set of seeds were prepared for each treatment for laboratory and nursery studies. Altitude and chilling duration significantly influenced the germination characteristics of *Abies pindrow*. The germination percent, germination energy and germination value declined as we move from lower altitudes to higher altitude in Tangmarg forest division whereas the MGT showed increasing trend. The germination percentage at lower, middle and upper altitude under laboratory conditions was recorded as 35.55, 30.80 and 29.80 % respectively with MGT of 22.73, 23.41 and 23.69 days respectively. The germination value of such seeds was recorded as 3.93, 2.89 and 2.34 whereas the germination energy was recorded as 24.00, 21.70 and 20.25 % respectively. Under the nursery conditions, the germination and MGT of the same altitude were recorded as 29.30 % and 29.66 days respectively. In Sind forest division middle altitude registered the superiority and the seed germination, germination energy and germination value under laboratory conditions were recorded as 35.05%, 26.20 % and 3.67 respectively. The germination and the MGT of the same altitude under nursery conditions were recorded as 30.00% and 30.94 days respectively.

Study conducted to study the germination performance of seeds in response to different chilling durations revealed that extended chilling duration periods significantly increased germination percentage, germination value and germination energy besides decreasing mean germination time. Maximum values for germination percentage, germination value and germination energy were recorded when seeds were subjected to 60 days chilling. In Tangmarg forest division, the germination percentage increased from 19.75 (control) to 40.83 (60 days chilling duration) while the germination value and germination energy increased from 0.98 (control) to 4.96 (60 days chilling duration) and 14.25 (control) to 27.83% (60 days chilling duration) respectively. The mean germination time of seeds declined from 25.30 (control) to 21.73 days (60 days chilling duration). Chilling durations significantly improved the nursery performance of seeds. In Tangmarg forest division, the germination percent increased from 14.41 % (control) to 33.33 (60 days chilling duration) and was recorded as maximum whereas the MGT decreased from 36.63 (control) to 28.79 (60 days chilling duration) days. In Sind forest division under the same chilling duration period, germination percent, germination energy and germination value excelled and were recorded as 40.50 %, 29.66 % and 4.97 respectively. Under the nursery conditions maximum germination percent was recorded as 33.08 after 60 days chilling duration with MGT of 30.86 days.

The seedling characteristics were also influenced by altitude as well as chilling duration. Maximum radicle length (2.40 cm), plumule length (3.24 cm) and vigour index (205.28) was recorded at lower altitude in Tangmarg forest division. The seed collected from lower altitude of Tangmarg forest division produced the quality seedlings with maximum height (4.69cm), root length (8.93 cm), collar diameter (1.00 mm), biomass (0.41 g) and survival (75.64 %). In Sind forest division middle altitude proved superior. Maximum radicle and plumule length and vigour index in this division was recorded as 2.34 and 3.17 cm and 198.76 cm respectively. The seeds of this altitude excelled in seedling height (4.39 cm),collar diameter (0.97 mm), root length (8.72 cm), biomass (0.36 g) and survival (69.92 %) under nursery conditions. Chilling durations significantly improved the seedling characteristics. Maximum radicle length (2.64 cm), plumule length (3.29cm) and vigour index (243.89) were recorded after 60 days chilling duration in Tangmarg forest division. Maximum seedling height was recorded as 4.58 cm after 60 days chilling duration in Tangmarg forest division. The root number,root length, collar diameter, biomass and survival percent for such seedlings was recorded as 4.50, 8.91 cm, 1.01 mm, 0.41 g and 72.21% respectively**.**

The regeneration survey conducted to determine the status of regeneration at the selected sites was done in 50×50 m which was further subdivided into 10×10m plots for trees and 2×2 m for seedlings and saplings revealed progressive decrease in seedling, sapling and tree density from lower altitudes to higher altitudes in both the forest divisions. Seedlings were seen growing profusely on nurse logs and under shrubs. Towards higher altitudes the forests were characterized with gap openings which at upper altitudes became more prominent and replaced the forest with vast pasture lands with scanty fir individuals often seen growing gregariously.

Key words: *Abies pindrow,*altitude, phenology, maturity, chilling duration, germination percent, germination value, germination energy, MGT, seedling height, biomass survival, nurse logs and regeneration.

Signature of Student
Dated____________

Signature of Major Advisor
Dated ___________________

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Hiilal Ahmad Bhat

Place :Benhama, Ganderbal

Dated: ________________

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Chapter 1

INTRODUCTION

State forests and challenges

The state of Jammu and Kashmir has distinct agro-climatic zones comprising of subtropical, intermediate, temperate and cold arid zone. As a result of this agro-climatic diversity, the forest of the state are phyto-geographically very diverse and complex. The different forest types of the state are subtropical dry evergreen, Himalayan moist temperate, Himalayan dry temperate, subtropical pine, sub-alpine and alpine.

The valley of Kashmir lies in temperate zone.The forests consist of conifers as well as broad leaved tree species. Main conifer species growing in the forests include deodar (*Cedrus deodara*), kail (*Pinus wallichiana*), fir (*Abies pindrow*), and chir (*Pinus roxiburghi*), occupying an area of 1,07,527, 1,96,837, 3,40,093 and 1,82,482 hectares respectively (Anonymous,2010).

Over the past few decades, the Himalayan forests have experienced unprecedented land-use changes driven by rapid human population growth and intensifying anthropogenic activities, such as agriculture and expanding human settlements (Nayar andSastry, 1990; Tikader, 1983). Traditionally, people of the Himalayan region have been fulfilling their energy needs almost entirely from forests (Bhatt *et al.*, 1994). Himalayan forests are very much de-graded due to nomadic activities, sedentary livestock overgrazing, legal as well as illegal tree cutting (Ahmed *et al.*, 2006). The pressure is developing on conifer species which aresignificant timber wood species, but due to ignorance and acute shortage of alternate fuelsources, these species are preferred for fuel. Due to increasing fuel wood and timber demands, very extensive and heavy extraction is going on thereby causing their fragmentation.The natural factorsthat significantly contribute totheirdegradation include poor regenerationdue to presence of undecomposed raw humus on forest floor, low germinative capacity of seeds and infrequent good seed years(Troup,1921).In many fir species high percentages of empty seeds have been observed (Franklin, 1974; Keen,1968;Khutortsov, 1987; Nanu, 1979). The proportion of empty seeds increases in poor seed years up to 90%(Nekrasova, 1978) thereby rendering it morevulnerable to anthropogenic pressure. To ease out increasing pressure and slow down or halt the degradation of our forests, there is a need of immediate action plan for up gradation of forests to make it a sustainable resource.

Distribution,description and utility of silver fir

Silver fir, an important conifer species of Kashmir valley is distributed from Kashmir to Nepal at an altitudinal range of 2,550-3,350ma.s.l.Sometimes the tree species descends below 2,150 m in case of cool ravines or may ascend to 3,650 ma.s.l. It can be seen as pure forest crop or mixed with other forest tree species the chief associate being th*e Picea smithiania.*Fir is a large ever green tree growing up to 40-60 m tall with girth up to7.5m. The leaves are bifid at the tip flattened in cross section, glossy dark green with two whitish bands on the underside. The seed cones are dark purple10-17.5cm long and 5-6cm in diameter. The yellow pollen cones arise in the lowersides of the previous years branches in clusters.

*Abies pindrow*has got significance due to their demand as wood based raw material for shook industry, packing cases, match wood,paneling cabnet making and paper and pulp. The leaf extract of *Abies pindrow* is used as carminative, stomachic, astringent, expectorant and tonic (Burdi*et al.,* 2007). The seeds contain fair percentage of essential oil which can be exploited commercially. As the tree has been found under wide altitudinal belt, it significantly affects many aspects of tree including tree form by affecting tree growth and height performance (Wang *et al.*, 2002). Owing to its adaptability to diverse altitudinal conditions,it can therefore, be taken as a model tree species for investigating variation in tree form and vegetative and reproductive phenology along the altitudinal gradient.

Phenology

Phenology is the study of the periodicityor timing of recurring biological events like flowering, fruiting, leaf flushing etc. Phenology determines the different phases of life cycle of a woody species (trees or shrubs) in a forest ecosystem which have direct impact on the productivity of forest ecosystem and its biodiversity. This consists of seedling, vegetative and reproductive phase of a species. The vegetative phenology is the growth of leaves and stems while the reproductive phenology determines flowering, and fruiting including seed dispersal. This in turn has direct impact on the productionof seeds in the forestecosystem(Humberto*etal.*, 2014).

Phenological events are controlled by proximate causes or ultimate causes. Proximate causes include short term environmental events that may trigger phenological pattern while theultimate causes are the evolutionary forces that are responsible for these events(Lobo *etal.,* 2003). The schedule of these events have important effect on the life cycle of the tree. Proximate causes likes climatic variables, which vary with the altitude, have been identified as the causes that trigger the phenological events (Ashton *et al.,* 1998). Adaptive responses of tree phenology to their local environment in temperate or boreal zones are either to avoid late frost damages and/or to increase their growing season length(Lechowicz, 1984)therefore, impacting tree growth. Recent climate warmings impacts on tree phenology has increased the scope for phenological research especially at high altitudes because of their short growing season(Walther *etal.*,2002). There has been a significantly increased interest in phenology primarily due to shifts in the timing of different phenological phases in trees, due to climate change. Species level phenological studies are therefore crucial for elucidating tree species response to altitudinal changes. Besides, phenological studies are important for better understanding of ecological adaptations, interactions of individual species and also from the point of view of germplasm conservation (Stern and Roche, 1974; Waser 1979; Thompson, 1978).

Knowledge of phenological pattern provides the ecological information viz individual plant reproductive success; interactions of the plants with other organisms; inter-specific interactions among plants; population dynamics ofplants, pollinators, and the other micro and macro flora and fauna; andinformation on plant community structure and ecosystem functioning (Newsstrom *et al.*, 1994; McIntosh, 2002; Batalha and Martins, 2004).

Cone and seed maturity indices

The knowledge of exact stage of cone collection is of immense importance to avoid collection of immature and non-viable seeds (Willian, 1985). The seeds collected when fully mature retain viability longer than the seeds collected when immature (Harrington, 1970) and havehigher vigour for seedling establishment (Pollock and Ross, 1972) Early-collected cones on the other hand are more sensitive to handling methods.This sensitivity declines in later collections(Edwards, 1980).

Cone maturity indices are very important for firs to decide proper seed collection time for regeneration works.Fir cones disintegrate and seeds disperse at maturity, thereby making seed collection impossible, it is therefore necessary to collect cones in advance of seed dispersal.The extent to which collections can be made in advance of seed dispersal islargely governed by the fact that fir seed development ceases if the cones are detached from the parent tree too soon,especially if the primary organic-accumulation phase isincomplete.Low viability of white fir and red fir seeds often is the result of collecting immature seeds(Oliver, 1974). Seed handlers need to know when acceptable seed viability is reached in the maturing cone. As a general recommendation, no single criterion shouldbe relied on when judging maturity of fir seeds are undertaken (Oliver, 1974;Snyder, 1976).Insteadseveral characteristics such as cone colour, seedcoat and wing colour, seed detachment from cone scale, and embryo colour should be taken into consideration before large-scale cone collections are undertaken (Oliver, 1974), as these serve as reliable indices for proper seed collection stage.

Seed source variation

According to Oliver and Larson(1996), management of naturalforests rely largely on natural regeneration. Harmonisingthe rates of exploitation and production is possible only if adequate information on regeneration dynamics is available.Besides, in conifers the natural regeneration practically depends on the seeds which in turn depends on production, dispersal germination capacity and successful establishment of seedlings. However, seeds contain a lot of variation depending upon the source of origin (Gera *et al.,* 2000). This variation in seeds has been reported in many trees and the variation is dictated by environmental factors. This may be due to altitudinal variation as reported by Barnett and Farmer (2006) or region of collection (Bonner, 1984). Seed traits polymorphism and seed source variation have been found to play a great role in seed germination, survival and seedling growth. Source of variation in seed and seedling traits have been well documented in a number of trees species viz.*Santalum album* (Sindhuveerendra*et al.,* 1999) and *Acacia nilotica* (Gera *et al.*, 2000), *Cedrus deodara* (Mughal, 2002).This necessitates the collection of seeds from different seed sources. The essence of variability studies is well recognized for developing tree improvement strategy (Wright, 1976). Genetic variation within and between populations is essential to exploit their improvement potential and is considered to be a substantial determinant of adaptive abilities of populations (Subramanium*etal.*,1992). These studies are necessary for scanning the available genetic variation, to utilize the best material for obtaining maximum productivity for breedingprogrammes(Shiv Kumar and Banerjee, 1986).Efforts are therefore to be made to assess the effect of seed sources on germination behaviour and seedling characteristics with a view to have more quality seedlings for tree improvement works.

Seed stratification

Seedling emergence at the right place and time is important for a plant's life (Fenner and Thompson, 2006). Sometimes, this requirement is satisfied by germination as soon as seeds are shed, but in most *Abies* species there is delay of few months. One important mechanism for this delay is seed dormancy (Fenner and Thompson, 2006). Generally the seed of conifers have intermediate physiological dormancy(Nikolaeva, 1969).

Most, if not all, fir species exhibit some degree of dormancy, the alleviation of which is succeeded by stratification (moist chilling) (Edwards, 1982). The stratification are set to approximate the natural environments that autumn ripening seeds might find themselves exposed to upon dispersal (Krugman *et al.,* 1974).

Stratification is often performedby refrigerating previously hydrated seeds in plastic bags or other containers. More traditionally, dry seeds (at storage moisture contents) are placed on a moist medium (filter paper, vermiculite, or wet sand) and refrigerated. The moist filter paper method produce higher germinationbecause it is believed that the preliminary water soak that is the first step in the naked stratification procedure damage the seeds by too-rapid tissue hydration, a phenomenon well-documented in legumes (Jones and others, 1991). The length of stratification required depends upon the degree of dormancy which is influenced by seed source (Bonner *et al.*, 1974).Longer periods of stratification should be approached with care because it may result in fungal damageand premature germination(Edwards,1982).Stratification temperature range is often specified as 1 to5 °C (Franklin, 1974), although testing laboratories typically use a narrower window of 3 to 5 °C. Stratification has been shown to improve the germination (in terms of capacity and/or speed) of several *Abies* species, which also proves that dormancy is relevant to these seeds (Edwards, 1982).Cold moist stratification is a commonly practice used to break dormancy in seeds to attain vigorous,speedy,maximum and uniform germination for laboratory testing and nursery sowing(Wang *et al.*,2000). The stratification treatment therefore assumes importance.

Stratification is known to influence seedling traits.The seedling raised from stratified seeds have better growth in early stages of seedlings(Rawat *et al.,* 2010) which helps in their early establishment. Higher survival percent of seedlings raised from stratified seeds have significantly increased its application and are now commonly practiced in raising sound seedlings.Stratification can be more advantageous in raising conifers seedlings because of their slow growth. Significant improvement in seedling growth has been achieved in *Pinus gerardiana*by Malik and Shamet (2009) by deploying stratification as a presowing treatment.

Regeneration

Natural regeneration is the renewal of forests by means of natural process of seed dispersal, and establishment. Forest dynamics depend largely on tree regeneration which is influenced by biotic and abiotic factors acting at different spatial and temporal scales (Clark *et al*., 1998). Seed production and dispersal, germination and seedling establishment are among the main processes determining successful tree recruitment (Dovciak*et al.*, 2003). Constraints acting on tree regeneration include low amount of viable seeds, restricted spatial extent of seed dispersal and reduced availability of suitable microsites for seedling establishment(Grubb, 1977). At an individual level, seed production is directly related to tree size (Greene andJohnson, 1994). However, there are other factors affecting seedproduction at wide spatiotemporal scalessuch asstand density, tree-to-tree competition or climatic conditions triggering reproductive events or prolonging seed dormancy(Greene *et al.,* 2002; Debain *et al.,* 2003, 2007).

Regenerationis the most important process to maintain the stable age structure of the plant species. Adequate seed supply, effective dispersal, good viability and longevity of seeds, successful establishment of seedlings and their conversion to mature trees are all unavoidable for a sustainable forest management. Regeneration contributed by seedling bank which is considered as a pool of suppressed seedlings waiting for the improvement in the prevailing growing conditions for further growth(Antos*etal.,*2005) is fundamental to the dynamics of forest tree and can form the future canopy(Duchesneau and Morin, 1999).Seedlings in the seed bank have head start when there are canopy openings as they effectively compete the under storey vegetation.

Regeneration from seeds, which is natural regeneration of high forests, depend almost entirely on the physical characteristics of the microsite surface on which the seeds land such as moisture content and the amount of light that reaches theyoung seedling (Kozlowski, 2002).

Microsites under the forest canopy and their conditions are important factors in forest regeneration because they affect the establishment of seedlings of component tree species (Grubb, 1977). Some microsites are more suitable for seed germination andseedling survival than others, and that suitability depends on microtopography,canopy cover, understory type or presence of decayedwood (Beckage *et al.,* 2000; Dovciak *et al*., 2003). Forest floors provide regeneration habitats that generally consist of various substrata, such as mineral soil, nurse logs, mosses, litter, etc.However, in case of *Abiespindrow*natural regeneration is reportedly hampered by paucity of seed, infrequent seed years, thick undecomposed acidic humus and dense weed growth (Prakash, 1998).

Keeping in view the above mentioned facts, a project entitled "Altitudinal Variation in Phenology, Seedling Characteristics and Natural Regeneration of *Abiespindrow*"was carried out with the following objectives:

- To study the phenological characteristics of *Abies pindrow* at different altitudes
- To study maturity of cone, seed and germination behavior of seeds in response tochilling for overcoming dormancy
- To study regeneration status of *Abies pindrow* at different altitudes

Chapter 2

REVIEW OF LITERATURE

2.1 Phenology

Phenology is the study of the timing of recurring biological events, the causes of their timing with regard to biotic and abiotic forces, and interrelation between phases of the same or different species (Leith, 1974). Recently, there has been a significantly increased interest in phenology primarily due to shifts in the timing of different phenological phases in trees, due to climate change. The phenological studies are important for better understanding of ecological adaptations, interactions of individual species and also from the point of view of germplasm conservation (Stern and Roche, 1974).

Anonymous (2010) studied the phenodynamics of few multipurpose trees of Kashmir under Shalimar conditions. The largest growing season was witnessed by *Salix caprea* and the shortest growing period by *Fraxinus floribunda.*Earliest bud break was also observed in *Salix caprea*and late in *Albizia julibrissin.*

Vitasse*etal.* (2009) made a comparative study on phenological sensitivities to temperature of seven woody species between each other and within-species between two geographical areas using both altitudinal and temporal gradients (*Abies alba*,*Acer pseudoplatanus*, *Carpinus betulus*, *Fagus sylvatica*, *Fraxinus excelsior*, *Ilex aquifolium* and *Quercus petraea*). Across the temporal gradient, they found significant advances in leaf unfolding for oak and ash whereas no significant advance was observed for beech and hornbeam. They emphasized that phenological sensitivity to temperature was very similar between the two geographically separated populations in Pyrenees and Fontainebleau forests.

Ziello *etal.* (2009) in their studies in high mountain regions reported that flowering phenologychanges along elevation gradients, with plants at lower elevations typically flowering earlier than plants of the same species that grow at higher elevations.

Doi and Katano (2008)reported that timing of tree phenological events is known to be tightly correlated to temperature and photoperiod.

Krishnan (2004) studied reproductive phenology of 27 endemic and 33 non- endemic species, monitored at monthly intervals for 20 months in a mid-elevation wet forest in the Southern Western Ghats. Peak flowering occurred during the dry and post-monsoon seasons for the endemic species, while the non-endemic species flowered during the dry season.

Leinonen and Hanninen (2002) concluded that an earlier leaf unfolding provides a longer growing season but also induces a higher risk to late frost damage on leaves, resulting in reduction of leaf area and photosynthetic carbon gains.

Pinto *et al.* (2011) studied in detail the phenologyinMediterranean evergreen oaks inrelationto effects of environment.The results revealed that budburst in *Quercus suber* is triggered by temperature within specific photoperiod limits.

Inouye and Wielgolaski (2003) maintained that variation in aspect and inclination strongly creates variable microclimates within mountain regions, which lead to differences between phenology at high altitudes compared to lower sites.

Chmura and Rozkowski (2002) revealed that the phenology of temperate woody plants is commonly assumed to be locally adapted to climate and a number of studies using provenance tests highlighted phenological differences between populations.

Singh *et al.*(2015) studied the phenological events along the elevation gradient and effect of climate change on *Rhododendron arboreum* in Kumaun Himalaya. The results showed a high synchrony throughout the elevation gradient, especially for peak flowering. Temperature, rainfall, age of the observed trees and site characteristics were related to initial and peak flowering dates.All the phenological events began early at low elevation and were delayed at higher elevation. *R. arboreum* had a sharp flowering peak from January to March. Wet season flowering was rare, and seed formation occurred in summer. The climatic conditions affected the phenological characters of *R. arboreum*.

Ranjitkar (2013) studied the effect of elevation and latitude on spring phenology of rhododendron at Kanchenjunga conservation area in east Nepal. The study revealed delay in flower onset with the increase in elevation, full bloom phase was found highly synchronized throughout the elevation gradient with contraction of flowering duration. High synchrony also indicates that the reproductive timing might plastic enough to cope with short-term change in environment

Pellerin *et al.*(2012) studied the effects of air temperature, altitude and local topography on spring tree phenology in the Alps. Altitude was recorded as a main predictor variable of budburst and leafing dates with delays ranging from 2.4 to 3.4 days per 100 m. Ash was the only species with strong evidence of a year difference in the altitudinal gradient with the warm year (2007) characterized by a weaker altitudinal gradient. A latitudinal gradient was found in the appearance of budburst for one coniferous species (larch) and curvature affected leafing in ash.

Vashistha *et al.*(2009) explored the phenology of 103 speciescategorized in 10different growth forms of an alpine expanse of North-West Himalaya, India and concluded that in majority of the growth forms, growth initiation was recorded in May whereas senescence in October. Flowering occurred in July-August in most of the growth forms. Phenological characters *viz.*, initiation, flowering, fruiting etc. depended on the climate of the particular regions and most of the species initiate growth after snow melts in alpine regions (April-May).

Rai *et al.*(2012) carried out a study in Hindu Kush Himalayas on *Betula utilis* at different altitudes and found that the pheno-phases (bud set, bud burst, flowering, fruit formation and leaf fall) were delayed with increasingaltitude because of the low soil temperature due to variation in the accumulation in the snow cover and short growing seasons.

Rousi and Pusenius (2004) explored the variations in phenology and growth of European white birch (*Betula pendula*) clones. Considerable genetic variation and large interannual variation in the date of bud burst and especially in the termination of growth, in phenological characteristics among the birch clones was observed. A large clonal variation in the duration of bud burst was also observed. Height growth was correlated with timing of growth termination, length of growth period and bud burst, but the relationships were weak and varied among years.

Inouye and Wielgolaski (2003) found that phenological events are constrained at high altitudes by the short growing season delimited by cold temperatures and snow cover. The time of snowmelt appears to have an almost universal effect on high-altitude phenology.

2.2 Maturity of cone, seed and germination behavior of seed

Seed harvesting should be started only when the seeds are sufficiently mature corresponding to the indices of maturity for individual species. It requires an understanding of seed ripening and dispersal characteristics therefore indicators of maturity are a must so that collection is made right in time.

Krajnakova *et al.*(2008) states that seed germinability of many *Abies* species is improved when seeds are collected as close as possible to seed fall, *i.e.,* when the embryo reaches its complete form.

Mughal and Thapliyal (2006) reported that cone weight showed significant decrease towards maturity in *Cedrus deodara* from 131.11 to 97.46 g in north Kashmir. South Kashmir showed a fall of 31.67 g within one month while in Jammu region cone weight decrease from 148.80 to 80.64 g. They further found that there was a significant decrease in the cone specific gravity at all the three sites which ranged from 1.0 in August to 0.78 at maturity in October in North

Kashmir, whereas in South Kashmir it decreased from 1.0 in August to 0.98 in September and at Jammu cone specific gravity decreased from 1.0 in August to 0.66 in October.

Mughal and Thapliyal (2006)revealed increase in the germination percentage in seeds of *Cedrus deodara* towards the cone maturity. It increased from 0.02% in August to 59.50% at maturity in October at North Kashmir. In South Kashmir, germination percentage increased from 6.55% in August to 75.50% at maturity in September while germination percentage increased from 1.0% in August to 67.50% at maturity in the month of October at Jammu.

Upadhayay *et al.* (2006) observed change in seed colour from green to whitish brown as a useful indicator of maturity in case of *Bauhiniaretusa* Ham.

Singh (1998) reported decrease in the cone specific gravity of *Abies pindrow* from 1.04 in August to 0.97 at maturity in October.

Singh (1989) studied the maturity indices in spruce with relation to specific gravity. The specific gravity of mature cones varied from 0.97 to 0.99. The germination percentage of the seed collected from such cones varied from 47.2 to 50.4 per cent.

Study under taken by Mughal *et al.* (2007) in Jammu and Kashmir found that the average specific gravity of *Picea smithiana* was 0.96 at maturity. The specific gravity of the seeds is another quick and reliable method of judging maturity of the seed.

Bhat*et al.* (2014) recorded that specific gravity of *Robinia pseudoacacia* decreased towards maturity and varied between 1.08 and 0.97 over the collection period. He also reported that with decreasing specific gravity the germination increased.

Bhat *et al.* (2014)while studying the seed maturity in *Robinia pseudoacacia*concluded that the colour change from green to blackis a reliable indicator in judging seed maturity.

Bhat *et al.* (2007) studied that the seeds of *Ulmus wallichiana* collected at maturity showed weight of 10.14 g/100 seeds as compared to seeds collected at immature stage which weighed 7.10g/1000 seeds

Harrington (1972) concluded that the most generally accepted criteria means of maturity is when the seeds have reached its maximum dry weight a point called physiological maturity.

The study conducted by James *et al.* (1988) revealed that *Juniperus occidentalis* and *Juniperus osteosperma* seedling emergence was improved by cold moist stratification at $5^{o}C$ for 14 weeks but the total emergence as well as total seedling growth parameters of both species were enhanced by outdoor stratification over winter in moist sand for the same period.

Mugloo *et al.* (2009) reported that cone diameter has direct correlation with seed weight and germination parameters in silver fir (*Abies pindrow*). They further investigated that the germination per cent and germination value increased with the increase in cone diameter.

Singh and Kumar (2004) carried out studies to find out the effect of cone diameter on seed quality of chir pine (*Pinus roxburghii* Sargent). The large cone diameter class (7-18 cm) showed superiority in germination parameters over other cone diameter classes of medium (6-<7 cm) andsmall (5-<6 cm).

2.3 Seed stratification and germinability

For enhancing the rate and percentage of germination and for breaking the dormancy, moist chilling or cold stratification has been widely used as a pre-sowing treatment (Wang and Berjak, 2000). This is simple, inexpensive and effective technique for overcoming the seed dormancy.

Jones *et al.* (2002) found that the stratification for 56 days at $5^{o}C$ increased the germination percentage from 11 to 16% of water birch (*Betula occidentalis*) and 0-16% in thin leaf alder (*Alnus tenuifolia*).

Rawat *et al.* (2008) while working on germination behaviour of seeds of *Abies pindrow* observed that the seeds pre-treated with GA_3 (100 mgl^{-1}) followed by chilling treatment for 15 days gave optimum germination.

Veena (2005) reported that freshly harvested chilgoza seeds failed to germinate in 28 days period. However, after increasing duration of moist chilling to 20 weeks the radical emergence was seen in 78 per cent of seeds placed for germination.

Majeed *et al.* (2010) on dormancy studies in *Aesculus indica* reported increase in germination with an increase in the time of cold stratification.

Mughal and Shoaib (2010) reported that the *Fraxinus floribunda* seeds have intermediate physiological dormancy and the same can be overcome by cold stratification for a period of 4 weeks. Cold stratification recorded a significant steady increase in germination percentage from 26% after 1 week cold stratification to 78% after 4 week cold stratification at 4±1^{o}C, where as in control it was recorded 15% only, mean germination value which in control was 0.93 increased to 26.67% after 4 weeks of cold stratification.It was also recorded that mean germination time (days) in *Fraxinus floribunda* seeds in control was 27.56 days which went down to 16.42 days after 4 weeks of cold stratification at 4±1^{o}C.

Malik *et al.* (2008) reported that the seeds of *Pinus gerardiana* are highly dormant when freshly harvested. To break the dormancy; six stratification periods and four stratification temperatures were used to enhance the germinability of *Pinus gerardiana* seeds. Treatment of seeds for 45 days at outdoor pit temperatures (16.5/4.5^{o}C: day/night) in moist sand enhanced the germination behavior of the species.

Rawat *et al.* (2010) studied the germination response of *Punica granatum* seeds to different stratification periods. The germination of *P. granatum* significantly improved with increasing stratification periods. Stratification for 30 days at 50^{o}C showed highest germination percentage.

Mittal *etal.* (1987) reported that chilling of white spruce (*Picea glauca*) and eastern white pine (*Pinus strobus*) at 2 to 4^{o}C up to 15 weeks increased the rate of germination in both the species. Singh (1989) examined that stratification of spruce seeds for 60 days resulted in an increase of 19.75 per cent more germination than control.

2.4 Seed stratification and seedling characteristics

Significant in improvement has been achieved in seedling characteristics in many tree species by deploying the chilling treatment as a presowing treatment and has beengiven as:

Rawat *et al.* (2010) reported that stratification for 30 days in *Punica granatum* at 5^{o}C showed longest radicle, maximum root and shoot length, number of leaves and highest survival of seedlings.

Sofi (2005) working with *Cedrus deodara* revealed that seedling growth parameters were maximum for 75 days of wet stratification at 2-3^{o}C followed by 60 days of pre-chilling. The stratification treatment beyond 75 days showed decreasing seedling growth parameters.

Malik and Shamit (2009) studied the effect of stratification on growth of seedlings under nursery conditions in *Pinus gerardiana.* 60 days stratification significantly improved seedling parameters.

2.5 Seed source variability

Seed source variation is well documented for a number of tree species(Singh *et al.*, 1996; Thapliyal and Dhiman, 1997; Roy *et al.*, 2004; Mukherjee 2005).

Sehgal (1994) reported significant variations in length, width, fresh weight and number of seeds per cone in different seed sources of *Pinus roxburghii.*

Rawat and Bakshi (2011) reported that seed traits, namely seed length, width, weight, thickness, volume and germination parameters vary significantly among seed sources in case of *Pinus wallichiana.*

Lester (1969) in a study of variation pattern of ten characters of conemorphology of *Abies balsamea* found that variation in the cone length could beportioned approximately equally between locations, between trees within locations and between cones within trees. These suggest a combined control of genotypic environmental factors, such as climate, soil and position in the crown and stand density.

Pitcher (1984) reported clinal variation in seed weight, size, endocarp and kernel weight in relation to altitude. Farmerand Barnett (1972) observed greater seed size at higher altitude in *Prunus serotina.*

Mughal and Thapliyal (2013) revealed a significant differences in germination percentage among 12 seed sources of *Cedrus deodara.* Germination percent among seed sources varied from 38.67 in Panchalthan to 84.31 in Srinagar seed source.

Sindhuveerendra*et al.* (1999) reported significant variations in seed parameters viz., seed length, seed width and seedweight of *Santalum album* collected from various provenances.

Isik (1986) reported slow germination and smaller seedlings in seeds of high altitude provenances as compared to those of middle and low altitudeprovenances in *Pinus brutia.*

Mughal and Thapliyal (2013) reported that cone size and weight varied significantly at different provinces irrespective of elevation. The maximum cone length and diameter of *Cedrus deodara* was 12.90 cm and 6.35 cm respectively at Banihal. They observed the similar trend in cone weight which differed from place to place with maximum of 172.00 g at Akingam.

2.6 Regeneration

It is the most important process to maintain the stable age structure of the plant species in a community, affected directly or indirectly by various climatic as well as edaphic factors (Singh and Singh 1992). The issue of regeneration is mainly important for those forests which are under various anthropogenic pressures such as felling tree, grazing, trampling, etc. (West *et al*., 1981).

Malik *et al.* (2012) revealed that the *Pinus gerardiana* has maximum established regeneration of the (291.66 plants/ha) in semiarid zone on the western aspect. Overall, the mean natural regeneration status of the species was very poor (15%). Thus, he concluded that species is facing higher risk of extinction and needs to be considered as 'Critically Endangered in the forests of Kinnuar of HimachalPradesh, India.

Lanker *et al.*(2010) reported that in northwest Himalaya in India, that recruitment of *Taxus baccata* was higher at higher elevations due to the least anthropogenic activities butreduced at lower altitude due to the over-harvesting and other anthropogenic pressureswhich were higher at lower elevations, leading to poor regeneration.

Coop and Schoettle (2009) found limber pine (*Pinus flexilis*) regeneration increased in burned sites relative to unburned ones.

Acharya (2004) inmixed *Abies spectabilis* forest of Manang, found high human interference as the main factor leading to the destruction of species of high girth classes. There was less natural regeneration of *Abies spectabilis* due to radiation, low moisture and high human pressure.

Darabant *et al.* (2007) found seedling growth considerably higher in grazed plots regardless of tree species mainly dueto increased light interception with reduced bamboo height as a result of grazing.

Gairola *et al.* (2008) reported *Abies pindrow* as dominant species (importance percentage 16.44%) and *Betula utilis* as co-dominant species (importance percentage 16.10%) in north-western slope of mixed *Abies-Betula*forest of Indian Himalayas and in that forest the two tree species shared nearly equal dominance in the community.

Hussain *et al.* (2008) has reported a tree density of 151 and 85 trees ha^{-1} for *Abies pindrow* and *Betula utilis* group respectively in Kumaon forests.

Qiaoying *et al.* (2008) in their studies concluded that in timberline population of *Abies georgei* the number of seedlings accounted for 79%of the total population, which showed a good regeneration of this species.

Galhidy *et al.* (2006) found more seedlings in small gaps than in large ones in European beech (*Fagus sylvatica*) forest of northern Hungary.

Diaci *et al.* (2005) reported that in *Picea abies* forest of Slovenian Alps, seedling density of *Picea abies* was higher in depressions with a mean of 2,85,000 per ha compared to slopes where the mean was 1,62,000 ha^{-1}due to high solar radiation.

Dolezal and Srutek (2002) reported that species composition of Acer forests on south-east facing slope in Slovakia was influenced by soil depth and altitude. Vegetation height decreased linearly along the altitudinal gradient from 43 m (tall trees at low elevations) to 42 cm (tall grasses in exposed high mountain crests).

Kuluuvainen and Kalmari (2003) established that variety of microsites created by windthrow disturbance was important for *Picea* regeneration, as they found significantly more *Picea* seedling on disturbed microsites.

Chen and Popadiouk (2002) expect that proportion of small gaps and large gaps can change species recruitment and proportions because of light conditions since light is one of the most important resources for seedling establishment.

Caccia and Ballare (1998) in a study of regeneration and understorey vegetation found that dense canopies of saplings and understorey vegetation reduced survival and total biomass of seedlings.

Mori and Takeda (2004) reported thatlack of sufficient regeneration is a major problem of mountain forests. Most studies on subalpine forests have reported poor seedling recruitment in under stories of undisturbed old-growth forests.

Chapter 3

MATERIAL AND METHODS

The present investigation entitled "Altitudinal Variation in

Phenology,Seedling Characteristics and Natural Regeneration of *Abies pindrow*" was conducted at Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir during the years 2013 and 2014. Details about the study site, experimental site, materials used and methodology adopted during the course to achieve the aims and objectives of study are discussed in this chapter.

3.1 Study site

S. No.	Name of Forest Division	Sites	Available Aspects	Altitudes (m)	Latitude	Longitude
1.	Sindh	LowerSonamarg	NE	2,300-2,600	34° 17′	75° 17″
		MiddleThajwas	NE	2,600-2,900	34° 20′	75° 18″
		UpperThajwas	SW	>2900	34°25′	75° 21″
2.	Tangmarg	Tangmarg	SE	2,300-2,600	34 °18′	74 ° 20″
		Gulmarg	SW	2,600-2,900	34° 12′	74°22″
		Kongdari	NW	>2900	34°19′	74° 23″

Thestudy were concentrated along the three altitudinal gradients 2,300-2,600m, 2,600m-2,900m and above 2,900m amsl with following edaphic and climatic characteristics.

3.1.2 Geology and soil

The major portion of Sindh Forest Division is covered by massive panjal traps with little vegetation, while as the recent alluvium and karewa deposits cover the remaining area leaving very small portion occupied by Triassic limestone and other formations of the older age. The main litho units exposed are traps, slates, quartzites, limestone and shales besides the alluvium and karewa clays. The underlying rock determines various soil formations. The depth of the soil depends upon the slope and the dip of the rock. In general steeper the slope shallower the soil. In Tangmarg Forest Division the geological formation of the area are agglomeratic slates and trap, lower gondwana beds composed of charts, slicabus shales, carbonaceous shales and flaggy beds of guartazita which in their constitution are largely pyroclastic Lime stones,slates and dolomites are theimportant components of the rocksystem.Rocks are of light blue or grey tint, compact and homogeneous and sometimes dolomites in composition.

3.1.1 Climate

The area has temperate climate experiencing four distinct seasons: a severe winter (December to February), a cold spring (March to May), a mild summer (June to August) and a pleasant autumn (September to November). The mean annual temperature in Sonamarg ranges from a minimum of -8.1°C in January to a maximum of 19.1°C in July. The average annual precipitation at Sonamarg varies from 932-1050mm, of which about 73% is recorded during winter and spring and the rest during autumn. The mean annual temperature along the Tangmarg ranges from -1.4 to -10.3°C in January to a maximum of 17.6°C in July. The mean temperature during the warmest month of July is 22.0°C. The average annual precipitation varies from 1049-1100 mm of which about 69% is recorded during winter and spring and the rest during autumn.

3.2 Nursery experimental site

3.2.1 Location

The laboratory work was carriedout at the Forest Laboratory of Faculty of Forestry, Camp Wadura of Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir during 2013 and 2014. The experimental site i.e. forest nursery Wadura is located between 34.08^{o} N latitude and 74.83^{o} E Longitude and is about 1,587 meters above mean sea level. Average altitude of Kashmir (valley zone) ranges between 1,500-2,300 meter above mean sea level. The experimental site is roughly 80 km from Srinagar city.

3.2.2 Climate

The climate in general is temperate type. Winter is severe extending from December to March. The region faces a wide temperature range from a minimum of -8^{o}C in winter to a maximum of 33^{o}C in the summer. Winter frost is common and medium to heavy snowfall is witnessed. The area receives an annual precipitation of 675-1,193 mm.

3.3 Altitudinal variation in morphometric observationsin *Abies pindrow* at different altitudes in Kashmir

To study variation inmorphometric observationsfollowingobservations were recorded:

i) *Height of trees* (*m*):Average height of trees was measured by Ravi's multimeter.

ii) *Diameter at breast height* (*cm*): Average diameter of trees was measured at breast height by using diameter tape.

iii) *Crown depth* (*m*)*:* It is the height of a crown as measured vertically from the top of crown to the point half way between the lowest green branch and the branches forming green crown all round.

iv) *Crown width* (*m*): The crown width was measured in two directions(North-South and East-West) and average was calculated as suggested byChaturvedi and Khanna (1982).

$$CW = \frac{D_1+D_2}{2}$$

Where, CW= Crown width (m)

D_1 = First measured crown basal diameter in meters.

D_2 = Second measured crown basal diameter at right angle to the first measured inmeters.

For taking these observations 15 trees were selected randomly at least 100m apart at each selected site.

v) *Basal area of trees* (m^2):Basal area was calculated by the formula:

$$\text{Basal area} = \frac{\pi d^2}{4}$$

Where, d = diameter at breast height

3.4 Studyof phenological characteristic of *Abies pindrow*at different

altitudes

To study phenological observations of *Abies pindrow* below mentioned observations were recorded fortnightly from March at selected sites(Altitudes) to November.

i) *Leaf fall*: Leaf fall was recorded fortnightly fromMarch to November by markingthe trees at all the sites (altitudes) bytying a net around the selected branches of canopy in all four directions. 20 trees replicated thrice were selectedat each altitude for taking the observations

ii) *Leaf renewal* : Leaf renewal was also recorded fortnightly w.e.f.March to November by ocular observations. 20 trees replicated thrice were selected per site for taking the observations.

iii) *Appearance of male and female cones*:Trees with well-developed crown were visited after every 10 days from the late Marchtill their appearance and observation was taken from the ground level.

3.5 Study of altitudinal variation in cone and seedmaturity in seeds of *Abies pindrow* at differentstages of maturity

3.5.1 Maturity indices (Physical)

Cones were harvested from randomly selected phenotypically superior trees, fortnightly with effect from July till their maturationfrom all the selected sites. Thestudy was conducted on the cones of 10 phenotypically superior trees about 100 m apart from one another from each site on each collection date. 40 cones were harvested from 10 trees selected and following parameters were recorded at each collection date.

a) *Cone colour*: The cone colour was recorded by ocular estimation The cones were harvested with effect from July fortnightly and observations with regard to change in cone colour to different shadesby using colour chart till their maturation was recorded.

b) *Cone weight* (*g*): Cones were harvested with effect from July from all the sites till their maturationat an interval of fifteen days. Cone Weight of 40 cones replicated thrice was taken from each site by using top pan balance.

c) *Cone specific gravity*: Floating test or water displacement method (Barnett, 1979) was used to determine the cone specific gravity at each collection date and value was determined by the ratio of unit weight of cones to unit weight of volume of water displaced.

$$\text{Specific gravity} = \frac{\text{Weight of cone (g)}}{\text{Weight of volume of water displaced (cc)}}$$

d) *Cone length and diameter* (*cm*): Length of 20 collected cones replicated thrice from each site was measured with the help of electronic digital vernier caliper.

e) *Seed number/cone*: Seed number per cone was determined after manual extraction of seeds from 20 cones from each site replicated four times.

f) *Seed colour:*The seed colour was recorded by ocular estimation by using colour chart.

g) *Seed weight*: Seed weight of 100 seeds was recorded using eight replications of 100 seeds each with the help of sensitive top pan balance and was finally transformed into 1,000 seed weight by multiplying the seed weight of 8 replicates by 1.25 (ISTA,1993).

h) *Seed dimensions* : Seed dimensions were measured from 20 seeds replicated thrice with the help of electronic digital vernier caliper.

i) *Moisture content* : Moisture content was calculated as per ISTA 1993 rules (oven drying at103±3°C for 16±3 hrs) and moisture content was expressed in percentage on fresh weight basis determined by the following formula:

$$\frac{\text{Fresh seed weight} - \text{Dry weed weight}}{\text{Fresh seed weight}} \times 100$$

j)*Seed viability:* The viable seeds include the seeds that germinated during the test period and the seeds that were sound at the end of the testperiod

k) *Germination percent* (%):Germination test was conducted in glass Petri glass plates on top of a germination paper. Four replicates of 100 seeds each were used for the test. Germination percent was recorded by the formula:

$$\text{Germination (\%)} = \frac{\text{Number of seeds germinated}}{\text{Total number of seed sown}} \times 100$$

3.6 Germination behaviour of seeds in response to chilling

The seeds collected from different altitudes atthe time of maturitywere cleaned and dewinged after which the seeds were placed on moistened filter paper for two days to avoid the damage caused by rapid hydration when seeds are soaked. The seeds were then refrigerated at a temperature of 3±1^{o}C for varying periods of time as given below.Two sets of seeds were prepared for each treatment simultaneously and subjectedto laboratory and nursery performance.

Treatments		Moist stratification
T_1	:	Control
T_2	:	15 days
T_3	:	30 days
T_4	:	45 days
T_5	:	60 days

Laboratory performance of the seeds

No. of replications = 4

No. of Seeds per replication = 100

Design = CRD

Following observations were recorded during thelaboratory studies:

3.6.1 Germinability characteristics

a) *Germination percent* (%):Germination test was conducted in glass petri plates on top of a germination paper. Four replicates of 100 seeds each were used for the test. Germination percent was recorded by the formula:

$$\text{Germination (\%)} = \frac{\text{Number of seeds germinated}}{\text{Total number of seed sown}} \times 100$$

b)*Germination value* (*GV*)*:* Czabator (1962) coined the word GV, and related it to mean daily germination and peak value (MDG x PV). The same was later modified by Djavanshir and Pourbeik (1976).

$$GV = \frac{\Sigma DGS}{N \times (GP \times 10)}$$

Where,

DGS=Daily germination speed=Cumulative germination (%)/No. of test days.

N= Frequency or number of DGS during the test

GP= Germination per cent at the end of the test

c)*Mean germination time* (*MGT*):It is an expression of total germination at the end of test period withtime taken to complete germination Bonner (1983).

$$MGT = \frac{\Sigma\ (\text{Daily germination} \times \text{days})}{\text{Number of seeds sown}}$$

Ungerminated seeds at the end of the test will be given value of n+1

Where n = Number of days in the test and these values were included in the calculation ofmeans.

d)*Germination energy* (%): Germination energy was calculated by the formula:

$$\text{Germination energy} = \frac{\text{No. of seeds that germinated upto peak time of germination}}{\text{No. of seeds sown}} \times 100$$

3.6.2 Seedling parameters under laboratory conditions

Following seedling parameters were taken at the end of the test period

a)*Plumule length* (*cm*):Length of the plumule of 10 seedlings replicated thrice was recorded using scale upto two decimal places at the end of the germination test.

b) *Radical length* (*cm*):Length of radical was measured up to two decimal places at the end of germination test.

c) *Vigour index:* For this total length of seedling (length of plumule+ length of radical) was multiplied by total germination percent (Bhattacharya *et al*., 1991).

Vigour index (VI) = Total seedling length × germination per cent

d) *Number of cotyledons*: They were counted at the time of emergence of seedling in petri glass plates and recorded.

3.6.3 Nursery performance of theseeds of *Abies pindrow*

Poly bag Size	=	5″ x 7″
Media	=	2:1:1 (Soil, Sand, FYM)
No. of replications	=	4
No. of Seeds per replication	=	100
Design	=	CRD

The stratified seed weresown in poly bags (5″×7″) containing sand and soil in the ratio of 1:1 and following observations were recorded.

a)*Germination percent* (%):It is the percent of sown seeds that germinated at the completionof germination.

b)*Mean germination time* (*MGT*): It was calculated by the formula:

$$MGT = \frac{\Sigma \text{ (Daily germination} \times \text{days)}}{\text{Number of seeds sown}}$$

Ungerminated seeds at the end of the test will be given value of n+1

Where n = Number of days in the test and these values were included in the calculation of means.

c)*Seedling height* (*cm*):The height was taken at the end of the growing season by measuring scale.

d) *Collar diameter* (*mm*)*:* It was taken at the end of growing season with the help of electronic Vernier caliper in millimetre.

e)*Length of root*(*cm*)*:*Length of the root included the length of the longest root at the end of the growing season and was recordedwith a measuring scale.

f)Number of roots/seedling: The number of roots included the secondary roots counted at the end of the growing season.

g)*Biomass:* Itis expressed in grams as the sum of fresh root weight and fresh shoot weight.

h)*Shoot : Root ratio:*The ratio was worked out on fresh weight basis by dividing the weight of fresh shoot by weight of fresh root ofthat plant.

i)*Survival percent:* It is the percent of germinated seeds survived at the completion of growing season

3.7 Natural regeneration status of *Abies pindrow* at different altitudes

Sampling methodology

Step I: At each selected forest division, three altitudinal/elevation zones/stratas viz.2,300-2,600 m, 2,600-29,00 m and, above 2,900 m, were selected.

Step II: Three plots measuring 50×50 m were laid at each elevation zone for collecting the requisite information.

Step III: Within each 50 × 50 m plot, five (10 × 10 m) quadrate werelaid randomly for collecting informationpertaining to mature trees.

Step IV: Within each 10 × 10 m quadrate five (2 × 2 m) quadrates were laid for recording the information pertaining to seedlings and saplings.

The natural regeneration of *Abies pindrow*was determined by the procedure followed by Uma Shankar (2001) and Anitha,*et al.* (2010).The individuals with >11 cm girth at breast height (1.37m) and > 2 meter height were considered as trees.Individuals having 1-11 cm collar girth and 0.5-≤ 2 meter height were considered as saplings and individuals≤ 1cm collar girth and ≤ 0.5 m was recorded as seedlingand the status was catogorised as:

Good:- If present in the order of seedling> sapling> mature strata

Fair:- If present in the order of seedling> sapling< mature strata

Poor:- If a species survive only in the sapling stage, but not as seedlings (even through saplings may be less than, more than, or equal to mature).

None:-If the individuals were absent in sapling and seedling stage but present only as mature individuals.

3.8 Statistical analysis

The entire data generated from the present investigation were subjected to statistical analysis as per methods described by Gomez and Gomez (1984). The least significant difference at 5 per cent level were used for testing the significant differences among treatments. The data for both the years of investigation were pooled after performing homogeneity test. The heterogeneous data were pooled by the weighed means method as described by Nigam and Gupta (1979). Statistical package used was OP Stat.

Chapter-4

EXPERIMENTAL FINDINGS

The results derived from the statistical analysis of data pooledover 2 years (2013 and 2014)in the present investigation entitled“Altitudinal Variation in Phenology, Seedling Characteristics and Natural Regeneration of *Abiespindrow*”are presented in this chapter under the following headings :

4.1 Altitudinal variation in morphometric characteristics of *Abies pindrow*

at different altitudes

4.1.1 Tree height (m)

The data (Table1) revealed that there is decrease in the tree height from lower altitudes to higher altitudes in both the forest divisions. In Tangmarg Forest Division no significant decrease in height was recorded between lower (2,300-2,600 m) and middle altitude (2,600-2900 m) in which the tree height was recorded as 28.28 and 25.04m respectively. Statistically least tree height was recorded as 17.18 m at upper altitude (>2,900 m) in Tangmarg Forest Division.

Similarly in Sindh Forest Division the tree height at lower (2,300-26,00 m), middle (2,600-2,900 m)and upper altitude(>2,900 m)were recorded as 31.60, 25.66 and 17.28m respectively with no statistical difference between upper and middle altitude.

4.1.2 Diameter of tree at breast height (cm)

Diameter of trees at breast height revealedthatlower(2,300-2,600 m) and middle(2,600-2,900 m) altitude in Tangmarg Forest Division were atpar and the diameter was recorded as 35.66 and 31.10 cm respectively. The minimum diameter recorded at upper altitude (>2,900 m) varied significantly from lower altitude and middle altitude and was recorded as 17.00 cm.

In Sindh Forest Division, the diameter at lower (23,00-2,600 m), middle(2,600-2,900 m) and upper altitude (>2,900 m)were recorded as 38.90, 29.93 and 14.88 cm respectivelyandallwerestatisticallydifferent from one another (Table1).

4.1.3 Tree basal area $(cm)^2$

The results on basal area (Table1) showed that there is a sharp decline in the basal area from lower altitudes to higher altitudes. Tree basal area declined significantly from lower altitudes to higher and was recorded as 998.70, 755.91 and 226.86 cm^2 at lower (2,300-2,600m), middle(2,600-2,900m) andupper altitude (>2900 m) in Tangmarg Forest Division.

In Sindh Forest Division, similar results were recorded. The basal area at lower (2,300-2,600 m), middle (2,600-2,900 m) and upper altitude (>2900 m) were recorded as 1186.86, 703.28 and 157.00cm^2 respectively and were statistically different.

4.1.4 Tree crown spread (m)

The crown spread differed significantly at all the altitudinal sites in Tangmarg Forest Division. The maximum crown spread of 4.06 m was recorded at middle altitude (2,600-2,900 m). The crown spread at lower (2,300-2,600 m), and upper altitude (>2900 m) were recorded as 3.32 and 2.56 m respectively (Table1).

In Sindh Forest Division, the crown spread at lower (2,300-2,600 m) and middle (2,600-2,900 m) altitudes were at par and were recorded as 3.45 and 3.77 m respectively. The minimum crown spread of 2.20 m was recorded at upper altitude (>2,900 m) which differed significantly from other two altitudes (Table1).

4.1.5 Tree crown length (m)

The data presented on crown length (Table 1) shows significant difference among the selected altitudes. In Tangmarg Forest Division maximum crown length of 22.16 m was recorded at middle altitude. The crown length at lower and upper altitudes were recorded as 19.24 and 14.24 m respectively. Similarly in Sindh Forest Division, the maximum crown length of 22.95 m was recorded at middle altitude (2,600-2,900 m). The crown length at lower (2,300-2,600 m) and upper altitude (>2900 m)were recorded as 20.40 and 12.58 m respectively.

Table1:Altitudinal variation inmorphometriccharacteristics of Fir (*Abies pindrow*)

Altitude (m)	Tangmarg ForestDivision					Sindh ForestDivision				
	Tree height (m)	Tree diameter (cm)	Tree basal area(cm)^2	Tree crown spread(m)	Tree crown length(m)	Tree height (m)	Tree diameter (cm)	Tree basal area (cm)^2	Tree crown spread(m)	Tree crown length (m)
2300-2600	28.28	35.66	998.70	3.32	19.24	31.60	38.90	1186.86	3.45	20.40
2600-2900	25.07	31.10	755.91	4.06	22.16	25.66	29.93	703.28	3.74	22.95
>2900	17.18	17.00	226.86	2.56	14.24	17.28	14.88	157.00	2.20	12.58
Mean	**23.51**	**27.92**	**660.49**	**3.30**	**18.55**	**24.85**	**27.90**	**682.38**	**3.13**	**18.64**
CD (≤ 0.05)	**7.51**	**5.85**	**41.23**	**0.69**	**2.55**	**6.85**	**6.15**	**66.74**	**0.77**	**1.75**

Leaf renewal (Mid April)

Female cone (Late April)

Male cones (Late April)

Plate 1: Phenological events in *Abies pindrow*

4.2 Phenological variations in *Abies pindrow* at different altitudes

4.2.1 Leaf renewal

The altitude exerted a strong influence on leaf renewal. The leaf renewal took place in the 2^{nd} fortnight of April at lower altitudes (Plate-1) whereas at middle and upper altitudes it took place during first fortnight of May in both the forest divisions (Table 2).

4.2.2 Leaf fall

The leaf fall took place throughout the year at all the selected altitudes in both the forest division and was not influenced by the altitude. Thus the leaf fall lacked seasonality (Table 2).

4.2.3 Appearance of male and female cones

Both the male and female cones were seen during 2^{nd} fortnight of Aprilat (Plate-1)lower altitudes (2,300-2,600 m) whereas at middle (2,600-2,900 m) and upper altitude (>2,900 m) they were visible during 1^{st}fortnight of May in both the forest divisions (Table 2).

4.3 Altitudinal variation in cone and seed maturity at different altitudes as influenced by collection dates

In order to develop cone and seed maturation indicators, for judging seed maturity, seeds were collected regularly from ten phenotypically superior trees from 1^{st}July till maturation at an interval of 15 days from the selected altitude and following observations were recorded.

4.3.1 Cone colour

The cone colour in*Abies pindrow* as indicated in Table 3 was initially observed as deep purple (Plate-3)and no change in cone colour was recorded for the first three collections throughout the selected altitudinal stratas in both the forest divisions. By the 15^{th} August the cones lost the lusture and the cones colour changed to light purple. However, thecones were still deep purple at the upper altitude

Table 2 :Altitudinal variation inphenology of fir (*Abies pindrow*)

Observation recorded	Tangmarg Forest Division			Sindh Forest Division		
	2300-2600	**2600-2900**	**>2900**	**2300-2600**	**2600-2900**	**>2900**
Appearance of male cone	April	May	May	April	May	May
Appearance of female cone	April	May	May	April	May	May
Leaf renewal	April	May	May	April	May	May
Leaf fall	Throughout the year	Throughout the year	Throughout the year	Throughout the year	Throughout the year	Throughout the year

Plate 2: Fir cones collection from standing trees

Stage 1^{st} Stage 2^{nd} Stage 3^{rd}

Plate 3: Cone color changes at different maturity stages

Table 3:Altitudinal variation in cone colour as influenced by collection dates at different altitudes

Forest Division	Cone colour										
	Altitude(m)	Collection dates									
		1st fortnight of July	2nd fortnight of July	1st fortnight of Aug	2nd fortnight of Aug	1st fortnight of Sep	2nd fortnight of Sep	1st fortnight of Oct	2nd fortnight of Oct	1st fortnight of Nov	2nd fortnight of Nov
Tangmarg	2300-2600	Deep purple	Deep purple	Deep purple	Light purple	Purple with chocolate patches	Chocolatewith purple scale edges	Chocolatewith purple scale edges	Chocolatewith purple scale edges	Dispersed	Dispersed
	2600-2900	Deep purple	Deep purple	Deep purple	Light purple	Purple with chocolate patches	Chocolatewith purple scale edges	Chocolatewith purple scale edges	Chocolatewith purple scale edges	Dispersed	Dispersed
	>2900	Deep purple	Deep purple	Deep purple	Deep purple	Light purple	Purple with chocolate patches	Chocolatewith purple scale edges	Chocolatewith purple scale edges	Chocolatewith purple scale edges	Dispersed
Sindh	2300-2600	Deep purple	Deep purple	Deep purple	Light purple	Purple with chocolate patches	Chocolatewith purple scale edges	Chocolatewith purple scale edges	Chocolatewith purple scale edges	Dispersed	Dispersed
	2600-2900	Deep purple	Deep purple	Deep purple	Deep purple	Purple with chocolate patches	Chocolatewith purple scale edges	Chocolatewith purple scale edges	Chocolatewith purple scale edges	Dispersed	Dispersed
	>2900	Deep purple	Deep purple	Deep purple	Deep purple	Light purple	Purple with chocolate patches	Chocolatewith purple scale edges	Chocolatewith purple scale edges	Chocolatewith purple scale edges	Dispersed

(>2,900 m) in both the forest divisions. By the 1st September, chocolate patches appeared in the cone at lower and middle altitudes and changed to chocolate with purple scale edges by the 15th September at lower (2,300-2,600 m) and middle altitudes (2,600-2,900 m). At the upper altitude (>2,900 m) the cone colour at the same collection date was recorded as purple with chocolate patches in both the forest divisions. By the 1st October, the cone colour at all the selectedaltitudes in both the forest divisions was recorded as chocolate with purple scale edges after which no further change was recorded.

4.3.2 Cone weight (g)

The cone weight increased from first collection period (1st July) to fourth collection (15th August) and then declined as the collection progressed at all the selected altitudes in both the forest divisions (Table 4).

In Tangmarg Forest Division, at lower altitude (2,300-2,600 m), the cone weight was 70.33 g on 1st July and increased initially and reached to a maximum of 104.32g by the 15th August. Thereafter it started decreasing as the collection advanced and was recorded as 87.18 g at maturity on 15th October. Similarly at middle altitude (2,600-2,900 m), the cone weight on first collection date was recorded as 51.00 g which increased to 83.48 g by the 15th August and then decreased to 73.33 g by 15th October. At the upper altitude (>2,900m), the cone weight recorded as 41.16 g onfirst collection period (1st July) reached to a maximum of 78.13 g by the 15th August and thendecreased to 69.36 g at maturity (1st November). Progressive decrease was recorded in cone weight as we moved from lower altitude to higher altitude.

In Sindh Forest Division, much similar trend was recorded. At lower altitude (2,300-2,600 m),thecone weightrecorded as 70.56 g on first collection (1st July) date increased to 91.19 gby the 15thAugust. Thereafter the cone weight started decreasing and was recorded as 78.60 g by 15th October at maturity. At middle altitude (2,600-2,900m), the cone weight recorded as66.59g on first collection date

Table 4:Altitudinal variation in cone weight as influenced by collection dates at different altitudes

Forest Division	Altitude (m)	Cone weight (g) (±SD)									
		Collection dates									
		1st fortnight of July	2nd fortnight of July	1st fortnight of Aug	2nd fortnight of Aug	1st fortnight of Sep	2nd fortnight of Sep	1st fortnight of Oct	2nd fortnight of Oct	1st fortnight of Nov	2nd fortnight of Nov
Tangmarg	2300-2600	70.33 ±4.98	81.33 ±5.67	93.64 ±5.11	104.32 ±3.84	97.76 ±6.35	91.67 ±5.93	86.48 ±6.00	87.18 ±3.13	Dispersed	Dispersed
	2600-2900	51.00 ±5.60	66.48 ±7.08	76.46 ±8.01	83.48 ±6.95	80.56 ±4.96	77.80 ±7.48	74.48 ±3.95	73.33 ±2.00	Dispersed	Dispersed
	>2900	41.16 ±4.41	54.4±4.08	65.76 ±4.00	78.13 ±3.49	74.61 ±4.26	71.76 ±5.11	71.35 ±2.85	70.33 ±4.34	69.36 ±4.30	Dispersed
Sindh	2300-2600	70.56 ±3.80	76.43 ±3.89	85.19 ±5.12	91.19 ±6.08	86.28 ±5.91	83.48 ±4.06	81.52 ±4.60	78.60 ±5.92	Dispersed	Dispersed
	2600-2900	66.59 ±5.52	79.37 ±5.97	92.29 ±4.02	98.18 ±6.88	89.13 ±4.77	86.30 ±5.91	85.46 ±4.94	82.48 ±5.93	Dispersed	Dispersed
	>2900	37.30 ±4.75	48.5±5.02	60.41 ±5.90	77.58 ±7.34	71.33 ±6.00	70.29 ±4.93	68.1±7.44	65.11 ±3.55	61.66 ±3.46	Dispersed

(1st July) increased to a maximum of 98.18 by the 15th August. Thereafter a decreasing trend was recorded in the subsequent collections and the cone weight decreased to 82.48 by 15th October at maturity. Similarly, at upper altitude (>2,900 m),the cone weight recorded as 37.30 g on first collection date (1st July)increased to 77.58 gby the 15th August and then decreased to 61.66 g at maturity(1st November) (Table 4).

4.3.3 Cone specific gravity

It is evident from the Table 5 as the collection progressed the cone specific gravity decreased. In Tangmarg Forest Division, at lower altitude (2,300-2,600 m), the specific gravity recorded as 1.18 on first collection(1st July)decreased to 0.76 at maturity (15th October). The specific gravity at middle (2,600-2,900 m) and upper altitude (>2,900 m) decreased from 1.20 to 0.84 and 1.21 to 0.70 from first collection to final collection respectively.

In Sindh Forest Division, at lower altitude (2,300-2,600 m), the specific gravity recorded as 1.20 on first collection date (1st July)decreased to 0.79 at maturity (15th October). Similarly at middle altitude (2,600-2,900 m), the specific gravity decreased from 1.21 on first collection date (1st July)to 0.81 at maturity. At upper altitude (>2,900 m), the specific gravity on first collection date (1st July) recorded as 1.25 decreased to 0.74 at maturity (1st November).

4.3.4 Cone length (cm)

The cone length increased as the collection progressed (Table 6). At lower altitude (2,300-2,600 m) the cone length increased from 11.20 cm (1st July) to 12.00 cm at maturity (15th October) and was recorded as the maximum when compared to other altitudes of Tangmarg and Sindh Forest Divisions. At middle (2,600-2,900 m) and upper altitude (>2,900 m),the cone length was recorded as 9.16 and 8.81 cm at the commencement of collection (1st July) which at maturity increased to 10.89 and 10.50 cm respectively.

Table 5:Altitudinal variation in cone specific gravity as influenced by collection dates at different altitudes

Forest Division	Cone specificity gravity (±SD)										
	Altitude (m)	Collection dates									
		1st fortnight of July	2nd fortnight of July	1st fortnight of Aug	2nd fortnight of Aug	1st fortnight of Sep	2nd fortnight of Sep	1st fortnight of Oct	2nd fortnight of Oct	1st fortnight of Nov	2nd fortnight of Nov
Tangmarg	2300-2600	1.18±0.06	1.13±0.05	1.07±0.03	1.04±0.03	1.02±0.04	0.99±0.01	0.93±0.02	0.76±0.03	Dispersed	Dispersed
	2600-2900	1.20±0.05	1.15±0.04	1.08±0.02	1.07±0.02	1.06±0.05	0.96±0.06	0.92±0.03	0.84±0.04	Dispersed	Dispersed
	>2900	1.21±0.03	1.15±0.04	1.09±0.03	1.08±0.05	1.06±0.07	0.98±0.04	0.97±0.02	0.74±0.03	0.70±0.04	Dispersed
Sindh	2300-2600	1.20±0.04	1.14±0.03	1.10±0.01	1.08±0.06	1.04±0.06	0.99±0.01	0.95±0.02	0.79±0.04	Dispersed	Dispersed
	2600-2900	1.21±0.05	1.10±0.04	1.06±0.03	1.03±0.04	1.01±0.03	0.98±0.02	0.94±0.04	0.81±0.06	Dispersed	Dispersed
	>2900	1.25±0.06	1.12±0.03	1.10±0.02	1.08±0.04	1.05±0.03	0.98±0.04	0.94±0.06	0.77±0.05	0.74±0.03	Dispersed

Table 6:Altitudinal variation in cone length as influenced by collection dates at different altitudes

Forest Division	Cone length (cm) (±SD)										
	Altitude (m)	Collection dates									
		1st fortnight of July	2nd fortnight of July	1st fortnight of Aug	2nd fortnight of Aug	1st fortnight of Sep	2nd fortnight of Sep	1st fortnight of Oct	2nd fortnight of Oct	1st fortnight of Nov	2nd fortnight of Nov
Tangmarg	2300-2600	11.20 ±0.17	11.32 ±0.11	11.43 ±0.04	11.46 ±0.45	11.86±0.25	11.88±0.58	11.98±0.44	12.00±0.17	Dispersed	Dispersed
	2600-2900	9.16 ±0.16	10.35 ±0.06	10.45 ±0.04	10.64 ±0.12	10.81±0.18	10.86±0.23	10.93±0.27	10.89±0.30	Dispersed	Dispersed
	>2900	8.81 ±0.20	9.50 ±0.23	10.29 ±0.19	10.40±0.11	10.43±0.07	10.45±0.16	10.48±0.12	10.51±0.07	10.50±0.20	Dispersed
Sindh	2300-2600	10.92 ±0.20	11.10 ±0.11	11.15 ±0.17	11.20±0.05	11.24±0.05	11.33±0.11	11.36±0.15	11.40±0.13	Dispersed	Dispersed
	2600-2900	10.03 ±0.22	11.14 ±0.15	11.18 ±0.17	11.40±0.10	11.63±0.15	11.61±0.18	11.65±0.15	11.65±0.23	Dispersed	Dispersed
	>2900	8.19 ±0.20	9.09 ±0.22	10.04±0.30	10.09±0.32	10.16±0.20	10.16±0.13	10.24±0.10	10.28±0.19	0.22±0.10	Dispersed

In Sindh Forest Division, At lower altitude (2,300-2,600 m),the cone length recorded as 10.92 cm on first collection date (1^{st} July)increased to 11.40 cm at maturity (15^{th} October). At middle altitude (2,600-2,900 m), the cone length increased from 10.03 cm on first collection date(1^{st} July)to 11.65 cm on maturity (15^{th} October)and was recorded maximum in this division. At upper altitude (>2,900 m), the cone length increased from 8.19 (1^{st} July) to 10.22 cm at maturity (1^{st} November).

4.3.5 Cone diameter(cm)

An inquisition of average data (Table 7) reveals that the cone diameter increased as the collection progressed. In Tangmarg Forest Division, at lower altitude (2,300-2,600m), conediameter increased from 3.97cm (1^{st} July) to 4.42 cm(15^{th} October) and was recorded as the maximum compared to other sites. At middle (2,600-2,900 m), and upper altitude (>2,900 m), conediameter increased from 3.12 (1^{st} July) to 3.94 cm (15th October) and 3.05 (1^{st} July) to 3.75cm(1^{st} November) respectively. The cone diameter decreased with increase in altitude

In Sindh Forest Division, at lower altitude(2,300-2,600 m), conediameter was recorded as 3.44 cm on first collection date(1^{st} July)which increased to 4.32 cm at maturity (15^{th} October). Atmiddle altitude (2,600-2,900 m), conediameter on first collection date (1^{st} July)recorded as 3.84 cm increased to 4.34cm at maturity (15^{th} October) and was recorded maximum in this division. At upper altitude (>2,900 m), cone diameter of 3.02 cm recorded on first collection date (1^{st} July) increased to 3.69 cm at maturity (1^{st} November).

4.3.6 Number of seeds/cone

The seed number was found more in the cones with greater cone length (Table 8). However the collection dates did not influence seed number and showed only small fluctuations. In Tangmarg Forest Division, at lower altitude (2,300-2,600m), which resulted in the highest cone length also had the highest seed number of 354.30 compared to all other altitudinal sites. Similarly in Sindh Forest Division

Table 7:Altitudinal variation in cone diameter as influenced by collection dates at different altitudes

Forest Division	Cone diameter (cm) (±SD)										
	Altitude (m)	Collection dates									
		1st fortnight of July	2nd fortnight of July	1st fortnight of Aug	2nd fortnight of Aug	1st fortnight of Sep	2nd fortnight of Sep	1st fortnight of Oct	2nd fortnight of Oct	1st fortnight of Nov	2nd fortnight of Nov
Tangmarg	2300-2600	3.97 ±0.32	4.19 ±0.20	4.33 ±0.26	4.27 ±0.22	4.31 ±0.30	4.35 ±0.26	4.36 ±0.17	4.42 ±0.23	Dispersed	Dispersed
	2600-2900	3.12 ±0.13	3.40 ±0.17	3.54 ±0.27	3.61 ±0.20	3.73 ±0.22	3.83 ±0.23	3.93 ±0.06	3.94 ±0.10	Dispersed	Dispersed
	>2900	3.05 ±0.15	3.31 ±0.30	3.51 ±0.30	3.55 ±0.26	3.60 ±0.17	3.64 ±0.19	3.70 ±0.30	3.74 ±0.22	3.75 ±0.16	Dispersed
Sindh	2300-2600	3.44 ±0.20	3.51 ±0.29	4.12 ±0.12	4.20 ±0.19	4.25 ±0.26	4.27 ±0.28	4.30 ±0.25	4.32 ±0.24	Dispersed	Dispersed
	2600-2900	3.84 ±0.26	4.15 ±0.19	4.24 ±0.30	4.19 ±0.25	4.28 ±0.28	4.33 ±0.30	4.31 ±0.32	4.34 ±0.27	Dispersed	Dispersed
	>2900	3.02±0.10	3.25 ±0.24	3.49 ±0.26	3.55 ±0.30	3.55 ±0.28	3.61 ±0.13	3.69 ±0.27	3.66 ±0.30	3.69 ±0.15	Dispersed

Table 8:Altitudinal variation in seed number as influenced by collection dates at different altitudes

Forest Division	Altitude (m)	Seed number(±SD)									
		Collection dates									
		1st fortnight of July	2nd fortnight of July	1st fortnight of Aug	2nd fortnight of Aug	1st fortnight of Sep	2nd fortnight of Sep	1st fortnight of Oct	2nd fortnight of Oct	1st fortnight of Nov	2nd fortnight of Nov
Tangmarg	2300-2600	352 ±10.00	363.00 ±12.00	356.30 ±12.02	353.87 ±9.02	349.66 ±11.02	354.00 ±11.00	357.34 ±12.50	354.30 ±10.50	Dispersed	Dispersed
	2600-2900	311.30 ±10.07	313.60 ±9.61	318.00 ±12.00	317 ±13.11	322.00 ±12.00	316.49 ±14.00	324.36 ±10.07	321.60 ±17.00	Dispersed	Dispersed
	>2900	265.50 ±14.50	268.40 ±14.00	275.70 ±17.80	276.85 ±12.66	276.66 ±14.47	279.28 ±11.53	275.20 ±12.77	280.10 ±11.93	274.00 ±10.09	Dispersed
Sindh	2300-2600	330.25 ±5.03	329.60 ±5.69	329.14 ±12.77	334.18 ±11.02	339.49 ±6.66	325 ±8.54	329.78 ±9.02	330.10 ±10.07	Dispersed	Dispersed
	2600-2900	340.70±5.13	346.80 ±7.77	340.33 ±5.51	345.72 ±11.59	351.45 ±8.08	342 ±9.17	338.30 ±7.64	343.12 ±7.73	Dispersed	Dispersed
	>2900	240.30 ±7.51	244.70 ±10.02	246.12 ±6.00	237.48 ±10.79	246.39 ±4.73	245.68 ±5.69	247.79 ±6.43	250.29 ±2.52	241.45 ±5.21	Dispersed

Stage 1st **Stage 2nd** **Stage 3rd**

Plate 4: Seed colour changes at different stages of maturity

Stage 1^{st}

Stage 2^{nd}

Stage 3^{rd}

Plate 5: Cone colour changes associated with changes in seed colour at different stages of maturity

Plate 6: Cone dispersal in *Abies pindrow* at upper altitude (above 2,900 m)

the middle altitude which resulted in the maximum cone length also yielded more seeds than lower altitude and upper altitude. The seed number at maturity was recorded as 343.12. The least number of seeds were recorded as 241.45 at upper altitude (>2,900) in Sindh Forest Division.

4.3.7 Seed colour

The seed colour (Table 9) was recorded as deep pink throughout (Plate-4)the altitudinal collection in both the forest divisions at the commencement of collection (1^{st}July)and then changed to pinkish at lower (2,300-2,600 m) and middle altitudes(2,600-2,900 m) during second collection whereas at the upper altitudethe seed colour was again recorded as deep pink. By 1^{st} August the seed colour changed from pinkish to light chocolate at lower and middle altitudes whereas at the upper altitude (>2,900), the seed colourat the same collection period was recorded as pinkish. On the 5^{th} collection (1^{st} Sep), the seed colour was recorded as deep chocolate at all the selected altitudes of both the forest divisions. No further change in seed colour was recorded till their dispersal.

4.3.7 Seed weight (g/1000)

The seed weight per 1,000 seeds (Table 10) increased as the collection progressed. In Tangmarg Forest Division, the seed weight at lower altitude (2,300-2,600m) increased from 37.36 g/1000 (1^{st} July) to 79.47 g/1000 (15^{th} October) and was recorded as the maximum. At middle (2,600-2,900 m), and upper altitude (>2,900 m), the seed weight increased from 28.34 g/1000 (1^{st} July) to 69.22 g/1000 (15^{th} October) and 26.40 g/1000 (1^{st} July) to 65.25 g/1000 (1^{st} November) respectively. The seed weight decreased with increase in altitude.

In Sindh Forest Division, at lower altitude (2,300-2,600 m), seed weight was recorded as 33.46 g/1000 on first collection date (1^{st} July)which increased to 71.14 g/1000 at maturity (15^{th} October). At middle altitude (2,600-2,900 m), the seed weight on first collection date (1^{st} July)recorded as 31.47 g/1000 increased to 75.38g/1000at maturity (15^{th} October) and was recorded maximum in this

Table 9:Altitudinal variation in seed colour as influenced by collection dates at different altitudes

Forest Division	Seed colour										
	Altitude (m)	Collection dates									
		1st fortnight of July	2nd fortnight of July	1st fortnight of Aug	2nd fortnight of Aug	1st fortnight of Sep	2nd fortnight of Sep	1st fortnight of Oct	2nd fortnight of Oct	1st fortnight of Nov	2nd fortnight of Nov
Tangmarg	2300-2600	Deep pink	Pinkish	Light chocolate	Deep chocolate	Deep chocolate	Deep chocolate	Deep chocolate	Deep chocolate	Dispersed	Dispersed
	2600-2900	Deep pink	Pinkish	Light chocolate	Deep chocolate	Deep chocolate	Deep chocolate	Deep chocolate	Deep chocolate	Dispersed	Dispersed
	>2900	Deep pink	Deep pink	Pinkish	Deep chocolate	Deep chocolate	Deep chocolate	Deep chocolate	Deep chocolate	Deep chocolate	Dispersed
Sindh	2300-2600	Deep pink	Pinkish	Light chocolate	Deep chocolate	Deep chocolate	Deep chocolate	Deep chocolate	Deep chocolate	Dispersed	Dispersed
	2600-2900	Deep pink	Pinkish	Light chocolate	Light chocolate	Deep chocolate	Deep chocolate	Deep chocolate	Deep chocolate	Dispersed	Dispersed
	>2900	Deep pink	Deep pink	Pinkish	Light chocolate	Deep chocolate	Deep chocolate	Deep chocolate	Deep chocolate	Deep chocolate	Dispersed

Table 10:Altitudinal variation in seed weight as influenced by collection dates at different altitudes

Forest Division	Seed weight (g/1000) (±SD)										
	Altitude (m)	Collection dates									
		1st fortnight of July	2nd fortnight of July	1st fortnight of Aug	2nd fortnight of Aug	1st fortnight of Sep	2nd fortnight of Sep	1st fortnight of Oct	2nd fortnight of Oct	1st fortnight of Nov	2nd fortnight of Nov
Tangmarg	2300-2600	37.36 ±2.01	42.36 ±4.00	52.48 ±4.03	63.32 ±7.01	70.54 ±4.93	75.34 ±3.00	78.77 ±1.54	79.47 ±2.35	Dispersed	Dispersed
	2600-2900	28.34 ±1.87	31.44 ±5.02	40.50 ±3.68	47.25 ±4.89	57.21 ±3.19	65.23 ±5.18	68.35 ±4.35	69.22 ±3.32	Dispersed	Dispersed
	>2900	26.40 ±3.05	30.46 ±3.98	40.04 ±5.02	45.59 ±2.11	53.54 ±6.16	60.36 ±5.19	61.49 ±3.94	63.15 ±4.00	65.25 ±3.23	Dispersed
Sindh	2300-2600	33.46 ±3.05	40.41 ±3.92	50.13 ±4.98	62.43 ±4.05	67.61 ±2.71	68.39 ±5.04	70.83 ±2.02	71.14 ±3.66	Dispersed	Dispersed
	2600-2900	31.47 ±5.95	42.13 ±4.62	54.93 ±3.68	63.37 ±3.19	70.27 ±4.91	72.98 ±5.37	75.26 ±6.03	75.38 ±5.75	Dispersed	Dispersed
	>2900	25.38 ±5.17	28.34 ±4.04	36.10 ±5.97	44.11 ±4.10	48.46 ±2.43	54.19 ±4.91	57.35 ±6.94	62.11 ±3.37	62.16 ±3.32	Dispersed

upper altitude (>2,900 m), the seed weight of 25.38 g/1000 recorded at first collection date (1^{st} July)increased to 62.16 g/1000 at maturity (1^{st} November).

4.3.8 Seed length (mm)

The seed length increased (Table 11) as the collection progressed. At lower altitude (2,300-2,600 m) the seed length increased from 7.65 mm (1^{st} July) to 11.62mm at maturity (15^{th} October) and was recorded as the maximum when compared to other altitudes. At middle and upper altitude the seed length was recorded as 7.12 and 6.78mm at the commencement of first collection (1^{st} July) which at maturity increased to 10.41 and 9.98 mm respectively.

In Sindh Forest Division, At lower altitude the seed length recorded as 7.35 mm on first collection date (1^{st} July)increased to 11.21 mm at maturity (15^{th} October). At middle altitude, the seed length increased from 7.11 mm on first collection date (1^{st} July) to 11.35 mm and was recorded maximum in this division. At upper altitude, the seed lengthincreased from 6.70 mm (1^{st} July) to 9.78mm at maturity (1^{st} November).

4.3.9 Seed width(mm)

The data presented in the Table 12 revealed that seed width increased as the collection progressed during the entire collection period. In Tangmarg Forest Division, at lower altitude (2,300-2,600 m), the seed width increased from 3.62 mm (1^{st} July)to 5.54 mm (15^{th} October).The seed width at middle (2,600-2,900 m) and upper altitude (>2,900 m)on first collection date (1^{st}July) was recorded as 3.32 and 3.25 mm respectively and it increased to 5.27 and 4.56 mm respectivelyat maturity. Maximum seed width among altitudes was recorded as 5.54 mm at lower altitude (2,300-2,600 m) in Tangmarg Forest Division.

In Sindh Forest Division at lower altitude theseed width recorded as 3.41 mm on first collection date (1^{st} July)increased to 5.40 mm at maturity (15^{th} October). At middle altitude (2,600-2,900m), the seed width increased from 3.21 mm on first collection date (1^{st} July) to 5.48 mm and was recorded maximum in

Table 11:Altitudinal variation in seed length as influenced by collection dates at different altitudes

Forest Division	Altitude (m)	Seed length (mm) (±SD)									
		Collection dates									
		1st fortnight of July	2nd fortnight of July	1st fortnight of Aug	2nd fortnight of Aug	1st fortnight of Sep	2nd fortnight of Sep	1st fortnight of Oct	2nd fortnight of Oct	1st fortnight of Nov	2nd fortnight of Nov
Tangmarg	2300-2600	7.65 ±1.05	8.76 ±1.01	9.48 ±1.02	10.69 ±1.04	11.29 ±0.99	11.43 ±0.99	11.58 ±0.97	11.62 ±0.94	Dispersed	Dispersed
	2600-2900	7.12 ±1.01	8.45 ±1.01	8.87 ±1.02	9.37 ±1.00	10.09 ±0.99	10.18 ±0.95	10.36 ±1.04	10.41 ±1.02	Dispersed	Dispersed
	>2900	6.78 ±1.00	7.14 ±0.96	8.58 ±1.00	9.14 ±0.98	9.60 ±1.02	9.86 ±0.99	9.91 ±0.32	9.98 ±0.30	9.98 ±0.31	Dispersed
Sindh	2300-2600	7.35 ±1.03	8.21 ±0.20	9.09 ±1.01	10.14 ±0.36	11.04 ±0.35	11.09 ±0.99	11.18 ±0.87	11.21 ±0.79	Dispersed	Dispersed
	2600-2900	7.11 ±1.01	8.47 ±1.02	9.26 ±0.97	10.26 ±0.97	11.25 ±0.30	11.28 ±1.00	11.33 ±0.99	11.35 ±1.02	Dispersed	Dispersed
	>2900	6.70 ±1.00	7.02 ±0.47	8.33 ±0.65	9.05 ±0.45	9.36 ±0.33	9.50 ±0.50	9.61 ±0.60	9.71 ±0.61	9.78 ±0.94	Dispersed

Table 12:Altitudinal variation in seed width as influenced by collection dates at different altitudes

Forest Division	Altitude (m)	Seed width(mm) (±SD)									
		Collection dates									
		1st fortnight of July	2nd fortnight of July	1st fortnight of Aug	2nd fortnight of Aug	1st fortnight of Sep	2nd fortnight of Sep	1st fortnight of Oct	2nd fortnight of Oct	1st fortnight of Nov	2nd fortnight of Nov
Tangmarg	2300-2600	3.62 ±0.22	3.81 ±0.08	4.30 ±0.31	4.38 ±0.32	5.45 ±0.15	5.47 ±0.17	5.53 ±0.17	5.54 ±0.15	Dispersed	Dispersed
	2600-2900	3.32 ±0.22	3.40 ±0.30	4.02 ±0.24	4.16 ±0.17	5.00 ±0.22	5.18 ±0.20	5.24 ±0.21	5.27 ±0.24	Dispersed	Dispersed
	>2900	3.25 ±0.25	3.30 ±0.30	3.49 ±0.15	3.55 ±0.20	4.40 ±0.14	4.50 ±0.32	4.53 ±0.20	4.58 ±0.21	4.56 ±0.24	Dispersed
Sindh	2300-2600	3.41 ±0.20	3.51 ±0.14	4.10 ±0.19	4.16 ±0.14	5.12 ±0.10	5.25 ±0.24	5.32 ±0.22	5.40 ±0.10	Dispersed	Dispersed
	2600-2900	3.21 ±0.21	3.65 ±0.25	4.24 ±0.25	4.36 ±0.34	5.40 ±0.26	5.47 ±0.19	5.46 ±0.19	5.48 ±0.10	Dispersed	Dispersed
	>2900	3.19 ±0.19	3.23 ±0.21	3.33 ±0.24	3.48 ±0.27	4.00 ±0.17	4.02 ±0.23	4.06 ±0.10	4.25 ±0.25	4.26 ±0.26	Dispersed

this division. At upper altitude (>2,900 m), the seed width increased from 3.19 mm (1st July) to 4.26 mm at maturity (1st November) and was minimum amongst all other altitudes.

4.3.10 Seed moisture (%)

Themoisture content of the seeds decreased with each collection date(Table 13). In Tangmarg Forest Division, at upper altitude(2,300-2,600m), the moisture (%)was recorded as 82.41% in the seeds collected on first July which by maturity declined to 14.28%. At middle altitude (2,600-2,900m), the moisture (%) on first collection date (1st July)recorded as 90.41% declined to 15.35% at maturity (15th October). At the upper altitude (>2,900 m), the moisture (%) recorded as 91.88% on first collection date (1st July)declined to 11.08% at maturity (1st November).

In Sindh Forest Division, at lower division altitude (2,300-2,600 m),the moisture content recorded as 85.20% on first collection date (1st July) decreased to 12.54% at maturity (15th October). Similarly at middle (2,600-2,900 m) and upper altitude (>2,900 m), the moisture content decreased from 88.42% (1st July)to 14.38% at maturity (15th October) and 92.26% (1st July) to 11.51% at maturity (1st November).

4.3.11 Seed viability (%)

No viability in seeds was recordedfor the first two collections as no germination was recorded for these two collection periods (Table 14). The seed viability commenced on 1st August at all the altitudes and then kept on increasing up to dispersal. In Tangmarg Forest Division, at lower altitude (2,300-2,600 m) the viability increased from 12.50% (1st August) to 52.75% at maturity and was recorded as maximum when compared to other altitudinal collections in both the forest divisions. The viability at middle (2,600-2,900 m) and upper altitude (>2,900 m) on its commencement (1st August)was recorded as 7.75 and 7.00% respectively which on maturity increased to 43.25 and 40.25% at middle (2,600-

Table 13:Altitudinal variation in seed moisture as influenced by collection dates at different altitudes

Forest Division	Altitude(m)	Seed moisture (%) (±SD)									
		Collection dates									
		1st fortnight of July	2nd fortnight of July	1st fortnight of Aug	2nd fortnight of Aug	1st fortnight of Sep	2nd fortnight of Sep	1st fortnight of Oct	2nd fortnight of Oct	1st fortnight of Nov	2nd fortnight of Nov
Tangmarg	2300-2600	82.41 ±4.03	76.32 ±6.04	61.35 ±4.00	50.69 ±6.50	42.23 ±6.18	29.65 ±3.52	23.63 ±3.00	14.28 ±1.79	Dispersed	Dispersed
	2600-2900	90.41±3.00	81.44 ±5.10	71.61 ±7.13	64.29 ±4.05	46.28 ±5.90	31.36 ±3.14	24.41 ±3.06	15.35 ±1.99	Dispersed	Dispersed
	>2900	91.88 ±4.45	85.08 ±5.50	76.16 ±5.49	67.38 ±7.09	50.59 ±4.68	35.43 ±3.28	23.20 ±3.31	13.00 ±0.27	11.08 ±1.93	Dispersed
Sindh	2300-2600	85.2 0 ±2.80	76.57 ±3.76	66.39 ±4.99	54.38 ±3.80	41.32 ±3.01	28.37 ±4.20	24.58 ±2.27	12.54 ±1.01	Dispersed	Dispersed
	2600-2900	88.42 ±3.95	79.28 ±3.87	72.29 ±4.00	61.45 ±3.97	44.38 ±3.98	31.00 ±4.47	20.26 ±2.17	14.38 ±1.00	Dispersed	Dispersed
	>2900	92.26 ±4.79	86.38 ±3.95	73.35 ±3.13	64.63 ±3.70	46.60 ±3.35	35.63 ±3.70	23.41 ±1.91	16.53 ±2.62	11.51 ±0.72	Dispersed

Non-viable empty seeds **Viable seeds**

Plate 7: Seed viability

Plate 8: Seed germination studies in laboratory

Plate 9: Seed arrangement around and along the cone axis

Table 14:Altitudinal variation in seed viability as influenced by collection dates at different altitudes

Forest Division	Seed viability (%)										
	Altitude (m)	Collection dates									
		1st fortnight of July	2nd fortnight of July	1st fortnight of Aug	2nd fortnight of Aug	1st fortnight of Sep	2nd fortnight of Sep	1st fortnight of Oct	2nd fortnight of Oct	1st fortnight of Nov	2nd fortnight of Nov
Tangmarg	2300-2600	0.00	0.00	12.50 ±2.45	17.00 ±3.56	25.00 ±4.76	42.75 ±3.59	49.75 ±3.59	52.75 ±3.50	Dispersed	Dispersed
	2600-2900	0.00	0.00	7.75 ±1.70	16.25 ±4.03	23.50 ±3.70	28.25 ±3.59	40.25 ±2.63	43.25 ±2.64	Dispersed	Dispersed
	>2900	0.00	0.00	7.00 ±1.63	16.50 ±3.32	20.50 ±4.80	25.25 ±4.43	35.25 ±4.35	38.25 ±4.79	40.25 ±5.06	Dispersed
Sindh	2300-2600	0.00	0.00	11.50 ±1.73	15.50 ±3.51	22.00 ±4.08	36.50 ±5.92	45.50 ±7.51	46.50 ±4.20	Dispersed	Dispersed
	2600-2900	0.00	0.00	9.00 ±2.94	19.50 ±3.11	24.00 ±4.83	39.25 ±3.00	46.25 ±2.99	48.25 ±5.00	Dispersed	Dispersed
	>2900	0.00	0.00	6.75 ±2.50	10.50 ±1.29	15.25 ±1.50	19.75 ±3.86	29.50 ±4.65	34.50 ±4.65	36.50 ±2.38	Dispersed

2,900 m) and upper altitude(>2,900 m) respectively. Similarly in Sindh Forest Division the seed viability increased towards maturity. The middle altitude (2,600-2,900 m) resulted in higher viability at maturity and was recorded as 48.25%. The seed viability at lower (2,300-2,600 m) and upper altitude (>2,900 m) also kept on increasing with each collection date and at maturity were recorded as 46.50 and 36.50% respectively.

4.3.12 Germination percent

Results presented in Table 15 revealed that no seed germination was recorded for the first two collections (1st and 15th July). Germination commenced from 1st August (Plate-3) at all the selected altitudes in both the forest divisions. In Tangmarg Forest Division the seed germination on 1st August was recorded as 10.00, 5.75and 4.25% at lower (2,300-2,600 m), middle (2,600-2,900 m) and upper altitude (>2,900 m) respectively. The seed germination increased with each collection date and on maturity the seed germination was recorded as 40.25, 35.75 and 31.25% at lower(2,300-2,600 m), middle (2,600-2,900 m)and upper altitude (>2,900 m) respectively.

In Sindh Forest Division, at lower altitude (2,300-2,600m), thegerminationincreased from 9.00% (1st August) to 34.25% at maturity (15th October) whereas the germination% atmiddle (2,600-2,900 m) and upper altitude (>2,900 m)increased from 7.25% (1st August) to 37.25% (15thOctober) and 4.25% (1st August) to 28.00%at maturity (1st November) respectively. Amongst the altitudes maximum germination was recorded at lower altitude (2,300-2,600 m). Germination percentage decreased with increase in altitude.

Table 15:Altitudinal variation in seed germination as influenced by collection dates at different altitudes

Forest Division	Altitude (m)	Seed germination (%) (±SD)									
		Collection dates									
		1st fortnight of July	2nd fortnight of July	1st fortnight of Aug	2nd fortnight of Aug	1st fortnight of Sep	2nd fortnight of Sep	1st fortnight of Oct	2nd fortnight of Oct	1st fortnight of Nov	2nd fortnight of Nov
Tangmarg	2300-2600	0.00	0.00	10.00 ±1.36	14.25 ±1.89	22.50 ±5.51	35.25 ±2.50	38.25 ±2.63	40.25 ±3.92	Dispersed	Dispersed
	2600-2900	0.00	0.00	5.75 ±1.25	13.75 ±1.70	17.25 ±2.50	23.25 ±2.50	31.25 ±5.74	35.75 ±3.59	Dispersed	Dispersed
	>2900	0.00	0.00	4.25 ±0.95	11.25 ±1.70	15.25 ±1.70	21.00 ±2.45	23.25 ±2.87	30.00 ±3.46	31.25 ±2.87	Dispersed
Sindh	2300-2600	0.00	0.00	9.00 ±1.41	11.25 ±2.22	18.00 ±5.72	29.25 ±1.70	33.25 ±7.80	34.25 ±4.99	Dispersed	Dispersed
	2600-2900	0.00	0.00	7.25 ±1.25	16.25 ±2.63	20.25 ±4.20	31.25 ±5.12	36.50 ±5.92	37.25 ±2.87	Dispersed	Dispersed
	>2900	0.00	0.00	4.25 ±1.25	8.75 ±1.25	12.25 ±2.87	14.00 ±3.16	21.25 ±2.99	27.25 ±2.99	28.00 ±4.69	

4.4 Altitudinal variation in germinability and seedling characters in *Abiespindrow* under laboratory conditions

4.4.1 Germination percent

The effect of altitude and chilling on germination is presented in Table 16. A perusal of the table shows that in Tangmarg Forest Division maximum germination of 35.55% was recordedat lower altitude (23,00-2,600 m)which decreased to 30.80 and 29.80% at middle(2,600-2,900 m) and upper altitude (>2,900 m) respectively though the two were not significantly different.

Chilling duration effected germination of seeds significantly. The germination percentage increased from 19.75% in control to 28.58, 33.25, 37.83 and 40.83% after 15, 30, 45 and 60 days of chilling duration.

Regarding the interaction of altitude and the chilling duration maximum germination percent of 48.75% was recordedatlower altitude (23,00-2,600 m) after 60 days of chilling duration followed by 40.75% at the same altitude after 45 days of chilling duration. A minimum of 17.50% germination was recorded in control at middle altitude (2,600-2,900 m).Most of the interaction results differed significantly. All the chilling durations for different seed lots collected from different altitudes increased the germination percentage.

In Sindh Forest Division maximum germination percent of 35.05 was recorded at middle altitude (2,600-2,900 m) andwas significantly different from 32.70 and 26.55% recorded at lower altitude (23,00-2,600 m)and upper altitude(>2,900 m) respectively.

Chilling period increased germination percent significantly. The germination percentage increased from 19.16% in control to 26.75, 32.66, 38.08 and 40.50% after 15, 30, 45 and 60 days chilling period respectively.

Interaction results were also significant. The interaction of altitude and the chilling duration shows that the maximum germination of 46.75% was recorded at middle altitude (2,600-2,900 m) after 60 days of chilling duration followed by 42.50% after 45 days of chilling duration at the same altitude. A minimum germination of 17.00% was recorded in control at upper altitude (>2,900 m).

Table 16: Altitudinal variation in germination percentage of Fir (*Abies pindrow*) under laboratory conditions as influenced by different chilling durations

Altitude(m)	Germination percentage											
	Sites											
	Tangmarg ForestDivision					Mean	Sindh ForestDivision					Mean
	Chilling Duration(Days)						Chilling Duration(Days)					
	Control	15	30	45	60		Control	15	30	45	60	
2300-2600	22.25(27.92)	31.25 (33.89)	34.75 (36.07)	40.75 (39.65)	48.75 (44.26)	**35.55 (36.36)**	19.75 (26.32)	29.00 (32.42)	33.75 (35.26)	39.50 (38.91)	41.50 (40.07)	**32.70 (34.60)**
2600-2900	17.50 (24.50)	27.25 (31.31)	33.75 (35.50)	37.50 (37.73)	38.00 (38.02)	**30.80 (33.41)**	20.75 (26.96)	29.25 (32.67)	36.00 (36.80)	42.50 (40.66)	46.75 (43.11)	**35.05 (36.04)**
>2900	19.50 (26.17)	27.25 (31.43)	31.25 (33.94)	35.25 (36.40)	35.75 (36.69)	**29.80 (32.92)**	17.00 (24.32)	22.00 (27.95)	28.25 (32.07)	32.25 (34.56)	33.25 (35.18)	**26.55 (30.82)**
Mean	**19.75 (26.20)**	**28.583 (32.21)**	**33.25 (35.17)**	**37.83 (37.93)**	**40.83(39.66)**	**32.05 (34.23)**	**19.16 (25.87)**	**26.75` (31.01)**	**32.66 (34.71)**	**38.08 (38.04)**	**40.50 (39.46)**	**31.43 (33.82)**
CD (≤ 0.05)							CD (≤ 0.05)					
Altitude			1.53				Altitude				1.72	
Chilling duration			1.97				Chilling duration				2.22	
Altitude x Chilling duration			3.42				Altitude x Chilling duration				3.85	

Values in the parenthesis are arc sine transformation

4.4.2 Germination Value (GV)

The effect of altitude and chilling duration is presented in Table 17. In Tangmarg Forest Division maximum germination value of 3.93 was recorded at lower altitude (2,300-2,600 m) and it decreasedto2.89 and 2.34at middle (2,600-2,900 m) and upper altitude (>2,900 m) respectively with non-significant difference between middle and upper altitude.

Chilling durations also significantly influenced germination value. Minimum germination value was recorded as 0.98 in control. Progressive increase was recorded in germination value as the chilling duration increased. Maximum germination value was recorded as 4.96 after 60 days chilling duration and was not statistically different from 4.08 recorded after 45 days chilling duration.

Interaction results of altitude and chilling duration shows thatmaximum germination value was recorded as 6.96 after 60 days chilling duration at the lower altitude(2,300-2,600 m)followed by 5.08 after 45 days chilling duration at the same altitude. The minimum germination value was recorded as 0.80 in control at the lower altitude (>2900 m).

In Sindh Forest Division maximum germination value was recorded as 3.67 at the middle altitude (2,600-2,900 m) and differed non-significantly from 3.26 recorded at lower altitude (2,300-2,600 m). Minimum germination value was recorded as 2.04 at upper altitude (>2,900 m).

Chilling duration significantly increased the germination value. Minimum germination value was recorded as 0.89 which increased to 1.87, 3.05, 4.16 and 4.97 when chilling duration were extended to 15, 30, 45 and 60 days respectively. No significant increase was observed with the increase in chilling duration from 45 days to 60 days.

Interaction of altitude and chilling duration revealed that significant results were recorded. Maximum germination value was recorded as 6.46 after 60 days chilling duration at the middle altitude whereas the minimum germination value was recorded as 0.65 in control at the upper altitude.

Table 17: Altitudinalvariation in germination value of Fir (*Abies pindrow*) under laboratory conditions as influenced by different chilling durations

Altitude(m)	Germination value										
	Sites										
	Tangmarg ForestDivision					Mean	Sindh ForestDivision					Mean
	Chilling Duration(Days)						Chilling Duration(Days)					
	Control	**15**	**30**	**45**	**60**		**Control**	**15**	**30**	**45**	**60**	
2300-2600	1.37	2.43	3.83	5.08	6.96	**3.93**	0.94	2.36	3.17	4.67	5.15	**3.26**
2600-2900	0.83	1.86	3.42	4.02	4.31	**2.89**	1.09	2.06	3.87	4.90	6.46	**3.67**
>2900	0.80	1.76	2.35	3.15	3.62	**2.34**	0.65	1.19	2.12	2.92	3.30	**2.04**
Mean	**0.98**	**2.02**	**3.20**	**4.08**	**4.96**	**3.05**	**0.89**	**1.87**	**3.05**	**4.16**	**4.97**	**2.99**
CD (≤ 0.05)							CD (≤ 0.05)					
Altitude			0.72				Altitude			0.80		
Chilling duration			0.94				Chilling duration			1.03		
Altitude x Chilling duration			1.62				Altitude x Chilling duration			1.78		

4.4.3 Germination energy (%)

The effect of altitude and chilling duration is given in Table 18.The data presented in table shows that both altitude and chilling exerted a strong influence on germination energy. In Tangmarg Forest Division the maximum germination energy of 24.00% was recorded at the lower altitude (2,300-2,600 m).The germination energy% at middle (2,600-2,900 m) and the upper altitude (>2,900 m) was recorded as 21.70 and 20.25% respectively. Both the two values were statistically at par but significantly different from 24% recorded at the lower altitude.

The chilling duration increased germination energy significantly. Minimum germination energy of 14.25% was recorded in control and it increased to 19.83, 22.83, 25.16 and 27.83% when the seeds were subjected to 15, 30, 45 and 60 days chilling duration respectively. Significant difference were recorded amongst the different chilling durations.

The interaction results showed significant influence on germination energy. Minimum germination energy of 13.25%was recorded in control at the middle altitude (2,600-2,900 m) followed by 14.25%in control at the upper altitude(>2,900 m).The maximum germination energy percent of 32.50 was recorded after 60 days of chilling duration at the lower altitude (2,300-2,600 m).This was followed by 27.00% after 45 days chilling duration at the same altitude.

In Sindh Forest Division middle altitude (2,600-2,900 m) resulted in maximum germination energy of 26.20% and was not significantly different from 23.80% recorded at the lower altitude (2,300-2,600 m). Minimum germination energy was recorded as 18.20% at the upper altitude (>2,900 m).

The chilling duration improved germination energy significantly. Maximum germination energywas recorded as 29.66% after 60 days chilling duration and was not statistically different from 28.75% after 45 days chilling duration. Minimum germination energy was recorded as 12.75% in control.

Table 18: Altitudinal variation in germination energy of Fir (*Abies pindrow*)under laboratory conditions as influenced by different chilling durations

Altitude(m)	**Germination energy (%)**											
	Sites											
	Tangmarg ForestDivision					**Mean**	**Sindh ForestDivision**					**Mean**
	Chilling Duration(Days)						**Chilling Duration(Days)**					
	Control	**15**	**30**	**45**	**60**		**Control**	**15**	**30**	**45**	**60**	
2300-2600	15.25 (22.91)	20.00 (26.39)	25.25 (30.01)	27.00 (31.28)	32.50 (34.70)	**24.00 (29.06)**	13.50 (21.20)	19.25 (25.83)	23.25 (28.55)	32.00 (34.41)	31.00 (33.75)	**23.80 (28.75)**
2600-2900	13.25 (21.28)	20.25 (26.52)	23.00 (28.63)	25.75 (30.47)	26.25 (30.77)	**21.70 (27.53)**	15.50 (23.09)	23.50 (28.90)	28.50 (32.18)	31.00 (33.79)	32.50 (34.42)	**26.20 (30.48)**
>2900	14.25 (22.14)	19.25 (25.83)	20.25 (26.71)	22.75 28.43	24.75 (29.77)	**20.25 (26.58)**	9.25 (17.55)	13.00 (20.98)	20.00 (26.53)	23.25 (28.75)	25.50 (30.31)	**18.20 (24.82)**
Mean	**14.25 (22.11)**	**19.83 (26.25)**	**22.83 (28.45)**	**25.16 (30.06)**	**27.83 (31.75)**	**21.98 (27.72)**	**12.75 (20.61)**	**18.58 (25.24)**	**23.91 (29.09)**	**28.75 (32.32)**	**29.66 (32.83)**	**22.73 (28.02)**

CD (≤ 0.05)		CD (≤ 0.05)	
Altitude	1.79	Altitude	2.19
Chilling duration	2.31	Chilling duration	2.83
Altitude x Chilling duration	4.00	Altitude x Chilling duration	4.91

Values in the parenthesis are arc sine transformation

The interaction revealed significant results. Minimum germination energywas recorded as 9.25%in control at the upper altitude (>2,900 m) followed by 13.50%in control at the lower altitude(2,300-2,600m).The germination energy significantly increased to a maximum of 32.50% after 60 days chilling duration at the middle altitude(2,600-2,900 m).

4.4.4 Mean Germination Time (MGT)

The results presented in Table 19 revealed that in Tangmarg Forest Division, the mean germination time increased from lower altitude (2,300-2,600 m) to upper altitude (>2,900 m). Minimum mean germination time was recorded as 22.73 days at lower altitude (2,300-2,600m) which increased significantly to 23.41 and 23.69 daysat middle(2,600-2,900m)and upper altitude (>2900m).

The chilling duration significantly decreased the mean germination time. Maximum mean germination time was recorded as 25.30 days in control. With increase in chilling duration to 15, 30, 45 and 60 days,the mean germination time decreasedto 24.18, 22.95, 22.21 and 21.7 days respectively.

The interaction of altitude and chilling duration recorded significant results. Maximum mean germination time was recorded as 25.66 days in control at middle altitude (2,600-2,900 m)whereas the minimum mean germination time was recorded as 20.59 days after 60 days chilling duration at lower altitude (2,300-2,600 m) followed by 21.78 days after 45 days chilling duration under the same altitude. The chilling durations decreased the mean germination time of all the altitudinal seed sources.

In Sindh Forest Division, maximum mean germination time was recorded as 24.12 days at upper altitude (>2,900 m).The mean germination time at lower (2,300-2,600 m) and middlealtitude(2,600-2,900 m) was recorded as 23.22 and 22.88 days respectively. Significant difference was recorded in this regard amongst the altitudes.

Table 19: Altitudinal variation in mean germination time of Fir (*Abies pindrow*) under laboratory conditions as influenced by different chilling durations

Altitude(m)	Mean germination time (days)											
	Sites											
	Tangmarg ForestDivision					Mean	Sindh ForestDivision					Mean
	Chilling Duration(Days)						Chilling Duration(Days)					
	Control	15	30	45	60		Control	15	30	45	60	
2300-2600	24.99	23.82	22.45	21.78	20.59	**22.73**	25.24	24.08	23.27	21.91	21.62	**23.22**
2600-2900	25.66	24.33	22.58	22.31	22.17	**23.41**	25.12	23.79	22.75	21.83	20.89	**22.88**
>2900	25.26	24.40	23.83	22.55	22.43	**23.69**	25.58	24.98	23.95	23.25	22.85	**24.12**
Mean	**25.30**	**24.18**	**22.95**	**22.21**	**21.73**	**23.28**	**25.31**	**24.28**	**23.32**	**22.33**	**21.79**	**23.41**
	CD (≤ 0.05)								CD (≤ 0.05)			
	Altitude			0.24					Altitude		0.22	
	Chilling duration			0.31					Chilling duration		0.29	
	Altitude x Chilling duration			0.54					Altitude x Chilling duration		0.50	

The chilling period influenced mean germination time significantly. Maximum mean germination time was recorded as 25.31 days in control. The mean germination time decreased significantly with the increase in chilling duration and was recorded as 24.28, 23.32 ,22.33 and 21.79 days after 15, 30, 45 and 60 days chilling duration respectively.

The interaction data revealed significant results. Maximum mean germination time was recorded as 25.58 days in control at the upper altitude(>2,900 m) whereas the minimum mean germination time was recorded as 20.89 daysafter 60 days of chilling duration at the middle altitude(2,600-2,900 m) followed by 21.83 days after 45 daysat the same altitude. At all the altitudinal seedsources, chilling duration decreased mean germination time.

4.4.5 Radicle length (cm)

The influence of altitude and chilling duration is given in Table 20. A perusal of the table shows that the altitude significantly influenced the radical length. In Tangmarg Forest Division maximum radicallength was recorded as 2.40 cm at the lower altitude (2,300-2,600 m).The radicallength at the middle (2,600-2,900 m) and the upper altitude (>2,900 m)wasrecorded as 2.04 and 2.03 cm. Both the two were significantly differentfrom the radicle length recorded at the lower altitude.

The chilling duration significantly improved the radical length. With the increase in chilling duration, the radical length also increased. Minimum radicle length of 1.57 cm was recorded in control whereas the maximum radicle length was recorded as 2.64 cm after 60 days chilling duration. The radical length recorded as 2.42 cm after 45 days of chilling duration was statistically at par with 2.64 cm after 60 days chilling duration.

Regarding the interaction the results obtained revealed significant variation. The minimum radical length was recorded as 1.39 cm in control at the upper altitude (>2,900 m)and differed significantly from 2.78 cm recorded as the maximum after 60 days chilling duration at the lower altitude (2,300-2,600 m).

Table 20: **Altitudinal variation in radicle length (cm) of Fir (*Abies pindrow*) under laboratory conditions as influenced by different chilling durations**

Altitude(m)	Radicle length(cm)											
	Sites											
	Tangmarg ForestDivision					Mean	Sindh ForestDivision					Mean
	Chilling Duration(Days)						Chilling Duration(Days)					
	Control	15	30	45	60		Control	15	30	45	60	
2300-2600	1.89	2.31	2.40	2.58	2.78	**2.40**	1.46	1.91	2.05	2.42	2.60	**2.09**
2600-2900	1.43	1.81	2.00	2.36	2.58	**2.04**	1.85	2.23	2.39	2.55	2.69	**2.34**
>2900	1.39	1.86	2.02	2.32	2.56	**2.03**	1.35	1.80	1.98	2.26	2.46	**1.97**
Mean	**1.57**	**1.99**	**2.14**	**2.42**	**2.64**	**2.15**	**1.55**	**1.98**	**2.14**	**2.41**	**2.58**	**2.13**

CD (≤ 0.05)		CD (≤ 0.05)	
Altitude	0.25	Altitude	0.22
Chilling duration	0.32	Chilling duration	0.29
Altitude x Chilling duration	0.56	Altitude x Chilling duration	0.50

In Sindh Forest Division significant difference was observed in radical length between lower (2,300-2,600 m) and the middle altitude (2,600-2,900 m)andwas recorded as 2.09 and 2.34 cm respectively. Minimum radicle length of 1.97cm recorded at the upper altitude (>2,900 m) wassignificantly differentfrom2.34 cm recorded atthe middle altitude.

Chilling duration improved radical length significantly. The radicle length recorded as 2.41 and 2.58 cm after 45 and 60 days chilling duration respectively were statistically at par. However both the two were significantly different from 1.55 and 1.98 cm recorded after control and 15 days chilling period respectively.

The interaction results revealed significant improvement in radical length. The minimum radicle length was recorded as 1.35 cm in control at the upper altitude (>2,900 m) followed by 1.46 cm under the same chilling duration at the lower altitude. Significantly maximum radical length was recorded as 2.69cm after 60 days chilling duration at the middle altitude (2,600-2,900 m).

4.4.6 Plumule length (cm)

The effect of altitude and chilling duration on plumule length is given in Table 21. It is evident from the table that the plumule length decreased with the increase in altitude in Tangmarg Forest Division. Maximum plumule length of 3.24 cm was recorded at the lower altitude (2,300-2,600m) which decreased to 2.89 and 2.72 cm at the middle(2,600-2,900 m)and the upper altitude(>2,900 m)respectively. The plumule length at the middle and the upper altitude were statistically at par.

The chilling duration significantly increased the plumule length. The minimum plumule length of 2.54cm was recorded in control and increased to 2.82,3.01,3.09 and 3.29 cm with the increase in chilling duration to 15, 30, 45 and 60 days respectively with non-significant difference between 45 and 60 days chilling duration.

Table 21: Altitudinal variation in plumule length of Fir (*Abies pindrow*) under laboratory conditions as influenced by different chilling durations

Altitude(m)	Plumule length (cm)											
	Sites											
	Tangmarg ForestDivision					Mean	Sindh ForestDivision					Mean
	Chilling Duration(Days)						Chilling Duration(Days)					
	Control	**15**	**30**	**45**	**60**		**Control**	**15**	**30**	**45**	**60**	
2300-2600	2.84	3.06	3.24	3.48	3.58	**3.24**	2.61	2.81	2.97	3.00	3.06	**2.89**
2600-2900	2.52	2.78	2.94	2.97	3.23	**2.89**	2.69	2.98	3.19	3.47	3.53	**3.17**
>2900	2.25	2.61	2.85	2.84	3.06	**2.72**	2.23	2.56	2.84	2.80	2.96	**2.68**
Mean	**2.54**	**2.82**	**3.01**	**3.09**	**3.29**	**2.95**	**2.51**	**2.78**	**3.00**	**3.09**	**3.18**	**2.91**

CD (≤ 0.05)		CD (≤ 0.05)	
Altitude	0.18	Altitude	0.17
Chilling duration	0.23	Chilling duration	0.22
Altitude x Chilling duration	0.40	Altitude x Chilling duration	0.39

The interaction results in this regard were significant. The minimum plumule lengthwas recorded as 2.25 cm in control at the upper altitude (>2,900 m) whereas the maximum plumule length was recorded as 3.58 cm after 60 days of chilling duration at the lower altitude followed by 3.48 cm after 45 days of chilling duration at the same altitudinal zone.

In Sindh Forest Division the maximum plumule length of 3.17 cm was recorded at middle altitude (2,600-2,900 m) and differed significantly from lower (2,300-2,600 m) and upper altitude (>2,900 m) in which the plumule length was recorded as2.89 and 2.68 cmrespectively.

With the increase in chilling duration the plumule length also increased. A minimum plumule length of 2.51 cm in control increased to 3.18 cm after 60 days of chilling duration. The plumule length recorded as 3.00 and 3.09 cm after 30 and 45 days of chilling duration was statistically at par.

The interaction of altitude and chilling duration revealed significant variation. The minimum plumule length was recorded as 2.23cm in control at upper altitude (>2,900 m)whereas on the other hand maximum plumule length was recorded as 3.53 cm at middle altitude (2,600-2,900 m) after 60 days of chilling duration. This was followed by 3.47cm after 45 days chilling duration at the same altitude.

4.4.7 Vigour index

The influence of altitude and chilling duration on vigour index is given in Table 22. An inquisition of the data shows the altitudes differ significantly amongst themselves in vigour index. In Tangmarg Forest Division maximum vigour index was recorded as 205.28at the lower altitude (2,300-2,600m).Thevigour index at the middle (2,600-2,900m) and the upper altitude(>2,900 m)wasrecorded as 156.42 and 145.45 respectively.

Table 22: Altitudinal variation in vigour index of Fir (*Abies pindrow*) under laboratory conditions as influenced by different chilling durations

Altitude(m)	Vigour index										
	Sites										
	Tangmarg ForestDivision					Mean	Sindh ForestDivision					Mean
	Chilling Duration(Days)						Chilling Duration(Days)					
	Control	15	30	45	60		Control	15	30	45	60	
2300-2600	105.29	167.90	196.20	247.06	309.95	**205.28**	80.43	136.96	169.34	213.89	234.47	**167.02**
2600-2900	69.69	125.07	166.82	199.72	220.78	**156.42**	94.16	152.48	200.81	255.55	290.78	**198.76**
>2900	70.88	121.75	152.03	181.64	200.95	**145.45**	60.77	95.76	135.88	163.28	180.15	**127.17**
Mean	**81.95**	**138.24**	**171.68**	**209.47**	**243.89**	**169.05**	**78.45**	**128.40**	**168.68**	**210.91**	**235.13**	**164.31**

CD (≤ 0.05)		CD (≤ 0.05)	
Altitude	6.18	Altitude	11.04
Chilling duration	7.99	Chilling duration	14.25
Altitude x Chilling duration	13.94	Altitude x Chilling duration	24.69

With the increase in chilling duration, the vigour index also increased. Minimum vigour index of 81.95 was recorded in control which increased to138.24, 171.68, 209.47 and 243.89 when chilling duration was increased to 15, 30, 45 and 60 days. Significant difference was found amongst chilling durations.

The interaction of altitude and chilling duration revealed significant variation. The minimum vigour index was recorded as 69.69 in control at the middle altitude (26,00-2,900 m)followed by 70.88 in control at the upper altitude (>2,900 m). Significantly maximum vigour index was recorded as 309.95 under 60 days chilling duration at lower altitude (2,300-2,600 m).

In Sindh Forest Division, the maximum vigour index was recorded as 198.76 at middle altitude (2,600-2,900 m). The vigour index at lower (2,300-2,600 m) and upper altitude (>2,900 m) was recorded as 167.02 and 127.17 respectively. Significant difference was found among altitudes.

Chilling duration significantly improved vigour index. Maximum vigour index was recorded as 235.13 after 60 days chilling durations. The vigour index in control, 15, 30 and 45 days was recorded as 78.45, 128.40, 168.16 and 210.91 respectively.

The interaction results were highly significant. Minimum vigour index of 60.77 was recorded in control at upper altitude (>2,900 m) followed by 80.43 in control at lower altitude (2,300-2,600 m) with no significant difference between the two. Significantly maximum vigour index was recorded as 290.78 after 60 days chilling duration at middle altitude (2,600-2,900 m).

4.4.8 Cotyledon number

The effect of altitude and chilling duration on cotyledon number is given in Table 23.The Table shows that there was non-significant difference in cotyledon number in Tangmarg at different altitudes and were recorded as 4.83, 4.86, and 4.70 at lower (2,300-2,600 m), middle (2,600-2,900 m)and upper altitude (>2,900 m) respectively.

Table 23: Altitudinal variation in cotyledon number of Fir (*Abies pindrow*) under laboratory conditions as influenced by different chilling durations

Altitude(m)	Cotyledon number											
	Sites											
	Tangmarg ForestDivision					Mean	Sindh ForestDivision					Mean
	Chilling Duration(Days)						Chilling Duration(Days)					
	Control	**15**	**30**	**45**	**60**		**Control**	**15**	**30**	**45**	**60**	
2300-2600	4.78	4.99	4.89	4.67	4.83	**4.83**	4.53	**4.80**	**5.23**	**4.65**	**4.75**	**4.79**
2600-2900	4.64	4.83	5.23	4.70	4.88	**4.86**	4.56	4.58	5.23	4.98	4.62	**4.79**
>2900	4.63	5.05	4.65	4.63	4.55	**4.70**	4.75	4.66	4.71	4.90	4.66	**4.74**
Mean	**4.68**	**4.95**	**4.92**	**4.66**	**4.75**	**4.80**	**4.61**	**4.68**	**5.06**	**4.84**	**4.68**	**4.77**

CD (≤ 0.05)		CD (≤ 0.05)	
Altitude	NS	Altitude	NS
Chilling duration	NS	Chilling duration	NS
Altitude x Chilling duration	NS	Altitude x Chilling duration	NS

Similarly chilling duration did not influence cotyledon number and non-significant difference was recorded in cotyledon number amongst different chilling duration and were recorded as 4.68, 4.95, 4.92, 4.66 and 4.75 in control,15,30,45 and 60 days respectively.

The interaction results in this regard were also non-significant. Maximum number of cotyledons were recorded as 5.23after 30 days chilling duration at middle altitude(2,600-2,900 m)whereas the minimum number of cotyledons were recorded as 4.63 after45 days of chilling duration at the upper altitude (>2,900 m).

Similar trend was observed in Sindh Forest Division. Non-significant difference in cotyledon number at different altitudes and were recorded as 4.79, 4.79 and 4.74 at lower (2,300-2,600 m), middle (2,600-2,900 m)and upper altitude(>2,900 m) respectively.

Chilling duration alsocould not influence cotyledon number and were non-significant amongst themselves. Maximum number of cotyledonswere recorded as 5.06 after 30 days of chilling duration whereas the minimum value was recorded as 4.61 in control.

Similarly the interaction results were non-significant with a minimum of 4.53 in control at the lower altitude(2,300-2,600m) and a maximum of5.23 after 30 days chilling durationat lower (2,300-2,600 m) and middle altitude (2,600-2,900 m).

4.5 Altitudinal variation in germinability and seedling characters under nursery conditions

4.5.1 Germination percent

The effect of altitude and chilling on germination is presented in Table 24. A perusal of the table shows that in Tangmarg, maximum germination was recordedas 29.30% at the lower altitude (2,300-2,600 m)and was significantly different from 24.53 and 22.35% recorded at middle (2,600-2,900 m) and upper altitude(>2,900 m)respectively (Plate-4).

Table 24: Altitudinal variation in germination percentage of Fir (*Abies pindrow*)under nursery conditions as influenced by different chilling durations

Altitude(m)	Germination percentage											
	Sites											
	Tangmarg ForestDivision					Mean	Sindh ForestDivision					Mean
	Chilling Duration(Days)						Chilling Duration(Days)					
	Control	15	30	45	60		Control	15	30	45	60	
2300-2600	16.50 (23.93)	23.75(29.14)	28.75 (32.40)	38.25 (38.17)	39.25 (38.76)	**29.30 (32.48)**	12.00 (20.18)	23.25 (28.74)	26.50 (30.95)	30.75 (33.64)	34.25 (35.79)	**25.35 (29.86**
2600-2900	14.00 (21.90)	24.00 (29.23)	25.18 (30.09)	27.00 (31.27)	32.50 (34.73)	**24.53 (29.44)**	16.25 (23.69)	28.50 (32.24)	30.75 (33.66)	36.25 (36.99)	38.25 (38.17)	**30.00 (32.95)**
>2900	12.75 (20.79)	19.00 (25.77)	24.25 (29.45)	27.50 (31.60)	28.25 (32.06)	**22.35 (27.93)**	13.00 (20.97)	21.00 (27.22)	24.25 (29.45)	24.75 (29.78)	26.75 (31.09)	**21.95 (27.70)**
Mean	**14.41 (22.21)**	**22.25 (28.05)**	**26.06 (30.64)**	**30.91 (33.68)**	**33.33 (35.19)**	**25.39 (29.95)**	**13.75 (21.61)**	**24.25 (29.40)**	**27.16 (31.35)**	**30.58 (33.47)**	**33.08 (35.02)**	**25.76 (30.17)**

CD (≤ 0.05)		CD (≤ 0.05)	
Altitude	0.57	Altitude	0.86
Chilling duration	0.73	Chilling duration	1.11
Altitude x Chilling duration	1.27	Altitude x Chilling duration	1.93

Values in the parenthesisare arc sine transformation

Chilling duration significantly increased the germination percent. The minimum germinationrecorded as 14.41% in control was significantly different from 22.25, 26.06, 30.91 and 33.33% recorded after 15, 30, 45 and 60 days chilling duration respectively.

The interaction results obtained were also significant. The minimum germination was recorded as 12.75% in control at the higher altitude (>2,900 m) followed by 14.00% in control at the middle altitude (2,600-2,900 m).The maximum germination was recorded as 39.25% after 60 days chilling duration at lower altitude (2,300-2,600 m) followed by 38.25% after 45 days of chilling durationat the same altitude though both the two were statistically at par.

All the chilling durations improved the germination percent in different altitudinal seed collections.

In Sindh Forest Division the maximum germination was recorded as 30.00% at the middle altitude (2,600-2,900 m). The germination percent at the lower (2,300-2,600 m)and the upper altitude (>2,900 m) was recorded as 25.35 and 21.95% respectively. The altitudes differ significantly amongst themselves in this regard.

Chilling duration significantly increased the germination percentage. The minimum germinationof 13.75% was recorded in control. The germination percent after 15, 30, 45 and 60 days chilling period were recorded as 24.25, 27.16, 30.58 and 33.08% respectively. Significant difference was recorded amongst the different chilling durations.

The interaction results revealed significant results. The minimum germination was recorded as 12.00% in control at the lower altitude (2,300-2,600 m). Significantly maximum germination was recorded as 38.25% after 60 days chilling duration at the middle altitude (2,600-2,900 m). This was followed by 36.25% after 45 days of chilling duration at the same altitude.

4.5.2 Mean germination time (days)

The effect of altitude and chilling duration on MGT is given in Table 25.

Plate 10:*Abies pindrow* seedlings growing in polybags

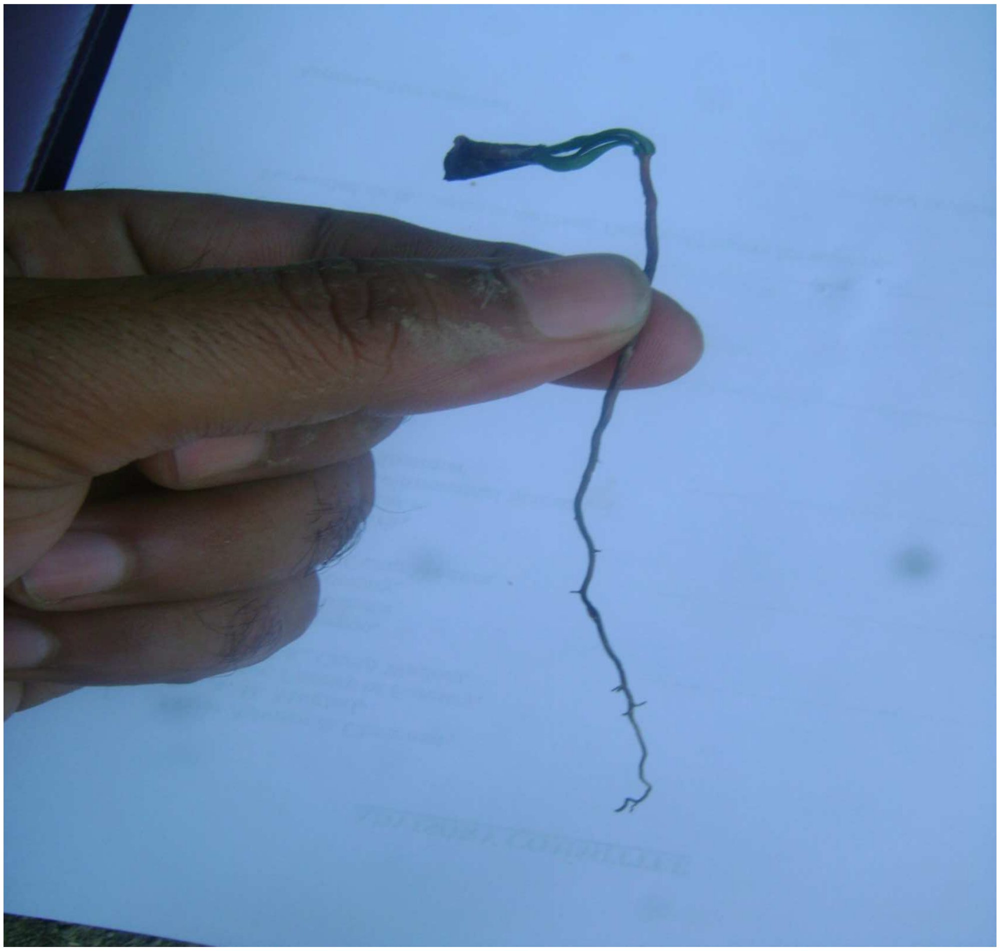

Plate 11: Seed germination under nursery conditions showing initiation of lateral roots

Thedata shows that in Tangmarg Forest Division, the minimum mean germination time of 29.66 days was recordedat the lower altitude (2,300-2,600 m) and differed significantly from 33.50 and 34.11 days at middle (2,600-2,900 m) and upper altitude (>2,900 m)respectively.

Chilling durations significantly impacted the mean germination time. Progressive and significant decrease in MGT was recorded as the chilling period was increased. Maximum mean germination time of 36.63 days was recorded in control. As the chilling duration was increased to 15, 30, 45 and 60 days the mean germination time decreased and was recorded as 34.24, 31.76, 30.70 and 28.79 days respectively with significant difference amongst themselves.

The interaction between altitude and chilling duration indicated that significant results. Significantly maximum mean germination time of 38.13 days was recorded in control at the upper altitude (>2,900 m)followed by 37.48 days at the middle altitude (2,600-2,900 m). As the chilling duration was increased to 60 days, mean germination time significantly decreased to 25.13 days and was recorded as minimum, at lower altitude (2,300-2,600 m).

In Sindh Forest Division, the mean germination time at lower (2,300-2,600 m), middle (2,600-2,900 m) and upper altitude (>2,900 m) was recorded as 31.96, 30.94 and 37.12 days respectively with significant difference amongst themselves.

Chilling duration significantly decreased the mean germination time. Maximummean germination time of 37.49 days was recorded in control which onextending the chilling duration to 15, 30, 45 and 60 days decreased to 34.32, 32.58, 31.46 and 30.86 days respectively. However non-significant difference was recorded between 45 and 60 days chilling interval.

Theinteraction resultsbetween altitude and chilling periods shows that the maximum mean germination time of 41.61 dayswas recorded in control at the upper altitude (>2,900 m). This was followed by 36.13 days in control at the lower altitude (2,300-2,600 m). Significantly minimum value was recorded as 28.29 days after 60 days of chilling duration at middle altitude(2,600-2,900m)followed by 29.05 days after 45 days of chilling durationat the same altitude.

Table 25: Altitudinal variation inmean germination time of Fir (*Abies pindrow*)under nursery conditions as influenced by different chilling durations

Altitude(m)	Mean germination time (days)											
	Sites											
	Tangmarg ForestDivision					Mean	Sindh ForestDivision					Mean
	Chilling Duration(Days)						Chilling Duration(Days)					
	Control	15	30	45	60		Control	15	30	45	60	
2300-2600	34.28	32.40	29.24	27.26	25.13	**29.66**	36.13	33.23	31.19	29.83	29.41	**31.96**
2600-2900	37.48	35.09	32.44	32.25	30.22	**33.50**	34.72	32.56	30.09	29.05	28.29	**30.94**
>2900	38.13	35.23	33.60	32.59	31.02	**34.11**	41.61	37.17	36.45	35.50	34.87	**37.12**
Mean	**36.63**	**34.24**	**31.76**	**30.70**	**28.79**	**32.42**	**37.49**	**34.32**	**32.58**	**31.46**	**30.86**	**33.34**
CD (≤ 0.05)							CD (≤ 0.05)					
Altitude			0.78				Altitude			1.01		
Chilling duration			1.00				Chilling duration			1.30		
Altitude x Chilling duration			1.74				Altitude x Chilling duration			2.26		

4.5.3 Seedling height (cm)

The effect of altitude and chilling period on seedling height is presented in Table 26.

In Tangmarg Forest Division, maximum seedling height of 4.69 cm was recorded at the lower altitude (2,300-2,600 m) and was significantly different from 3.82 and 3.61 cm recorded at middle (2,600-2,900 m) andupper altitude (>2,900 m) respectively. However non-significant difference was recorded between 3.82 and 3.61 cm.

Chilling duration significantly increased the seedling height. The minimum seedling height of 3.40 cm was recorded in control followed by 3.88 cm recorded after 15 days of chilling duration. Maximum seedling height was recorded as 4.58 cm after 60 days chilling durationfollowed by4.25 cm after 45 days of chilling duration though the two were not significantly different.

Significant interaction results were obtained between altitude and chilling duration. Minimum seedling height of 3.01 cm was recorded in control at the upper altitude (>2,900 m) followed by 3.20 cm in control at the middle altitude (2,600-2,900m). Maximum seedling height was recorded as 5.21 cm after 60 days chilling interval at the lower altitude (2,300-2,600m) followedby 4.99 cm after 45 days of chilling duration at the same altitude with non-significant difference between the two.

In Sindh Forest Divisionnon-significant difference in seedling height was recorded between the lower (2,300-2,600 m) and middle altitude (2,600-2,900 m) and was recorded as 4.13 and 4.39 cm respectively. Minimum seedling height was recorded as 3.43 cm at the upper altitude (>2,900 m).

Chilling duration improved seedling height. Minimum seedling height of 3.49 cm was recorded in controland itincreased to 3.70, 3.99, 4.18 and 4.57 cm with the increase in chilling duration to 15, 30, 45 and 60 days respectively. No significant difference was recorded in seedling height among control, 15, 30 and 45 days chilling durations.

Table 26: Altitudinal variation in seedling height(cm) of Fir (*Abies pindrow*)under nursery conditions as influenced by different chilling durations

Altitude(m)	Seedling height (cm)											
	Sites											
	Tangmarg ForestDivision					Mean	Sindh ForestDivision					Mean
	Chilling Duration(Days)						Chilling Duration(Days)					
	Control	**15**	**30**	**45**	**60**		**Control**	**15**	**30**	**45**	**60**	
2300-2600	4.01	4.46	4.80	4.99	5.21	**4.69**	3.63	3.87	4.11	4.31	4.74	**4.13**
2600-2900	3.20	3.74	3.78	4.03	4.34	**3.82**	3.84	4.07	4.39	4.63	5.04	**4.39**
>2900	3.01	3.44	3.67	3.73	4.19	**3.61**	3.01	3.17	3.46	3.61	3.92	**3.43**
Mean	**3.40**	**3.88**	**4.08**	**4.25**	**4.58**	**4.04**	**3.49**	**3.70**	**3.99**	**4.18**	**4.50**	**3.99**

CD (≤ 0.05)		CD (≤ 0.05)	
Altitude	0.39	Altitude	0.55
Chilling duration	0.51	Chilling duration	0.71
Altitude x Chilling duration	0.88	Altitude x Chilling duration	1.23

Interaction results shows that significant improvement in seedling height was recorded. Minimum seedling height of 3.01 cm was recorded in control at the upper altitude (>2,900 m)followed by 3.17 cm after 15 days of chilling duration at thesame altitude and both were statistically at par. The maximum seedling height was recorded as 5.04 cm after 60 days chilling duration at the middle altitude (2,600-2,900 m) followed by 4.74 cm after the same chilling period at the lower altitude (2,300-2,600 m).

4.5.4 Collar diameter (mm)

An inquisition of the data given in Table 27 revealed that the collar diameter at lower (2,300-2,600 m), middle (2,600-2,900 m) and upper altitude (>2,900 m) wasrecorded as1.00, 0.87 and 0.85mm respectively with non-significant difference between middle and upper altitude.

Chilling duration increased the collar diameter. Non-significant difference was found among control, 15, 30 and 45 days chilling duration in which the collar diameter was recorded as0.80, 0.85, 0.89 and 0.97 mm respectively. Maximum collar diameter was recorded as 1.01 mm after 60 days chilling duration and was significantly different from control.

Interaction results between altitude and chilling durationsrevealed that the minimum collar diameter was recorded as 0.75 mm in control at upper altitude (>2,900 m) and differed significantly from 45 and 60 days chilling duration at lower altitude (2,300-2,600 m) in which the collar diameter was recorded as 1.11 and 1.12 mm respectively. All other interaction results were non-significant.

In Sindh Forest Divisionnon-significant difference in collar diameter was recorded between lower (2,300-2,600) and middle altitude (2,600-2,900 m) and collar diameter was recorded as 0.90 and 0.97 mm respectively. Minimum collar diameter was recorded as 0.80 mm at upper altitude (>2,900 m).

Chilling durations increased collar diameter non-significantly from 0.78 mm in control to 0.99 mm after 60 days chilling duration.

Table 27: Altitudinal variation in collar diameter(mm) of Fir (*Abies pindrow*)under nursery conditions as influenced by different chilling durations

Altitude(m)	Collar diameter (mm)											
	Sites											
	Tangmarg ForestDivision					Mean	Sindh ForestDivision					Mean
	Chilling Duration(Days)						Chilling Duration(Days)					
	Control	15	30	45	60		Control	15	30	45	60	
2300-2600	0.87	0.91	0.97	1.11	1.12	**1.00**	0.81	0.88	0.90	0.94	0.98	**0.90**
2600-2900	0.79	0.82	0.85	0.90	0.97	**0.87**	0.84	0.90	0.95	1.03	1.11	**0.97**
>2900	0.75	0.80	0.85	0.89	0.94	**0.85**	0.70	0.77	0.81	0.83	0.89	**0.80**
Mean	**0.80**	**0.85**	**0.89**	**0.97**	**1.01**	**0.90**	**0.78**	**0.85**	**0.89**	**0.93**	**0.99**	**0.89**

CD (≤ 0.05)		CD (≤ 0.05)	
Altitude	0.12	Altitude	0.16
Chilling duration	0.19	Chilling duration	0.24
Altitude x Chilling duration	0.30	Altitude x Chilling duration	0.40

The interaction results presented in the tablerevealed that the minimum collar diameter was 0.70 mm in control at upper altitude (>2,900 m) and itdiffered non-significantly from all other resultswith the only exception of 1.11 mm recorded after 60 days chilling duration at middle altitude (2,600-2,900 m).

4.5.5 Root length (cm)

The effect of altitude and chilling duration on root length is given in Table 28. The table depicts that the root length decreases with the increase in altitude in Tangmarg Forest Division. Maximum root length of 8.93 cm was recorded at the lower altitude (2,300-2,600 m). Root length at middle (2,600-2,900 m) and upper altitude (>2,900 m) was recorded as 7.56 and 6.65 cm respectively. Significant difference in root length was recorded amongst the selected altitudes.

Chilling durationalso significantly increased the root length. Minimumroot length of 6.44 cm was recorded in control and it increased while increasing the chilling duration. The maximum root length of 8.91cm was recorded after 60 days of chilling duration followed by 8.46 cm after 45 days of chilling duration though the two were not significantly different.

Regarding interaction, significant results were recorded. Minimum root length of 5.36 cm was recorded in control at the upper altitude (>2,900 m) followed by 6.55 cm in control at middle (2,600-2,900 m)altitude. Maximum root length was recorded as 9.81 cm after 60 days of chilling period at the lower altitude (2,300-2,600 m) and was followed by 9.47 cm recorded after 45 days of chilling duration at the same altitude with non-significant difference between the two.

In Sindh Forest Division, significant difference in root length was recorded among the selected altitudes. The respective root length at the lower (2,300-2,600 m), middle (2,600-2,900 m)and the upper altitude (>2,900 m) was recorded as 7.59, 8.72 and 5.94 cm.

Table 28: Altitudinal variation in root length (cm) of Fir (*Abies pindrow*)under nursery conditionsas influenced by different chilling durations

Altitude(m)	Root length (cm)											
	Sites											
	Tangmarg ForestDivision					Mean	Sindh ForestDivision					Mean
	Chilling Duration(Days)						Chilling Duration(Days)					
	Control	15	30	45	60		Control	15	30	45	60	
2300-2600	7.43	8.72	9.22	9.47	9.81	**8.93**	6.24	7.10	7.81	8.23	8.54	**7.59**
2600-2900	6.55	6.62	7.81	8.40	8.42	**7.56**	7.16	8.52	8.90	9.32	9.69	**8.72**
>2900	5.36	5.50	6.40	7.49	8.51	**6.65**	5.42	5.43	5.28	6.18	7.41	**5.94**
Mean	**6.44**	**6.95**	**7.81**	**8.46**	**8.91**	**7.71**	**6.27**	**7.02**	**7.33**	**7.91**	**8.55**	**7.42**

CD (≤ 0.05)		CD (≤ 0.05)	
Altitude	0.44	Altitude	0.36
Chilling duration	0.57	Chilling duration	0.46
Altitude x Chilling duration	0.99	Altitude x Chilling duration	0.80

Chilling durationincreased the root length of seedlings. The minimum root length of 6.27cm was recorded in control followed by 7.02cm recorded after 15 days of chilling duration.The maximum root length was recorded as 8.55 cm after 60 days of chilling duration. This wasfollowed by 7.91 cm recorded after 45 days of chilling duration.

Interaction between altitude and chilling durations depicted significant results. The maximum root length of 9.69 cm was recorded after 60 days of chilling duration at middle altitude (2,600-2,900 m) followed by 9.32 cm recorded after 45 days of chilling duration at the same altitude. Both the chilling duration were statisticallynon-significant.

4.5.6 Root number/seedling

The effect of altitude and chilling duration given in Table 29reveals that non-significant difference was recordedin root number amongst the selected altitude. The root number at the lower (2,300-2,600 m), middle (2,600-2,900 m) and the upper altitude (>2,900 m) was recorded as 4.42, 3.68 and 3.70 respectively.

Chilling duration also increased the root number non-significantly from 3.37 in control to 4.50 after 60 days of chilling duration.

The interaction result between altitude and chilling duration were non-significant exceptthe maximum recorded as5.50 after 60 days of chilling duration at lower altitudethat differed significantly from3.50 and 3.30innon-stratified seeds at the lower (2,300-2,600 m) and middle (2,600-2,900 m) altitude.

In Sindh Forest Division maximum root number of 4.32 was recorded at the lower altitude (2,300-2,600 m), and differed non-significantly from 4.24 recorded at middle altitude (2,600-2,900 m). Minimum root number was recorded as 3.56 and was significantly lower than 4.32 recorded at the lower altitude.

Chilling duration increased the root number. Minimum root number was recorded as 3.30 in control. The root number recorded as 4.27, 4.43 and 4.77 after 30, 45 and 60 days were statistically at par but differ significantly from control.

Table 29: Altitudinal variation in root number Fir (*Abies pindrow*)under nursery conditions as influenced by different chilling durations

Altitude(m)	Root number/seedling											
	Sites											
	Tangmarg ForestDivision					Mean	Sindh ForestDivision					Mean
	Chilling Duration(Days)						Chilling Duration(Days)					
	Control	15	30	45	60		Control	15	30	45	60	
2300-2600	3.50	3.60	4.50	5.00	5.50	**4.42**	3.40	3.40	4.70	4.80	5.30	**4.32**
2600-2900	3.30	3.30	3.80	4.00	4.00	**3.68**	3.30	3.60	4.50	4.80	5.00	**4.24**
>2900	3.30	3.60	3.80	3.80	4.00	**3.70**	3.20	3.30	3.60	3.70	4.00	**3.56**
Mean	**3.37**	**3.50**	**4.03**	**4.27**	**4.50**	**3.93**	**3.30**	**3.43**	**4.27**	**4.43**	**4.77**	**4.04**

CD ($\leq$ 0.05)		CD ($\leq$ 0.05)	
Altitude	NS	Altitude	0.68
Chilling duration	NS	Chilling duration	0.88
Altitude x Chilling duration	1.99	Altitude x Chilling duration	1.53

The interaction results revealed significant difference in root number amongst the non-stratified seedsand the seeds subjected to 60 days chilling duration at lower and middle altitude in which the root number was recorded as 5.30 and 5.00 respectively. The minimum root number was recorded as 3.20 in control at the upper altitude (>2,900 m).

4.5.7 Fresh shoot weight (g)

The effect of altitude and chilling duration on shoot weight is depicted in Table 30. It is evident from the table that in Tangmarg Forest Division, shoot weight decreased with the increase in altitude. Maximum shoot weight of 0.24 g was recorded at the lower altitude (2,300-2,600 m) which decreased to 0.18 and 0.15 g at the middle (2,600-2,900 m) and the upper altitude (>2,900 m) respectively. Non-significant difference was found in shoot weight between middle (2,600-2,900m) and upper altitude (>2,900 m).

Chilling duration revealed a non-significant difference in shoot weight amongst control, 15 and 30 days chilling duration and was recorded as 0.12, 0.15 and 0.21 g respectively. The maximum shoot weight was recorded as 0.24 g after 60 days of chilling duration followed by 0.22 g after 45 days of chilling duration.

Interaction results were also significant. Minimum shoot weight was recorded as 0.08 g in control at the upper altitude (>2,900 m). Maximum shoot weight of 0.29 g was recorded after 60 days of chilling duration at the lower altitude (2,300-2,600 m) followed by 0.27 g after 45 days of chilling duration at the same altitude.

In Sindh Forest Division maximum shoot weight of 0.22 g was recorded at middle altitude (2,600-2,900 m). The shoot weight at lower (2,300-2,600 m) and upper altitude (>2,900 m) was recorded as 0.19 and 0.13 g, respectively.Non significant difference in shoot weight was recorded between loweraltitude (2,300-2,600 m) and middle altitude (2,600-2,900 m).

Chilling duration increased shoot weight. Minimum shoot weight was recorded as 0.09 g in control and was at par with 0.14 g recorded after 15 days of chilling duration. The maximum shoot weight was recorded as 0.24 g after 60 days of chilling duration.

Table 30: Altitudinal variation in fresh shoot weight(g) of Fir (*Abies pindrow*)under nursery conditions as influenced by different chilling durations

Altitude(m)	Fresh shoot weight (g)											
	Sites											
	Tangmarg ForestDivision					Mean	Sindh ForestDivision					Mean
	Chilling Duration(Days)						Chilling Duration(Days)					
	Control	**15**	**30**	**45**	**60**		**Control**	**15**	**30**	**45**	**60**	
2300-2600	0.17	0.20	0.26	0.27	0.29	**0.24**	0.10	0.15	0.21	0.22	0.26	**0.19**
2600-2900	0.10	0.13	0.20	0.21	0.24	**0.18**	0.11	0.19	0.25	0.26	0.28	**0.22**
>2900	0.08	0.11	0.17	0.19	0.20	**0.15**	0.07	0.10	0.15	0.17	0.18	**0.13**
Mean	**0.12**	**0.15**	**0.21**	**0.22**	**0.24**	**0.19**	**0.09**	**0.14**	**0.20**	**0.22**	**0.24**	**0.18**
CD (≤ 0.05)							CD (≤ 0.05)					
Altitude				0.06			Altitude				0.05	
Chilling duration				0.08			Chilling duration				0.07	
Altitude x Chilling duration				0.13			Altitude x Chilling duration				0.11	

Regarding the interaction between altitude and chilling duration, significant results were recorded. Minimum shoot weight of 0.07 g was recorded in control at the upper altitude (>2,900 m).Maximum shoot weight of 0.28 g was recorded after 60 days of chilling duration at middle altitude (2,600-2,900 m) followed by 0.26 g recorded after 45 days of chilling duration at the same altitude.

4.5.8 Fresh root weight (g)

The effect of altitude and chilling duration on root weight is presented in Table 31.The data reveals maximum biomass of 0.17 g at the lower altitude (2,300-2,600 m) and differed significantly from theroot weight recorded as 0.11 and 0.10 g at the middle(2,300-2,600m) and the upper altitude(>2,900 m).

Chilling duration increased root weight. Minimum root of 0.07 g was recorded in control and it increased to 0.10, 0.14, 0.15 and 0.17 g after 15, 30, 45 and 60 days chilling duration respectively. The maximum root weight recorded as 0.17 g differed significantly from control.

Interaction between altitude and chilling duration indicates that the minimum root weight recorded as 0.05 g in control at the upper altitude (>2,900 m) differed significantly from 0.22, 0.20 and 0.19 g recorded after 60, 45 and 30 days of chilling duration respectively at the lower altitude(2,300-2,600m).

In Sindh Forest Division, maximum root weight was recorded as 0.14 g at middle altitude (2,600-2,900m) followed by 0.13 g recorded at the lower altitude (2,300-2,600 m). Significantly minimum root weight of 0.09 g was recorded at upper altitude (>2,900 m).

Chilling duration increased root weight. Maximum root weight of 0.17 g was recorded after 60 days of chilling duration. The root weight of 0.13 and 0.15 g was recorded after 30 and 45 days of chilling duration respectively.

Interaction of altitude and chilling duration depicted significant results. Minimum root weight of 0.04 g was recorded in control at the upper altitude (>2,900 m) which increased significantlyto 0.20 g after 60 days of chilling duration at the middle altitude (2,600-2,900 m).

Table 31: Altitudinal variation in fresh root weight (g)of Fir (*Abies pindrow*)under nursery conditions as influenced by different chilling durations

Altitude(m)	Fresh root weight (g)											
	Sites											
	Tangmarg ForestDivision					Mean	Sindh ForestDivision					Mean
	Chilling Duration(Days)						Chilling Duration(Days)					
	Control	15	30	45	60		Control	15	30	45	60	
2300-2600	0.09	0.13	0.19	0.20	0.22	**0.17**	0.06	0.10	0.14	0.18	0.19	**0.13**
2600-2900	0.06	0.10	0.12	0.13	0.16	**0.11**	0.07	0.12	0.15	0.16	0.20	**0.14**
>2900	0.05	0.08	0.10	0.12	0.14	**0.10**	0.04	0.08	0.09	0.11	0.12	**0.09**
Mean	**0.07**	**0.10**	**0.14**	**0.15**	**0.17**	**0.13**	**0.06**	**0.10**	**0.13**	**0.15**	**0.17**	**0.12**

CD (≤ 0.05)		CD (≤ 0.05)	
Altitude	0.06	Altitude	0.03
Chilling duration	0.08	Chilling duration	0.06
Altitude x Chilling duration	0.13	Altitude x Chilling duration	0.10

4.5.9 Biomass (g)(fresh weight based)

The effect of altitude and chilling duration depicted in Table 32 reveals a significant influence on biomass of seedlings. Significant decrease in biomass was recorded in Tangmarg Forest Division as we moved from the lower altitude to higher altitude and was recorded as 0.41, 0.29 and 0.25 g at the lower (2,300-2,600 m),middle (2,600-2,900m) andthe upper altitude (>2,900 m)respectively.

Chilling duration also increased biomass significantly. However there was non-significant increase in biomass after 30, 45 and 60 days of chilling duration and was recorded as 0.35, 0.37 and 0.41 g respectively

Regarding interaction between altitude and chilling duration highly significant results were recorded. Minimum biomass of 0.13 g was recorded in control at the upper altitude (>2,900 m) followed by 0.16 g in control at middle altitude (2,600-2,900 m). Maximum biomass was recorded as 0.51 g after 60 days of chilling duration at the lower altitude (2,300-2,600 m).

In Sindh Forest Division, non-significant difference was recorded in biomass between the lower (2,300-2,600 m) and the middle altitude (2,600-2,900 m) and was recorded as 0.32 and 0.36 g respectively. Significantly minimum biomass of 0.22 g was recorded at the upper altitude (>2,900 m).

Chilling duration significantly increased biomass. Minimum biomass of 0.15 g in control increasedto 0.24, 0.33, 0.37 and 0.41 g on increasing the chilling duration to 15, 30, 45 and 60 days of chilling duration respectively.Non-significant difference was recorded among 30, 45 and 60 days chilling durations.

Interaction results were significant. Minimum biomass was recorded as 0.11 g in control at the upper altitude (>2,900) whereas maximum biomass was recorded as 0.47 g at middle altitude (2,600-2,900 m) after 60 days of chilling duration followed by 0.45 again after 60 days of chilling duration at the lower altitude.

Table 32: Altitudinal variation in fresh biomass of Fir (*Abies pindrow*)under nursery conditions as influenced by different chilling durations

Altitude(m)	Fresh biomass weight (g)											
	Sites											
	Tangmarg ForestDivision					Mean	Sindh ForestDivision					Mean
	Chilling Duration(Days)						Chilling Duration(Days)					
	Control	15	30	45	60		Control	15	30	45	60	
2300-2600	0.26	0.33	0.45	0.48	0.51	**0.41**	0.16	0.25	0.35	0.40	0.45	**0.32**
2600-2900	0.16	0.23	0.32	0.34	0.39	**0.29**	0.18	0.31	0.40	0.42	0.47	**0.36**
>2900	0.13	0.19	0.27	0.30	0.34	**0.25**	0.11	0.17	0.24	0.28	0.30	**0.22**
Mean	**0.19**	**0.25**	**0.35**	**0.37**	**0.41**	**0.31**	**0.15**	**0.24**	**0.33**	**0.37**	**0.41**	**0.30**

CD (≤ 0.05)		CD (≤ 0.05)	
Altitude	0.06	Altitude	0.06
Chilling duration	0.08	Chilling duration	0.08
Altitude x Chilling duration	0.14	Altitude x Chilling duration	0.13

4.5.10 Shoot root ratio (weight based)

The effect of altitude and chilling duration on shoot root ratio is depicted in Table 33. A perusal of the table shows that in Tangmarg Forest Division, minimum shoot root ratio of 1.46 was recorded at the lower altitude (2,300-2,600 m). The shoot root ratio at middle (2,600-2,900 m)and the upper altitude (>2,900 m) was same and was recorded as 1.56. However thedifference in shoot root ratio among the altitudes were non-significant.

Similarly chilling duration could not influence shoot root ratio significantly. Maximum shoot root ratio recorded as 1.73 in control decreased to 1.42 recorded after 60 days chilling duration

Interaction results of altitude and chilling duration were also non-significant. Minimum shoot root ratio was recorded as 1.30after 15 days of chilling duration at middle(2,600-2,900m)altitude whereas the maximum shoot root was recorded as 1.81 in control at the lower altitude(2,300-2,600 m).

In Sindh Forest Division, again non-significant difference were recorded amongst thelower (2,300-2,600 m), middle (2,600-2,900 m) and the upper altitude (>2,900 m).

Non-significant difference was also recorded amongst the different chilling durations. Maximum shoot root ratio was recorded as 1.66 in control where as its minimum value was recorded as 1.42 after 60 days of chilling duration.

Again the interaction results between altitude and chilling duration revealed non-significant difference. Minimum shoot root ratio was recorded as 1.20 after 45 days of chilling duration at the lower altitude(2,300-2,600 m)where as the maximum shoot root ratio was recorded as 1.75 in control at the upper altitude (>2,900 m).

Table 33: Altitudinal variation in shoot root ratio of Fir (*Abies pindrow*)under nursery conditions as influenced by different chilling durations

Altitude(m)	Shoot root ratio											
	Sites											
	Tangmarg ForestDivision					Mean	Sindh ForestDivision					Mean
	Chilling Duration(Days)						Chilling Duration(Days)					
	Control	**15**	**30**	**45**	**60**		**Control**	**15**	**30**	**45**	**60**	
2300-2600	1.81	1.51	1.32	1.34	1.32	**1.46**	1.72	1.48	1.50	1.20	1.35	**1.45**
2600-2900	1.72	1.30	1.67	1.58	1.54	**1.56**	1.51	1.59	1.62	1.63	1.40	**1.55**
>2900	1.66	1.41	1.70	1.61	1.40	**1.56**	1.75	1.31	1.70	1.65	1.50	**1.58**
Mean	**1.73**	**1.41**	**1.56**	**1.51**	**1.42**	**1.53**	**1.66**	**1.46**	**1.61**	**1.49**	**1.42**	**1.53**

CD (≤ 0.05)		CD (≤ 0.05)	
Altitude	NS	Altitude	NS
Chilling duration	NS	Chilling duration	NS
Altitude x Chilling duration	NS	Altitude x Chilling duration	NS

4.5.11 Survival percent

The influence of altitude and chilling duration in Tangmarg Forest Division on survival percent is depicted in Table 34. A perusal of the table shows that the survival percent decreased with the increase in altitude. Maximum survival of 75.64% was recorded at the lower altitude (2,300-2,600 m) and it differedsignificantly from65.71 and 69.92% recorded atmiddle (2,600-2,900 m) and the upper altitude(>2,900 m)respectively.

Chilling duration similarly increased the survival percent. Minimum survival of 64.26% was recorded in control. Maximum survival was recorded as 72.21% after 60 days chilling duration followed by 70.38% after 45 days of chilling duration with non-significant difference between these two chilling periods.

Interaction results depicts that altitude and chilling duration exerted a strong influence on survival percent. Minimum survival of 59.96% was recorded in control at the upper altitude (>2,900 m) followed by 61.84% in control at the middle altitude (2,600-2,900 m) though the two were statistically at par. Maximum survival percent was recorded as 79.91% after 60 days chilling duration at the lower altitude (2,300-2,600 m) followed by 78.68% after 45 days of chilling duration at the same altitude with non-significant difference between these two chilling periods.

In Sindh Forest Division altitudesrecordedsignificant differences andmaximum survival percent was69.92% atmiddle altitude (2,600-2,900 m).The survival at the lower(2,300-2,600m)and at upper altitude(>2,900 m) wasrecorded as66.80 and 61.13% respectively.

Chilling duration also increased the survival percent significantly. Minimum survival percent of 59.89% was recorded in control and it increased to 64.27, 67.45, 68.38 and 69.97% after the seeds were subjected to 15, 30, 45 and 60 days chilling duration respectively. However non-significant increase was recorded in survival percent between 45 and 60 days chilling duration.

Table 34: Altitudinal variation in survival percent of Fir (*Abies pindrow*) under nursery conditions as influenced by different chilling durations

Altitude(m)	Survival per cent										
	Sites										
	Tangmarg ForestDivision					Mean	Sindh ForestDivision					Mean
	Chilling Duration(Days)						Chilling Duration(Days)					
	Control	15	30	45	60		Control	15	30	45	60	
2300-2600	70.98 (57.41)	74.26 (59.59)	74.39 (59.69)	78.68 (62.78)	79.91 (63.58)	**75.64 (60.61)**	61.79 (51.83)	63.03 (52.56)	68.84 (56.07)	69.57 (56.55)	70.76 (57.29)	**66.80 (54.86)**
2600-2900	61.84 (51.90)	64.16 (53.22)	66.01 (54.35)	67.38 (55.18)	69.16 (56.25)	**65.71 (54.18)**	60.30. (50.94)	69.65 (56.56)	71.99 (58.05)	73.31 (58.92)	74.36 (59.61)	**69.92 (56.82)**
>2900	59.96 (50.73)	61.39 (51.57)	60.61 (51.12)	65.07 (53.78)	67.56 (55.31)	**69.92 (52.50)**	57.57 (49.35)	60.13 (50.84)	61.51 (51.65)	62.26 (52.08)	64.18 (53.23)	**61.13 (51.43)**
Mean	**64.26 (53.35)**	**66.60 (54.79)**	**67.00 (55.05)**	**70.38 (57.24)**	**72.21 (58.38)**	**68.09 (55.76)**	**59.89 (50.71)**	**64.27 (53.32)**	**67.45 (55.26)**	**68.38 (55.85)**	**69.77 (65.95)**	**65.95 (54.37)**

CD (≤ 0.05)		CD (≤ 0.05)	
Altitude	2.14	Altitude	1.71
Chilling duration	2.77	Chilling duration	2.21
Altitude x Chilling duration	4.80	Altitude x Chilling duration	3.82

Values in the parenthesisare arc sine transformation

Interaction results show significant variation.Minimum survival percent was recorded as 57.57 in control at upper altitude (>2,900 m) followed by 60.30 in control at middle altitude (2,300-2,600 m).Both were statistically at par. Significantly maximum survival of 74.36% was recorded after 60 days of chilling duration at middle altitude.

4.6 Regeneration status of *Abies pindrow* at different altitudes

The regeneration status of *Abies pindrow* at the selected altitudes of Tangmarg and Sindh Forest Division is summarized in Table 35. The average density of seedling, sapling and mature tress/ha at lower altitude (2,300-2,600 m) were recorded as 845, 512 and 643 respectively. At middle altitude (2,600-2,900 m) the average density of seedling, sapling and trees/ha were recorded as 815, 410 and 540 respectively. At upper altitude (>2,900 m), the average density of seedling, saplings and mature trees/ha were recorded as 415, 335 and365 respectively. Furthermore the table depicts that average seedling, sapling and tree density decreased as we moved from lower altitude to upper altitude. The results further depict that the regeneration status was fair at lower and middle altitude where as it was good at higher altitude in Tangmarg Forest Division.

In Sindh Forest Division, the lower altitude (2,300-2,600 m) recorded the good regeneration status with respective seedling and sapling density of 833 and 796/ha. Average number of trees was 702/ha. At middle (2,600-2,900 m) and upper altitude (>2,900 m), the regeneration status was recorded as fair and the average seedling, sapling and tree density/ha at middle altitude were recorded as 610,405 and 490/ha respectively. At upper altitude, the average seedling and sapling density/ha were recorded as310 and 295/ha respectively. Tree density was recorded as 335/ha. Seedling, sapling and tree density decreased as we moved from lower altitude to upper altitude.

Plate 12: Natural regeneration of fir (*Abies pindrow*) on nurse log in Sind Forest Division

Table 35: Regeneration status of Fir (*Abies pindrow*) at different altitudes

Altitude (m)	Tangmarg Forest Division				Sindh Forest Division			
	Seedling/ha	Sapling/ha	Mature strata/ha	Status	Seedling/ha	Sapling/ha	Mature strata/ha	Status
2300-2600	845	512	643	Fair	833	796	702	Good
2600-2900	815	410	540	Fair	610	405	490	Fair
>2900	415	365	335	Good	310	295	335	Fair

Mature strata Height =>2m

Sapling Height=0.5m-≤2m

Seedlings Height=≤0.5m

Good=seedling>saplings> mature strata

Fair =seedlings>saplings<mature strata

Poor=if the species survives only in sapling stage but not as seedlings

Chapter -5

DISCUSSION

The results obtained from the present investigation entitled "AltitudinalVariation in Phenology, Seedling Characteristics and Natural Regeneration of *Abies pindrow* have been discussed in this chapter and an effort has been made to establish causes supported by available literature. The results obtained are discussed under the following heads:

5.1 Altitudinal variation in morphometriccharacteristics of Fir (*Abies pindrow*)

During the study of morphometric characteristics, it was revealed that there is decline in the tree height, diameter at breast height and basal area from lower altitudes to higher altitudes. In contrast, the crown spread and crown length were recorded maximum at the middle altitudes

Inboth the forest division the tree height was foundmaximum at lower altitude(2,300-2,600 m)recorded as 28.28 and 31.60 m in Tangmarg and Sindh Forest Divisionrespectively which at upper altitude (>2,900 m)declined to 17.18 and 17.28 m respectively. Similarly the diameter declined from 35.66 to 17.00cm and38.90 to 14.88cm from lower altitudes(2,300-2,600 m) to upper altitudes (>2900 m) in Tangmarg and Sindh Forest Division respectively. The basal area recorded as 998.70cm^2 at lower altitude in Tangmarg Forest Division witnessed a sharp decrease and was recorded as 223.86cm^2 at upper altitude. In Sindh Forest Division the maximum basal area recorded as 1186.86cm^2 at lower altitude declined to 226.86 cm^2 at upper altitude.

Maximum tree height at lower altitudes may be attributed to comparatively higher tree density. Maximum tree height is an important indicator for understanding several properties of plant communities, including total standing biomass and resource use (Enquist *et al.*, 2009). Trees under high density tend to attain more and more height as an adaptative measure for light competition while stunted growth at higher elevations is local adaptative measure to prevailing harsh site conditions. These results are in agreement with the results ofKampes *et al.* (2012). They reported that maximum/mean tree height and mean annual growth rate decreased with altitude in Smith fir (*Abies georgei*). High-altitude environmental conditions (such as low temperature, low temperature-induced water stress, low nutrient availability and strong winds) affect important aspects of tree performance. Environmental factors, especially low temperatures, at high altitudes restrict the physiological processes responsible for tissue formation, such as photosynthesis, respiration, allocation of food and shoot growth (Sklenar *et al.*, 2011) thereby reducing significantly tree morphometric characteristics viz. dbh, basal area tree height and tree crown spread. Korner (2012) also maintained tree growth is constrained by changing environmental conditions with increasing altitude. However, the maximum crown length and width at middle altitudes is as a result of gap openinings found at middle altitudes which finally at upper altitudes changed into vast stretches of pasture lands. Light improvement as a result of gap openings promoted both crown length and crown width. Under sufficient light conditions trees tend to develop deeper crown and *Abies pindrow* has tendency to branch low down under improved light conditions (Troup, 1921).

5.2 Altitudinalvariation in phenological characteristics of *Abies pindrow* at different altitudes

5.2.1 Leaf renewal and leaf fall

Timing of tree phenological events is known to be tightly correlated to temperature and photoperiod(Doi and Katano,2008). The phenology of temperate woody plants is commonly assumed to be locally adapted to climate and a number of studies using provenance tests highlighted phenological differences between populations(Wuehlisch *et al.*, 1995; Ducousso *et al.*, 1996;Chmura and Rozkowski, 2002; Chmura, 2006).

In the present study leaf renewal commenced in the month of April at the lower altitude(2,300-2,600 m)whereas at the middle (2,600-2,900 m)and upper altitude(>2,900 m)it started during early May in both the selected forest divisions. The difference in the leaf onset may be due to the local adaptative responses to their local environment. Early arrival of the growing season at the lower altitude as compared to higher altitude initiates the early leaf unfolding at lower altitudes as has been reported by Vitasse *et al.* (2009) who showed that there were strong altitudinal trends in leaf phenology with a delay of 1.1–3.4 days for every 100m increase in elevation.Early leaf unfolding serves as an important phenological event to lengthen the growing season. With the increase in altitude, there is sharp decline in temperature which in turn delaysthe leaf renewal. Temperature is regarded as an important climatic variable which is tightly correlated to leaf unfolding. Significant correlation has been found between leaf unfolding and temperature in *Abies alba, Acer pseudoplatanus, Carpinus betulus, Fagus sylvatica, Fraxinus excelsior, Ilex aquifolium* and *Quercus petraea* by Vitasse*et al.* (2009).Pellerin *et al.* (2012) also reported altitude as a main predictor variable of budburst and leafing dates with delays ranging from 2.4 to 3.4 days per 100 m.

The leaf fall did not show any marked seasonality. The leaf fall was recorded asa continuous process. Strong seasonality in a leaf fall is a characteristics of a deciduous forest tree species as reported by Justiniano and Frederickson (2002). In the study it was revealed that abscised leaves were seen as a permanent feature which in turn resulted in the continuous leaf fall throughout the year. Conifer species shed their leaves throughout the year without any marked seasonality.

5.2.2 Appearance of male and female cones

The male and female cones appear during late April at lower altitude (2,300-2,600 m) whereas at middle(2,600-2,900 m) and upper altitude(>2900 m) their appearance were recorded during early May. This difference though small, may be due to the early onset of the favourable growth condition at lower altitudes as compared to higher altitude. The trees at the lower elevations witness the early onset of spring and hence early development that might have caused the difference in their appearance. Singh *et al.*(2015) also reported that the phenological events began early at low elevation and delay at higher elevation. Ziello *etal.* (2009) in their studies in high mountain regions reported that flowering phenology changes along elevation gradients, with plants at lower elevations typically flowering earlier than plants of the same species that grow at higher elevations.

5.3 Altitudinal variation in cone and seed maturity at different altitudes asinfluenced by collection date

Seed handlers need to know when acceptable seed viability is reached in the maturing cone. In this study, following cone and seed characteristics were observed in an attempt to find a simple, effective and reliable index of cone and seed ripeness as maturity indices for fir.

5.3.1 Cone and seed colour

Cone and seed colour serves asan important indices to judge the exact stage of seed collection. Workable indices of cone maturation have been devised based on the change in cone colour by Mughaland Thapliyal (2006) in *Cedrus deodara.* They reported that the cones of *Cedrus deodara* turn dark brown with green patches at maturity. In case of *Abiespindrow*, the cone colour changed from dark purple to chocolate with purple scale edges by the 15 th September. The change in cone colour was associated with the change in seed colour. The seed colour changed from deep pink to deep chocolate at the stage of maturity. Collection made close to this colour change resulted in the higher germinability thus serves as an useful and easy index of maturity. Similar findings were observed in seeds of *Bauhinia retusa* which undergo change in colour from green to brownish red at maturity (Upadhyyay *et al.*, 2006). Bonner (1972) established a relationship between colour change in fruits/seed and maturation in Sweet Gum and American Sycamore seeds. Similarly, Willian (1985) has considered colour change in cone/fruit as areliable index for judging seed maturity. Singh (2011) reported that the cone colour turn glossy red at maturity in case of *Pinus* *helpensis.* Cone colour change indicated that the cones maturation is earlier at lower altitudes and the cones are mature enough for collection in mid-September at lower and middle altitudes. Bhat *et al.*(2014)while studying the seed maturityrevealed that the colour change from green to black in *Robinia pseudoacacia*is an easy indicator in judging seed maturity.

At lower and middle altitudes most of the cones dispersed in the month of October whereas at higher altitude, though the dispersal commenced in the same month but peak cone dispersal month was recorded as November. Giami (1970) also reported the delay of date of seed fall of European silver fir with increasing altitude. Similar findings were reported by Patrizia *etal.* (2011).They reported that seed dissemination in *Abies cephalonica* started from the lower elevations and began in October but has also been recorded in late-September and early-November. Thus the cone collection should be started from the lower altitudes and then at higher altitudes in order to lengthen the collection period.

5.3.2 Cone weight

During the study of cone collection it was revealed that the cone weight increased from 1st July to 15th August and then decreased as the collection progressed. The cones attained maximum weight by the 15th August at all the selected altitudes. At lower altitude which resulted in the production of heaviest cones in the Tangmarg Forest Division, the cone weight increased from 70.33 (1st July) to 104.32 g (15th August) and then declined to 87.18 g at maturity. In Sindh forest though the maximum cone weight of 82.48 g was recorded at middle altitude but the trend of increasing and thereafter decrease in cone weight was similar.

The increase in the cone weight initially is due to the increase in the seed size and seed weight as was revealed during the study. The decrease for the later collections, though the seed weight increased throughout the collection period may be due to the desiccation of cones which is a characteristic feature of maturity (Mughal and Thapliyal 2006). Similar decreasing trend in cone weight towards later collections has been reported by Lavania *et al*. (2010) while studying the influence of collection dates on cone weight in *Pinus wallichiana.*

5.3.3 Cone specific gravity

Specific gravity serves as in important index of maturity. There is general agreement that the cones are mature enough for collection when the specific gravity of cones has fallen below 0.90. In the present study, the cone specific gravity showed a declining trend throughout the collection period. The cone specific gravity during 1st collection date was recorded as 1.18, 1.20 and 1.21 at lower, middle and upper altitude respectively in Tangmarg Forest Division which at maturity declined to 0.76, 0.84 and 0.70 respectively. Similar declining trend was recorded in Sindh Forest Division. Singh (1989) also observed similar decreasing trend with cones of spruce where specific gravity decreased from 1.07 to 0.99 at maturity at 2,400 m elevation whereas at 2,700 m elevation it decreased from 1.0 to 0.97. This decrease in specific gravity is attributed to cone and seed ripening towards later collections. Bhat *et al.*(2014) also recorded the decrease inspecific gravity towards maturity in seeds of*Robinia pseudoacacia.* Similarly Mughal and Thapliyal (2006) also reported a decreasing in specific gravity in seeds of *Cedrus deodara*.

5.3.4 Cone dimensions and seed number/cone

The cones dimensions and seed number varied with the collection date. In Tangmarg Forest Division, the cone dimensions decreased as we moved from lower altitude to higher. The maximum cone length and diameter at maturity was recorded as 12.00 and 4.42 cm respectively at lower altitude. The seed number for the same collection date and altitude was recorded as 354.30 (maximum) whereas in Sindh Forest Division middle altitude (2,600-2,900 m) resulted in the maximum cone length (11.65cm), cone diameter (4.34cm) and seed number (343.12) at maturity. By the time the collection started, cone length has almost ceased at lower altitudes and only a small increasein cone length was recorded at middle and upper altitude. This could be attributed to difference in pollination time as cone elongation follows immediately after pollination. Delayed pollination may cause delay in cone length. The difference in cone length may be due to various locality factors like edaphic, climatic or general tree health which individually or in combination affect the tree growth or literally due to source variation. Similar variability in cone characteristics has been reported by Rawat *et al.* (2008) in *Abies pindrow* collected from different seed sources. Similarly in cone diameter only small increase was recorded. Initially the increase in cone diameter may be attributed to cone growth whereas the increase towards the collections close to dispersal is due to loosening of scales. Furthermore, it was revealed that cones with higher length yielded more seed number and vice versa. Significant correlation between cone length and seed number has been reportedbyRawat*et al.* (2008) in *Abies pindrow.* Similarly Ching (1960) also reported a significant correlation between seed yield and cone length in grand fir.

5.3.5 Seed weight (g/1000 seeds)

The seed weight increased throughout the collection period. In Tangmarg Forest Division Maximum seed weight was recorded as 79.47 g/1000 seeds at maturity and it decreased with the increase in altitude. In Sindh Forest Division, maximum seed weight of 75.38 g/1000 at maturity was recorded at middle altitude. The increase in seed weight is attributed to allocation and accumulation of food materials in the seeds.During the accumulation phase of seeds, nutrient status of the seeds is improved in the form of proteins, carbohydrates and proteins so the germinative capacity is continuously improved up to seed dispersal (Yanagisana, 1965). Similar results were recorded by Mughal and Thapliyal (2006) in *Cedrus deodara* in which the seed weight increased from 91.28 g/1000 (August) to 130.60 g/1000 (October) in North Kashmir where as in South Kashmir, it increased from 143.25 g/1000 (August) to 152.50 g/1000 (September). Singh (2011) also reported an increase in seed weight in *Pinus helpensis* towards maturity. The variability in seed weight at different altitudes may be attributed to diverse environmental conditions under which the species is found to grow. Rawat and Bakshi (2011) has reported edaphic factorsas the crucial factor affectingseed traits. Salazar and Quesda (1989)reported variations in seed parametersin *P. wallichiana* may be attributed to different genetic architectures developed as a result of adaptation to diverse environmental conditions exiting throughout their distributional range starting from north-eastern part of India to the state of Jammu and Kashmir.

5.3.6 Seed moisture (%)

The seed moisture decreased as the collection progressed. In Tangmarg Forest Division, the moisture percent of the seeds at different altitudes varied from 91.88 to 82.41% on the first collection date which at maturity decreased and ranged between 11.08 to 14.28% at maturity. Similarly the moisture percent on first collection date recorded as 85.20, 88.32 and 92.26% at lower(2,300-2,600 m), middle (2,600-2,900 m) and upper altitude (>2,900 m) respectively decreasedto 12.54, 14.38 and 11.51% respectively at maturity in Sindh Forest Division. The decrease in the seed moisture is due to the replacement of water content by food materials as revealed by the change of megagametophyte from inconsistent (early collections) to firm and consistent gametophyte at the stage of maturity. Towards maturity, the megagametophyte solidifies as a result of desiccation which is a characteristic feature of maturity. Similar results were reported by Lavania *et al.* (2010) in blue pine. Decline in moisture content per cent from maturing seeds has been also reported by Bhat (2013) in maturing seeds of *Pinus wallichiana*. Singh and Kachari (2006) reported that the moisture content of khasi pine seeds collected on different dates varied from 36.42 per cent of immature seeds to 9.58 of mature seeds.

5.3.7 Seed dimensions

The study revealed that the seed dimensions increased as the collection progressed.Maximum seed dimensions were recorded at maturity. Furthermore it was also revealed that the cones with more dimensions produced larger seeds. In Tangmarg Forest Division, lower altitude (2,300-2,600 m) produced the seeds of maximum seed length (11.62 mm) and seedwidth (5.54 mm) whereas in Sindh Forest Division the middle altitude (2,600-2,900 m) resulted in the production of maximum seed length(11.35 mm)and width (5.48 mm).The increase in the seed size is attributed to growing megagametophyte which is a characteristic feature of maturity during the accumulation phase recognized as the first stage of maturity. The variation in the seed dimensions at various selected altitudes may be attributed to both internal (maternal influences) and external environmental conditions operating at the time of seed development (Harper *et al.*, 1970).The varying environmental conditions like edaphic and climatic factors prevalent at the collection sites include the important external conditions that might have initiated seed size variability. The seed traits are largely under maternal influences and are strongly controlled by age, general health and micro and macro habitats of the parent tree (Isik, 1986).

5.3.8 Seed viability (%)

During the first two collections the seeds were declared as non-viable as no germination was recorded for these collections. But as the collection progressed, the seed viability commenced and increased up to their dispersal. The viability at maturity at lower, middle and upper altitudes at maturity were recorded as 52.75,43.25 and 38.25% respectively in Tangmarg Forest Division. In Sindh Forest Division, the seed viability at maturity at lower, middle and upper altitude was recorded as 46.50,48.25 and 34.50% respectively. During the first two collections, the megagametophyte showed milky consistency and the seeds often bursted while separating them from their scales. Early collections are very sensitive and often nonviable. Early collection of the seeds results in the curtailment of accumulation of food reserves and metabolic changes thus rendering them non-viable (Speers, 1962). Towards maturity the embryo reaches to its fullest development and results in higher viability by reducing its sensitivity. Lavania *et al.* (2010) has also reported higher seed viability in *Pinus wallichiana* when collected close to their dispersal.

5.3.9 Seed germination (%)

The seed germination increased towards the maturity. No germination was recorded initially for the first two collection dates. Seeds started germination by the 1st August at all the altitudes. The germination percent which was recorded as 10.00, 5.75 and 4.215% at lower, middle and upper altitudes respectively by the first collection increased to 40.25,35.75 and 31.25% respectively at maturity in Tangmarg Forest Division. Furthermore the seed germination decreased from lower to upper altitudes.

In Sindh Forest Division the middle altitude resulted in the maximum germination. The germination increased from 7.25 (1stAugust) to37.25% (15th October). Lack of germination initially may be contributed to embryo immaturity. Due to early detachment of the seeds from the cones, the seed are deprived from the accumulation phase which is recognized as an early period of maturation. During this phase, cones continue to provide organic material necessary for maturation. Any collection of seeds before this phase or during this phase may reduce viability. The increase in the germination percent is as a result of accumulation of food reserves in the seed as indicated by increasing seed weight so that the germinative capacity is continuously improved up to seed dispersal (Yanagisawa, 1965). After the accumulation phase is completed, the seeds undergo metabolic changes which leadsto further higher germination till their dispersal. Similar results were recorded by Mughal *et al.*(2007) in *Cryptomeria japonica.* Further it is revealed that the altitudes which resulted in heavier seeds also recorded higher germination percent. Thus the wide variation displayed in germination percent may be attributed to varying seed weights recorded at selected altitudes. Variation in germination of seed sources has been reported in

Pinus greggi (Dvorak *et al*., 1996) *Acacia catechu* (Ramachandra 1996) and *Pinus roxburghii* (Roy *et al.,* 2004).

5.4 Altitudinal variation in germinability parametersin seeds of *Abies pindrow* as affected by different chilling durations

In the present study effect of altitude and chilling durations on the various germination characteristics viz. germination percent, germination energy, germination value, MGT were evaluated.

During the study it was revealed that altitude exerted a strong influence on germinabality in seeds of *Abies pindrow*. In the Tangmarg Forest Division lower altitude resulted in maximum germination (35.55%), germination energy (24.00%) and germination value (3.93) and the all the germination parameters decreased with the increase in altitude. Under the nursery conditions, the germination and MGT of the same altitude were recorded as 29.30% and 29.66 days respectively. In Sindh Forest Division middle altitude proved superior and the germination, germination energy and germination value were recorded as 35.05%, 26.20% and 3.67 respectively under controlled conditions. The germination and the MGT of the same altitude under nursery conditions were recorded as 30.00% and 30.94 days respectively. The altitude has exerted an influence by controlling the seed weight as was revealed during the study. The wide variation in the seed weight is the reason behind variability in the germinability. Variation in the seed weight may be attributed to different genetic architectures a speciesdevelops when found grown under diverse environment conditions (Salazar and Quesda, 1989). Higher seed weight resulted in greater germination than seeds with lower weight. This may be as a result of higher stocks of reserve food in heavy seeds. This is in agreement with the results of Mughal (2002) who has found a significant correlation between seed weight with germination percent and germination value. Khan and Uma Shankar (2001) have also reported that heavy seeds germinate early and achieve greater germination.

Stratification also significantly improved germinability of fir seeds both under laboratory and field conditions. Increase in stratification improved germination characteristics. Cold stratification or chilling under moist conditions has long been recognised as a useful method of treating seeds to improve the rate and the percentage of germinability (Outcall, 1991).Under laboratory conditions maximum germination (40.83%),germination energy (27.83%) and germination value (4.96) were recorded after 60 days chilling duration in Tangmarg Forest Division. The MGT under the same chilling duration was recorded as 21.73 days (minimum). Under the nursery conditions, the germination and MGT under the same chilling duration were recorded as33.33% (maximum) and 28.79 days(minimum). The increase in the germination percent, germination energy and germination value under extended stratification duration may be attributed to reduction of germination inhibitors during stratification (Rawat *et al.*, 2010) which in turn might have reduced MGT towards higher chilling durations. Similar result were reported by Mughal and Thapliyal (2013)while studying the effect of chilling durations on germination characteristics of *Cedrus deodara*.

The cold stratification is reported to increase the GA_3 levelswhich increases the germination. GA_3 is a natural growth regulator present in seeds of many woody plants which stimulates germination (Chen *et al.*, 2005).Yamuchi*et al.*(2004) explored that the stratification increased the germination by activating the gene responsible for biosynthesis of GA_3. In the dormant seeds (non-stratified) on the other hand, the inhibitors have balance with the growth promoters (Rehman and Park, 2002) which reduces the germination. Stratification alters the balance by increasing GA_3 thus improving germination.

As was revealed during the study both altitude and chilling interaction duration resulted in the significant improvement in the germination parameters. In Tangmarg Forest Division, under laboratory conditions, maximum germination (48.75%), germination energy (32.50%) and germination value (6.96) were recorded at lower altitude after 60 days chilling duration. The MGT for such seeds was minimum(20.59 days). Under the nursery conditions, maximum germination

(39.25%) and minimum MGT (25.13 days) were recorded at the same altitude and same stratification duration. Similarly in the Sindh Forest Division, the seeds collected from middle altitude registered superiority after 60 days of chilling duration andmaximum germination, germination energy and germination value under laboratory conditionsin this division were recorded as 46.75%, 32.50% and 6.46 respectively.This could be attributed to the synergistic affect of seed weight and chilling duration. Altitudes with higher seed weight and higher chilling durations promoted germination characteristics.

5.5 Altitudinal variation in seedling characteristics of *Abies pindrow* under laboratory conditions as affected by different chilling durations

The study revealed maximum radical (2.40 cm) and plumule length (3.24 cm) and vigour index (205.28) were recorded at lower altitude (2,300-2,600m) and showed a declining trend with increase in altitude in Tangmarg Forest Division. However in Sindh Forest Division middle altitude resulted in maximum radical (2.34 cm) and plumule (3.17cm) length and vigour index (198.76). The study revealed that altitudes that produce heavy seeds also influence the seedling characteristics. The seedlings raised from heavier seed improved the seedling characteristics by increasing their radical and plumule length and vigour index. Seed weight is known to control seedling growth. Higher seed weight leads to good nutrition for growth and development of seedling. The larger seed size and weight has been generally observed to produce initial seedling growth. Seedling trait variation due to source variation has been documented in *Cedrus deodara* (Mughal 2002) and *Acacia nilotica* (Gera *et al*., 2000).

Increase in the chilling durations resulted in the increase in radical and plumule length. Similar results were recordedfor vigour index also. Maximum radical and plumule length were recorded as 2.64 and 3.29 cm respectively after 60 days chilling duration in Tangmarg Forest Division. The vigour index for the same chilling duration was recorded as 243.89 (maximum). The stratification influenced through the production or release of growth promoters. During the stratification it has been reported that there is increase in the soluble proteins and total sugar content (Sofi and Bhardwaj, 2007) which might have promoted radical and plumule elongation. The results are in close conformity with Rawat *etal.*(2010)who while studying effect of stratification on seed germination and seedlingperformance of wild pomegranate reportedsimilar results. The increase in the stratification resulted in increasing value of reducing sugars, total sugar and soluble proteins in the seeds which are taken by embryo for its subsequent growth and development. Highly improved seedling produced under 60 days chilling duration at the lower altitude in Tangmarg Forest Division as compared to other seedlings could be attributed to heavy seed weightand higher production of sugars during stratification.

5.6 Altitudinal variation in seedling characteristics under nursery as affected by different chilling durations

The altitudes affected significantly the seedling morphometric parameters viz. seedling height collar diameter, root length, shoot height number of roots and biomass. The survival percentage also increased. Maximum seedling height (4.69 cm), collar diameter (1.00 cm), root length (8.93cm) and number of roots (4.42), fresh shoot weight (0.24 g), fresh root weight (0.17 g), biomass (0.41 g) and survival percent (75.64%) were recorded atlower altitude of Tangmarg Forest Division. This is as a result of higher seed weight at lower altitude. Seed weight is known to control the growth of seedlings. Higher seed weight leads to good nutrition conditions for growth and development of healthy seedlings. Seed size has been found to regulate subsequent seedling growth in many species (Baldwin, 1942; Langdon, 1958; Willam, 1967; Kandya, 1978; Devagiri, 1997).

The stratification significantly improved the seedling characteristics. Maximum value for seedling height (4.58 cm), collar diameter (1.01 mm), root length (8.91 cm) and number of roots (4.50), fresh shoot weight (0.24 g), fresh root weight (0.17 g) biomass (0.41 g) and survival (72.21%) percent were recorded after 60 days of chilling duration in Tangmarg Forest Division. The stratification has contributed to this in a way that increasing the stratification resulted in increase in the growth substances like gibberlic acids and hence growth of the seedling. GA_3 has been found to stimulate the growth of stems (Jones, 1973). The production of seedlings with longer root system under extended stratification utilised the condition more efficiently than seedlings with comparatively less developed root system therefore improving growth parameters and survival.Malik and Shamet (2009) have also reported improvement in seedling parameters under 60 days stratification period in *Pinus gerardiana.*

During the study it was revealed that high quality seedlings were produced at lower altitude when seeds were subjected to 60 days chilling duration. This may be attributed to synergistic effect of heavy seed weight and more production of growth substance under longer stratification periods.

5.7 Altitudinal variation innatural regeneration of *Abies pindrow*

One of the chief requirements of the natural regeneration is the production of abundant seeds, their germination, establishment and conversion of seedling to mature strata. Studies on seedling density and distribution of the tree species help us to understand its status and ecology (Harper,1977) which have significant implications on the managementand conservation of natural forests (Swaine, 1996).

The population structure in terms of seedling, saplingsand mature trees varied greatly. The highest average density was recorded at lower altitudes in both the forest divisions. In Tangmarg Forest Division the average seedling density, sapling density and mature tress/ha at loweraltitude were recorded as 845, 512 and 643 respectively and decreasedto 415, 365 and 335 respectively at higher altitude.Similarly in Sindh Forest Division, the average seedling density, sapling density and tree density recorded as 833, 796 and702declined to310, 295 and 335 respectively. The higher seedling and sapling density at the lower altitudes may be attributed to greater number of mother trees at lower altitudes. Abundant seed rain which is considered a primary requirement of natural regeneration especially in confers maintains the forest structure by their germination, establishment and their conversion to mature trees. For successful regeneration of any specie, there must be initiation of new seedlings, their survival and their growth. Towards the higher altitudes, huge gap openings were found reducing the tree density. At upper altitude vast stretches of pastures with occasional *Abies pindrow*patches replaced the forests with few cone bearing seeds which in turn resulted in lesser number of seedling and saplings. These pastures act as grazing hotspots which in turn reduce the conversion of seedlings into saplings thus affecting the structure of the forest badly. Grubb (1977) reported that constraints hampering the tree regeneration include low amount of viable seeds, restricted spatial extent of seed dispersal and reduced availability of suitable microsites for seedling establishment.Furthermore it was revealed that the seedlings were found abundantly under shrub cover and on nurse logs. The decaying logs provided the ideal germination bed and seedlings were found in abundance on these decaying logs. These logs help regeneration by avoiding ground vegetation competition, long lasting snow cover and low soil temperatures (Ester*et al.*, 2015). Kuluuvainen and Kalmari (2003) also revealed that nurse logs on the forest floor play very important roles in the natural regeneration of conifers. During the study it was also revealed that the seedlings were found growing abundantly under shade as compared to gap openings which receive sufficient sun light. Gupta (1996) reported that regeneration of fir varied with the elevation and site due to the variation in locality conditions at Chhachpur and Narkanda forest of Himachal Pradesh. Acharya (2004), in mixed *Abies spectabilis* forest of Manang, found high human interference as the main factor leading to the destruction of species of high girth classes andless natural regeneration of *Abies spectabilis* due to radiation, low moisture and high human pressure.

SUMMARY AND CONCLUSION

The forests of Jammu and Kashmir are mainly known for conifer species growing in the foreststhat include deodar (*Cedrus deodara*), kail (*Pinus wallichiana*), fir (*Abies pindrow*), and chir (*Pinus roxiburghii.* All these conifer species are facing severe degradation owing to high biotic interference. Besides there are some other natural causes like piling of undecomposed litter, infrequent good seed years, high percentage of empty seeds, low germinability of seeds due to dormancy and/or early seed collection and insect infestation that has resulted in their poor regeneration and vulnerability. Intervention with emphasis on seed technology is the need of the hour to help the species to overcome regeneration and long gap in good seed years.

Abies pindrow, an important conifer species of Kashmir valley enjoys a wide altitude. Thealtitude has been found a strong agent that trigger changes in vegetative as well as reproductivephenology. Phenological studies are important for elucidating tree responses to altitudinalchanges and judging proper stage of seed collection. Besides, altitude has been reported to induce seed variation whichneed to be taped to screen the best seed sources for improvement works. As the fir seeds are dormant owing to which there is delay of germination which prove detrimental both under natural as well as controlled conditions and thus need moist chilling.

Natural regeneration of any species is essential for perpetuation of forest crops. Adequate seed supply, effective dispersal, good viability and longevity of seeds, successful establishment of seedlings and their conversion to mature trees are all unavoidable for a sustainable forest management. In this backdrop, a project entitled "Altitudinal Variation in Phenology, Seedling Characteristics and Natural Regeneration of *Abiespindrow*" was carried out with the following objectives:

- To study the phenological characteristics of *Abies pindrow* at different altitudes.

- To study maturity of cone, seed and germination behavior of seeds in response tochilling for overcoming dormancy.
- To study regeneration status of *Abies pindrow* at different altitudes.

The results of the experiments are summarized and concluded under the following heads:

6.1 Altitudinal variation in morphometric characteristics of *Abies pindrow* at different altitude

Tree height decreased with the altitude. In Tangmarg Forest Division maximum tree height was recorded as 28.28 m at lower altitude (2,300-26,00 m)whereas minimum was recorded as 17.18 m at upper altitude(>2,900 m). Similar trend was observed in Sindh Forest Division with maximum height of 31.60 m at lower altitude (2,300-26,00 m)and minimum of 17.28 m at upper altitude (>2,900 m).

Average diameter at breast height declined with altitude in both the forest division. Average diameter at breast height in Tangmarg Forest Division was recorded as 35.66, 31.10 and 17.00 cm at lower (2,300-2,600 m), middle (26,00-2,900m) and upper altitude (>29,00 m)respectively. In Sindh average diameter at breast height was recorded as 38.90, 29.93 and 14.88 cm at lower (2,300-2,600 m), middle (26,00-2,900 m) and upper altitude (>29,00 m) respectively.

Tree basal area decreased sharply with increase in altitude and was recorded as 998.70, 755.91 and 226.86cm^2 lower (>2900 m), middle (2,300-2,600m) and upper altitude (2,600-2,900m) in Tangmarg Forest Division. In Sindh Forest Division, the basal area at lower (2,300-2,600 m), middle (2,600-2,900 m) and upper altitude (>2900 m) were recorded as1186.86, 703.28 and 157.00 cm$^{2.}$ respectively.

6.2 Altitudinal variation in phenology of *Abies pindrow* at different

altitude

The leaf renewal took place in the2nd fortnight of April at lower altitudes whereas at middle and upper altitudes, it took place during first fortnight of May in both the forest divisions.

The leaf fall lacked seasonality and was recorded as a continuous process.

Male and female cones were seen during 2nd fortnight of April in lower altitudes (2,300-26,00 m) whereas at middle (2,600-2900 m) and upper altitude(>2,900 m),they were visible during1st fortnight of May in both the forest divisions.

6.3 Altitudinal variationin cone and seed maturityof*Abies pindrow*

To decide the proper stage of cone/seed collection, phenotypically superior trees were selected at the different altitudes from 1st July till their maturity and following conclusions were drawn:

Cone colour serves a reliable indicator of maturity and cones should be collected when their colour changes from deep purple to chocolate with purple scale edges.

Cone weight increased initially and then decreased as the collectionprogressed. Maximum cone of weight 87.18 g at maturity was recorded at lower altitude in Tangmarg Forest Division. The cone weight decreased as we moved from lower altitude to higher altitude. In Sindh Forest Division middle altitude producedheavier cones and the cone weight was recorded as 82.48 g at maturity.

Cone length and cone diameter increased as the collection proceeded towards maturity. Maximum cone length of 12.00 cm and cone diameter of 4.42cm was recorded at maturity at lower altitude in Tangmarg Forest Division.

Specific gravity of cones decreased throughout the collection period and ranged between 0.70 to 0.84 at maturity.

Seed yield was greater in cones with more cone dimensions and was not influenced by collection dates. Seed numberdid not change from immature stage to maturity and ranged between 241.45 (upper altitude) and 354.30 (lower altitude)

6.3.1 Seed maturity indices

Change of cone colour from deep purple to purple with chocolate wing edges indicated cone maturity.

Seeds reach maturity earlier at lower altitudes as compared to higher altitudes. Cone/seeds mature in late-September at lower (2,300-2,600 m) and middle altitudes (2,600-2,900 m) whereas at upper altitude (>2900 m) cone maturity is attained in early-October.

Seed weight increased as the collection progressed at all the altitudes and seeds should be collected close to their dispersal. The seed weight at maturity oscillated between 62.16 and 79.74g/1000 seeds.Collection from higher altitudes should be avoided.

Seed dimensions increased as the collection progressed. Seed dimensions were higher for larger cones and vice versa. Seed length and seed width at maturity oscillated between 9.78 to11.62 mm and 4.26 to 5.54mm respectively.

Seed moisture declined towards maturity and oscillated between at 11.08 and 15.35% at maturity.

Seed germination and seed viability increased towards maturity. Higher viability and germination were recorded when seeds were collected just before their dispersal. In Tangmarg Forest Division the seed viability oscillated between40.25 (upper altitude) and 52.75% (lower altitude). The germination for the same division ranged between 31.25(upper altitude) and 40.25% (lower altitude). In Sindh Forest Division, middle altitude resulted in more seed viability of 48.25% and germination of 37.25%.

6.3.2 Laboratory performance of the seeds

The seeds collected from different altitudes from Tangmarg Forest Division and Sindh Forest Division were cleaned, dewinged and subjected to different chilling durations and their performance wastested both underlaboratory and nursery conditions.

In Tangmarg Forest Division, both the germinability and seedling characteristics decreased with increase in altitude. At lower altitude germination percent,germination energy and germination value recorded as 35.55%, 24.00%and 3.93 declined to29.80%, 20.25% and 2.34 at upper altitude. The MGT increased from 22.73 to 23.69 days. At lower altitude the radicle, plumule and vigour index recorded as 2.40 cm, 3.24 cm and 205.28 decreased to2.03 cm, 2.72 cm and 145.45 at upper altitude. In Sindh Forest Division no such regular trend was noted and middle altitude proved superior. The germination percent, germination energy, germination valueand MGT at middle altitude was recorded as 35.05%, 26.20% 3.67 and 22.82 days respectively while as radicle, plumule and seedling vigour recorded was 2.34cm, 3.17 cm and 198.76 respectively.

Chilling duration improved both germinability and seedling characteristics at all the altitudes. Significant improvement in germinability and seedling characteristics was achieved under longer chilling durations. In Tangmarg Forest Division, maximum germination (40.83%), germination energy (27.83%) and germination value (4.96) were recordedunder 60 days chilling duration .The radicle length, plumule length and vigour index for such seeds were recorded as 2.64 cm, 3.29 cm and 243.89respectively.In Sindh Forest Division,maximum germination(40.50%), germination energy (29.66%) and germination value (4.97) were recorded under the same chilling duration. The radicle length, plumule length and vigour index was recorded as 2.58 cm,3.18 cm and 235.13 respectively after 60 days of chilling duration.

6.3.3 Nursery performance of seeds

The seedling raised under natural conditions revealed significant difference among thealtitude and chilling durations.

Lower altitude of Tangmarg Forest Division to be the best altitude with the germination percent of 29.30% (maximum) and MGT of 29.66 (minimum). The seedlings raised from that altitude had higher values for collar diameter (1.00 mm), height (4.69 cm), root length (8.93 cm), root number (4.42), fresh biomass (0.41 g) and survival (75.64%) compared to other altitudes. In Sindh Forest Division middle altitude proved superior in terms of germination (30.00%)MGT (30.94 days), collar diameter (0.97 mm), height (4.39cm), root length (8.72cm), root number (4.24), biomass (0.36 g) and survival (69.92%)

Chilling duration significantly improved the seed and seedling performance of all the altitudinal seed sources. Higher germination and quality seedling were produced after 60 days chilling duration. In Tangmarg Forest Division, the germination percent increased from 14.41% in control to 33.33% after 60 days of chilling duration. The MGT oscillated between 36.63 (control) and 28.79 (60 days chilling duration).In Sindh, the germination oscillated between 13.75% (control) to 33.08% (60 days chilling duration) and MGT ranged between 37.49 (control) and 30.86 days (60 days chilling duration). The seedlings raised under 60 days chilling duration showed significant improvement in seedling characteristics. In Tangmarg Forest Division maximum seedling height (4.58 cm), collar diameter (1.01 mm), root number (4.50), root length (8.91 cm), fresh biomass (0.41 g) survival(72.21%) were recorded after 60 days chilling duration. Similarly in Sindh forest more seedling height (4.57 cm), collar diameter (0.99 mm), root number (4.77), root length (8.55 cm), fresh biomass (0.41 g) and survival (69.77%) were recorded after 60 days chilling duration.

6.4 Regeneration status

The number of seedlings, saplings and mature tree decrease with the increase in altitude in both the forest divisions. The regeneration in Tangmarg Forest Division was fair at lower and middle altitude whereas it was recorded as good at upper altitude. In Sindh forest division, the regeneration status was recorded as good at lower altitude whereas it was recorded as fair at middle and upper altitude.

The seedlings were found growing abundantly under shrubs and on nurse logs and thus play crucial role towards regeneration of the species.

CONCLUSION

- Leaf initiation at lower and middle altitudes took place in the month of April whereas at upper altitude it commenced in the month of May.
- Male and females cones appeared in April at lower altitude whereas at middle and upper altitude, they were visible during May.
- Leaf fall lacked seasonality and was observed throughout the year.
- Tree height, tree diameter and tree basal area decreased as we moved from lower altitude to higher altitude. Tree crown length and width was recorded more at middle altitude.
- Cones/seed are ready for collection in the month of September at lower and middle altitudes but at upper altitudes cones should be collected in the month of October.
- The seeds of *Abies pindrow* are dormant and thus need moist stratification for dormancy release.
- Higher chilling duration improved seed germination characteristics and seedling performance in fir seeds. Significant improvement in seedling was achieved when seeds were subjected to higher chilling durations.
- Both cone and seed characteristics varied with the altitude. In Tangmarg Forest Division, lower altitude produced the highest quality

cones/seeds whereas in Sindh Forest Division middle altitude was found superior. Significant decline in cone and seed characteristics were recorded at higher altitudes.

- The altitudes that produced heavy seeds improved the seed germinability and seedling performance.
- The number of seedlings, saplings and trees decreased with the increase in altitude.
- The regeneration status was recorded as good at upper and lower altitude of Tangmarg and Sindh Forest Division respectively whereas it was fair at all other altitudes of the selected forest divisions.

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Certificate

Certified that all the corrections/amendments as suggested by External Examiner Dr. M. A. Khan, Ex-Dean, Faculty of Forestry, SKUAST-Kashmir during Viva-Voce examination held on 20-07-2017 have been incorporated in the manuscript entitled **"Altitudinal Variation in Phenology, Seedling Characteristics & Natural Regeneration of *Abies pindrow*Spach"**submitted by **Mr. Hiilal Ahmad Bhat (Regd. No. 2011-373-D).**

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