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Climate to Forest Productivity: Implication of Paterson's CVP Index

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ABSTRACT

Climate is the prime factor that influences forest growth, composition and distribution. There are many ways to determine forest productivity in terms of climatic factors like temperature, precipitation, length of growing season, effective sun hour etc. When edaphic and topographic factors remain constant, climatic factors become more prominent for forest growth and productivity. Among many methods of assessment of forest productivity, Paterson's Climate Vegetation Productivity (CVP) index-requires less efforts and fieldwork to determine productive potential of any forest land. The index is not stand and species specific, hence, it can be put in use for overall assessment of the forest and vegetation productivity in any country, region and continent or even for the globe. This index may be used for comparison of forest lands, even non-forested lands with higher index value that may be established as a productive forest.

Key words: Forest productivity, temperature, precipitation, growing season, productive potential

INTRODUCTION

Climate supports vegetation and productivity of the climax vegetation at a site depending on the maximum sustained utilization of environmental resources (Champion *et al*., 1965). So far, the best-known climatic index for predicting forest productivity is Paterson's CVP index (Vanclay, 1992). Based on the close correlation found between this index and the known forest productivity of certain sites, Paterson (1956) computed the potential production of forest areas throughout the world, which was proved by Weck (1957). Later, this index was applied on regional scales for Scandinavia (Sweden, Scotland, Ireland, Greenland and Norway) by Paterson (1962) and for East (Present Bangladesh) and West Pakistan (Present Pakistan) by Champion *et al*. (1965). Nonetheless, on a national level, it was used for a number of countries like Sweden (Paterson, 1959), France (Parde, 1959), Australia (Howden and Gorman, 1999), Italy (Gambi, 1960), India (Kant, 2005; Champion and Seth, 1968), Bangladesh (Rahman *et al*., 2015) and Spain (Benavides *et al*., 2009; Palomares and Serrano, 2000). Even this was used to assess on a local or even at stand level like in Eastern Canada (Lemieux, 1961).

Paterson (1956) defined Climate Vegetation and Productivity (CVP) index as one of the significant methods for assessing the productivity of any forested vegetation that correlates the relationship between climate and biosphere productivity. The CVP index has the key process to determine the climatic productivity potential of any region. Spatially this tool helps to indicate how potential the area is, with respect to its vegetation growth according to its climatic parameters.

Paterson based his index on the hypothesis that the stem volume is primarily the function of the parameters in the areas, where the climate has had enough time to develop soils (Nabuurs *et al*., 1998).

Paterson's regression could be the solution for calculating forest productivity in terms of wood volume using only environmental factors (Parde, 1958; Kant, 2005). He has calculated index CVP for hundreds of points in the world besides "potential productivities" (ideal site class) which vary from 0-15-16 m^3 ha^{-1} $year^{-1}$. The existence of a direct correlation marked between his index and the productions envisaged has been noted (Parde, 1958). The aim of the present study was to review implication of paterson's CVP index in forest ecosystem to better understand their potential productivity, with respect to local climatic factors by drawing some existing work done using the regression model done by him.

Weather data: Meteorological data is required to analyze Paterson's CVP index and it requires at least thirty years of weather data or more for better analysis. These include mean maximum yearly temperature, mean maximum and mean minimum monthly temperature, mean annual precipitation, sun hour etc. Data may be gathered from the set-up meteorological stations of any country or region. This may also be generated from data available by the World Meteorological Organization (WMO) for regions.

CVPI function: Paterson (1956) showed that when the physiographic and soil factors are optimum, the productivity of the site is chiefly determined by the factors of climate e.g., solar radiation reaching the ground, amount of water available for life processes and the period during which, temperature is favorable to growth. Paterson's Climate, Vegetation and Productivity index (CVP) is given by the following formula (Eq. 1):

$$\text{CVP index, } I_{CVP} = \frac{Tv \times P \times G \times E}{Ta \times 12 \times 100} \quad (1)$$

where, T_v is the mean maximum temperature during the year in degrees centigrade, Ta is the range between the mean maximum and the mean minimum in degrees centigrade, P is the mean annual precipitation in mm, G is the growing periods in months. Calculation of this is very much crucial and discussed later and E is the light factor.

Growing period (G): The determination of the beginning of growing period is based on the start of the monsoon (FAO., 1996). It represents the number of months during which the mean monthly temperature exceeds 30°C in warm climates, where the temperature is always over the value, Index of Aridity of De Martonne (Eq. 2) (De Martonne, 1926) was used to determine G and expressed as (mm $°C^{-1}$). Only the humid months with an index above 20 are included in the growing season (Fig. 1):

$$I_{Ar}\ DM = \frac{12p}{t+10} \quad (2)$$

where, p in this case denotes the mean monthly precipitation in mm and t the mean monthly temperature in degrees centigrade.

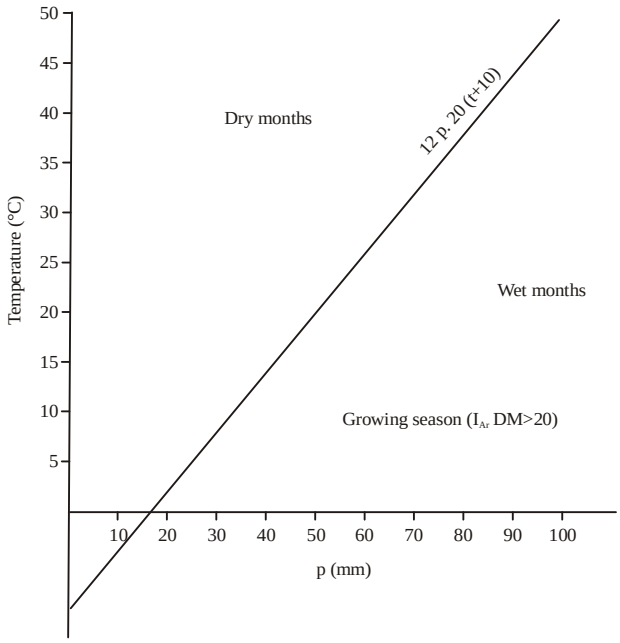

Fig. 1: De Martonnes index of aridity and the temperature-precipitation correlation (Parde, 1958)

Dry regions contain lower productivity than wet tropical regions with favourable climate. To assess the crop production potential, length of the growing period zones, a concept introduced by the UN Food and Agriculture Organization, is very useful as it describes an area within, which rainfall and temperature conditions are suitable for crop growth for a given number of days in the year. Parameters as temperature regime, total rainfall and evapotranspiration and the incidence of climatic hazards are more relevant, when calculated for the growing period, when they may influence crop growth, rather than averaged over the whole year (FAO., 1996).

Weck (1957) set a lower threshold of 2 months for the growing season as a necessity for forest and woodland ecosystems. An advantage of the De Martonne's index (I_{Ar} DM) has been its use in Paterson's Climate-Vegetation Productivity (CVP) model (Paterson, 1956; Parde, 1958) for forest stands. It was calibrated against tree productivity on favourable sites, those with sites with optimal soil depth, adequate fertility and adequate soil aeration, averaged over species. Hence, the model offered an opportunity to relate changes in growing season, temperature and rainfall patterns to changes in forest productivity (Lemieux, 1961).

Light factor (E): There, E is the light factor and is the radiation received at the pole expressed as a percentage of the radiation received at the latitude in question. This can be read off for different values of latitude from a graph prepared by Paterson. Champion *et al*. (1965) showed that the amount of insolation received at any point on the earth's surface depends on its latitude and altitude and the time of the year and the day. It is further modified by such features of the atmosphere and surface of the earth as cloudiness, haze, topography and vegetation.

Effect of latitude on temperature: The intensity of radiation reaching the periphery of the atmosphere is about 1.94 g calories per square centimeter per minute, normal to the rays. The

Table 1: Annual means of incoming and outgoing radiation on g/cal per minute (Champion *et al*., 1965)

Latitude	Received	Radiated	Balance
25	0.319	0.292	+0.027
30	0.305	0.289	+0.016
35	0.289	0.285	+0.004
40	0.269	0.279	-0.010

Table 2: Relationship between altitude and radiation received on earth (Geiger, 1959)

Altitude (m)	Radiation (g cal cm^{-2} min^{-1})
100	0.8
500	1.2
1500	1.4
4000	1.6

amount of radiation reaching the earth's surface decreases with increasing latitude as it is illustrated by the following table (Table 1) which shows the radiation received at the earth's surface for West Pakistan latitudes (Khan, 1958).

Since the amount of insolation received at any point on the earth's surface decreases with increasing latitude, a corresponding decrease in temperature would be expected. The effect of latitude on the rate of decrease of temperature is, however, greatly modified by such factors as altitude, topography, winds, aspects, amount of cloudiness, distance from the sea, season and duration of rains and the isotherms.

Effect of altitude on temperature: The amount of insolation received at any point on the earth's surface also varies directly with its altitude. The rate of increase is much higher in the lower layer with greater dust content. This phenomenon is exemplified by the following data (Table 2) based on observations in central Europe (Geiger, 1959).

Although, the amount of insolation received increases with elevation, the temperature decreases owing to a reduction in the absorption and diffusion of radiation by the rarer atmosphere of the higher altitudes. Therefore, E = 1.94 gcal cm^{-2} min^{-1} for reaching normal solar rays which can be written as 1.358 kJ m^{-2} sec^{-1} (Khan, 1958).

Forest productivity: If considering productivity in terms of volumetric calculations, using Paterson's dynamic regression, following regression equation (Eq. 3) was found to assess forest productivity in terms of volume production, which was enumerated by m^3 ha^{-1} $year^{-1}$ (Paterson, 1956):

$$Y = 5.20 \log X - 7.25 \quad (3)$$

Here, X was used for calculated CVP and Y denoted for potential forest productivity. Using the formula forest productivity in ideal sites under ideal conditions of management may be estimated (Parde, 1958; Champion and Seth, 1968; Lal, 1992). The determination coefficient (r^2) of the index regression is quite satisfactory ranging between 0.64 and 0.86 (r_{xy} = 0.64-0.86) (Paterson, 1962). This means that the variance of volume growth determined by the variance of height and increment to an extent of 64 and 86%, respectively.

Paterson has calculated CVP. index for hundreds of points in the world. In addition, each time that he was able, he has placed beside the 'potential productivities' (ideal site class) corresponding, which they vary from 0-15-16 m^3 ha^{-1} $year^{-1}$ (Fig. 2). He has noted the existence of a direct correlation marked between his index and the productions envisaged (Parde, 1958).

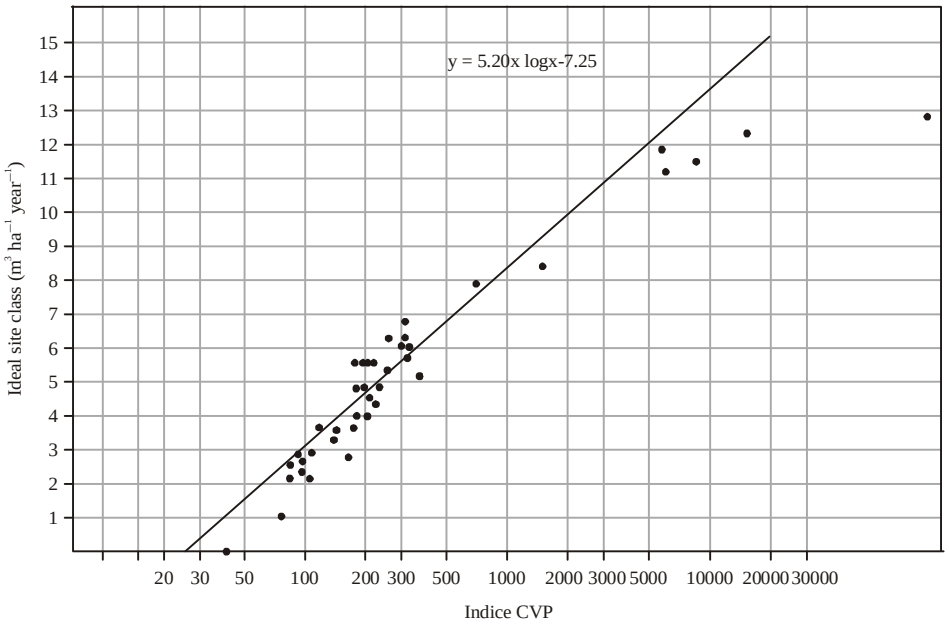

Fig. 2: Relationship between an ideal site class and CVP index (Paterson, 1956)

Table 3: Forests productivity calculated from CVPI in India by Kant (2005)

Forests type	Productivity from CVPI (m^3 ha^{-1} $year^{-1}$)
Tropical dry and moist forests	6-9
Gangetic plains	6-9
Evergreen and moist deciduous forests	9-12
Coastal belts of west and east coasts	>12
Moderately high hill range	>12

Table 4: CVPI and forest volume productivity at different ecosystem sites in Bangladesh (Rahman *et al*., 2015)

Forest ecosystems	Calculated CVPI	Productivity (m^3 ha^{-1} $year^{-1}$)
Evergreen-semievergreen	2150-2800	10.36
Wet deciduous (moist sal)	1223-1896	9.15
Dry deciduous (dry sal)	1277-1280	8.91
Natural mangrove (sundarbans)	1307	8.95
Mangrove plantations	1946-2531	10.15

Paterson's regression (Eq. 3) could be the solution for calculating productivity in terms of wood volume using only environmental factors (Rahman *et al*., 2015; Parde, 1958; Kant, 2005). Forest productivity at different eco-regions calculated from CVPI in India by Kant (2005) listed below (Table 3).

One thing should be noted that, volume production in Table 4 denotes only the fact that these could be the potential maximum production from different sites. Actual tree volume production is much more less as because of inefficiency in forest management.

Advantages: It is probably only useful for economic geography and general forest statistics, where estimates of potential production are required for large inaccessible and non-inventoried areas (Lemieux, 1961). The CVP estimation is simple to apply in its basic form, using monthly averages and applicable only to sites with optimal soil depth, adequate fertility and adequate soil aeration, averaged over species (Howden and Gorman, 1999). In spite of its limitations, it can be very useful

for comparing zones located within the same region, regardless of the presence or absence of trees, the age of the stand or the species (Vanclay, 1992). It could be served to provide a valuable indication of the maximum-likely steady-state increment of stem-wood dry matter of 'mature' stands and hence, long-term carbon sequestration rate, as well as more complex models (Howden and Gorman, 1999). Despite of its limitations, Paterson's CVP index may be used in all vegetation type irrespective of time.

Limitations: There are 2 major criticisms at the C.V.P. index, (i) Considering timber volume instead of dry matter (biomass), while comparing with site classes because this index designed to predict the maximum growth potential in terms of volume production (Hagglund, 1981; Johnston *et al*., 1967), (ii) Not considering soil factor in his model. Some other limitations are using pre-selected climatic parameters excluding insolation, exposure, aspect and humidity. The CVP Index derived by Weiskittel *et al*. (2011) are often derived from latitude, longitude and elevation, which can result in imprecise local estimates, (2) Short-term weather events can have more of an influence on estimated productivity than long-term climate 'normal's', (3) Climate varies strongly from year to year and decade to decade, (4) Variables are often highly correlated, which can make it difficult to find the most influential variable and (5) Climate is influential at larger geographic scales, while other factors may control productivity at the local scale.

However, climate information is not widely used to assess forest site productivity because of the relative lack of weather stations in forested situations and the inability to estimate climate conditions for any given site (Weiskittel *et al*., 2011). For example, there are only thirty four meteorological stations present in Bangladesh of which, hardly has presence in major forest types like the hill forest or the Sundarbans (Bangladesh Meteorological Department).

Difference between CVP and site index: The CVP index is different from site index as the first one deals with regional or areal productivity (Parde, 1958), where the later one deals with a particular tree species performance over different sites (Sajjaduzzaman *et al*., 2005) or for a particular stand (Vanclay, 1994). Edaphic and climatic are the two main factors influencing the characters of a site in plantation and the climatic effect is diluted at the stand level (Vanclay, 1994), conversely CVP depends on only climate (Paterson, 1956). These climatic variables including radiation, precipitation and temperature influence species composition and productivity (Stage and Salas, 2007).

Productivity scenario and actual growth: Measuring past forest productivity for areas may be used in scenario building for future production potential of regional or national level. Nabuurs *et al.* (1998) reported that in Europe, forest productivity (net annual increment in terms of $m^3\ ha^{-1}\ year^{-1}$) is increasing towards Paterson's productivity values and this value compared as 52% in 1950, 83% in 1990 and forecasted to be 91% in 2040. Thus, forests productivity would increase toward potential scenario of the soil in future. This may be due to changes in site productivity (Spiecker *et al*., 1996) or improves accuracy in increment estimations (Kuusela, 1994).

CONCLUSION

Various researchers at various scales used Paterson's CVP index. Since the index is age old, some may think of it otherwise. However, with its mode of ease and less requirement to produce more accurate data on forest and vegetation productivity; this may apply with large forested areas

to calculate a numerical value for forest productivity potential with respect to meteorological factors. Thus, this may relate growth and production of vegetation with the climate instead. Moreover, the ease of decision in decision support system may be enhanced using CVP whether any are should be turned into forest or not considering it's potential productivity. Potential future production of any forest region may assess from past CVP values and this may help in calculating future revenues for that forested region. Therefore, Paterson's climate vegetation and productivity model would be a great tool for forest managers and planners.

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