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Agroclimatic Evaluation of Net Primary Productivity of Natural Vegetations

(1) Chikugo Model for Evaluating Net Primary Productivity

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Abstract

Theoretical considerations concern the relationship between net primary productivity of natural vegetations and climatic conditions. Those suggest that net primary productivity (*NPP*) of natural vegetations linearly increases with increasing annual net radiation (R_n) and that the proportionality constant between R_n and *NPP* decreases very rapidly with increment of the value of radiative dryness index (*RDI*) that is the ratio of R_n to the product of annual precipitation and latent heat of evaporation. *NPP* data (682 set) of about 260 locations over the world were used to verify the theoretical prediction. A nonlinear regression equation describing the dependence of *NPP* on R_n and *RDI* was obtained and named "Chikugo model". The *NPP*-distribution map over Japan was made on the basis of the Chikugo model using the climatic data of Japan. It was found that *NPP* over Japan changes from about 8 t DW/(ha yr) in mountain districts of Hokkaido to about 18 t DW/(ha yr) in southern coastal areas of Kyushu and Shikoku. These results agreed well with the net primary production of forests obtained by plant ecologists.

1. Introduction

In recent years, attention has been focused on the amount of biomass and *NPP* of vegetations, because plant biomass is alternative energy source and an important component of CO_2 balance in the atmosphere. This problem was also extensively studied in the International Biological Programme (IBP) during the period 1964 to 1972. The biomass and *NPP* of vegetations have been assessed in several ways such as climatic, ecological and dendrological methods. The data of biomass and *NPP* obtained in that programme have been successfully used to make clear the world distribution of biomass and *NPP* of vegetations (e.g., Lieth, 1973; Efimova, 1977).

Plant biomass is not only a most important source for alternative energy, but also plays a vital role in the ecological functions and in the protection of natural and controlled ecosystems. It is not reasonable, therefore, to assume that most residues of crop and forest can be used as an alternative energy source. To achieve the balance between the use of plant biomass as an alternative energy source and the return of plant biomass for the protection of ecosystems, we must consider the following components of biomass balance per unit ground surface:

$$W_{eco},\ A_1,\ A_2 \text{ and } NPP$$

where W_{eco} is economic use of plant production (t DW/(ha yr)), A_1 and A_2 are, respectively, return of plant biomass necessary to maintain soil fertility, and that to protect natural and controlled ecosystems (t DW/(ha yr)). Therefore, the effective biomass utilizable as an alternative energy source W_{eff} (t DW/(ha yr)) is given by

$$W_{eff} = NPP - (W_{eco} + A_1 + A_2) \qquad (1)$$

In the above equation, the accurate determination of *NPP* of vegetations is the starting point for evaluating the amount of W_{eff}. Many plant

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ecologists have concentrated their effort on the development of accurate methods for determining *NPP*. Of them, the so-called summation method is known to give an accurate estimate of plant biomass and *NPP*, although it is very laborious. The data of biomass and *NPP* so obtained have been used to establish climatic methods for evaluating *NPP* from climatic data (e.g., Kira, 1976; Lieth, 1977; Uchijima and Seino, 1984). Almost all those indirect methods consider separately effects of climatic factors on the amount of *NPP*. However, climatic factors are fluctuating simultaneously with some correlation between them. This clearly indicates that we need more reasonable indirect methods, taking account of simultaneous effects of climatic factors on *NPP*. In this paper, we discuss the construction of "Chikugo model" describing a nonlinear dependence of *NPP* on annual net radiation and radiative dryness index, and its application.

2. Theoretical Consideration

By applying the approach of Bierhuizen and Slatyer (1965) to the gas exchange between fully grown vegetations and the surface air layer, we can write for vapor flux due to transpiration (E_t)

$$E_t = \frac{b_0\ (e_l - e_a)}{(r_c + r_{s,w})} \tag{2}$$

and for CO_2 flux due to photosynthesis (p_n)

$$p_n = \frac{a_0\ (C_a - C_i)}{(r_c' + r_{s,c})} \tag{3}$$

where $b_0\ (=0.622\rho/P)$(g/(cm^3 mmHg)), ρ is air density (1.2×10^{-3} g/cm^3), P is atmospheric pressure (mmHg), e_l and e_a are water vapor pressures (mmHg) at a level of Z_C within vegetation and at a reference height (Z_R), respectively, C_a and C_i are mean CO_2-concentrations at Z_R and in stomatal cavities of leaves constituting vegetations, r_c and r_c' are, respectively, canopy resistances for turbulent transfer of water vapor and CO_2 between Z_C and Z_R (s/cm), $r_{s,w}$ and $r_{s,c}$ are average stomatal resistances of the leaves for water vapor and CO_2, respectively, and a_0 is a conversion factor from CO_2 flux to dry matter production.

The annual transpiration (E_T) and the annual dry matter production (*NPP*) of a vegetation can be approximated by

$$E_T = \int_0^{T_0} E_t(t)\,dt \simeq AT_0\, b_0\, b_1 \overline{[(e_l - e_a)/(r_c + r_{s,w})]} \tag{4}$$

$$NPP = \int_0^{T_0} p_n(t)\,dt \simeq AT_0\, a_0\, a_1 \overline{[(C_a - C_i)/(r_c' + r_{s,c})]} \tag{5}$$

where T_0 is the time length of a year, A is a conversion factor from g/(cm^2 s) to t/(ha yr), a_1 and b_1 are, respectively, proportionality constants for connecting daily means to daytime means, and upper bar denotes annual mean of the related quantities. Using the above relations, we can define the water use efficiency (*WUE*) as follows:

$$WUE = \frac{NPP}{E_T} \simeq \frac{a_0\, a_1 \overline{(r_c + r_{s,w})}\ \overline{(C_a - C_i)}}{b_0\, b_1 \overline{(r_c' + r_{s,c})}\ \overline{(e_l - e_a)}} \tag{6}$$

On the other hand, when vegetations fully cover ground and can absorb most of incoming solar radiation, one can expect the following relation,

$$E_T \simeq E_\Sigma = \frac{B\, R_n}{l\,(1+\beta)} \tag{7}$$

where E_Σ is annual evapotranspiration (t H_2O/(ha yr)), R_n is annual net radiation (kcal/cm^2), l is latent heat for evaporation of water (cal/g H_2O), β is Bowen ratio characterizing the partition of solar energy at the earth's surface, B is a conversion factor from g H_2O/(cm^2 yr) to t H_2O/(ha yr). By combining Eqs. (6) and (7), the net primary productivity of vegetations can be expressed as follows:

$$NPP \simeq A_0 \frac{R_n}{\overline{(e_l - e_a)}\ \overline{(1+\beta)}} \tag{8}$$

where A_0 is a proportionality constant and given by

$$A_0 \simeq \frac{a_0\, a_1\, B \overline{(r_c + r_{s,w}) C_a (1 - C_i/C_a)}}{l\, b_0\, b_1 \overline{(r_c' + r_{s,c})}} \tag{9}$$

Since air temperature at Z_C within vegetations is generally not known, e_l is approximated by the saturation vapor pressure at the air temperature as is usually done. Namely, the difference in water vapor pressure between Z_C and Z_R is approximated by the water vapor deficit of air as the first approximation. Using this approximation, one can rewrite Eq. (8) as follows:

$$NPP = \frac{A_0\, R_n}{\overline{d\,(1+\beta)}} \tag{8 a}$$

where d is the water vapor deficit of air (mmHg).

The experimental results due to Wong et al. (1979) indicate that the term $(1-C_i/C_a)$ in the proportionality constant A_0 is approximated by

$$\begin{aligned} (1-C_i/C_a) &\simeq 0.3 \quad \text{for } C_3 \text{ plants} \\ (1-C_i/C_a) &\simeq 0.7 \quad \text{for } C_4 \text{ plants} \end{aligned} \tag{10}$$

If the conversion factors and the related quantities in the constant A_0 were given by experiments, using the above values for $(1-C_i/C_a)$ and ambient CO_2 concentration, Eq. (8 a) enables us to take implicitly account of effects of increasing CO_2 concentration, which is now becoming an urgent and important problem, on *NPP* of vegetations.

Eq. (8 a) describing the nonlinear dependence of *NPP* on R_n, d and $(1+\beta)$ is the theoretical basis of our "Chikugo model" to be presented below. This predicts evidently that *NPP* is proportional to R_n and is inversely proportional to the product of d and. $(1+\beta)$.

3. Materials and Methods

1) Materials

To verify the validity of Eq. (8 a) and to build the "Chikugo model" which serves as a physical basis for the calculation of *NPP* of natural vegetations, the following materials of plant production and climatic factors were used.

Plant production data:

(1) Cannell, M. G. R., (1982) World Forest Biomass and Primary Production Data. Academic Press, 391 p.

Climatic data:

(1) Müller, M. J., (1982) Selected Climatic Data for a Global Set of Standard Stations for Vegetation Science. Dr. W. Junk Publishers, 306 p.

(2) Golts'berg, I. A., (1972) World Atlas of Agroclimatic Resources. Gidrometeoizdat (in Russian), 115 p.

(3) Japan Meteorological Agency, (1982) Climatic Tables of Japan (Normals, 1951–1980). 280 p.

Cannell (1982) compiled the data of plant biomass and *NPP* of forests distributed in various climatic zones of the world collected throughout the IBP-work. This book includes 270 data set of net primary production measured at 107 locations and 412 data set of above-ground net primary production (NPP_{ab}) obtained at 151 locations. The following empirical relation was used to convert the data of above-ground net primary production to the data of net primary production (*NPP*).

$$NPP \simeq 1.2\, NPP_{ab} \tag{11}$$

Müller (1982) proposed climatic data for the study of dry matter production of vegetations over the world. His book includes the data of temperature, precipitation, humidity, sunshine duration and solar radiation at approximately 1000 stations over the world. World Atlas edited by Golts'berg (1972) shows the geographical distribution of agroclimatic resources affecting plant production, particularly crop production. The Climatic Tables published from the Japan Meteorological Agency in 1982 contain the normals (1951–1980) of atmospheric pressure, temperature, relative humidity, sunshine duration, solar radiation and precipitation at approximately 150 stations in Japan.

2) Methods

To calculate values of R_n, *RDI*, β and d at different districts and locations, the following methods were used.

Annual solar radiation (S_t) was evaluated from the following relation due to Yoshida and Shinoki (1978)

$$S_t = \sum_{i=1}^{12} S_{t,i} = \sum_{i=1}^{12} S_{0,i} \left[0.146 + 0.534 \left(\frac{\tau_i}{\tau_{0,i}} \right) + 0.047 G_{10,i} + 0.036 \sin h_{\circ,i} \right] \tag{12}$$

where $S_{0,i}$ and $S_{t,i}$ are total monthly solar radiations at the top of the atmosphere and the ground surface in the i-th month (kcal/cm^2), respectively, $\tau_{0,i}$ and τ_i are, respectively, possible and actual sunshine durations in the i-th month, $G_{10,i}$ is numerical index characterizing snow cover in the i-th month and $h_{\circ,i}$ is monthly mean of noon solar height in the i-th month.

Annual net radiation (R_n) was estimated from the following relation due to Chang (1970)

$$R_n = \sum_{i=1}^{12} \left[(1-\rho_i) S_{t,i} + \sigma T_{a,i}^4 \left\{ 286.18 - 202.6 B_1 - (52.23 - 12.61 B_1) \sqrt{e_a} \right\} \right] \cdot \tag{13}$$

where ρ_i is albedo of natural vegetation that is assumed to be 0.15 when $G_{10,i}$ equals to 0.0 and to be $(0.15+0.5\, G_{10,i})$ when $G_{10,i}$ is larger than 0.0, σ is the Stefan-Boltzmann constant, $T_{a,i}$ is monthly mean of temperature (K), $B_1 = S_{t,i}/S_{0,i}$

calculated from Eq. (12), and e_a is water vapor pressure of air (mmHg).

Although several ways have been used to estimate the magnitude of Bowen ratio (β) in agrometeorology, the following relation was used to estimate the regional mean of annual Bowen ratio

$$\beta = [RDI/\{1-\exp(-RDI)\}] - 1.0 \qquad (14)$$

where *RDI* is radiative dryness index and is defined by

$$RDI = R_n / l r$$

r is annual precipitation (cm) and *l* is latent heat of evaporation (cal/g H_2O). Water vapor deficit of air (d) was evaluated from

$$d = R \cdot e(T_a)$$

where R is relative humidity of air (0.0–1.0) and $e(T_a)$ shows saturation water vapor pressure (mmHg) at air temperature T_a.

4. Results and Discussion

1) Dependence of *NPP* on net radiation

The prediction previously described indicates that *NPP* increases proportionally with increment of annual net radiation, under conditions that both Bowen ratio and d characterizing the climatic dryness are maintained at a constant level independently of increment in net radiation. To verify this prediction the data of primary production of forests were firstly grouped every *RDI*-band with a width of 0.2. Secondly, the primary production data within each *RDI*-band were averaged over each R_n-band with a width of 5 kcal/cm^2. The results so obtained are depicted as a function of the respective averages of R_n over each R_n-band in Fig. 1. Inspection of Fig. 1 suggests clearly that *NPP* in each *RDI*-band is proportional to annual net radiation and can be expressed as

$$NPP = \alpha R_n \qquad (15)$$

The magnitude of the proportionality constant (α) between R_n and *NPP* decreases drastically with increment of *RDI*. This implies clearly that the efficiency of dry matter production of natural vegetations decreases considerably as climate becomes dry.

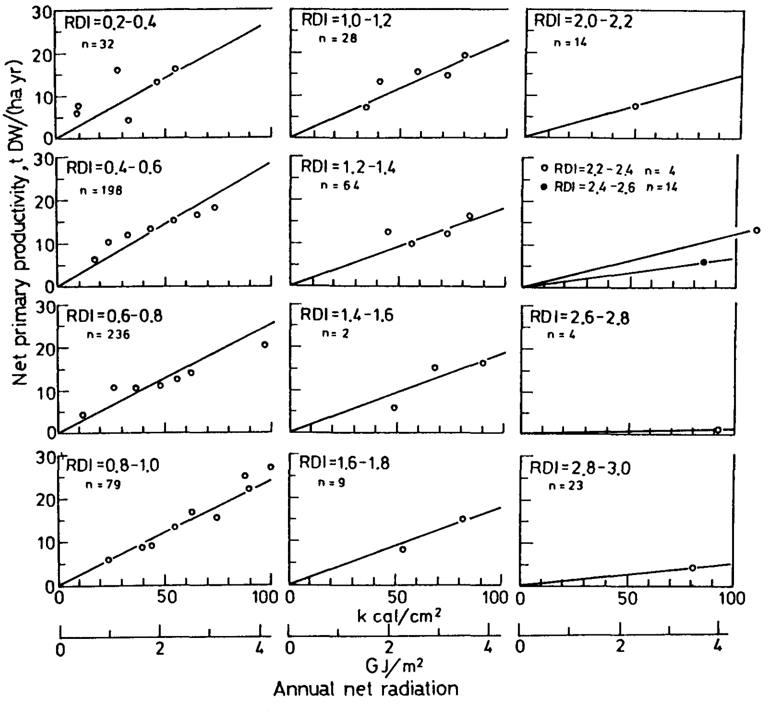

Fig. 1. Dependence of *NPP* on R_n for each *RDI*-band. Numeral (n) on each section of this figure denotes the number of primary production data in each *RDI*-band.

2) Dependence of proportionality constant α on *RDI*

The values of proportionality constant α are presented as a function of *RDI* in Fig. 2, which indicates that α decreases with increasing *RDI* drastically from about 0.28 in *RDI* between 0.2 and 0.4 to a level of 0.01 in *RDI* above 3. This can be approximated by

$$\alpha = 0.52\,(0.6+RDI)^{1.6}\,\exp(-1.5\,RDI) \qquad (16)$$

or more simply

$$\alpha = 0.29\,\exp[-0.216(RDI)^2] \qquad (16\,a)$$

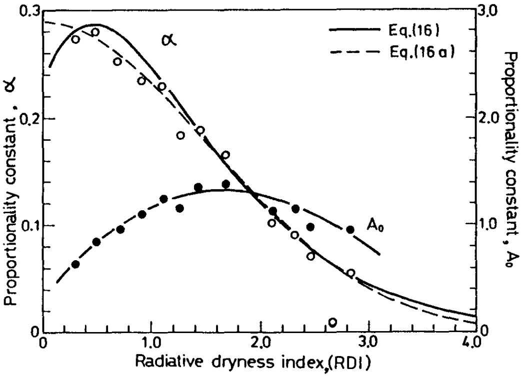

Fig. 2. Dependence of α and A_0 on *RDI*.

The above relations, however, are not applicable to a range of *RDI* lower than 0.2, because no primary production data are available in that range of *RDI*.

By comparing Eqs. (8 a) and (15), one can obtain the following relation

$$\alpha = \frac{A_0}{d(1+\beta)} \qquad (17)$$

Eq. (14) shows evidently that $(1+\beta)$ in the denominator of the right hand side of the above relation has a close correlation with *RDI*. It is also reasonable to assume that there is a close correlation between d and *RDI*. Using the meteorological data of approximately 1000 stations over the world, the relationship between *RDI* and the product of d and $(1+\beta)$ was studied. The data were firstly grouped every *RDI*-band of width of 0.2. Secondly, the data of $d(1+\beta)$ for each *RDI*-band were averaged. The results are presented in Fig. 3.

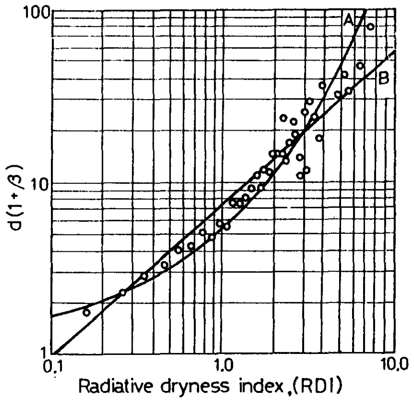

Fig. 3. Dependence of $d(1+\beta)$ on *RDI*.

Although there is somewhat large scatter of points in Fig. 3, the magnitude of the product increases considerably with increment of *RDI*. The relationships between *RDI* and $d(1+\beta)$ can be expressed by

$$A\colon\ d(1+\beta)=10^{\delta} \qquad r=0.97 \qquad (18)$$

$$B\colon\ d(1+\beta)=7.267(RDI)^{0.897} \qquad r=0.95 \qquad (18\,a)$$

where $\delta = 0.7\,(RDI)^{0.54}$.

Since Eq. (9) contains unknown physical and physiological constants of vegetations, it is very difficult to estimate directly the magnitude of A_0 from this equation. Therefore, we tried to estimate it by using the empirical data presented in Figs. 2 and 3, and Eq. (17). The results obtained are presented as a function of *RDI* in Fig. 2. The magnitude of proportionality constant A_0 increased firstly from 0.6 in an *RDI*-range of 0.2–0.4 to 1.4 in an *RDI*-range of 1.4–1.8 with increment of *RDI*, followed by the decrease of A_0 in an *RDI*-range larger than 1.8. The curvilinear change in A_0 with *RDI* as illustrated in Fig. 2 may be due to changes in physical and ecological or physiological properties of vegetations with change in climate. To find out main factors affecting the magnitude of constant A_0 and predict the change in A_0 with climatic conditions, further experiments are needed of interactions between plants and their environment under field conditions with different *RDI* ranges.

3) Chikugo model for evaluating net primary productivity

Combining Eqs. (15), (16) and (16 a) yields

$$NPP = 0.52\,(0.6+RDI)^{1.6}\,\exp(-1.5\,RDI)\,R_n \qquad (19)$$

or

$$NPP = 0.29\,[\exp\{-0.216(RDI)^2\}]\,R_n \qquad (19\,a)$$

The above equations similar to Eq. (8 a) in form are the "Chikugo model" for the calculation of the net primary productivity of natural vegetations from climatic data. The Chikugo model describes simultaneous effects of R_n and RDI on the net primary productivity of vegetations. Fig. 4 shows a family of curves of NPP as a function of both RDI and R_n obtained from Eq. (19). The original data of primary production of forests used for obtaining Eqs. (19) and (19 a) are also presented in this figure. From the comparison of the family of curves and the original data, we can conclude that the "Chikugo model" could be used to estimate NPP of natural vegetations in various climatic zones over the world.

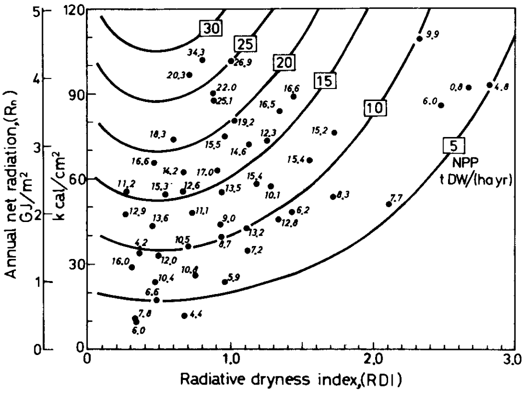

Fig. 4. Family of RDI and R_n vs. NPP curves calculated from Eq. (19).

4) Comparison of *NPP*-values evaluated by several methods

As already described, several ways have been developed to estimate NPP in various climatic zones. Lieth (1973) proposed the so-called Miami model as follows:

$$NPP_r = 30\,[1 - \exp(-0.000654r)] \qquad (20)$$

$$NPP_T = 30/\,[1 + \exp(1.315 - 0.119T)] \qquad (20\,\mathrm{a})$$

where NPP_r and NPP_T are, respectively, NPP evaluated by precipitation and temperature data, r is annual precipitation (mm), and T is annual mean temperature (°C). In a previous paper (Uchijima and Seino, 1984), we proposed the following relation using Efimova's data (1977)

$$NPP_{old} = \frac{9.58\exp[0.0534R_n/\{1+0.1914\exp(3.316RDI) - 1.3264\}]}{[1+4.655\exp\{-2.005RDI+0.802\}]} \qquad (21)$$

Meteorological data pairs from about 150 stations distributed over Japan were processed by Eqs. (19), (20), (20 a) and (21) to compare NPP-values. The results obtained are shown in Fig. 5. Fig. 5 A indicates that NPP_r has no systematic relation with NPP. Fig. 5 B shows that NPP_T changes in parallel with NPP estimated from Eq. (19), although NPP_T-values are larger than the NPP by about 10 per cent throughout a whole range of NPP. The above results shows that net primary production of vegetations over Japan with plentiful rainfall is strongly affected not by rainfall but by annual mean temperature.

As shown in Fig. 5 C, in a range of NPP lower than about 14 t DW/(ha yr), the value of NPP_{old} from Eq. (21) agrees fairly with the value of NPP from Eq. (19). However, in a range of NPP above 14 t DW/(ha yr), the discrepancy between NPP_{old} and NPP increased remarkably with increment in NPP. At NPP of 20 t DW/(ha yr), NPP_{old} was 1.5 times as large as NPP. This is probably because of the overestimation of the net primary productivity reported by Efimova (1977).

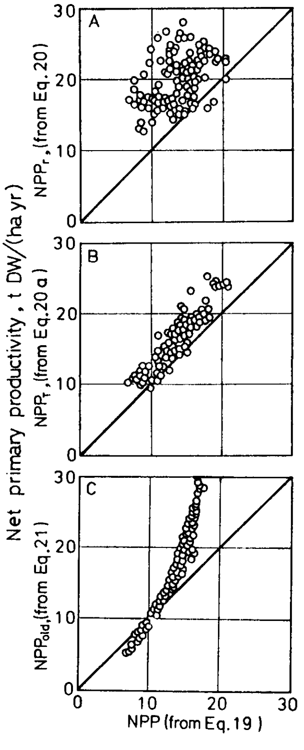

Fig. 5. Comparison of NPP-values estimated from Eqs. (19), (20), (20a) and (21).

5) Dependence of *NPP* on altitude

Altitude has an important effect on the value of *NPP*, because temperature decreases monotonically with increasing height above the sea level. This is mainly due to the shortening of a duration of photosynthetic activity with altitude. To make clear the dependence of *NPP* on altitude, the following relative net primary productivity (NPP_*) was calculated using the *NPP* data in the central part of Honshu.

$$NPP_* = NPP/\langle NPP\rangle_{0-200} \tag{23}$$

where $\langle NPP\rangle_{0-200}$ is the average of *NPP* over 0–200 m altitude band. The results so obtained are presented in Fig. 6. A solid line in Fig. 6 is to guide the reader's eyes. Although there is somewhat large scatter of points, one can conclude that NPP_* is nearly constant up to the altitude of about 500 m, followed by very rapid decrease in a range of altitude higher than 500 m.

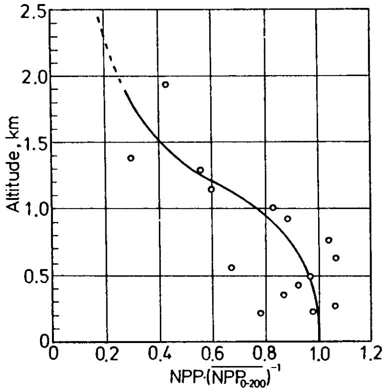

Fig. 6. Altitude dependence of NPP_* in the central part of Honshu.

NPP_* at the altitude of 1500 m decreased to only 40 per cent of NPP_* in the altitude range 0 to 200 m. At the altitude of 2500 m near the timber limit in this district (Horikawa, 1968), NPP_* was found to be about 10 per cent. The vertical change in NPP_* corresponds to the change in forest types with increasing altitude: evergreen broad-leaf forests in the altitude zone below 200 m, intermediate conifer forests in the 200–400 m zone, deciduous broad-leaf forests in the 400–1500 m zone, conifer forests in the 1500–2400 m zone, and alpine desert and heath in the altitude above 2500 m.

6) Geographical distribution of *NPP* over Japan

Climate of Japan changes considerably from north to south, because she consists of four main islands: Hokkaido, Honshu, Shikoku and Kyushu, and stretches in an arc 2,400 km long from northeast to southwest in middle latitude between 24°N and 45°N. Particularly, mountainous ranges with the altitude of 1,000–3,000 m in the main islands make clearly distinguishable difference of climate among the districts. It is expected that such a difference in climate among the districts affects strongly the growth of plants and net primary productivity of natural and controlled vegetations.

NPP values estimated by the Chikugo model (Eq. 19) at about 150 locations over Japan and the altitude dependence of *NPP* described in the preceding section were used to make clear the geographical distribution of *NPP* of natural vegetations. The results obtained are presented in Fig. 7, together with the distribution of solar energy efficiency of net primary production (ε) and of major forest types. The energy efficiency was calculated from the following relation, on the basis of annual solar radiation (S_t) reaching vegetation surface.

$$\varepsilon = 100 \cdot \lambda NPP/S_t \tag{22}$$

where λ is calorific value of dry matter, 4,700 cal/g DW.

As illustrated in this figure, *NPP* values change from 8 t DW/(ha yr) and less in central mountainous areas of Hokkaido to 18 t DW/(ha yr) and more in southern coastal areas of Kyushu, Shikoku, Kii-peninsula and Tokai district. Lower net primary productivity is observed in backbone areas of the main islands of Japan. The isopleth of 14 t DW/(ha yr) extends from Miyako on the Pacific Ocean side, southwards along the foot of mountainous areas, turns to the north on the northeastern coast of Lake Biwa, and then exactly northwards to near Sakata on the Japan Sea side of Honshu. The distribution of this isopleth agrees well with that of the southern limit of deciduous broad-leaf forest and intermediate conifer forest depicted in the bottom of Fig. 7. The isopleth of 18 t DW/(ha yr) runs westwards along the southern coastal areas of Tokai district, intersects the pointed end of Kii-peninsula, passes westwards coastal areas of Shikoku and Kyushu islands, and reaches the west

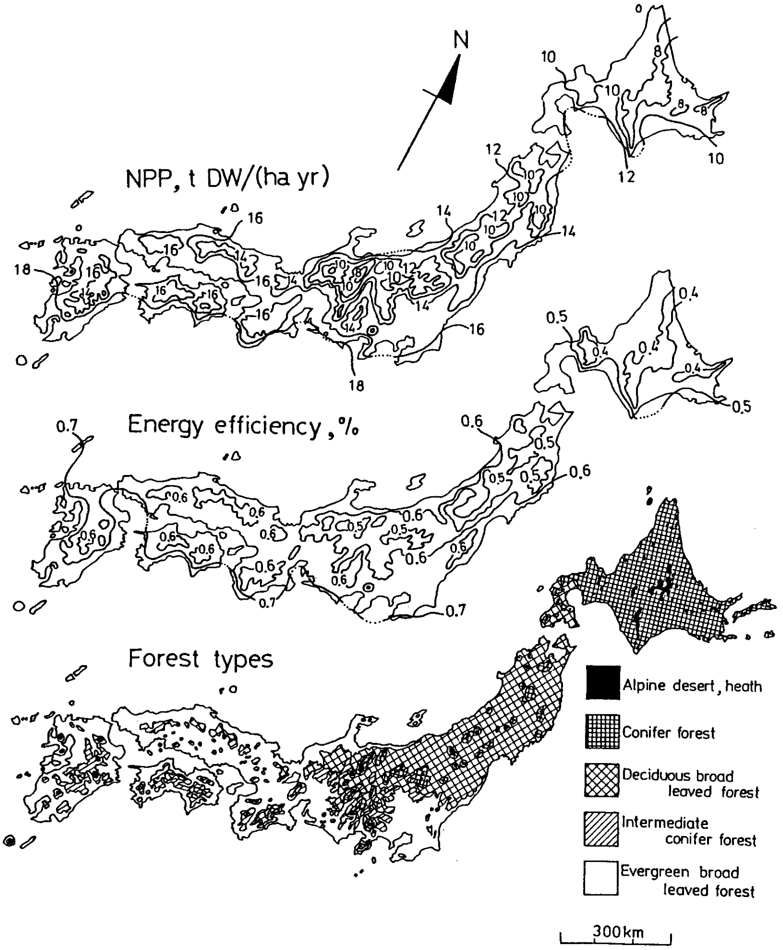

Fig. 7. Geographical distribution of *NPP*, ε and major forest types over Japan.

seaside of Kyushu. Characteristic distribution of *NPP* over Japan is mainly ascribed to latitudinal and altitudinal gradient of climatic condition, particularly annual net radiation.

Using the data of annual above ground net primary productivity of 258 forest stands of Japan, Kira (1973) has classified the forest stands of Japan into five major types: evergreen broad-leaf forests, forests of pines and temperate conifers, coniferous forest of boreal zone, coniferous forests of the subalpine zone and deciduous broad-leaf forests of the cool temperate zone. Tadaki and Hachiya (1968) and Kira (1973) evaluated the net primary productivity (t DW/(ha yr)) of the major forests in Japan as follows: deciduous broad-leaf forests – 8.7, deciduous coniferous forests – 10.1, evergreen coniferous forests – 13.5, pine forest – 14.8, Japan cedar forests and evergreen broad-leaf forests – 18.1. Referring to the distribution of *NPP* and the major forests shown in Fig. 7, we can conclude that the *NPP* of natural vegetations estimated by the Chikugo model is in good agreement with the *NPP* of major forests in Japan compiled by Tadaki and Hachiya, and Kira.

The middle of Fig. 7 shows the geographical distribution of energy efficiency of *NPP* on annual solar radiation basis. The distribution pattern of ε is quite similar to that of *NPP*, ranging from about 0.4 in mountainous areas of Hokkaido to about 0.7 in southern coastal areas of Kyushu and Shikoku. The magnitude of ε shown in Fig. 7 is somewhat smaller than that presented by Kira (1973) on the basis of forest biomass production data and of solar radiation for the vegetation period. The difference in ε is probably due to the difference in the period for the summation of solar radiation between them.

5. Conclusion

An approach for the water use efficiency of crop leaves can be used to build a model for evaluating the net primary productivity of natural vegetations from climatic data. The simplest model contains only three factors such as annual net radiation (R_n), Bowen ratio (β) and water vapor deficit (d), and requires values of solar radiation, precipitation, air temperature, air humidity and albedo. The model predicts that the net primary productivity (*NPP*) is proportional to annual net radiation and is inversely proportional to the product of water vapor deficit and Bowen ratio.

The primary production data of forests obtained throughout the IBP-work confirm that the prediction from the model is valid. By combining the simplest model and empirical relations, a semi-empirical "Chikugo model" was obtained. This model is possible to determine the net primary productivity of natural vegetations. Using the meteorological data of about 150 stations in Japan, the Chikugo model was used to estimate *NPP* of Japan. It was found that *NPP* varies from about 8 t DW/(ha yr) in mountainous areas of Hokkaido to 18 t DW/(ha yr) in southern coastal areas of Kyushu and Shikoku, agreeing well with the results obtained by plant ecologists. It is reasonable to say that this good agreement gives a strong support to the Chikugo model.

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自然植生の純一次生産力の農業気候的評価

(1)　純一次生産力評価のための筑後モデル

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要　約

作物葉の水利用効率の考え方を植物群落へ拡張することで，群落の純一次生産力と気候条件とを関係づける式をえた。これから，純一次生産力は純放射量に比例して増加し，その比例係数は気候の乾燥度を示す放射乾燥度につれて急減することが予想された。

この予想を確かめるため，IBP研究でえられた世界各地の森林の純一次生産力に関する資料ならびに気候データを解析した。そして，理論に則った純一次生産力予想式－筑後モデルを導いた。このモデルは実測された森林の純一次生産力とかなりよく一致した。このモデルで日本の気候資料を処理し，国内の純一次生産力の分布を研究した。生産力は北海道山岳地帯での8 t DW/(ha yr))以下から四国・九州の南部海岸地帯での約18 t DW/(ha yr)まで変化した。このような生産力の分布は，森林生態学者によって報告されている我が国の森林の年間生産力の分布とかなりよく一致することがわかった。