THE DEGRADATION OF GRASSLAND ECOSYSTEMS
AND THEIR RECOVERY*

Makoto Numata

Abstract

Some seral or climax grasslands are used as pastures for grazing and meadows for mowing. When the intensity of grazing and mowing is limited to within the carrying capacity, a grassland can maintain its dynamic equilibrium, however if it is overgrazed or mowed beyond its carrying capacity, it will be degraded. Such degradation and recovery of grassland ecosystems can be traced by the degree and rate of succession (DS and RS). The progressive rate of succession (RS) is not equal to the retrogressive rate (RS). Also the rate of succession in soil (RS_{soil}) is not equal to the rate of succession in vegetation (RS_{veg}). DS and RS are supported by life-form spectra, seed bank dynamics, dereasers and increasers under mowing and grazing stress, etc.

There are various approaches to judge the degradation of grassland ecosystems. Based on such diagnoses, several recommendations are proposed, such as measures for recovery by reseeding, fertilization, fallow, plowing to replace the surface soil and subsoil, soil dressing, and the proper use within the carrying capacity, etc.

The Denuded Quadrat Experiments

In early studies on secondary succession, I repeatedly conducted field experiments

using the denuded quadrat method (NUMATA 1982). The results of the experiments demonstrated the recovery and rehabilitation of herbaceous communities on bare ground which included buried-seed population.

The seed population dynamics of a plant community are shown by the following formula (Fig.1):

\[ s = (p + i) - (c + c' + o) \]

where \( s \) is the storage of buried seeds in the soil under a community per unit volume at a time, \( p \) is the production of seeds by a community per unit area of soil surface in one growing season (=SSP, seral seed production), \( i \) is the invasion of seeds into the community from the outside, \( c \) and \( c' \) are the consumption of the seeds by germination and by decay, respectively, and \( o \) is the outflow of seeds from the community to outside areas by various means of dispersal per unit area in one growing season (NUMATA 1984). I conducted two types of field experiments related to the analysis of seeds, i.e. 1) replacing surface soil with subsoil, and 2) replacing surface soil with burned soil without viable seeds (NUMATA and SUZUKI 1958). The latter was done in December of 1954, and the Setaria viridis community had only 80 individuals of 7 species per m² in June, 1955. The dominant of the first year after denudation, Setaria viridis was replaced by the second year dominant, Digitaria ciliaris with 2109 individuals of 23 species per m² in June of 1956. The third year community was dominated by Bromus unioloides with 1625 individuals of 21 species in June of 1957 (Table 1). This sequence of dominants was quite different from the normal sere in the same place: Ambrosia artemisiifolia – Erigeron annuus – Imperata cylindrica (or Miscanthus sinensis). The SSP of the Ambrosia stage was about 16,500 per m².
× 1 cm of surface soil. The input and output of seeds in a plant community is like energy flow or nutrient cycling in an ecosystem. The GSP (gross buried-seed population = the total number of buried-seeds at a time) is a kind of standing crop of seeds that represents the underground storage of seeds. The SSP of the *Ambrosia* stage is GSP (December) — GSP (June) (Numata, Aoki and Hayashi 1964).

Table 1. Floristic composition of plant communities on the burned-soil plot.

<table>
<thead>
<tr>
<th>Plant name</th>
<th>June, 1955</th>
<th>June, 1956</th>
<th>June, 1957</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>D</td>
<td>F</td>
<td>D F %</td>
</tr>
<tr>
<td>1. Setaria viridis</td>
<td>32</td>
<td>24</td>
<td>100.00</td>
</tr>
<tr>
<td>2. Cynarea japonica</td>
<td>14</td>
<td>10</td>
<td>42.65</td>
</tr>
<tr>
<td>3. Sonchus oleraceus</td>
<td>13</td>
<td>10</td>
<td>41.10</td>
</tr>
<tr>
<td>4. Ambrosia artemisiifolia</td>
<td>11</td>
<td>11</td>
<td>40.05</td>
</tr>
<tr>
<td>5. Digitaria ciliaris</td>
<td>6</td>
<td>5</td>
<td>19.75</td>
</tr>
<tr>
<td>6. Erigeron annuus</td>
<td>2</td>
<td>2</td>
<td>7.25</td>
</tr>
<tr>
<td>7. Artemisia asiatica</td>
<td>2</td>
<td>2</td>
<td>7.25</td>
</tr>
<tr>
<td>8. Vicia sativa</td>
<td>96</td>
<td>63</td>
<td>39.65</td>
</tr>
<tr>
<td>9. Erigeron canadensis</td>
<td>161</td>
<td>53</td>
<td>38.50</td>
</tr>
<tr>
<td>10. Bromus unioloides</td>
<td>47</td>
<td>37</td>
<td>22.65</td>
</tr>
<tr>
<td>11. Arthraxon hispidus</td>
<td>20</td>
<td>17</td>
<td>10.25</td>
</tr>
<tr>
<td>var. brevisetus</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12. Oxalis corniculata</td>
<td>6</td>
<td>6</td>
<td>3.50</td>
</tr>
<tr>
<td>13. Trisetum bifidum</td>
<td>4</td>
<td>4</td>
<td>2.35</td>
</tr>
<tr>
<td>14. Oenothera munica</td>
<td>3</td>
<td>3</td>
<td>1.70</td>
</tr>
<tr>
<td>15. Lamium amplexicaule</td>
<td>3</td>
<td>3</td>
<td>1.70</td>
</tr>
<tr>
<td>16. Veronica arvensis</td>
<td>3</td>
<td>3</td>
<td>1.70</td>
</tr>
<tr>
<td>17. Festuca rubra</td>
<td>2</td>
<td>2</td>
<td>1.15</td>
</tr>
<tr>
<td>18. Poa annua</td>
<td>2</td>
<td>2</td>
<td>1.15</td>
</tr>
<tr>
<td>19. Cerastium vulgatum</td>
<td>1</td>
<td>1</td>
<td>0.58</td>
</tr>
<tr>
<td>var. glomeratum</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20. Trigonostis peduncularis</td>
<td>1</td>
<td>1</td>
<td>0.58</td>
</tr>
<tr>
<td>21. Agropyron semicostatum</td>
<td>1</td>
<td>1</td>
<td>0.58</td>
</tr>
<tr>
<td>22. Stellaria media</td>
<td>1</td>
<td>1</td>
<td>0.58</td>
</tr>
<tr>
<td>23. Dactylis glomerata</td>
<td>31</td>
<td>22</td>
<td>15.10</td>
</tr>
<tr>
<td>24. Veronica agrestis</td>
<td>14</td>
<td>10</td>
<td>6.80</td>
</tr>
<tr>
<td>25. Issoria stolonifera</td>
<td>13</td>
<td>10</td>
<td>6.70</td>
</tr>
</tbody>
</table>

Species density / sq.m. | 7 | 23 | 21
Total no. of individuals | 80 | 2.109 | 1.625
Floristic and Life-Form Composition

In the normal progression of secondary succession, the number of seeds and species has a tendency related to the depth and season. The decrease in the number of seeds due to the progression of succession is remarkable (Table 2—Numata, Hayashi, Omura and Oki 1964). The floristic composition of three seral stages is shown in Table 3. In central Japan, the secondary orthosere will be Ambrosia artemisiifolia stage (summer annual stage)→ Erigeron annuus stage (winter annual or biennial stage)→ Imperata cylindrica stage (sea coast perennial grass stage)→ Pinus thunbergii stage (sea coast intolerant forest stage)→ Castanopsis cuspidata var. sieboldii stage (shade tolerant climax forest stage). Table 3 shows the progression of succession as an orthoseral sequence, as mentioned above.

The biological spectra corresponding to the floristic composition is shown in Table 4. It shows a remarkable increase of M, N, and 1 and a likewise remarkable decrease of Th. Another experiment shows a similar tendency according to the year after denudation (Table 5—Numata 1982).

Table 2. Seasonal variation of the number of species and of seeds per 400 cc soil in the buried-seed population at different soil depths

<table>
<thead>
<tr>
<th>Stage</th>
<th>I*</th>
<th>II*</th>
<th>III**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date</td>
<td>June' 60</td>
<td>Dec.' 60</td>
<td>June' 60</td>
</tr>
<tr>
<td>Depth (cm)</td>
<td>Seeds</td>
<td>Species</td>
<td>Seeds</td>
</tr>
<tr>
<td>0—1</td>
<td>1911</td>
<td>21</td>
<td>1449</td>
</tr>
<tr>
<td>1—2</td>
<td>415</td>
<td>13</td>
<td>418</td>
</tr>
<tr>
<td>2—5</td>
<td>181</td>
<td>12</td>
<td>115</td>
</tr>
<tr>
<td>5—10</td>
<td>66</td>
<td>8</td>
<td>24</td>
</tr>
<tr>
<td>10—20</td>
<td>23</td>
<td>7</td>
<td>—</td>
</tr>
<tr>
<td>20—30</td>
<td>11</td>
<td>7</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>2607</td>
<td>24</td>
<td>2006</td>
</tr>
</tbody>
</table>

I: Erigeron annuus stage, II: Imperata cylindrica stage, III: Imperata cylindrica-Pinus thunbergii stage
Table 3. Floristic composition of the three seral stages in terms of SDR (the summed dominance ratio) by the regular sampling of 10 quadrats (qt.size = 1m × 1m). Only the high species over 10 in SDR are listed. The buried-seed populations in the same stands were examined.

<table>
<thead>
<tr>
<th>Species</th>
<th>I</th>
<th>II</th>
<th>III</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>June'60</td>
<td>Dec.'60</td>
<td>June'61</td>
</tr>
<tr>
<td>Erigeron annuus</td>
<td>100.0</td>
<td>71.1</td>
<td>100.0</td>
</tr>
<tr>
<td>Ambrosia artemisiifolia</td>
<td>48.5</td>
<td>-</td>
<td>61.1</td>
</tr>
<tr>
<td>Artemisia vulgaris</td>
<td>38.9</td>
<td>20.9</td>
<td>52.3</td>
</tr>
<tr>
<td>Oxalis corniculata</td>
<td>32.5</td>
<td>18.9</td>
<td>7.3</td>
</tr>
<tr>
<td>Oenothera parviflora</td>
<td>30.5</td>
<td>28.4</td>
<td>23.8</td>
</tr>
<tr>
<td>Miscanthus sinensis</td>
<td>27.7</td>
<td>12.9</td>
<td>20.1</td>
</tr>
<tr>
<td>Cyperus rotundus</td>
<td>22.6</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Poa annua</td>
<td>16.3</td>
<td>11.5</td>
<td>-</td>
</tr>
<tr>
<td>Rumex conglomeratus</td>
<td>11.4</td>
<td>44.2</td>
<td>-</td>
</tr>
<tr>
<td>Chenopodium album</td>
<td>11.3</td>
<td>-</td>
<td>3.9</td>
</tr>
<tr>
<td>Microstegium viminalis</td>
<td>11.1</td>
<td>-</td>
<td>27.0</td>
</tr>
<tr>
<td>Solidago altissima</td>
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<td>28.2</td>
<td>27.0</td>
</tr>
<tr>
<td>Acalypha pstralis</td>
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<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Falcata japonica</td>
<td>7.9</td>
<td>-</td>
<td>23.6</td>
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<tr>
<td>Rosa multiflora</td>
<td>6.8</td>
<td>33.4</td>
<td>3.6</td>
</tr>
<tr>
<td>Agropyron semicostatum</td>
<td>6.6</td>
<td>-</td>
<td>19.4</td>
</tr>
<tr>
<td>Imperata cylindrica</td>
<td>-</td>
<td>86.6</td>
<td>-</td>
</tr>
<tr>
<td>var. koenigii</td>
<td>-</td>
<td>43.7</td>
<td>14.4</td>
</tr>
<tr>
<td>Vicia sativa</td>
<td>-</td>
<td>13.1</td>
<td>8.0</td>
</tr>
<tr>
<td>Erigeron canadensis</td>
<td>-</td>
<td>33.9</td>
<td>-</td>
</tr>
<tr>
<td>Phryma reptostachya</td>
<td>-</td>
<td>32.9</td>
<td>-</td>
</tr>
<tr>
<td>Polygonum sp.</td>
<td>-</td>
<td>22.4</td>
<td>-</td>
</tr>
<tr>
<td>Arundinella hirta</td>
<td>-</td>
<td>11.0</td>
<td>-</td>
</tr>
<tr>
<td>Setaria viridis</td>
<td>-</td>
<td>19.1</td>
<td>-</td>
</tr>
<tr>
<td>Lespedeza sericea</td>
<td>-</td>
<td>9.6</td>
<td>-</td>
</tr>
<tr>
<td>Cissus japonica</td>
<td>-</td>
<td>8.9</td>
<td>32.7</td>
</tr>
<tr>
<td>Commelina communis</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Equisetum arvense</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Sonchus oleraceus</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Sonchus asper</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Artemisia japonica</td>
<td>-</td>
<td>-</td>
<td>60.5</td>
</tr>
<tr>
<td>Paederia chinensis</td>
<td>-</td>
<td>58.5</td>
<td>-</td>
</tr>
<tr>
<td>Erigeron annuus (rosette)</td>
<td>-</td>
<td>50.6</td>
<td>-</td>
</tr>
<tr>
<td>Microlespedeza striata</td>
<td>-</td>
<td>35.5</td>
<td>-</td>
</tr>
<tr>
<td>Linum virginianum</td>
<td>-</td>
<td>35.1</td>
<td>-</td>
</tr>
<tr>
<td>Number of species</td>
<td>25</td>
<td>12</td>
<td>25</td>
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</tbody>
</table>
Table 4. Biological spectra of the three seral stages in terms of SDR (June, 1960)

<table>
<thead>
<tr>
<th>Life-form</th>
<th>Stage</th>
<th>I</th>
<th>II</th>
<th>III</th>
</tr>
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<tbody>
<tr>
<td>Raunkiaer's dormancy form</td>
<td>M</td>
<td>—</td>
<td>—</td>
<td>8.0</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>1.3</td>
<td>—</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td>Ch</td>
<td>—</td>
<td>7.1</td>
<td>7.1</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>16.8</td>
<td>37.5</td>
<td>29.6</td>
</tr>
<tr>
<td></td>
<td>G</td>
<td>15.2</td>
<td>8.5</td>
<td>23.5</td>
</tr>
<tr>
<td></td>
<td>Th</td>
<td>64.8</td>
<td>46.8</td>
<td>34.9</td>
</tr>
<tr>
<td>Numata's mignone form</td>
<td>D₁</td>
<td>47.8</td>
<td>57.5</td>
<td>60.3</td>
</tr>
<tr>
<td></td>
<td>D₂</td>
<td>0.7</td>
<td>—</td>
<td>1.2</td>
</tr>
<tr>
<td></td>
<td>D₃</td>
<td>15.2</td>
<td>11.5</td>
<td>1.7</td>
</tr>
<tr>
<td></td>
<td>D₄</td>
<td>35.1</td>
<td>31.0</td>
<td>36.7</td>
</tr>
<tr>
<td></td>
<td>D₅</td>
<td>10.0</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Radial form</td>
<td>R₁₋₃</td>
<td>23.5</td>
<td>46.3</td>
<td>28.7</td>
</tr>
<tr>
<td></td>
<td>R₄</td>
<td>4.4</td>
<td>2.3</td>
<td>1.7</td>
</tr>
<tr>
<td></td>
<td>R₅</td>
<td>72.1</td>
<td>51.3</td>
<td>69.7</td>
</tr>
<tr>
<td>Numata's growth form</td>
<td>e</td>
<td>32.0</td>
<td>23.0</td>
<td>27.9</td>
</tr>
<tr>
<td></td>
<td>t</td>
<td>20.0</td>
<td>39.2</td>
<td>25.8</td>
</tr>
<tr>
<td></td>
<td>b</td>
<td>12.0</td>
<td>9.2</td>
<td>6.0</td>
</tr>
<tr>
<td></td>
<td>r</td>
<td>—</td>
<td>—</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>p</td>
<td>12.0</td>
<td>2.4</td>
<td>1.7</td>
</tr>
<tr>
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<td>pr</td>
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<td>21.3</td>
<td>26.3</td>
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<tr>
<td></td>
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<td>4.0</td>
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</tr>
<tr>
<td></td>
<td>l</td>
<td>4.0</td>
<td>4.8</td>
<td>16.4</td>
</tr>
</tbody>
</table>

Table 5. Yearly variation of life-form spectra of pioneer communities after denudation

<table>
<thead>
<tr>
<th>Life-form</th>
<th>Year</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Th*</td>
<td>78.3</td>
<td>69.2</td>
<td>64.7</td>
<td></td>
</tr>
<tr>
<td>Ch</td>
<td>4.3</td>
<td>7.7</td>
<td>5.9</td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>13.0</td>
<td>7.7</td>
<td>11.8</td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>13.0</td>
<td>15.4</td>
<td>17.6</td>
<td></td>
</tr>
<tr>
<td>D₁₋₂***</td>
<td>43.5</td>
<td>53.8</td>
<td>47.1</td>
<td></td>
</tr>
<tr>
<td>R₁₋₃****</td>
<td>16.0</td>
<td>15.4</td>
<td>17.6</td>
<td></td>
</tr>
<tr>
<td>e****</td>
<td>30.4</td>
<td>24.0</td>
<td>17.6</td>
<td></td>
</tr>
<tr>
<td>pr</td>
<td>31.7</td>
<td>30.8</td>
<td>17.6</td>
<td></td>
</tr>
<tr>
<td>p</td>
<td>8.7</td>
<td>30.8</td>
<td>23.6</td>
<td></td>
</tr>
<tr>
<td>t</td>
<td>13.0</td>
<td>7.7</td>
<td>11.8</td>
<td></td>
</tr>
<tr>
<td>b</td>
<td>26.1</td>
<td>7.7</td>
<td>23.6</td>
<td></td>
</tr>
<tr>
<td>l</td>
<td>0</td>
<td>0</td>
<td>5.9</td>
<td></td>
</tr>
</tbody>
</table>

* Raunkiaer's life-forms
** Wide-dispersal disseminules (anemochores, hydrochores and zoochores)
*** Rhizomatous plants
**** Growth forms
The Degree and Rate of Succession

Summarizing these data, the degree of succession (DS) was measured for the three stages for two years (Table 6). The degree of succession is formulated as follows:

Table 6. Degree of succession (DS) of the three seral stages

<table>
<thead>
<tr>
<th>Stage</th>
<th>I</th>
<th>II</th>
<th>III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date</td>
<td>June’60</td>
<td>June’61</td>
<td>June’60</td>
</tr>
<tr>
<td>n</td>
<td>25</td>
<td>25</td>
<td>15</td>
</tr>
<tr>
<td>Σ dl/n</td>
<td>92.5</td>
<td>110.3</td>
<td>126.5</td>
</tr>
<tr>
<td>v</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>DS</td>
<td>92.5</td>
<td>110.3</td>
<td>126.5</td>
</tr>
</tbody>
</table>

DS = (Σ \( d_i l_i / n \)) \cdot v

where \( d = \) the relative importance (summed dominance ratio, SDR%), \( l = \) life span (years) of constituent species, \( n = \) number of species of a community, and \( v = \) ground cover (0~1) (NUMATA 1986). Based on this idea, I measured the successional characteristics of pastures and meadows all over Japan (NUMATA 1969). The same idea was applied to pastures in the Himalayas, particularly in Eastern Nepal (NUMATA 1986). The ranges of the biomass—DS curve and their modes (peaks) are concluded from those data. The mature phase with the modal DS of Zoysia japonica pasture on a plagiocere (DS = 250) and the mature phase with the modal DS of Miscanthus sinensis meadow on an orthosere (DS = 500) can be compared in terms of the distance of DS and the rate of succession (RS) (NUMATA 1982).

\[
\begin{align*}
\vec{RS} &= \frac{DS(t_{n+1}) - DS(t_n)}{\text{Length of time}^*} \\
\vec{RS} &= \frac{DS(t_n) - DS(t_{n-1})}{\text{Length of time}^*}
\end{align*}
\]

* Months or years between \( t_n + 1 \) and \( t_n \), or \( t_n \) and \( t_{n-1} \)

Thus, the progressive rate of succession (\( \vec{RS} \)) and/or the retrogressive rate of succession (\( \vec{RS} \)) is measured. Secondary succession initiated after denudation from the first year Ambrosia artmisifolia stage to the Pinus thunbergii stage was traced through the 2nd—3rd year Erigeron annuus stage and the 4th—5th year Imperata cylindrica stage,
with soil conditions, particularly nitrogen contents (OHGA and NUMATA 1965—Table 7). The increase in nitrogen from low density to high density in pine samplings was seen.

Table 7. Ecological characteristics of pine stands (Pinus thunbergii) in secondary succession. The ages of pine trees are 5~13 (OHGA and NUMATA 1965)

<table>
<thead>
<tr>
<th>Cover</th>
<th>Bare ground</th>
<th>Low density under the crown</th>
<th>Low density Imperata stand</th>
<th>Moderate density</th>
<th>High density</th>
</tr>
</thead>
<tbody>
<tr>
<td>mg N/g dry soil</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Depth 1 cm</td>
<td>1.55</td>
<td>2.25</td>
<td>3.73</td>
<td>4.45</td>
<td>8.15</td>
</tr>
<tr>
<td>Depth 5 cm</td>
<td>1.20</td>
<td>0.90</td>
<td>2.50</td>
<td>1.65</td>
<td>3.60</td>
</tr>
<tr>
<td>Density/100 m²</td>
<td>0</td>
<td>1</td>
<td>6</td>
<td>15</td>
<td>23</td>
</tr>
<tr>
<td>DS</td>
<td>0</td>
<td>500</td>
<td>500</td>
<td>700</td>
<td>900</td>
</tr>
<tr>
<td>Height</td>
<td>0</td>
<td>240</td>
<td>570</td>
<td>513</td>
<td>235</td>
</tr>
</tbody>
</table>

In Japan, there is a classical figure showing secondary succession of grassland with relative soil fertility in the stages by OSEKO (1937—Fig.2). when the values of DS are given for each stage, Table 8 is developed with OSEKO's data. The relative soil fertility was assumed by OSEKO based on the data accumulated until that time.

![Fig. 2. Successional relationships of grasslands and other vegetation types in Japan. Figures in parentheses represent fertility status of the soil (after OSEKO).](image-url)
Table 8. Relative soil fertility and DS of stages of grassland succession (Oseko 1937, Numata 1987)

<table>
<thead>
<tr>
<th>Stage</th>
<th>Fertility</th>
<th>DS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waste</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>Zoysia</td>
<td>25</td>
<td>250</td>
</tr>
<tr>
<td>Imperata</td>
<td>50</td>
<td>400</td>
</tr>
<tr>
<td>Sasa</td>
<td>50—60</td>
<td>800</td>
</tr>
<tr>
<td>Pleioblastus</td>
<td>50—60</td>
<td>600</td>
</tr>
<tr>
<td>Lespedeza</td>
<td>50—60</td>
<td>600</td>
</tr>
<tr>
<td>Fern</td>
<td>50—60</td>
<td>400</td>
</tr>
<tr>
<td>Miscanthus</td>
<td>75</td>
<td>500</td>
</tr>
<tr>
<td>Shrub</td>
<td>60—80</td>
<td>800</td>
</tr>
<tr>
<td>Coppice</td>
<td>80</td>
<td>1000</td>
</tr>
<tr>
<td>Pine wood</td>
<td>80</td>
<td>1000</td>
</tr>
<tr>
<td>Forest</td>
<td>100</td>
<td>3000</td>
</tr>
</tbody>
</table>

One soil fertility data shows fertility of Miscanthus sinensis meadow to be higher than that of Zoysia japonica pasture (Yamane and Izumi 1959—Table 9). The Z. japonica pasture is plagioseral stage under grazing, and the M. sinensis stage is an orthoseral stage under mowing. The soils under M. sinensis meadow and under Z. japonica pasture are quite different in the long term.

Table 9. Accumulation of matter in the grassland soil (%) (Yamane and Izumi 1959)

<table>
<thead>
<tr>
<th>Grassland</th>
<th>Layer</th>
<th>N</th>
<th>C</th>
<th>Humus</th>
<th>Changeable base</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>CaO</td>
</tr>
<tr>
<td>M.S.</td>
<td>0—3 cm</td>
<td>1.30</td>
<td>19.1</td>
<td>33.1</td>
<td>0.236</td>
</tr>
<tr>
<td></td>
<td>3—6 cm</td>
<td>1.01</td>
<td>16.0</td>
<td>27.7</td>
<td>0.065</td>
</tr>
<tr>
<td>Z.j.</td>
<td>0—3 cm</td>
<td>0.81</td>
<td>12.9</td>
<td>22.4</td>
<td>0.052</td>
</tr>
<tr>
<td></td>
<td>3—6 cm</td>
<td>0.76</td>
<td>11.4</td>
<td>19.8</td>
<td>0.026</td>
</tr>
</tbody>
</table>

The M. sinensis stage (modal DS=500) retreats to the Z. japonica stage (modal DS=250) under heavy grazing with a retrogressive rate of succession $\overrightarrow{RS} \approx 80$ (consequently 3 years). The Z. japonica stage proceeds to the M. sinensis stage as a normal succession without grazing having a progressive rate of succession $\overrightarrow{RS} \approx 50$ (consequently 5 years). These are average annual RS values. In this case, $\overrightarrow{RS}$ is slower than $\overrightarrow{RS}$. The typical
phases of the modal DS (250 in *Z. japonica* and 500 in *M. sinensis*) correspond to typical soil conditions, as shown in Table 9. However, the retrogressive rate of succession in soil (\( \text{RS}_{\text{soil}} \)) is slower than the retrogressive rate of successison in vegetation (\( \text{RS}_{\text{veg.}} \)). This means that the soil change cannot overtake the vegetational change. Under heavy grazing, the *M. sinensis* meadow retreats to a *Z. japonica* pasture in a few (3 or so) years (\( \text{RS} = 80 \) as described above), but the soil conditions remain similar to the *M. sinensis* meadow. \( \text{RS}_{\text{soil}} \) may be 50 or less. If \( \text{RS}_{\text{soil}} \) is almost 50, the soil change from an *M. sinensis* type to an *Z. japonica* type will take 5 years (Table 10).

Table 10. the rate of succession of vegetation in grasslands

1) Examples of *Zoysia* pasture and *Miscanthus* meadow in the Asama Farm, Gunma Pref., Japan (NUMATA 1969)

<table>
<thead>
<tr>
<th></th>
<th>Miscanthus</th>
<th>Zoysia</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \nu )</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>( n )</td>
<td>35</td>
<td>63</td>
</tr>
<tr>
<td>DS</td>
<td>449</td>
<td>228</td>
</tr>
<tr>
<td>SDR</td>
<td>100</td>
<td>85.0</td>
</tr>
<tr>
<td>SDR*</td>
<td>14.9</td>
<td>8.8</td>
</tr>
</tbody>
</table>

*relative SDR of the dominants

<table>
<thead>
<tr>
<th></th>
<th>( \text{RS} (M \rightarrow Z) )</th>
<th>( \text{RS} (Z \rightarrow M) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>RS</td>
<td>73.7</td>
<td>44.2</td>
</tr>
</tbody>
</table>

M: *Miscanthus* meadow  
Z: *Zoysia* pasture

On the other hand, the response of grasses and herbs was traced under different intensities of mowing assuming the grazing stress (NUMATA 1970). Four treatments were applied for the *Miscanthus sinensis* grassland, such as I: mowing three times a year (early in June, the end of July and early in September), II: mowing one time a year (July), III: one time every two years (July), and no mowing (control). In the experiment, three groups of species were found to be responding to the mowing stress, i.e. decreasers (↓), increasers (↑) and indifferent (→). The components of meadows (mowing grasslands) are decreasers under I, while the components of pastureess (grazing grasslands) are increasers under I.
Table 11. Decreasers and increasers in *Miscanthus sinensis* grassland

<table>
<thead>
<tr>
<th></th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Miscanthus sinensis</em></td>
<td>↓</td>
<td>↓</td>
<td>←</td>
<td>↓</td>
</tr>
<tr>
<td><em>Lespedeza bicolor v. japonica</em></td>
<td>↓</td>
<td>↓</td>
<td>↓</td>
<td>↑</td>
</tr>
<tr>
<td><em>Lysimachia clethroides</em></td>
<td>↓</td>
<td>→</td>
<td>↑</td>
<td>↑</td>
</tr>
<tr>
<td><em>Pteridium aquilinum</em></td>
<td>↑</td>
<td>↑</td>
<td>↓</td>
<td>→</td>
</tr>
<tr>
<td><em>Arundinella hirta</em></td>
<td>↑</td>
<td>↑</td>
<td>→</td>
<td>↑</td>
</tr>
<tr>
<td><em>Calamagrostis hakonensis</em></td>
<td>↑</td>
<td>↑</td>
<td>→</td>
<td>↑</td>
</tr>
<tr>
<td><em>Zoysia japonica</em></td>
<td>↑</td>
<td>↑</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td><em>Hydrocotyle raniflora</em></td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>x</td>
</tr>
<tr>
<td><em>Spodiopogon sibiricus</em></td>
<td>→</td>
<td>↑</td>
<td>→</td>
<td>↑</td>
</tr>
<tr>
<td><em>Carex caryophyllea v. nervata</em></td>
<td>→</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
</tr>
<tr>
<td><em>Carex humilis v. subpediformis</em></td>
<td>→</td>
<td>↑</td>
<td>↑</td>
<td>→</td>
</tr>
<tr>
<td><em>Viola mandshurica</em></td>
<td>→</td>
<td>↑</td>
<td>↑</td>
<td>→</td>
</tr>
</tbody>
</table>


**Synthesis and Recommendations**

I made a country-wide survey of pastures and meadows as well in Nepal and Brazil (Numata 1970) in relationship to the ecological diagnosis of grassland conditions and trends (Numata 1965, 1966). In my view, judging the dynamic situation of a pasture on a sere is a necessary basis for the diagnosis. DS and RS have been devised and used for succession diagnosis combined with productivity. It is not difficult to recognize a grassland belonging to the *Miscanthus sinensis* stage or the *Zoysia japonica* stage, because it is floristically conspicuous, particularly its dominant. Therefore, there is no problem in the interstage diagnosis. It is rather difficult but useful to judge the establishment, mature and degenerate phases in the same stage of the *M. sinensis* grassland.

Such an intrastage or phasic diagnosis is most important for judging the recovery and rehabilitation of grasslands. For that, the measurement of height and weight, the mode of distribution, the clump size and vigor of the dominant, the rate of shrubs and climbing plants, stratified structure and epigeic mosses, etc. as well as DS and RS are necessary.

Pastures deteriorate because of the heavy stocking rate, high cow-days, etc. beyond their carrying capacity. We must judge the condition and trend of pastures and then
consider methods of pasture improvement, e.g., eradication of noxious weeds and shrubs, reseeding or replanting palatable grasses and legumes, applying fertilizers (including dung and urine), limitation on the stocking rate and cow-days, etc. The dynamic situation of a pasture is indicated by the DS, and the progressive and retrogressive trends on a sere is shown by the RS. The grassland condition is quantified in the relationship to the grazing capacity by the IGC (index of the grassland condition) = \( \sum_{i=1}^{n} d_{i}k_{g_{i}}/n \) where \( g \) is the grazing rate (0~\( \leq 1 \)), \( N_{g} \) (palatability index) = (number of grazed species)/\( n \) \( \times 100 \), F% (forage percent) = (summed total of SDR of grazed species)/(summed total of SDR of constituent species) \( \times 100 \), etc. (NUMATA 1986).

**Literature Cited**


Taxon Analysis in Vegetation Science, 161–170.


