VEGETATION PATTERNS IN THE CONNECTICUT RIVER FLOOD PLAIN
IN RELATION TO FREQUENCY AND DURATION OF FLOODING

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Abstract

The lower part of the Connecticut River has an annual flood season that is 1-2 months behind that of local rivers, and severe floods occur occasionally in summer. This paper describes the floristic composition of the Acer saccharinum forests of the Connecticut River flood plain in relation to the frequency, duration and timing of floods, and it documents the large annual changes in the vegetation of some habitats. Long-term river level records, starting in 1896, were used to calculate the duration of flooding as well as the frequency of summer floods at any level in the flood plain. In the freely drained flood plain, elevation and location with respect to the river channel are the principal factors controlling the vegetation pattern. Elevation also affects flooding frequency of the sloughs and depressions that retain water after floods, but their vegetation pattern is controlled primarily by subsequent water level changes caused by evapotranspiration and percolation. Here, the occurrence and timing of summer floods determine the composition and development of the vegetation in any one year. This paper illustrates the value of water level duration and flood frequency curves in analyzing the vegetation patterns of a flood plain.

Introduction

The Connecticut River, flowing from southern Quebec to Long Island Sound is the largest river in New England. It drains approximately 29,100 km² and, with an average discharge of 560 m³/s, supplies more than one-half the freshwater input into Long Island Sound (Meade, 1966). The drainage area is relatively long and narrow, mostly hilly, and more than 70% forested. From northern Massachusetts through central Connecticut, the river flows through a broad lowland. Here the flood plain reaches its greatest development, overbank flow is substantial, and channel migration is prevalent.

Almost all of the high flood plain has been cleared and very little it is now forested. The low flood plain has also not escaped the effects of agriculture and urbanization but enough of the marshes and forests are left to show the original vegetation patterns. The most striking features of the flood plain forests are the sharp contrasts in species dominance and floristic composition of the ground vegetation and the dramatic year to year variation in its floristic composition. These
are especially obvious on the frequently flooded parts of the flood plain.

In Connecticut, *Acer saccharinum* forests are restricted to flood plains (Bromley, 1935; Westveld, 1956). Nichols (1916) gave a general description of these forests as well as other vegetation on the flood plain of the lower Connecticut River. The vegetation of marshes and oxbows was described from an adjacent part of the flood plain in Massachusetts (Burk, 1977; Sackett, 1974, 1977).

The flooding history of the Connecticut River can be traced from 1683 (Thompson et al., 1964), and since 1896 excellent records have been kept on river level fluctuations at Hartford, Connecticut. This provides an opportunity to correlate vegetation boundaries with long term river level data, to determine the flooding frequency and duration to which plant communities are subjected, and to relate sudden changes in vegetation with unusual flooding events.

The purpose of this paper is (1) to describe the floristic composition of the flood plain forests in northern Connecticut, (2) to draw attention to the large year to year differences in the composition of some flood plain communities, (3) to correlate spatial and temporal differences in vegetation with flooding and habitat conditions, and (4) to describe and explain the topographical sequences of plant communities in the flood plain. This paper will focus on the forest vegetation of the low flood plain, partially because the effects of flooding are most clearly expressed on these sites, but also because a complete toposequence of vegetation units is still available for study.

**Geographical setting**

The study area includes the flood plain or the reach of the Connecticut River flowing through north-central Connecticut (Fig. 1). It is underlain by Triassic-Jurassic sandstones and shales. The surrounding topography is flat to rolling, with elevations averaging 15 to 75 m above sea level. Similar reaches can be found to the north, whereas to the south the river is confined within a bedrock channel until it reaches Long Island Sound. In the vicinity of Hartford, much of the flood plain was diked during the 1940's, increasing flood levels to the north by less than 30 cm during periods of high flow (L. Weiss, Water Resources Division, U.S. Geological Survey, pers. comm.).

The study area is located in the northern part of the Appalachian oak forest zone (Küchler, 1964), has a growing season of about 180 days, a mean annual temperature of 10°C, and mean monthly temperatures of −3°C and 27°C for January and July, respectively. Annual precipitation is well-distributed throughout the year and averages 1090-1200 mm (Brumbaugh, 1965).

The Connecticut River is an early spring flooding river (Hoyt & Langbein, 1955) with autumn flooding not uncommon. In most years, deep snow accumulates in the upper reaches of the basin causing high flood levels during spring thaws. In the late summer and early autumn, flooding is caused by heavy precipitation associated with equinoctial tropical storms. During periods of low flow, the Connecticut River is subject to tidal fluctuation with the upper limit of tidal influence corresponding to the bedrock riffles on the northern boundary of the study area. The maximum tidal amplitude in Hartford is approximately 30 cm.

Along the Connecticut River, erosional and depositional features are well represented with...
steep-cut banks, point bars, and scroll bars recording the history of lateral channel migration (Fig. 2). Oxbow-lakes and remnants of more ancient channels can also be found with meander cut-offs described and dated by Holland & Burk (1982) for the flood plain in Massachusetts and by Flint (1930) for the flood plain in the vicinity of Hartford. Natural levees parallel many of the straighter channels, and terracing caused by base-level changes gives a broad step-like appearance to the surface of the flood plain. Five terrace and flood plain levels have been described for the flood plain in Massachusetts with only the two lower levels presently inundated (Jahns, 1947): an upper level or high flood plain inundated for short periods during extreme floods and a low flood plain inundated annually for much longer periods of time.

Methods

The vegetation and habitat conditions were described during a survey of the Connecticut River flood plain from 1978-1980 and were supplemented with descriptions made in the flood plain forests south of Hartford from 1972-1982. Studies in the latter area also provided detailed information on the relationship between vegetation and flooding levels.

The floristic composition of the vegetation was described in plots uniform with respect to vegetation cover and soil conditions, and large enough to include the normal species combination of the habitat. Most plots were 20 x 20 m, but in order to sample areas with uniform vegetation and soil it was occasionally necessary to use rectangular or smaller plots. Plot sizes are indicated in the vegetation table. Within each plot, abundance-cover and sociability of all vascular plants and bryophytes present was estimated using the Braun-Blanquet scale (Mueller-Dombois & Ellenberg, 1974), except that no sociability values were used for trees and shrubs. Descriptions were tabulated and then organized into a vegetation synthesis table on the basis of similarities and differences in species composition (Mueller-Dombois & Ellenberg, 1974). Vegetation patterns identified in this table were checked during subsequent field work to refine or correct the classification.

The plant communities recognized are mostly at the level of subassociation in the Zürich-Mont-
peller tradition (Mueller-Dombois & Ellenberg, 1974), and variants and facies of some of the communities are recognized. These units are defined by differential species only. No association and subassociation names have been assigned to them. Such an informal classification is preferred until further data, collected over a much larger geographic area, provide a clear concept of the associations.

Elevational differences were measured with a transit on transects across the major topographical features, such as levees and sloughs. The elevation of vegetation boundaries was also recorded on these transects. The elevation of the transects was tied in with the Bulkeley Bridge gauge in Hartford, so that river-level records could be used in determining the flooding frequency and duration for plant communities.

Species density, based on number of stems, and height were recorded each autumn on several permanent transects. Density was determined in circular plots located at 1-m intervals on the transects; plot size varied from 0.1-1.0 m depending on the density of the species. Height was recorded as the maximum height within 0.5 m from the plot center.

Records of Connecticut River water levels at Hartford (supplied by the Water Resources Division, U.S. Geological Survey and the National Weather Service, U.S. Department of Commerce) were used in a variety of ways. A water level duration curve was prepared to show the average period of time in days and percent of year that water levels were at or above a certain level. This was based on data for the period 1896-1942 compiled by the Department of Engineering, City of Hartford. The number of years that a certain level was reached at least once during the summer (15 May-15 September) and during each of the periods 15-31 May, June, July, August, and 1-15 September, was calculated using river level records from 1905-1982. From this the probability of flooding was determined for various summer periods after the regular spring floods. The same data were also used to calculate the flood recurrence intervals for the period 1 June-15 September following the guidelines of the Water Resources Council (1981). The nomenclature of the vascular plants follows Fernald (1950), for mosses Crum et al. (1973) and for hepaticae Stotler & Crandall-Stotler (1977).

Results
FLOOD DURATION AND INUNDATION PERIOD

Flood duration is longest in the spring with peak flows occurring between 15 March and 15 May (Fig. 3). Therefore spring flooding often occurs well into the vegetative season and at a time when Acer saccharinum trees are already in full

![Graph showing daily maximum, mean, and minimum heights of the Connecticut River above mean sea level at Hartford, 1908-1957. Data are from the Greater Hartford Flood Commission, Hartford, Connecticut. The dates in the graph indicate years with maximum gauge heights; the level of some historic floods (Thomson et al., 1964), the July 1973 and the June 1984 floods are also shown.](image-url)
flower. By late May, flood waters have generally receded, and much of the flood plain has drained leaving only sloughs, backmarshes, and other depressions filled with water. Summer floods occur in some years (Fig. 3). Characteristically, they peak for very short periods and the river returns rapidly to regular summer levels.

Since flood duration was thought to be a major factor controlling the vegetation pattern of the flood plain, a flood duration curve was constructed from the river water levels at Hartford. This curve (Fig. 4) shows the inundation period for any level in the freely drained part of the flood plain.

The asymmetry of this curve is striking. River levels remain between 0.3 and 1.5 m mean sea level (MSL) for half the year and are between 0.8 and 1.5 m for 40% of the time, whereas during the remainder of the year they fluctuate between 1.5 and 10 m MSL. Consequently, elevational differences have their greatest effect on flood duration at low levels in the flood plain, and they become progressively less important with increasing height above sea level. For instance, an increase in elevation of 10 cm will reduce the inundation period by 30 days at 1 m MSL, by less than 4 days at 1.5 MSL and for only about one day at 3 m MSL.

Flood duration is of little value in predicting inundation periods in parts of the flood plain that do not drain freely after a flood, such as sloughs and depressions without an outlet into the river. Here, water is trapped and water levels will be lowered only by evapotranspiration and percolation. After a summer flood such sites will remain inundated for weeks or months and often for the remainder of the summer. Severe summer floods can return water levels throughout the flood plain to those of early spring, but less severe floods will only affect the low-lying sloughs. Therefore, it is not flood duration but its maximum level and its timing that are critical for the vegetation, and it is the frequency of such events that affect the vegetation pattern of these sites.

Two types of graphs are necessary to show the hydrological regime of these undrained or partially drained sloughs in such a way that they indicate the effect on the vegetation. One graph to show the recurrence interval and another to show the timing of the flooding events.

The relationship between flood level and its frequency of occurrence (Fig. 5) can be used to predict the recurrence interval of flooding; provided the lowest level at which river water can enter and leave the slough is known. In the low flood plain, sloughs with inflow thresholds below 0.5 m MSL will be flooded every summer. Those with an inflow level of 4 m MSL have a recurrence interval of 7 years for summer floods but they will be flooded every year in the spring. Figure 5 also shows the importance of summer floods for sloughs in the high flood plain, even for those at levels where spring floods are not an annual event.

The probability of a flood during each of the summer months is plotted in Figure 6. The chance of a flood decreases as the vegetative season progresses. For example, the probability of a 3 m flood occurring between 15-31 May is 42%, during June 24%, and during July, August or the first half of September only 5-10%. However, it is clear from Figures 3 and 6 that high flood levels (stage levels over 5 m MSL) can occur during any month of the year. Moreover, although severe summer floods are uncommon, it is worth emphasizing that they have occurred several times during one vegetative season, e.g. in 1973 in late May (4.9 m) and July (6.1), in 1969 in late May (3.0 m) and twice in August (3.4 m).

PLANT COMMUNITIES OF THE FLOOD PLAIN

Excluding the anthropogenic vegetation, the flood plain vegetation can be conveniently divided into: (1) forests on the high flood plain (2) forest on the low flood plain and (3) marshes and herbaceous riverbank vegetation. The major part of this section will be devoted to the forest vegetation of the low flood plain. The plant communities of the high flood plain and those without tree cover will be defined very briefly with respect to major physiognomical and floristic characteristics. This description will be limited to plant communities referred to in the discussion on ecological relationships.

High flood plain forests

The high flood plain forests differ floristically and ecologically from the Acer saccharinum forests of the low flood plain. They resemble the Acer saccharum-Fraxinus americana forests on fertile, upland soils (Damman & Kershner, 1977) and show a close floristic similarity to forests on moist lower slopes in basalt and limestone areas. Both contain species such as: Tilia americana, Ulmus americana, Carya cordiformis, Staphylea trifolia, Carex sprengelii, Asarum canadense, Dicentra cucullaria, Menispermum canadense and Hydrophyllum virginianum, all of which are absent in the low flood plain forests. Only small fragments of the high flood plain remain since it occurs on prime agricultural land. These forests are simply referred to as high flood plain forest.

Low flood plain forests

These forests are differentiated from those of the high flood plain by the dominance of Acer
Figure 4. Relationship between elevation, flood duration, and distribution of plant communities on the freely drained parts of the Connecticut River flood plain. The water level duration curve at left shows the percentage of the year that the river is at or above a certain level based on the period 1896-1942. The upper and lower limits of each plant community are shown on the right. These levels can be traced to the duration curve to find the period of inundation. Flood duration data were supplied by the Greater Hartford Flood Commission.

saccharinum and the common occurrence of *Populus deltoides*, *Sicyos angulatus*, *Echinocystis lobata*, *Cuscuta gronovii*, *Vitis riparia* and *Arisaema dracontium*. *Acer negundo* occurs sporadically on the low flood plain of the Connecticut River but is abundant on calcareous flood plains in western Connecticut.

Ecologically, there is a clear distinction between the *Acer saccharinum*- *Populus deltoides* forests on riverbanks and levees and the virtually pure *Acer saccharinum* forests of the inner portions of the flood plain. However, a floristic distinction between these two units cannot be easily made. Physiognomically, the low flood plain forests can be separated into: 1) those with a luxuriant herb layer and 2) those with a generally sparse ground cover that varies greatly in its development from year to year. The former includes the *Eupatorium-Acer saccharinum*, the *Onoclea-Acer saccharinum*, and the *Boehmeria-Acer saccharinum* communities, whereas the *Populus-Acer saccharinum*, the *Acer saccharinum* seedling, and the *Salix nigra* riverbank communities belong to the latter. Each of these is briefly described below.

*Eupatorium rugosum-Acer saccharinum* community. An Acer saccharinum forest with an admixture of *Populus deltoides* and *Ulmus rubra*. It is characterized by a lush ground cover of tall herbs and the presence of shrubs. Species of group c (Table I) differentiate this community from all other *Acer saccharinum* forests and it shares species of group b (Table I) with the *Onoclea-Acer saccharinum* community. Several other species of group a (Table I) reach their optimal development in both this and the *Onoclea-Acer* community. In a variant of this community, *La- portea canadensis* completely dominates the ground vegetation (Table I, no. 16-22).

*Populus deltoides-Acer saccharinum* community. A *Populus deltoides* forest with *Acer saccharinum* often occurring as a low tree under the *Populus* canopy. The herbaceous cover is generally sparse, but *Leersia virginica* is always present. Differential species of the low flood plain and species of group a (Table I) are poorly represented. *Populus del- toides* reaches its greatest abundance here.

*Salix nigra* riverbank community. A riverbank shrub community with *Salix nigra* as the dominant low tree and shrub. The composition of the ground cover is affected greatly by the adjacent vegetation but it is generally weedy and highly variable. Summer annuals such as *Panicum dichotomiflorum*, *Echinocloa crusgalli*, *Sicyos angulatus* and several *Bidens* and *Polygonum* species are often dominant. The composition and development of the vegetation varies greatly from year to year.
No descriptions are included in Table I because of the narrow and transitional nature of this zone along this part of the Connecticut River.

Onoclea sensibilis-Acer saccharinum community. An Acer saccharinum forest with an occasional Populus deltoides tree and scattered shrubs. Ulmus rubra and Fraxinus pennsylvanica occur commonly as low trees. Most characteristic for this community is the fern-covered forest floor. It is further distinguished from all other low flood plain forests, except the Eupatorium-Acer community, by the presence of species of group e (Table I).

This community has a wide ecological amplitude with flood duration determining the floristic composition of the ground cover. In its typical expression (Table I, no. 29-34), Onoclea sensibilis dominates the forest floor completely. A floristically impoverished variant (Table I, no. 35-38) occurs in the lower part of its elevational range; shrubs are absent here and the species of group b (Table I) are poorly represented. The Pterelis pensylvanica variant (Table I, no. 23-28) occupies the highest ridges in the inner flood plain.

Boehmeria cylindrica-Acer saccharinum community. An Acer saccharinum forest in which Boehmeria cylindrica either forms a luxuriant ground cover or is a prominent species in the herb layer. It is differentiated by the absence or very sporadic occurrence of species of groups b, c, and d (Table I).

Three variants can be recognized. A) Onoclea sensibilis variant (Table I, no. 39-46) with an open Boehmeria cylindrica cover in which clumps of Onoclea sensibilis occur regularly and Laportea canadensis, Rhus radicans and other species (Table I, group a) occur sporadically. B) Leersia virginica variant (Table I, no. 47-49) with Leersia as the dominant species on the forest floor. C) Boehmeria cylindrica variant (Table I, no. 50-55) dominated completely by a dense ground cover of Boehmeria cylindrica. This and the Leersia variant lack the differential species of group a (Table I) and Onoclea sensibilis occurs sporadically in both.

Acer saccharinum seedling community. This community occurs in undrained sloughs and depressions in which flood waters are ponded. Trees do not occur within this community, but the site is heavily shaded by the overhanging canopy of trees growing on adjacent higher soils. The ground cover is usually very open, but its cover

Figure 5. Recurrence interval of annual and summer floods of the Connecticut River at Hartford. Data for annual floods are based on maximum and historic flood levels calculated by the U.S. Geological Survey for the period 1683-1982. Data for the summer period are based on 7 AM readings from the U.S. National Weather Service and the U.S. Geological Survey for the period 1905-1932. Recurrence intervals were calculated following the guidelines of the Water Resources Council (1931).
and height are highly variable depending on the flooding regime during any one year. *Ricciocarpus natans* and *Lemna minor* are usually present on the muddy soil. Seeds of many species accumulate here with floating debris, and seedlings of a wide variety of plants, from *Quercus rubra* to garden vegetables, can occur. In some years, a facies dominated by *Pilea pumila* (Table I, no. 56-60) occupies the upper part of this habitat.

**Flood plain marshes and herbaceous riverbank vegetation**

These marshes occupy open sites in coves with tidal influence, in oxbows and sloughs that have permanent standing water, and in back-marshes that receive drainage from the adjacent upland. In contrast, the herbaceous riverbank vegetation occupies sandy beaches and shores adjacent to the river channel but above the influence of normal summer low water levels. For the purpose of this paper only three vegetation types will be described.

*Sagittaria latifolia* community. A herbaceous community occurring in the tidal zone of the river channel, inlets, and coves connected to the river. Along the river, this community generally has a sparse vegetation cover of *Sagittaria latifolia* and *Lindernia dubia*. However, in protected inlets and coves with a large expanse of tidal mud, a dense growth of annual grasses, such as *Zizania aquatica*, can dominate the vegetation. The *Sagittaria* community occupies very little area within the study area and is better expressed along the lower Connecticut River where intertidal mud flats are more extensive.

*Peltandra virginica-Cyperus strigosus* community. A herbaceous marsh community that develops in low-lying swales along the large meanders. These marshes have a low point of entry and are frequently flooded. After the floods recede, water is trapped in these shallow swales. The emergent marsh vegetation consists mainly of *Peltandra virginica* with *Sagittaria latifolia*, *Cyperus strigosus*, *Leersia oregoides*, *Lindernia dubia*, and *Ludwigia palustris*. *Peltandra virginica* is always abundant. *Cyperus strigosus* or *Leersia oregoides* are sometimes abundant and then determine the physiognomy of this community.

*Echinochloa-Panicum dichotomiflorum* community. A highly variable community that occurs on low riverbanks and shores above the influence of the summer river level. Summer annuals predominate: e.g. *Echinochloa pungens*, *E. crus-galli*, *Panicum dichotomiflorum*, *Polygonum pensylvanicum*, *P. lapathifolium*, *Xanthium pensylvanicum*, *Eragrostis hypnoides*, *Gnaphalium uliginosum*, *Mollugo verticillata*, and several *Bidens* species. The floristic composition varies from year to year with seed supply and the timing and duration of floods.

**FLORISTIC CHANGES IN UNDRAINED SLOUGHS**

The physiognomy and species composition of undrained sloughs can change dramatically from year to year depending on the history of flooding. The *Boehmeria* variant of the *Boehmeria-Acer* community occupying the upper part of the slough is little affected by summer floods, but during a year with summer floods most species below this zone are killed. Few *Acer saccharinum* seedlings survive. *Arisaema* resprouts but has small leaves and does not flower, and *Pilea* and *Bidens frondosa* seedlings occur as scattered, low plants. If a slough is not flooded for several
summers, *Boehmeria* seedlings become established throughout most of the slough and persist until the following summer flood.

Table II illustrates the changes during 3 consecutive years without summer flooding. The most luxuriant growth of *Pilea pumila* occurs during the first year a slough is not flooded in summer. This can be seen in Table II although the height of *Pilea* was also decreased by its greater density and by the short growth period during 1978 and 1979 when spring floods receded late in the season.

**Discussion**

**THE EFFECT OF RIVER WATER LEVELS ON THE VEGETATION**

The frequency, duration and timing of flooding are the master factors controlling the vegetation pattern in the low flood plain. Elevation above river level is clearly an important factor determining the vegetation pattern of flood plains (Barnes, 1978; Frye & Quinn, 1979), primarily because it is correlated with flooding frequency and duration as well as soil aeration. However, elevation alone does not adequately represent the gradient of site inundation and soil aeration in most flood plains (Robertson et al., 1978; Buchholz, 1981). This also applies to the Connecticut River flood plain.

In interpreting the vegetation pattern of the flood plain, a clear distinction has to be made between sites which drain freely into the Connecticut River and those in which river water becomes entrapped. Water levels in the former fluctuate with the river level, whereas the latter, once flooded, remain inundated for long periods after the flood waters have receded.

In the freely drained parts of the flood plain, the start of the vegetative season depends on the timing of the spring floods. Thus, the development of the ground vegetation is controlled by snow melt in Vermont and New Hampshire rather than by the spring temperatures in Connecticut. This does not apply to trees; *Acer saccharinum* is often in full flower when only the tree crowns are above the flood waters.

In the sloughs and depressions in which flood waters are trapped, the ground vegetation does not develop until water losses by evapotranspiration and percolation lower the water level and expose the soil surface. In these areas the effective vegetative season, at least for the ground vegetation, becomes shorter with increasing water depth.

**ECOLOGICAL RELATIONSHIPS IN THE FREELY DRAINED FLOOD PLAIN**

The freely drained part of the flood plain includes areas adjacent to the river channel as well as areas in the inner flood plain. Here, water levels fluctuate with the river level. Flooding duration increases at lower elevations (Fig. 4) and becomes increasingly important in controlling the floristic composition of the vegetation. Consequently, plant communities occupy increasingly smaller elevation ranges as one approaches mean sea level (MSL) (Fig. 4). Since the effect of flooding on the vegetation adjacent to the river channel differs greatly from the inner flood plain, it is necessary to discuss these areas separately.

**Inner flood plain**

The inner flood plain comprises all areas behind the river levees and away from swift water. Water is usually trapped in the sloughs after flooding, although channels and marshes with open connections to the river do occur. In general, sites in the inner flood plain are flooded by slowly moving water, receive fine textured sediments, and are not subjected to erosion or heavy sedimentation.

<table>
<thead>
<tr>
<th>Year</th>
<th><em>Pilea pumila</em></th>
<th><em>Boehmeria cylindrica</em></th>
<th>Latest date that river level exceeded slough entry level</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Height (cm)</td>
<td>Density (stems/m²)</td>
<td>Height (cm)</td>
</tr>
<tr>
<td>1976</td>
<td>4.9 ± 0.5</td>
<td>6.3 ± 1.2</td>
<td>11.0 ± 1.0</td>
</tr>
<tr>
<td>1977</td>
<td>40.8 ± 2.3</td>
<td>68.8 ± 9.7</td>
<td>21.6 ± 6.8</td>
</tr>
<tr>
<td>1978</td>
<td>31.8 ± 2.0</td>
<td>107.0 ± 14.2</td>
<td>42.8 ± 4.6</td>
</tr>
<tr>
<td>1979</td>
<td>17.0 ± 1.6</td>
<td>103.5 ± 23.2</td>
<td></td>
</tr>
</tbody>
</table>

*Data were collected in the middle of September when the species had reached their maximum height. A stage level of 3.20 m MSL will flood this slough.*
The low-lying parts of the inner flood plain are covered mostly with an *Acer saccharinum* forest. During spring floods these trees can be flooded up to their crowns but during the major part of the vegetative season most of the flood plain is above the river level. The distribution of the plant communities within the inner flood plain and their occurrence with respect to duration of flooding and elevation above MSL is shown in Figures 7 and 4, respectively.

*Acer saccharinum* forests do not occur on the wettest sites. In the detailed study area south of Hartford, sites below 75 cm MSL are occupied by an open marsh vegetation with *Sagittaria latifolia*, *Peltandra virginica* and *Zizania aquatica*. This corresponds to a flooding duration of approximately 340 days/year (Fig. 4). *Leersia oryzae*, *Cyperus striatus*, or *Peltandra virginica* can be dominant in sheltered inlets that are not drained completely at low tide during low river levels, with the *Peltandra* occupying the wettest sites.

The *Boehmeria-Acer* community includes the wettest *Acer saccharinum* forests. It occurs on sites that are still regularly flooded during the summer. Its upper boundary is just below 1.17 m; this corresponds with a flooding duration of 241 days/year.

The *Onoclea-Acer* community occurs above this level and occupies the entire range from about 1.2-5.4 m MSL. Flooding duration varies from 241 days at its lower boundary to about 8 days at its upper level. In essence, this community occupies the part of the inner flood plain that is above the river level from the time the spring floods recede, although it can be flooded occasionally during the summer. The recurrence interval of summer floods varies from 1.1 years at its lower to 11 years at its upper border.

The floristic composition of this community changes with elevation. The low-lying sites are occupied by an impoverished variant with the ground cover completely dominated by *Onoclea sensibilis*. Shrubs and low trees, such as *Fraxinus pennsylvanica* and *Ulmus rubra*, appear in the *Onoclea-Acer* community at higher elevations together with a large number of less flood-tolerant species, e.g. *Cinna arundinacea*, *Geum canadense* and *Chelone glabra* (Table I). These species, including *Onoclea sensibilis*, can grow on soils which are saturated throughout the vegetative season outside the flood plain. Their absence from the lower elevations of the flood plain appears to be associated with their vulnerability to inundation of their foliage during the vegetative season.

*Pteris pennsylvanica* can locally dominate this community on ridges over 3 m MSL. This *Pteris* variant occurs under openings in the *Acer saccharinum* canopy; the increased light intensity appears to be primarily responsible for this change in floristic composition compared to the typical *Onoclea-Acer* community at the same elevation above the river.

Forests similar in floristic composition to those of moist, nutrient-rich uplands occupy sites above the *Onoclea-Acer saccharinum* community. The exact lower boundary of these forests is difficult to determine because the high parts of the flood plain are mostly under cultivation. Therefore, the boundary had to be inferred from small patches of forest left in the flood plain. The lowest level at which these upland *Acer saccharinum-Fraxinus* forests have been found was 5.4 m MSL, and this has been used as the boundary between these types in Fig. 4.

**Areas adjacent to the river**

These include the levees, areas of active deposition such as scroll bars, and steep river banks cut into older deposits. These sites are exposed to fast flowing river water during periods of high flow, and their soils are coarser textured than those in the inner flood plain. Plants growing on these sites have to cope with mechanical damage during flooding, especially at lower elevations, and with erosion and sedimentation. The occurrence of *Populus deltoides* as a regular component of the forest appears to be associated with the better aeration of these soils.

Soils below 1.40 m MSL are occupied by a river bank vegetation. Four zones (Fig. 4) can usually be recognized.

A) A bare zone below 0.5 m which is flooded over 360 days/year.

B) A zone with the *Sagittaria latifolia* community. Its upper level coincides about with the high tide level during periods of low flow.

C) A zone with the *Echinocloa-Panicum* community, a weedy vegetation made up primarily of summer annuals and very variable in composition.

D) A transition zone to the forested flood plain with *Salix nigra* as a shrub or low tree. This occurs as a narrow, interrupted band along the river and separates the herbaceous river bank vegetation from the *Populus deltoides-Acer* community on the levees. It is located above the regular water level fluctuations of the river during the summer, but it takes the brunt of ice damage during spring break-up.

The *Populus-Acer* community occupies the low levees above 1.40 m MSL that are still sub-
jected to strong currents during flooding (Fig. 7). The swift currents and active sedimentation account for the very poorly developed ground vegetation. At about 3.5 m MSL it is replaced by the *Eupatorium-Acer saccharinum* community. Generally, these are steep river banks. Sites with active deposition are occupied by the *Laportea* variant.

Above about 5.4 m MSL these communities are replaced by *Acer saccharum-Fraxinus* forests comparable to those in the inner flood plain.

**ECOLOGICAL RELATIONS IN UNDRAINED SLOUGHS**

Undrained sloughs occur in the inner flood plain. Characteristically, they fill with water when the river level rises above the inflow level of the depression, but they do not drain when the river level falls. Such sites are filled with water at all elevations in the flood plain during spring flooding, and most of them are filled with water all winter long due to fall flooding. Most of these sloughs are narrow enough to be shaded completely by mature *Acer saccharinum* trees growing on the low ridges. Trash and debris carried by the river at flood stage is often trapped in these sloughs. For years after a severe sleet storm in late December 1973, the sloughs were filled with branches.

During a summer without floods, sites gradually become available for colonization. Some sloughs dry out completely while others have deep, permanently flooded parts. The period available for the development of the ground vegetation decreases from the level at which the water is trapped to the permanent water level. This results in 3 distinct vegetation belts (Fig. 7C).

A) The *Onoclea-Acer* community occupying the ridges and occurring to about 3 cm below the level at which the water is trapped in the slough.

B) A belt completely dominated by 75-85 cm high *Boehmeria cylindrica* and occurring to 35-50 cm below the *Onoclea* level. This is the *Boehmeria* variant of the *Boehmeria-Acer* community. It forms a very sharp boundary to both the *Onoclea-Acer* community and the lower part of the slough.

C) The remainder of the slough is occupied by the *Acer saccharinum* seedling community, unless the slough is deep enough to hold water during a summer without flooding. The vegetation here is well-developed and clearly differentiated into an upper part dominated by luxuriantly growing *Pilea pumila* (*Pilea facies*, Table II) and well-developed *Arisaema dracontium*, a central part with abundant *Acer saccharinum* seedlings and scattered *Arisaema dracontium*, and a lower part with exposed mud and scattered annuals.

In the undrained sloughs and depressions, the effects of summer floods can be disastrous. Below the *Boehmeria* belt the foliage rots and the plants have to resprout from seeds or rhizomes. Such events and their timing have a profound effect on the vegetation of the sloughs and of the flood plain as a whole.

Obviously, a summer flood only affects sloughs with inflow levels below its flood stage. Therefore, not all sloughs in the flood plain will have the same flooding history at any one time, and the vegetation patterns of adjacent sloughs with different inflow levels can be strikingly different. This highly dynamic nature of the slough vegetation below the persistent *Boehmeria cylindrica* belt (Table II) shows a temporal and spatial pattern in the flood plain that is difficult to understand without a knowledge of recurrence intervals (Fig. 5) and timing (Fig. 6) of summer floods.

**DISTINCTIVE CHARACTERISTICS OF THE FLOOD PLAIN**

Flood seasons in New England show a clear geographical pattern (Hoyt & Langbein, 1955). Winter flooding is dominant in the southern parts, whereas the northern and eastern parts are characterized by spring floods. However, since the Connecticut River is greatly affected by the snow melt in northern New England, water levels are clearly out-of-phase with those of other rivers in southern New England. As a result, major flooding occurs at a time that the vegetative season is well-advanced. This has two effects:

1) Spring ephemerals, such as *Claytonia virginiana*, *Erythronium americanum*, *Dicentra cucullaria* and *Sanguinaria canadensis*, which are a distinctive part of the vegetation along local rivers, are absent from most of the Connecticut River flood plain. Obviously, this is because in most years the tree canopy is in full foliage by the time the flood waters recede.

2) The boundary between the *Acer saccharinum* forests and the *Fraxinus-Acer saccharinum* forests occurs at a much higher level above the prevailing summer levels along the Connecticut River than in other local rivers. This partly a result of the large water level fluctuations of the river but apparently the duration of the flooding also eliminates species intolerant to flooding outside the dormant season.

Geographical variation in the vegetation is also apparent on different segments of the Connecticut River. South of the study area, for example, the proximity of Long Island Sound reduces the magnitude of the annual floods. Floods of long duration affect a much smaller part of the flood plain and as a result the *Onoclea-Acer saccharinum* com-
munity dominates much of the forested flood plain and extensive tidal marshes occupy low-lying areas. These types of hydrological variation within a river basin can complicate geographical comparisons of the vegetation; the flood season and the position in the basin are important in determining its characteristics.

Conclusions

Flood frequency, flood duration, and the timing of floods clearly control the pattern of plant communities on the flood plain. Water level duration curves and flood recurrence intervals for summer periods, when tied in with elevations on vegetation transects, proved valuable in analyzing the environmental conditions controlling the vegetation pattern. The long period of record of Connecticut River water levels permitted the correlation of long-term water fluctuation patterns with the distribution of plant communities on the flood plain.

Elevation above the summer river level integrates soil aeration and the duration and frequency of flooding. This is clearly reflected in the vegetation. However, this study shows that three other conditions are of critical importance in determining the vegetation pattern of the flood plain: 1) the ponding of flood waters in depressions and sloughs, 2) the sedimentation rate, and 3) the occurrence of summer floods.

The ponding of flood waters is not completely independent of elevation since inflow and outflow levels determine the frequency of flooding. The vegetation pattern of these ponded areas is determined by the water table changes after the river level has dropped below the outflow level. This pattern is highly dynamic with cyclical changes due to summer flooding being much more dramatic than the successional changes.

Differences in sedimentation rate, and the associated texture of the sediment, cause the development of two entirely different toposequences in the freely drained inner flood plain and near the river channel. Tidal fluctuations in this area, although only 30 cm, are clearly reflected in the vegetation, most extensively in shallow, muddy inlets and coves.
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