VEGETATION SUCCESSION ON MID-CHANNEL BARS OF THE FRASER RIVER, BRITISH COLUMBIA

by

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Vegetation succession on mid-channel bars of the Fraser River,

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ABSTRACT

Vegetation succession in a geomorphologically unstable environment has been examined through a field survey of stands on mid-channel bars of the Fraser River in British Columbia. Two successional stages are identified on the basis of stand age and species composition; colonisation and stand development. Analysis of variance and non-parametric statistical tests indicate that during colonisation the age and species composition of stands are associated with the elevation of the bar platform, the frequency and duration of flooding of the bar surface, and the physical characteristics of the surficial deposits. Black cottonwood and species of willow are the most successful colonising species on the bars, and seedlings rapidly develop into a pioneer stand. However, the processes of colonisation may be slowed or set back at any stage by severe flooding.

The processes of stand development are less influenced by environmental conditions, due to the reduced probability of inundation. Analysis suggests that tolerance of shade and species-species interactions are of more significance than substrate characteristics in determining which species attain dominance in the stand canopy, and which species become established in the understory. Black cottonwood is the dominant species in all stands sampled, while in the oldest stands western red cedar approaches co-dominance with cottonwood. The age structure and species composition of developing stands show

that vegetation development is seriously disrupted by episodic severe floods, and small scale logging. Disturbance makes the identification of a successional pathway unrealistic, and means that the rate of successional change cannot be determined.

The magnitude and frequency of disturbance events not only disrupt vegetation succession on the mid-channel bars of the Fraser River, but also reduce the validity of using botanical evidence to infer bar surface age and stability. Comparison of the results of the vegetation survey with aerial photographs indicates that the time lag between initial sediment deposition and successful colonisation is variable. As vegetation development may be set back at any stage by flooding or human disturbance, stand age cannot be used as a reliable indicator of bar surface age, and stand composition must be used with caution to infer bar development subsequent to colonisation.

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CHAPTER 1. INTRODUCTION

1.1. Vegetation Succession

Vegetation succession traditionally has been viewed as a sequential process, whereby plant communities progress to a stable end point, a climax association in equilibrium with the environment. This idea was developed by Clements (1916), who saw vegetation development as similar to the birth, ageing and death of an organism. More recent research on succession has shown that the end point of succession is not a static monoclimax, but is a dynamic equilibrium controlled by fluctuations in the environment, and that the magnitude and frequency of environmental fluctuations determine the nature and rate of successional change.

Where environmental change occurs on a geological timescale vegetation succession may proceed without interruption, and may tend towards a steady state. In environments characterised by frequent, low-intensity fluctuations succession may again be uninterrupted, due to the adaptations of the plant species. However where environmental fluctuations are of intermediate magnitude and frequency they may cause significant disruption to succession.

When pertubations result in changes in the organisation and structure of plant communities they can be considered as disturbance. Disturbance events include landslides, avalanches, hurricanes and floods. They occur on a geomorphological timescale (tens to several thousands of years), and as their frequency of occurrence is often greater than the recovery rate of plant communities, succession may be set back, deflected or slowed.

Most research on vegetation succession has been in geomorphologically stable areas. In unstable areas studies have commonly been in salt marshes, or on sand dunes or talus slopes where activity rates are high. Although the role of disturbance in disrupting succession is realised (Horn, 1976; Harper, 1977; Connell, 1977), field research in disturbed environments is limited.

1.2. Riparian Vegetation Succession

Floodplains are characterised by disturbance events of intermediate magnitude and frequency. Many rivers experience minor floods every year, with more major events occurring less often. The magnitude of flooding varies inversely with the frequency. Although most floods are not of sufficient intensity to destroy an entire plant community, they can damage forest stands seriously. As the longevity of trees on floodplains usually is greater than the timespans between disturbances, stands may preserve a record of flood events.

Early studies of floodplain succession focussed on the role of the river in controlling vegetation dynamics, by supplying sediment, raising elevation, and permitting the establishment of permanent vegetation. Hefley (1937), Harper (1938), and Featherley (1942), worked on the floodplain of the Canadian River in Oklahoma, Shull (1944) studied the vegetation of a river island in the Mississippi River, Wistendahl (1958) examined the Raritan River, New Jersey, and Jeffrey (1964) documented succession on the floodplain of the Lower Liard River, in the Northwest Territories. All these workers make a distinction between the lowest elevation deposits which are frequently mobilised, and support little or no vegetation, and the upper surfaces away from the river, where succession to a predictable community occurs.

Research using quantitative methods for vegetation surveying confirms these descriptions of riparian succession. Bliss and Cantlon (1957) studied vegetation adjacent to the Colville River, Alaska, and showed that successional change is associated with site changes. In the early stages the process is allogenic, but as the river declines in importance due to meander migration, succession becomes autogenic, and tends towards a predictable plant community. Dahlskog (1966) concluded from research on a Lapland mountain delta that no communities are in a static condition, and that none represent a climax. He suggested that succession is allogenic, with stands continually evolving according to channel activity. Gill (1972) examined the floristics of plant succession on the MacKenzie River delta, where succession in the early seres is allogenically controlled by sedimentation and flooding. Autogenic influences increase as a climax community evolves, at which stage biotic controls dominate.

In a study of vegetation succession and river terrace development in Olympic National Park, Washington, Fonda (1975) identified sequential forest communities and associated ages of land surfaces. He demonstrated that there is a strong correlation among zonation patterns, forest succession, the age of terraces, soil moisture and soil profile development.

Major vegetation changes of riparian succession on the Beatton River floodplain, British Columbia, were studied by Nanson and Beach (1975), and were shown to be either direct or indirect responses to sedimentation in the early stages of vegetation establishment. Similar results are reported by Johnson et. al. (1976) from research on the Missouri River floodplain. They emphasise the importance of the river in regulating the dynamics of the regional forest system. The meandering pattern of the river controls the vertical and horizontal distribution of the communities of the floodplain, while the rate of meandering determines stand types.

The results of these studies show that the influence of the river is most important in the early stages of succession, with sedimentation as the driving force which raises floodplain surfaces sufficiently above river levels for the establishment of vegetation. Changes in species composition, diversity and productivity occur on higher surfaces, in response to altered soil nutrient status, moisture availability and soil depth. The change from allogenic to autogenic succession, with communities developing to a stable state in the absence of further disturbance by the river, is confirmed by this research.

Several recent studies have demonstrated that plant species distributions vary with flood frequency and height above a stream. These include research by Yanosky (1982), on the floodplain of the Potomac River, and by Osterkamp and Hupp (1984), on northern Virginian streams. McBride and Strachan (1984) have examined establishment and survival of woody riparian species on gravel bars of an intermittent stream in California. Their study focusses on the role of fluvial geomorphic processes in creating and destroying habitats, and identifies the various factors of the gravel bar environment which influence establishment and survival.

The ecological effects of inundation have received little attention, except in relation to the tolerance of individual species. Brink (1954) examined differential killing of species following the 1948 flood of the Fraser River, British Columbia, Lees (1960) looked at the tolerance of white spruce seedlings to flooding, Lindsey et al. (op.cit.) used submergence experiments to investigate species tolerance, and Teversham (1973) studied vegetation response to fluvial activity on the Lillooet River in British Columbia (Teversham and Slaymaker, 1976). Barnes (1985) examined the population dynamics of woody plants on a river island in the Chippewa River, Wisconsin. He stresses the role of disturbance in limiting species establishment on the island. Van Cleeve and Viereck (1981) recognise the potential influence of flooding in disrupting riparian succession. Their research on floodplains in Alaska shows that at any point in time, depending on the severity of the disturbance, flooding may act to set back the system to an earlier stage in succession.

The lack of emphasis on vegetation response to severe flooding may be because most studies have been on the relatively stable floodplains of meandering rivers. In these environments, the floodplain is stabilised as a result of meander migration, and succession continues without interruption for long periods. The effects of disturbance by flooding on succession have not been studied on the mid-channel bars of a river characterised by multiple shifting channels. The high rates of geomorphic activity in such river channels may disrupt succession, and result in significantly different successional patterns and rates of change than those observed on meandering river floodplains.

1.3. Dendrochronology as Evidence of Floodplain Processes

It is difficult to find reliable information sources with which to reconstruct the history of a landform in a geomorphologically unstable environment such as a floodplain. This is because significant change occurs on a timescale longer than a human lifetime, and longer than many documentary records.

Information on the nature and rate of succession on mid-channel bars of an unstable channel can be used as evidence of bar development and stability, because the lifespans of trees on a floodplain are usually longer than the intervals between floods. The patchy, even-aged nature of many forest stands shows that they preserve a record of episodic disturbance. When long lived woody species are found in a geomorphologically unstable environment they provide one of the best lines of evidence available for the reconstruction of paleaoenvironments on a timescale between several decades and several hundred years (Church, 1980).

Interpretation relies on the analysis of annual tree rings (Fritts, 1976), as the age of the largest tree on a surface may provide an indication of the age of deposits (Hickin and Nanson, 1975), and of surface stability. Dendrochronology has been used in several historical studies on floodplains. Everitt (1968) constructed a model describing channel migration and sediment transport on the floodplain of the Missouri River, using ring counts in cottonwoods. The character of channel migration on the Beatton River in northeast British Columbia was studied by Hickin and Nanson (op. cit.), through a field survey of surface morphology and forest age structure on selected point bar complexes. Rates of incision and lateral migration were measured, based on dendrochronological surveys, and the ages of trees were used as indicators of surface age. The time lag between deposition and colonisation was assumed to be small and relatively constant.

The analysis of tree rings also has been used in hydrological research to provide historic flood information (Helley and LaMarche, 1973), and is particularly valuable in ungauged watersheds (Laing and Stockton, 1976). Sigafoos (1964) has shown that regenerating stems, and adventitious roots put out in response to sudden heavy siltation can be dated, and provide a chronolgy of flood events. Similarly counting the number of rings formed subsequent to scarring by flood abrasion is a valuable dating method (Sigafoos, op. cit.).

1.4. Objectives

The primary objective of this study is to examine vegetation succession on the mid-channel bars of an unstable river by undertaking a field study of the associations between the composition and age of the stands on the bars, the elevation of the bar platforms, the frequency and duration of flooding of the bar surfaces, and the physical and chemical characteristics of the surficial deposits. The relative importance of the environmental factors as controls of stand composition will be examined by means of analysis of variance, and non-parametric statistical tests. The influence of variable bar stability on the nature and rate of successional change will be assessed.

A secondary objective of this study is to determine the reliablility of botanical evidence in inferring the age and stability of mid-channel bar deposits, by comparing the results of the vegetation surveys with independent documentary evidence.

1.5. Study Area

The unstable reach of the Fraser River between Hope and the mouth of the Sumas River forms the study area (Figure 1). The river flows in a broad valley of late glacial and post glacial origin, which is up to 5 kilometres wide (Plate 1). The steep sided valley forms the boundary between the Coast Mountains to the north, and the Cascades to the south.

The Coast mountains primarily are composed of intrusive dioritic and metamorphic rocks, while the local Cascade mountains consist of sedimentary rocks of Upper Cretaceous and Tertiary ages, metamorphic rocks, and granitic batholiths, and are geologically complex. The valley floor is underlain mostly by Quaternary unconsolidated deposits, with occasional bedrock protrusions, such as Sumas mountain. Holocene floodplain deposits range from gravel/sand to the east, and sand interbedded with sand and silty loam to the west (Armstrong, 1984). Fine sediment is derived from the basin north of Lytton, 100 km upstream of Hope, while much of the coarse bedload is of local provenance.

Above Yale the Fraser River flows in a deep canyon. It flows in a relatively straight constricted channel from Yale to Hope, downstream of which the river widens, and flows in several

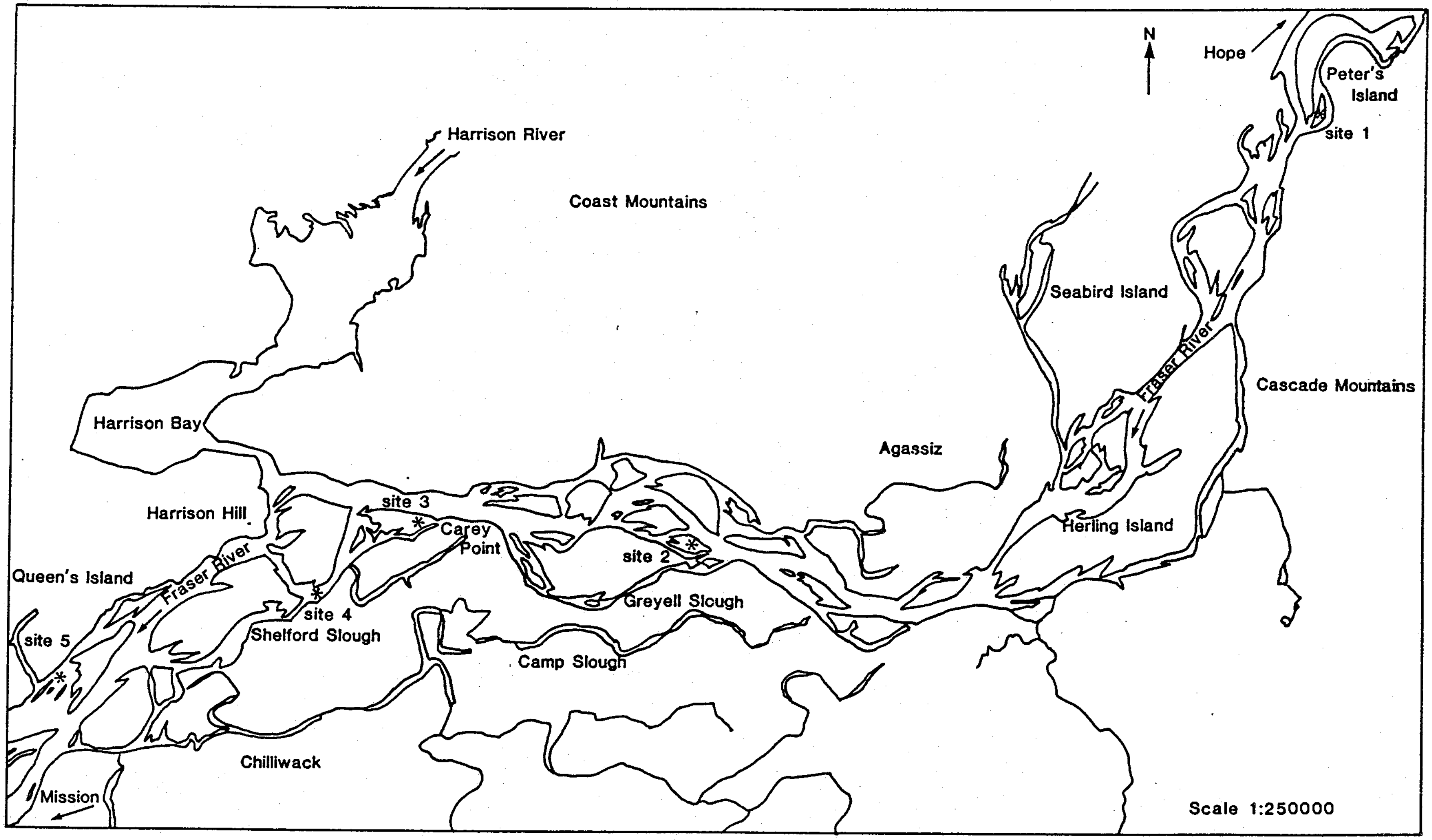


Figure 1. The study area.

Plate 1

The Study Area from Sumas Mountain

View to the North East

channels. The reason for the change in planform is the increase in valley width, and a decrease in slope. The river suddenly loses the capacity to transport the sediment which it has carried at high velocity through the canyon, so it stores it in an alluvial fill, the surface of which is characterised by multiple channels winding around storage bars (Plate 2). Further downstream this adjustment is nearly completed, and a single channel is reestablished. The variation in stability and form of the channel preclude classification, and it is referred to as unstable for the purposes of this study.

The mid-channel bars represent the most dynamic feature of this reach of the Fraser River. They range in length from tens to several hundreds of metres and corresponding with this variation in size is a range in stability. Some of the smaller bars are transient bedforms, while larger bars are relatively permanent features of the channel. The bars are typical of large gravel bed rivers (Kellerhals et al., 1976), and show characteristic downstream fining and fining-upward sequences (Bluck, 1982). They present a range of depositional and erosional environments, as they form both sediment stores and resistance elements in the channel (Church and Jones, 1982). They are compound features which have resulted from alternating periods of mobilization and sedimentation in sporadic high flows.

The nature of the flow regime of the Fraser River is apparent from the records of annual extremes of discharge at

Plate 2

Mid-Channel bars from Harrison Knoll

showing cottonwood and cedar stands

Hope (Figure 2). Discharges in excess of 10 000 m^3s^{-1} occur on average every five years. The seasonal nature of the river's flow is also very marked (Figure 3). Highest flows occur during spring snowmelt between May and July, with eighty percent of the sediment load of the river being carried at this time (Milliman, 1980). The average annual mean flow of the Fraser River at Hope is 2700 m^3s^{-1}. Several mountain rivers and creeks join the Fraser River between Hope and Mission, and add between fifteen and twenty percent to this annual mean flow. Material carried by the tributaries is coarser than the bedload of the Fraser River, and they contribute a significant input of sediment.

Vegetation on the mid-channel bars of the Fraser River shows a range of sizes and ages (Plate 2). The larger bars are densely forested, while new gravel surfaces are often sparsely colonised by young seedlings. Black cottonwood(*Populus trichocarpa* Torrey and Gray) is the most abundant species on the bars.

Smith (1957) examined site quality for black cottonwood growth on the mid-channel bars of the Fraser River, in the area of Chilliwack. He identified three site classes, ranging from good to poor, on the basis of understory vegetation, and related site indices to elevation. He did not study succession on the bars, stating that (p. 579)

"It would take a long and detailed ecological study to describe accurately the plant succession on alluvial soils such as those of the Chilliwack islands."

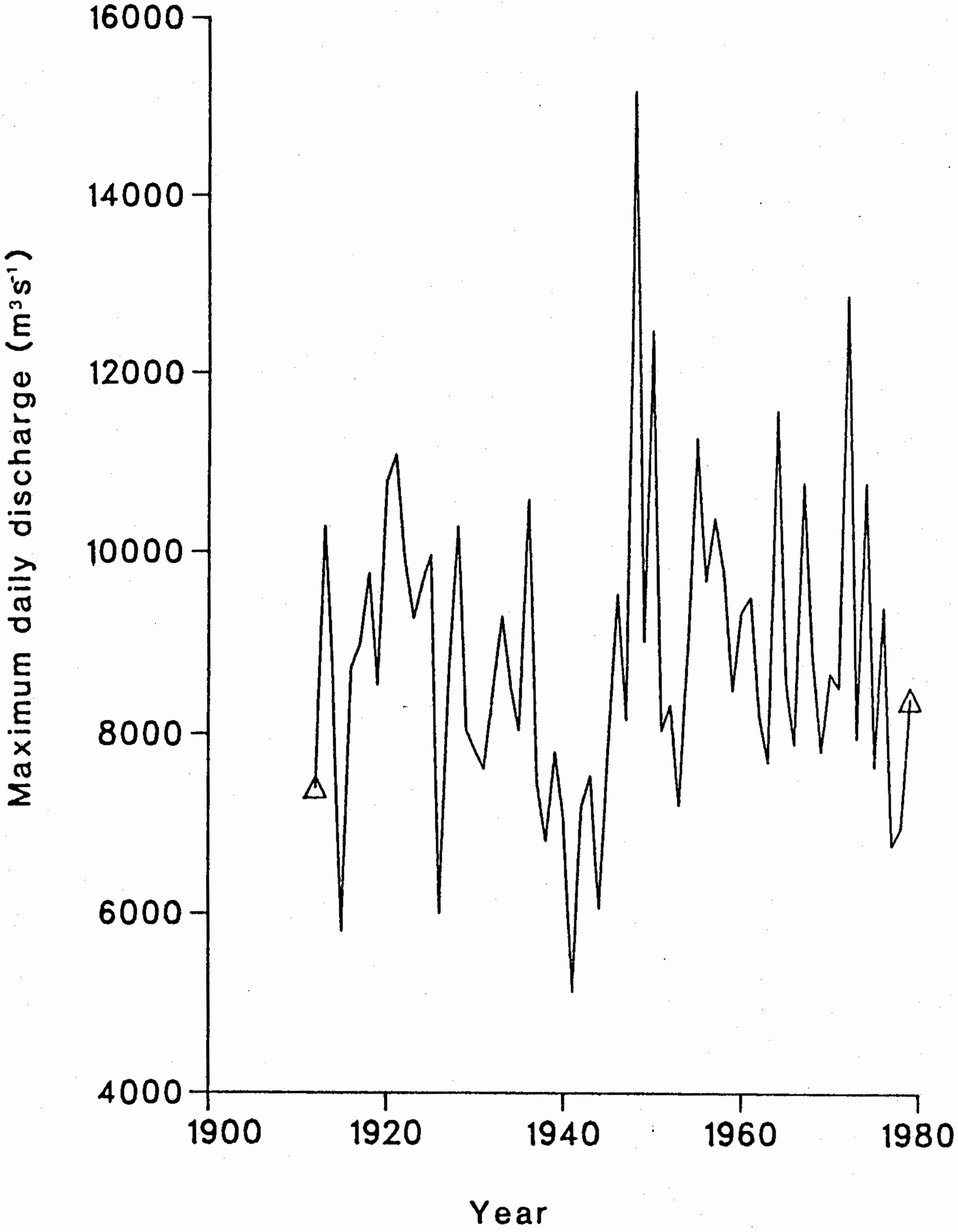


Figure 2. Annual maximum extremes of discharge,

Fraser River at Hope. (source: Environment Canada)

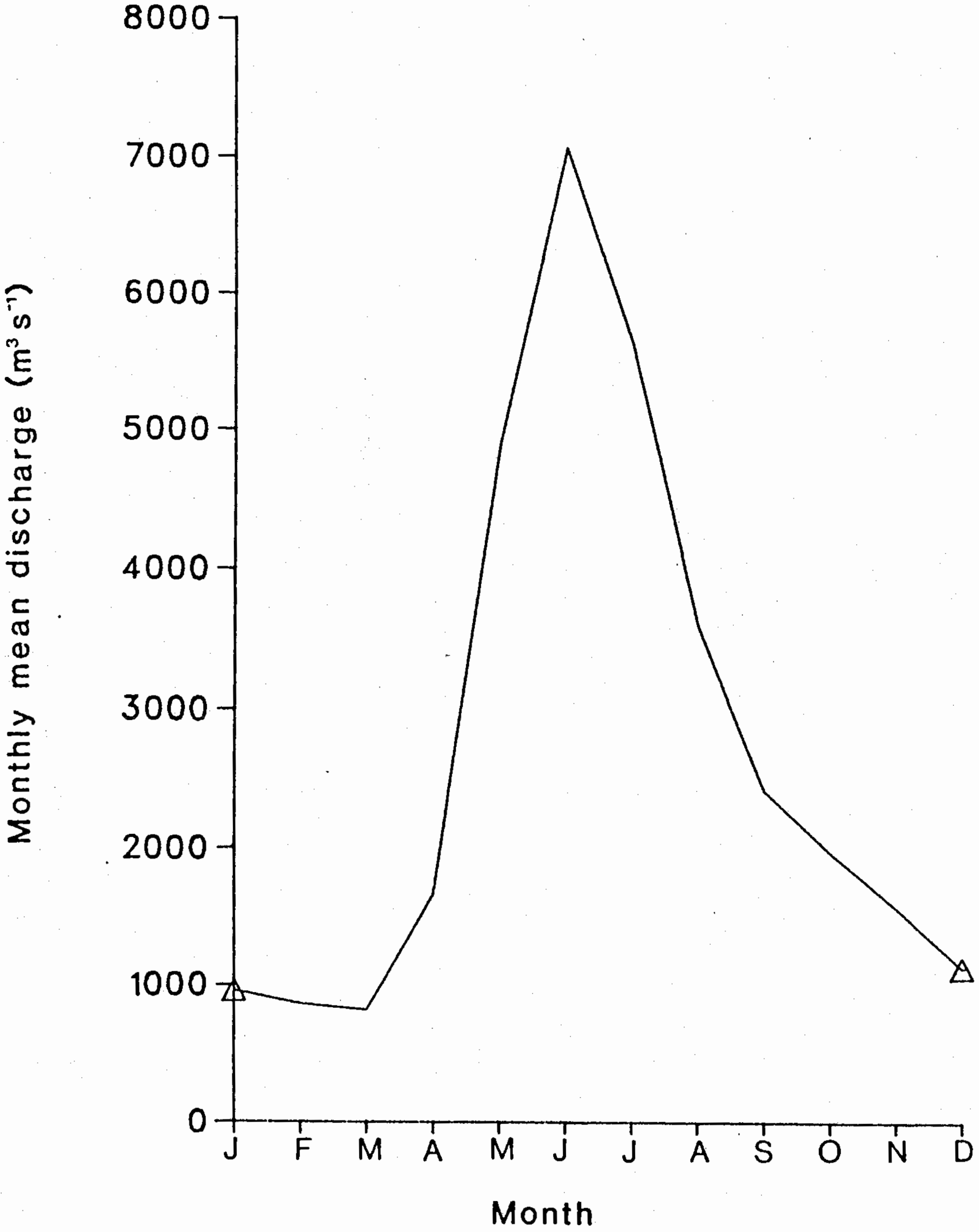


Figure 3. Monthly mean discharge, Fraser River at Hope. (source: Environment Canada)

The potential of the bars for good cottonwood growth has been realised by Scott Paper Co. Ltd., who have a tree felling license throughout the study area, and have been logging cottonwood in the area since 1950. In some instances new cottonwoods have been planted, while in others cottonwood regeneration through clonal growth has been permitted. Cedar is not currently being logged on the bars. Human disturbance on unlogged bars does not appear to be extensive. However, as much of the floodplain has been cleared and settled, timber also may have been cut from any accessible bars at some time. Several of the larger mid-channel bars such as Peter's Island and Herling Island (Figure 1) have been cleared and are farmed.

A large part of the reach downstream from Agassiz has been dyked, to prevent inundation of the lowlying farmland by catastrophic floods. Locally, dyking may have constrained the movement of the river channel, but the mid-channel bars remain undyked.

CHAPTER 2. METHODS

2.1 Vegetation Succession

2.1.(a) Sampling

Study sites were defined along the unstable reach of the Fraser River to sample longitudinal variations in channel stability and sediment texture. It is apparent from the channel planform that stability increases in a downstream direction. The transition from sand-gravel to sand-silt/loam floodplain deposits suggests that sediment fines in a downstream direction, but apparently there is little variation in channel sediment size throughout the study reach (D. McLean, pers. comm., 1984).

Mid-channel bars were chosen to represent a range of sizes and stabilities, and a variety of stand ages, from seedlings to mature trees (Plates 2 to 5). All sites were easily accessible, and apparently undisturbed by human activities. The sampling locales were Peter's Island, Greyell Slough, Carey Point, Dyke Road and Queen's Island (Figure 1).

Spatially homogeneous vegetation units were identified to form the basis for the study of succession. Pioneer vegetation was subdivided according to observations of seedling size, while forest stands were classified using the 1979 aerial photographs, and field observation. The structural vegetation classes (which

Plate 3

Scattered seedlings on gravel, Carey Point

Plate 4

Cottonwood and willow stand, Carey Point

The age of the saplings is 3 years

Plate 5

Cottonwood stand - Ferry Island

Approximate cottonwood age is 30 years

were assumed to correspond with successional stages) are:

1. Scattered seedlings (Plate 3)
2. Stands of cottonwood and willow seedlings
3. Stands of cottonwood and willow saplings (Plate 4)
4. Cottonwood stands (Plate 5)
5. Mixed stands
6. Cedar stands (Plate 2)

Several stands representing classes 1 to 4 were sampled, but due to human disturbance on the larger, older bars it was difficult to find sites suitable for sampling the upper two classes. Only one undisturbed site from each class was located.

2.1. (b) Stand composition

Vertical strata within the stand were defined as follows:

(i) Trees

(ii) Pioneer and understory vegetation

Strata were sampled separately, so that the sample size and procedure were appropriate to the vegetation type. Random samples were drawn from each of the vegetation classes. Sample size was based on the number of replicates required to provide a representative description of each class. Identification and taxonomic nomenclature follows Hitchcock and Cronquist (1973).

(i) Trees

Trees were sampled using the point centred, quarter plotless method of Cottam and Curtis (1956). The technique is based on an estimate of density and species abundance using plant to plant distances, and a measure of the area covered by each species. Each sampling point was considered to be the centre of four quarters, and the closest tree to the point in each of the four quarters was sampled. Distance to the tree was measured, and the species and circumference at breast height were recorded (Appendix I).

The data were analysed to give mean area per tree, mean density per hectare, mean basal area, and mean basal area per hectare for the stand (Table 1), together with the relative density, the number of trees per hectare, mean basal area, relative dominance and mean basal area per hectare for each species (Table 2).

(ii) Pioneer and understory vegetation

To obtain a quantitative description of species occuring at the random locations their presence and abundance within a quadrat was assessed. (Appendix II). Abundance was recorded on the basis of a visual estimate of percent cover.

Three strata were sampled. Percent cover of shrubs was estimated within a 2 m^2 square quadrat, while percent cover of

Table 1.

The Point Quarter Data Analysis

SPECIES	RELATIVE DENSITY(%)	TREES/Ha	MBA (cm^2)	RELATIVE DOMINANCE (%)	MBA/Ha (cm^2)
Site 1. Peter's Island					
Cottonwood	97.5	689	189	98.3	129951
Red alder	2.5	18	127	1.7	2248
Site 2. Greyell Slough, stand 3					
Cottonwood	40	537	893	77.5	479893
Red alder	40	537	23	2.0	12269
Cedar	15	201	415	13.5	83677
Hemlock	5	67	645	7.0	43322
stand 4					
Cottonwood	40	706	559	49	394857
Red alder	42	750	40	4	30053
Cedar	15	265	1422	47	376594
Willow	2.5	44	18	0.1	790
Site 3. Carey Point, stand 4					
Cottonwood	100	2822	165	100	465401
stand 5					
Cottonwood	100	2342	70	100	163067
Site 5. Queen's Island, stand 4					
Cottonwood	75	2893	179	93	519262
Red alder	25	964	39	7	37515
stand 5					
				7	
Cottonwood	30	1213	152	77	185351
Red alder	50	2022	23	19	46422
Willow	20	809	10	4	8448

Table 2.

Stand Density and Mean Basal Area/hectare, a Summary of the Point Quarter Data Analysis

SITE (stand)		MEAN AREA /TREE(m^2)	MEAN DENSITY /Ha(trees)	MBA (m^2)	MBA/Ha (m^2)
Peter's Island	(4)	14	706	1.87	1322
Greyell Slough	(3)	7.4	1344	4.61	6191
	(4)	5.6	1765	4.54	8022
Carey Point	(4)	3.5	2822	1.65	4654
	(5)	4.3	2343	0.70	1630
Queen's Island	(4)	2.6	3858	1.44	5567
	(5)	2.5	4044	0.59	2402

low shrubs and herbs was recorded within a 1 m^2 quadrat. The percent cover of Bryophytes was also noted. Ten samples usually provided sufficient replication due to the homogeneous nature of the vegetation.

2.1 (c) Environmental variables

The environmental variables pertinent to this study were collated from documentary sources, and from the field survey.

(i) Elevation

Large scale maps were used to determine site elevations (Table 3). The Barnston Island to Yale map project (1952) and the Fraser Valley Project (1958) were used together with recent survey data provided by D. McLean (pers. comm., 1984).

(ii) Flood frequency and duration

Logarithmic plots of the stage-discharge relationship for the study sites were drawn on the basis of a high and low water longitudinal profile of the reach downstream from Agassiz to Queen's Island (D. McLean, pers. comm., 1984), and rating curves from the gauging stations at Hope, Agassiz and Mission (Appendix IIIa). The stand elevations were plotted on a long profile of

Table 3.

Stand Surface Elevation

SITE	STAND	VEGETATION	ELEVATION (masl)
Peter's Island	4	cottonwood	(approximately 24.0)
Greyell Slough	1	cottonwood	14.5
	2	willow and cottonwood	14.0
	3	cottonwood and cedar	15.0
	4	cottonwood and cedar	15.0
Dyke Road	1	cottonwood	9.0
	2	cottonwood	10.0
	3	willow	9.5
Carey Point	1	cottonwood	10.6
	2	cotonwood	10.0
	3	willow	9.8
	4	cottonwood	11.3
	5	cottonwood	11.9
Queen's Island	1	cottonwood	7.0
	2	cottonwood	7.2
	3	willow and cottonwood	8.8
	4	cottonwood	7.8

the study reach (Figure 4), and the discharges required to submerge bar surfaces were determined from the derived stage-discharge relationships (Table 4). The recurrence intervals of these discharges were obtained from a flood frequency curve for Agassiz (Appendix IIIb), and the duration of submergence was determined using average daily discharge data for the period of record (1967 to 1983) from the gauging station at Agassiz (Environment Canada, 1982) (Appendix IIIb) (Table 4).

(iii) Physical characteristics of the substrate

Sediment texture was classified by feel. It was recorded as gravel, sand-gravel, sand or silt. Sediment depth to a gravel layer was recorded using a screw auger. The auger limited measurements of sediment depth to 1 metre, although sections in cut banks were also measured when present. The depth of surficial organic layers was recorded (Appendix II).

(iv) Chemical characteristics of the substrate

Soil pH was sampled within the forest stands (classes 4 to 6), as these were the only sites where any soil development occurred. Two surface soil samples were collected from each stand, and were analysed separately using the electromagnetic glass electrode method (Chapman and Pratt, 1961) with a soil to

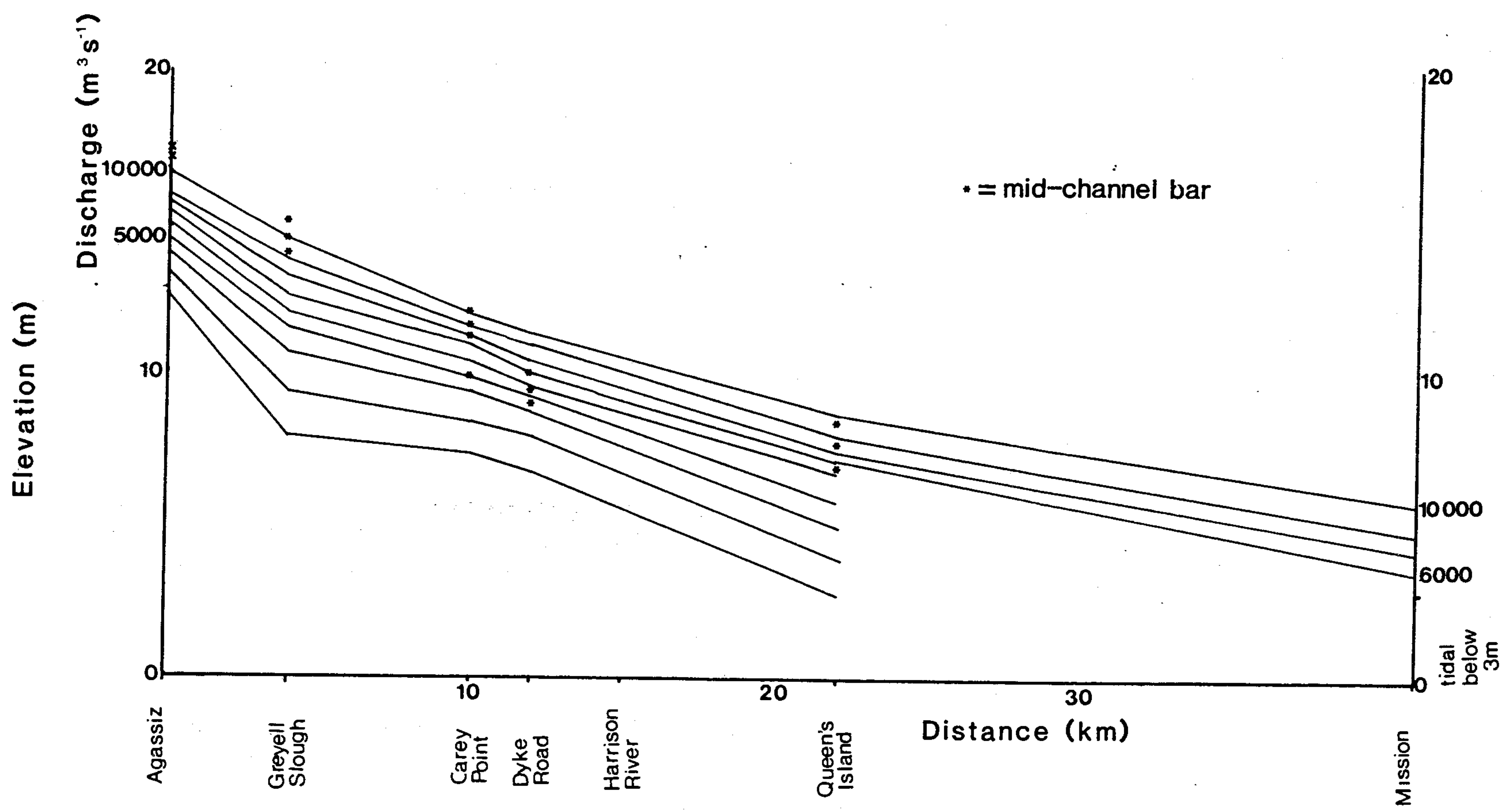


Figure 4. Long profile of the study reach

Table 4.

Flood Frequency and Duration for Stands

SITE	STAND INTERVAL	DISCHARGE (m^3s^{-1})	RECURRENCE (yrs)	DURATION (days)
Greyell Slough	1	9500-10500	3-5	3-5
	2	8000-9000	3-4	10-15
	3/4	11000-12000	5-15	
Carey Point	1	3500-4500	1	90-100
	3	6500-7500	1	30-35
	4	7500-8500	3-5	5-15
	5	9500-10500	4-5	3-5
Dyke Road	1	3000-4000	1	105-115
	2	5500-6500	1	75-90
	3	4000-5000	1	35-50
Queen's Island	2	5000-6000	1	55-65
	3	7000-80000	1-3	20-30
	4/5	8500-9500	3-5	5-10

water ratio of 1:2.5 (Table 5).

2.1. (d). Stand age

The ages of stands at the sample sites were determined using dendrochronology to indicate the rate of successional change, and to provide information on bar stability. The approximate age of a temperate forest tree can be established by counting the annual growth rings at the base of the stem (Fritts, 1976). The rings of diffuse porous species (which include black cottonwood) may be difficult to interpret from cores, and for this reason discs were cut from cottonwoods where possible (Appendix IV).

The age of the largest tree within a stand was taken as indicative of stand age (Table 6), and independent documentary evidence was used to test this assumption. The largest cottonwoods were not sampled, because they are too large to cut down, and because the bars are private land. Their age was inferred from an age-size relationship determined from available samples (Figure 5). There is no evidence of a decreasing growth rate as decadence approaches, and the straight line relationship is assumed to be accurate. This assumption is supported by Thomas and Podmore (1965) who dated cottonwoods up to 180 years old in the Fraser Valley.

The rings in gymnosperms are easier to interpret than those of cottonwood, and tree cores were taken from cedar using an

Table 5.

Soil pH Analysis

SITE	STAND	pH	SOIL TEXTURE
Peter's Island	4	6.6 6.6	sand/silt
Greyell Slough	3 4	6.3 6.2	organic matter
Carey Point	4	6.5 6.5	sand/silt
Queen's Island	4	6.8	sand/silt

Table 6.

Forest Stand Ages

SITE (stand)		SPECIES	CIRCUMFERENCE (m)	AGE (years)	STAND AGE (years)
Peter's Island	(4)	cottonwood	0.80	20	20
Greyell Slough	(3)	cottonwood	2.40	55	
		cedar	1.65	42	55
	(4)	cottonwood	1.25	31	
		cedar	2.00	55	55
Carey point	(4)	cottonwood	.90	22	22
	(5)	cottonwood	.70	18	18
Queen's Island	(4)	cottonwood	1.70	42	42
	(5)	cottonwood	.85	20	20

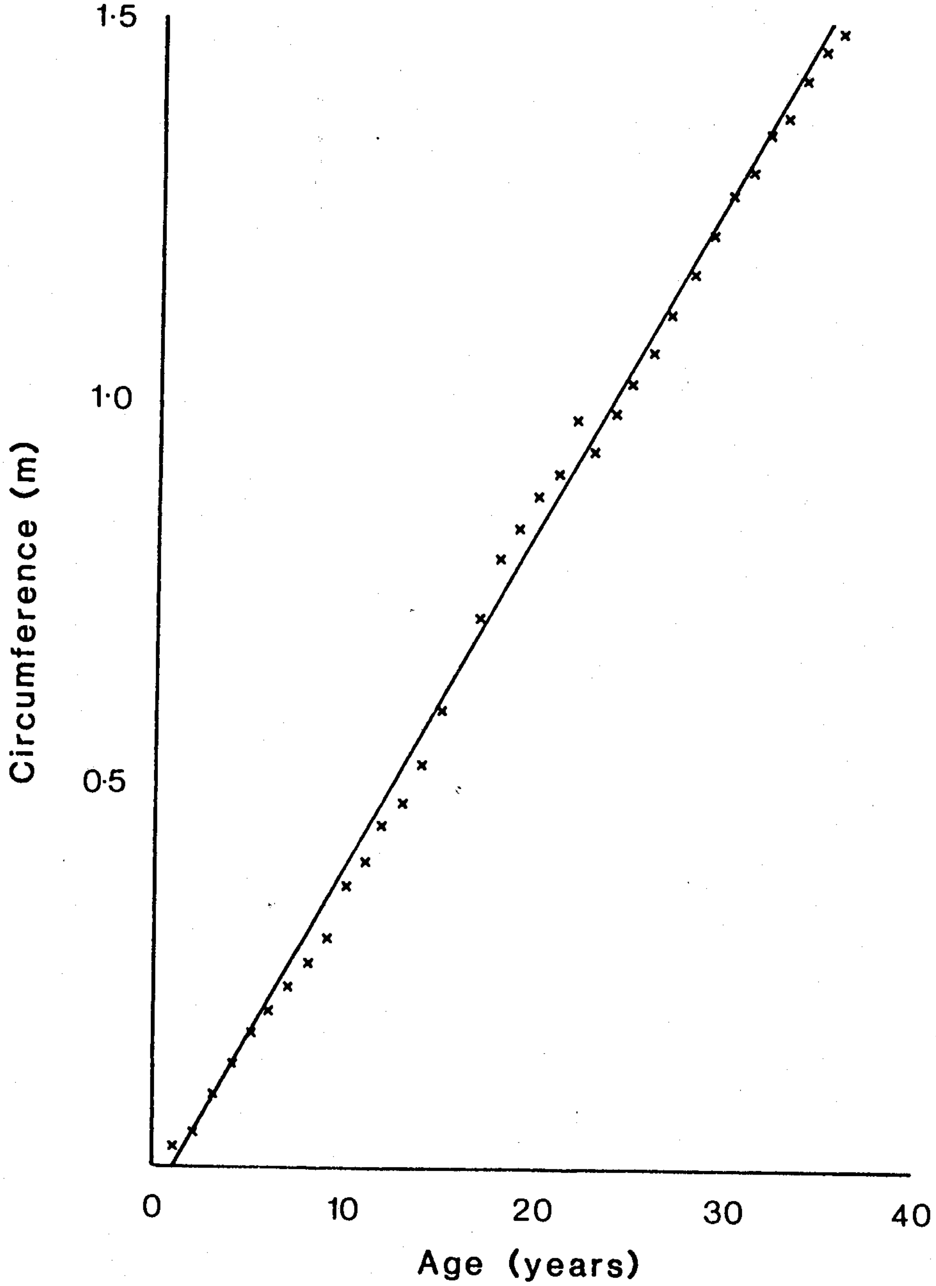


Figure 5. Age-size relationship for black cottonwood.

increment borer. The largest trees could not be dated due to heart rot but a minimum age was obtained (Appendix IV).

2.1. (e). Statistical analysis

The vegetation was subdivided into two classes on the basis of stand age and plant height. Pioneer vegetation was defined as those species sampled in the first three structural vegetation classes. Understory vegetation, for the purposes of this analysis, was defined as those species on the floor in the mature stands. Only those species with a percentage of occurrence greater than five percent throughout the sample quadrats are used in the analyses of plant-environment relations (Appendix V). These analyses aimed to assess the influence of substrate conditions, and vegetation class on species presence and abundance.

(i) Chi-square test

To examine the interrelationships among pioneer and understory species presence and the physical character of the substrate a chi-square test was used. Multiway frequency tables for presence of pioneer and understory vegetation were constructed, with three levels of the following variables: sediment texture, sediment depth and vegetation class for pioneer species; silt depth, organic matter depth and vegetation class for understory vegetation (Appendix VIa). The frequency tables were analysed by fitting log-linear models to cell frequencies (Dixon, 1983). The Pearson goodness-of-fit chi-square statistic, and the liklihood ratio statistic were used to test the goodness-of-fit of a log-linear model to a multiway frequency table. The test enables the identification of significant interactive effects on species presence.

(ii) Analysis of variance

To examine interactive environmental effects on plant species abundance a two-factor analysis of variance was employed. The factors in this analysis are sediment texture, sediment depth and vegetation class for pioneer species, and silt depth, organic matter depth and vegetation class for understory species.

The levels of the environmental factors used in the chi-square tests could not be used in this phase of the analysis due to structural zeros, and the low frequency of species within the cells. This is attributed to the sparse vegetation cover in the pioneer vegetation classes, and the small number of samples in the upper two classes. Instead two levels of all factors were defined (Appendix VIb).

The frequency distributions of species abundance are strongly positively skewed, and only the most abundant are used in the analysis of variance (Appendix V). These are Populus trichocarpa, Salix (L.) sp., Equisetum hyemale (L.) and species of Bryophytes in pioneer stands, and Populus trichocarpa, Alnus rubra (Bong), Equisetum hyemale, and species of Bryophytes, in the understory. Examination of the data shows no gross heterogeneity of variance for the selected species and the test was carried out without any transformation of the data.

2.2 Botanical Evidence of Mid-channel Bar Age and Stability

The reliability of botanical evidence for assessing mid-channel bar stability and bar surface age was tested using documentary evidence. Mid-channel bars were chosen from each sampling locale to encompass a range of bar sizes, stabilities and bar surface ages. Stand ages were determined from dendrochronological dating of the largest tree, and were used to assign minimum surface ages to the bars. Where both black cottonwood and western red cedar were present in a stand, the age of the largest tree of either species was used to ascibe a minimum age to the bar surface.

A series of aerial photographs subsequent to 1928 was used to prepare historical maps of the sites. From these the first trace of sediment deposition at a site, the first appearance of vegetation, and the time of successful stand establishment were determined. The time lag for the establishment of pioneer vegetation on a new mid-channel bar surface was derived. Actual surface age was compared with the estimates of surface age made using dendrochronological evidence, and the validity of the technique was assessed.

CHAPTER 3. DETAILED SITE DESCRIPTION

The stands at each of the sampling locales are described from field data, using figures and tables to show stand elevation (Figure 4 and Table 3), the frequency and duration of inundation (Table 4), stand age (Table 6), stand mean basal area and density (Table 2), and the pH of the substrate (Table 5). Maps of each site describe the location of stands on the bars.

3.1. Peter's Island

The mid-channel bars in the vicinity of Peter's Island form the upstream limit of the sampling area (Figure 1). This is the first deposition zone in the river below Hope, marking the beginning of the unstable reach. Sampling was carried out on a small bar close to the south bank, and vegetation classes from scattered seedlings to a mature cottonwood stand were sampled. No cedar was found although it is well established on the neighbouring floodplain. The exact elevation of these stands is undetermined. Figure 6 shows the stand locations on the bar.

(i) Stands 1 and 2

The tail of the bar is mostly bare sand, with scattered cottonwood seedlings (age 1), and some Juncus vaseyii (Engelm.) and Equisetum hyemale (L.) are colonising the deposits. The stands are probably inundated annually because of their low

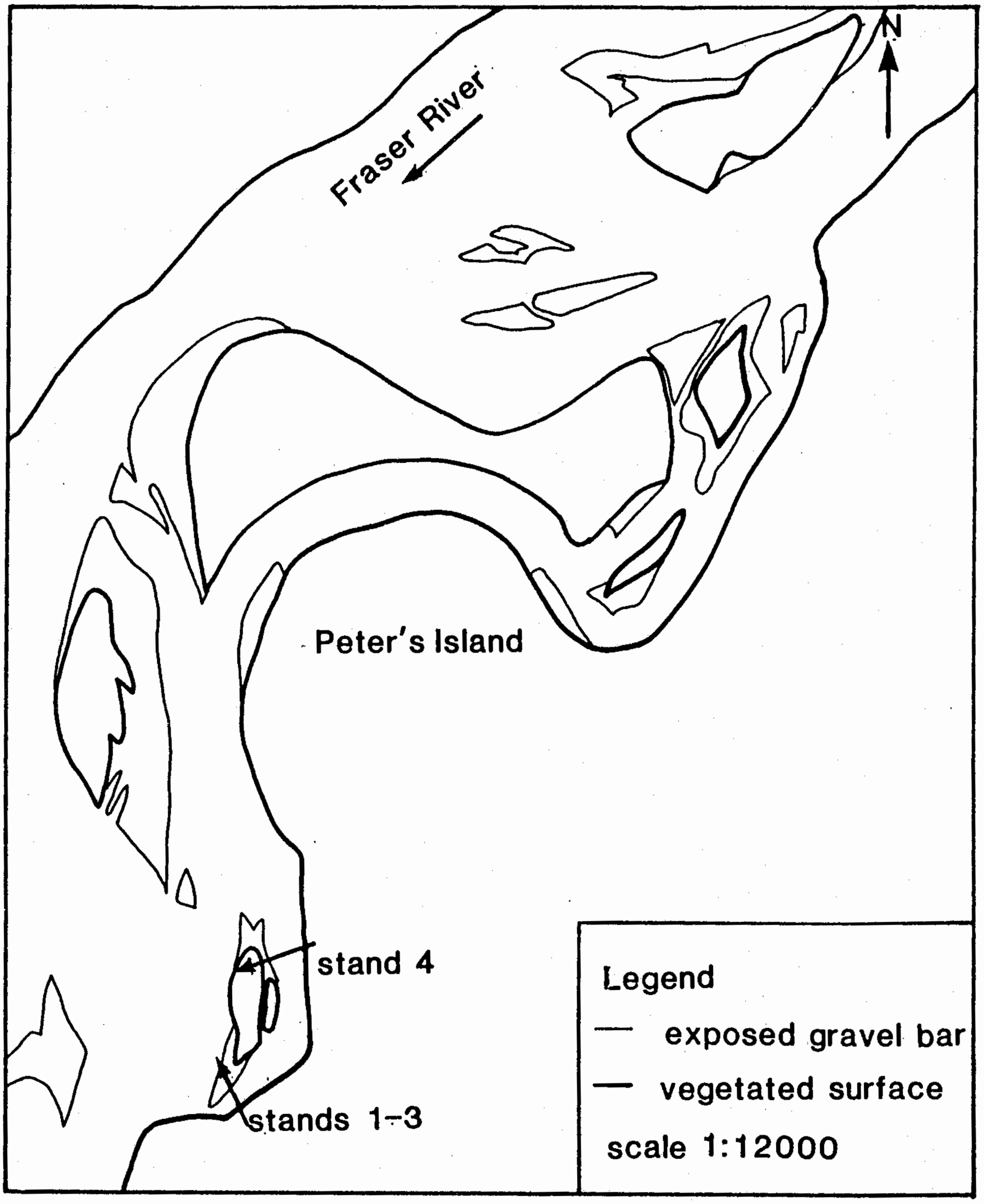


Figure 6. Stand locations at Peter's Island.

source: 1979 aerial photographs

relative elevation.

(ii) Stand 3

On the sandy ridge on the south side of the bar black cottonwood and species of willow are established, and a progression in seedling height from 0.5 m to 3 m is evident as substrate elevation increases. Seedling age varies from 1 to 3 years, and herbs and grasses such as Melilotus alba (Lam.) and Aster conspicuus (Lindl.) are growing beneath the seedlings. Surface elevation is up to 0.5 m higher than that of stands 1 and 2, but the site probably is still submerged each year.

(iii) Stand 4

An even-aged cottonwood stand occupies the major part of the bar. The age of the largest trees is 20 years. Black cottonwood is the dominant species, but some red alder was also recorded in the canopy, and seedlings of cedar, hemlock and red alder are present on the forest floor. There is no organic matter, although 0.1 to 0.3 m of silt overlie sand, and the high pH reflects the lack of soil development. The presence of cedar in the understory is evidence of the dispersability of cedar seed from mature trees on the Peter's Island Indian Reserve. Mean density per hectare in this stand is particularly low, possibly due to flood damage. Up to one metre of sand burying understory vegetation, and the bases of the stems of cottonwood trees at the bar head is evidence of this disturbance. The 1:25000 topographic map sheet shows that the stand is relatively low lying and is therefore inundated annually.

3.2. Greyell Slough

Several bars have formed at the head of Greyell Slough, as this is an area where the channel changes direction and widens (Figure 1). Pioneer vegetation was sampled on a small bar (Figure 7), at both the head (vegetation class 2), and the tail (class 3). Many of the cottonwood stands in this area have been logged. A cottonwood stand with some cedar (class 5) and a mixed stand with mature cedar (class 6) were sampled on an undisturbed bar (Figure 7).

(i) Stand 1

Vegetation is established on the gravel platform at the head of the bar. Black cottonwood (age 3 years) and species of willow have colonised this area with willows growing on the finer deposits. Herbs such as Solidago canadensis (L.), Melilotus alba and Crepis capillaris (L. Wallr.) survive beneath the seedlings. The lowest elevations of the bar margins are bare of vegetation, and the effects of inundation are shown by dead

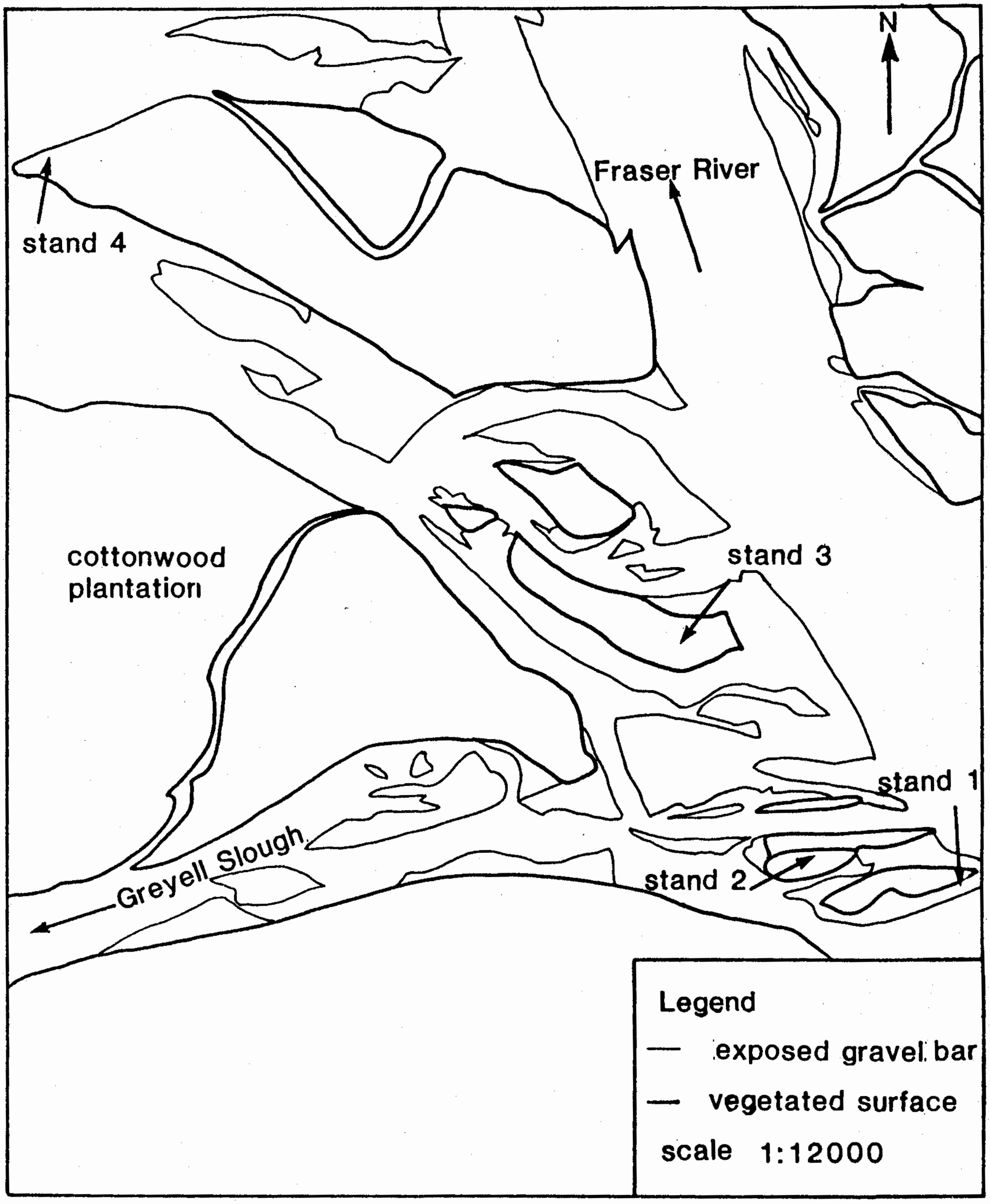


Figure 7. Stand locations at Greyell Slough.

source: 1979 aerial photographs

seedlings. Some seedlings are also flood trained, that is, prostrate stems aligned in the direction of water flow have produced new vertical shoots and continued to grow. The bar surface is only inundated by floods with discharges of 9500 to 10000 m^3s^{-1}, which recur on average every 4 to 5 years, and last 3 to 5 days.

(ii) Stand 2

At the tail of the bar, on fine sediments, a dense willow and cottonwood stand is established. The saplings are five years old, and form a closed canopy. This supresses understory vegetation, with the exception of Equisetum hyemale which grows up to 1.5 metres. Heavy silting is evidence of inundation, and the stand has been dissected by a chute channel. The area is submerged by floods with a recurrence interval of two years, and discharges from 8000 to 9000 m^3s^{-1}. Inundation may last for 10 to 15 days in a year.

(iii) Stand 3

In the mixed stand at the bar head the largest cottonwoods are approximately 55 years old. The stand also contains cedar, red alder, western hemlock and big leaf maple, of varying sizes and ages. The oldest cedar trees are 42 years old, and the species is approaching co-dominance in the stand (Table 2). Red alder is found at the sides of the bar together with young cottonwood. Both mean density per hectare, and mean basal area per hectare, are relatively high at this site. Where cedar grows in close proximity to cottonwood cedar growth is supressed.

A diverse assemblage of understory species are found beneath the canopy. The litter layer is composed of decaying leaf and woody material and overlies silt and sand. The stand is above the level of most floods, being inundated on average every 5 to 15 years when discharges are in excess of 11000 to 12000 m^3s^{-1}.

(iv) Stand 4

This is a mixed stand with large western red cedar trees, some black cottonwood, big leaf maple, and hemlock. The largest cedar in the stand has a circumference of 2.4 m, but could not be dated due to heart rot. A minimum age of 55 years was ascribed to a 2 m tree. The few cottonwoods in the stand are relatively young (30 years).

The understory varies beneath canopy dominants. Under black cottonwood *Rubus ursinus* (Cham. and Schlecht.) and *Rubus spectabilis* (Pursch) is prevailent, while in patches of mixed cottonwood and cedar the understory is diverse, including *Acer circinatum*, *Cornus stolonifera* (Michx.), red alder and cedar seedlings. Beneath cedar trees the most abundant species is

Polystichum munitum (Kaulf. Presl.), and a ground cover of Bryophytes.

Large amounts of leaf litter and organic matter up to 0.2 m in depth were recorded. The acidic pH indicates the effect of decomposing litter and dead wood in changing the soil reaction. The pH is slightly higher beneath cottonwood individuals than cedar. Mean basal area per hectare is high in this stand, reflecting the large size of the cedar stems, while relative density is lower than in more youthful stands. The site is inundated by floods with recurrence intervals of 5 to 15 years with discharges above 11000 to 12000 m^3s^{-1}.

3.3 Carey Point

Downstream from Carey Point, on the south side of the Fraser River, is a gravel bar which extends into the channel from the floodplain. The gravel platform has been built up where flow diverges. The margins of the bar are being colonised by pioneer vegetation (classes 1 to 3), and this was sampled (Figure 8), together with two cottonwood stands (class 4) on the upper bar surface. The stands are separated by a chute channel.

(i) Stands 1 and 2

On the lowest elevation deposits, at the bar margins, scattered, floodtrained cottonwood seedlings (age 1) are found.

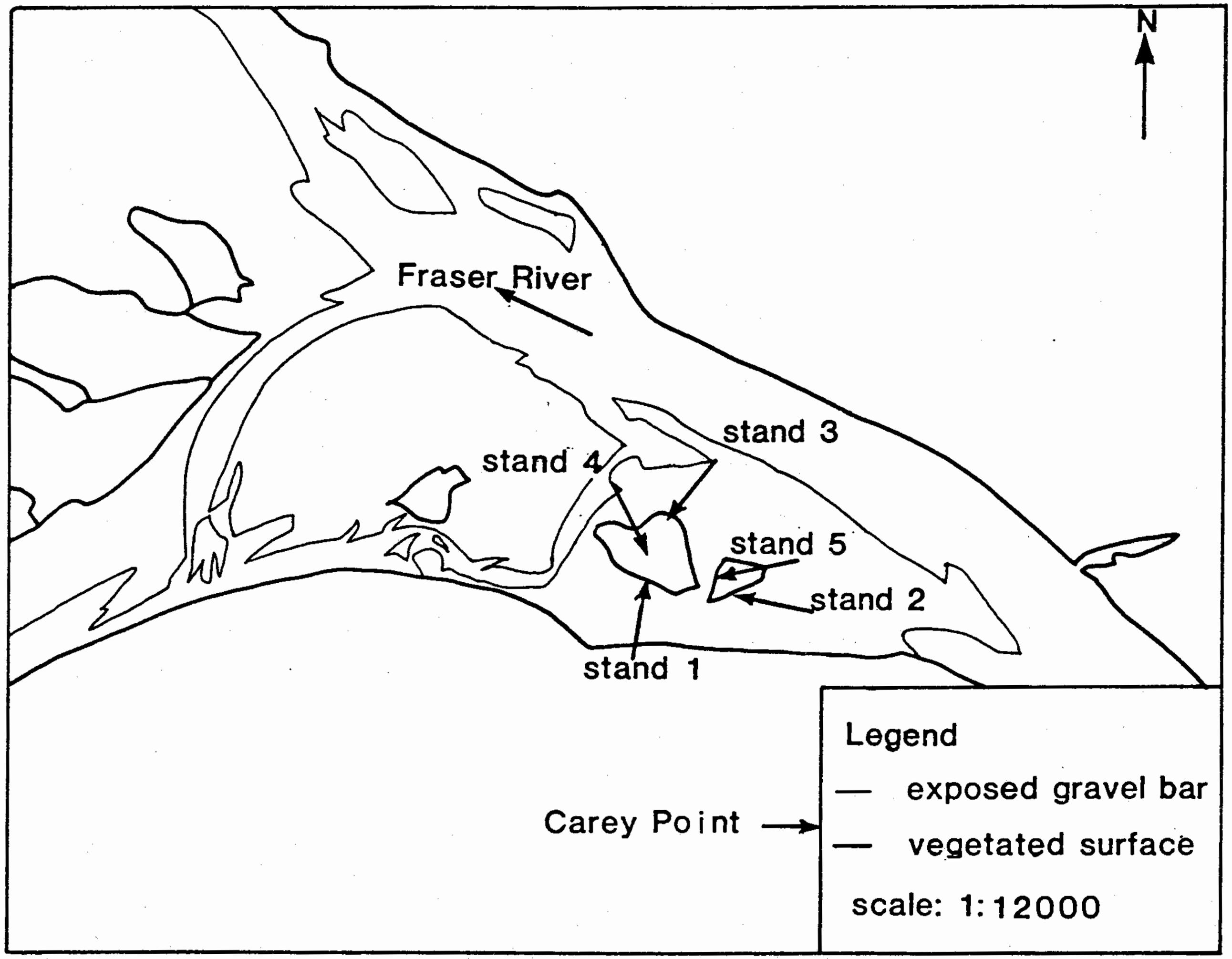


Figure 8. Stand locations at Carey Point
source: 1979 aerial photographs

On higher gravel ridges at the head of the bar cottonwoods up to half a metre high are established (age 1-3 years). Agrostis tenuis (Sibth.), Aster conspicuus, and Solidago canadensis are growing beneath the seedlings. These surfaces may be under water for 90 to 100 days each year, when discharges are above 3500 to 4500 m^3s^{-1}.

(ii) Stand 3

At the tail of the bar in a zone of sand deposition a dense, mixed cottonwood and willow stand is found. The seedlings are up to 4 metres high, and 3 years old. Further establishment under the seedling canopy depends on substrate stabilisation. Submergence by floods with a recurrence interval of 1 to 2 years may last from 30 to 35 days.

(iii) Stand 4

The cottonwood stand at the tail of the upper bar platform is even-sized, and is dated at 22 years. Cottonwood is the only species recorded in the canopy. Mean density per hectare is relatively high, while mean basal area per hectare is low. A mixture of species are found in the understory, including Rubus ursinus, Rubus spectabilis, Symphoricarpos alba (L. Blake), and Solidago canadensis. No tree seedlings are found beneath the closed canopy of cottonwoods. A little organic matter is on top of silt and sand, and a slightly acidic soil pH was recorded. The bar tail is submerged by floods which recur on average every 3 to 5 years with discharges above 7500 to 8500 m^3s^{-1}. Inundation may last 5 to 15 days.

(iv) Stand 5

The cottonwood stand at the head of the bar is younger than that at the tail and the largest trees are 18 years old. Cottonwood is the only species in the canopy. The relative density of the trees is as in stand 5, but a smaller mean basal area per hectare reflects the younger tree ages. Ground cover is sparser in this stand, and shallow sand overlies gravel with no soil development or organic matter, suggesting that flooding has killed the understory vegetation, and removed part of the soil profile, without killing the canopy dominants. The bar head is slightly higher than the tail, and is inundated on average every 4 to 5 years by discharges over 9500 to 10500 m^3s^{-1}, and for 3 to 5 days.

3.4. Dyke Road

On the south side of the river, beside the dyke road, is a small bar with pioneer vegetation. The bar has formed where the river channel is deflected away from the floodplain by the dyke. The resultant zone of slack water has led to the deposition and subsequent emergence of a gravel bar. Vegetation classes 1 to 3 were sampled. Figure 9 shows the location of the stands.

(i) Stand 1

On the gravel at the head of the bar scattered cottonwoods are established. These are floodtrained, and some have been uprooted. The stand is 3 years old. The ring structure of the cottonwoods shows suppression on the upstream side from flooding. The bark on many seedlings is broken. The surface is flooded for up to 115 days each year, by discharges in excess of 3000 to 4000 m^3s^{-1}.

(ii) Stand 2

A small remnant of a higher bar platform had 5 year old cottonwoods, some *Rubus ursinus* and *Cornus stolonifera*. This has been eroded since the time of sampling. The surface elevation suggested that it was submerged for 35 to 50 days each year.

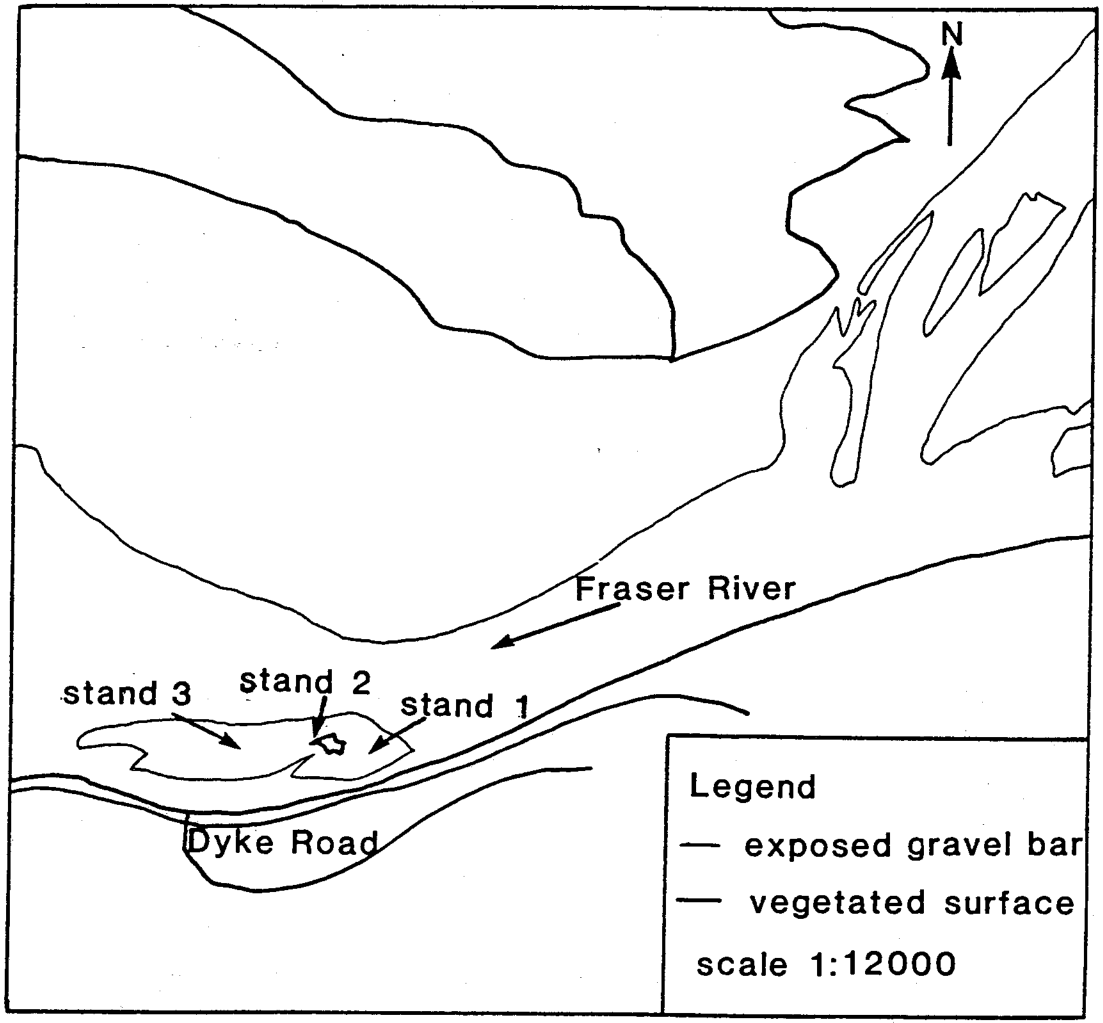


Figure 9. Stand locations at Dyke Road

source : 1979 aerial photographs.

(iii) Stand 3 and 4

The central area of the bar is the most densely vegetated. A mixed cottonwood and willow stand (age 3 years), grows on a sand-gravel ridge, while willows have colonised sand deposits at the tail of the bar. Equisetum arvense and Equisetum hyemale are understory species in the stands. Space and light are not limiting, and new stems can become established if the substrate remains stable. The probability of flooding each year is high, and surfaces may be under water for 75 to 90 days.

3.5. Queen's Island

South of Queen's island, on the north bank of the Fraser River, several bars have formed. The area is downstream from the mouth of the Harrison River, which contributes coarse sediment to the Fraser. At the confluence of the rivers a stretch of turbulent water gives way to a deposition zone, because the gradient of the Fraser River is less steep than that of the Harrison. Pioneer vegetation (classes 1-3) was sampled on bars at this site, together with a cottonwood stand (class 4) (Figure 10). Cedar is abundant on the neighbouring floodplain, but the only cedar stand found on a bar had been disturbed by the selective logging of cottonwoods, and was not sampled.

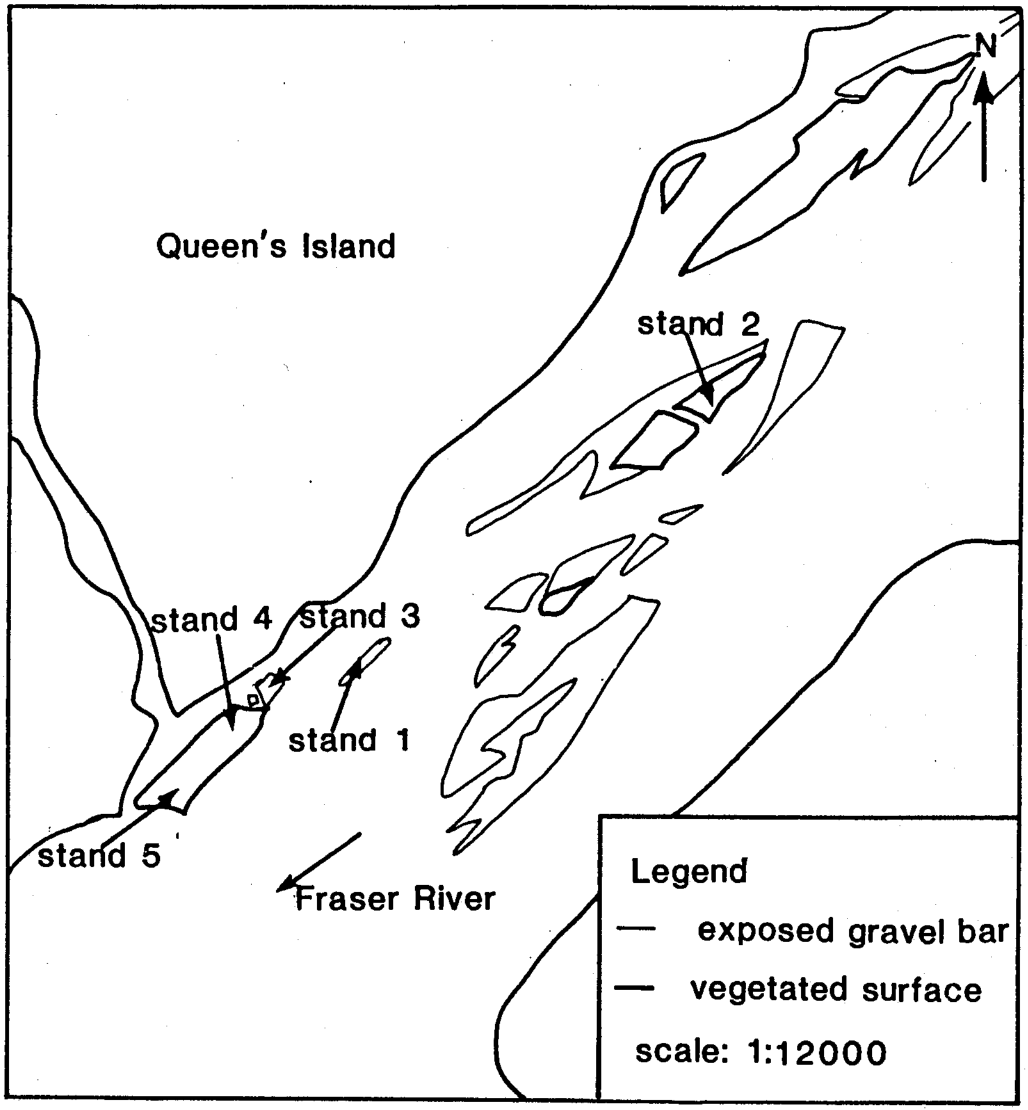


Figure 10. Stand locations at Queen's Island.
source: 1979 aerial photographs.

(i) Stand 1

A gravel ridge in the centre of a dry channel is colonised by cottonwood seedlings, some grass and *Aster conspicuus*. Seedlings in this area are very flood prone, and unlikely to survive the annual freshet. The surface is submerged yearly, although the exact elevation of the site is undetermined.

(ii) Stand 2

The small mid-channel bar shown in figure 10 is colonised by a mixed cottonwood and willow stand, on sand and gravel. The seedlings are 3 years old, floodtrained, and heavily silted. The elevation of this bar is relatively high, suggesting that the bar may have been more densely vegetated at one time. The surface is submerged on average every 3 to 5 years, for 5 to 10 days by floods with discharges above 8500 to 9500 m^3s^{-1}.

(iii) Stand 3

Gravel at the head of the bar (Figure 10) supports scattered cottonwood seedlings. The floodtrained seedlings are 3 years old, although the ring structure shows serious supression of growth and flood damage. The surface is submerged for 55 to

65 days every year.

(iv) Stand 4 and 5

On the upper bar platform a mixed-aged stand is growing. At the bar head the largest cottonwood trees are 42 years old. Cottonwood is dominant, although some red alder was recorded at the edge of the stand. The stand is relatively dense. An understory of *Rubus spectabilis* is found beneath the canopy. Despite deadfall in the centre of the bar there is no evidence of the development of a diverse understory. Red alder grows vigorously in gaps in the cottonwood stand, and may preclude the establishment of other tree species.

At the tail of the bar younger cottonwoods are found, the largest being 21 years old. Cottonwood is the dominant species, although red alder and willow are also present. The overall density is not as high as at the bar head. Mean basal area per hectare is lower, reflecting the smaller size of alder and willow stems. The soil pH is only slightly acidic, and there is no organic matter. The substrate is composed of silt overlying sand.

The stand shows evidence of disturbance by flooding, as several chute channels have dissected the bar surface. Logging debris found exposed in bar banks after sampling had been undertaken, also indicates human disturbance at this site. The relatively low elevation of the bar platform means that it is inundated on average every 1 to 3 years, when discharges exceed 7000 to 8000 m^3s^{-1}. Inundation may last 20 to 30 days.

CHAPTER 4. VEGETATION SUCCESSION

The vegetation composition and environmental conditions of the sampled stands are graphically portrayed in figures 11 to 20, with stands differentiated according to their age, and geographical location on a bar. Stand ages range from 1 to a minimum of 55 years, while location is described as a bar head or bar tail site. These figures, and a summary of the field data (Tables 7 and 8), provide the framework for a discussion of vegetation succession.

The figures show that the field data conform to two age groups, and correspond to two developmental stages:
(1) Colonisation (stands aged from 0-5 years)
(2) Stand development (stands aged from 18-55 years)
These stages are described in terms of the processes which operate within them.

Stands aged between 5-18 years did not correspond to the structural vegetation classes and consequently were not sampled. The paucity of data from the older stands is due to the high degree of human disturbance along the reach, and particularly to the selective logging of cottonwoods from mixed stands. Consequently discussion of the processes operating in the later stages of succession is speculative, and only initial observations are made.

Table 7

Summary of Field Data

Pioneer Stands

Site	Stand	Age (years)	Mean Number of Pioneer Species	Mean Percent cover of Moss	Sediment	Mean Sand depth (m)	Relative Elevation	Recurrence Interval of Submergence (years)	Duration of Submergence (days)	Geographical Location on Bar
Peter's Island	1	1	4.5	5	sand	1.0	No data			Tail
	2	2	5.2	29.3	sand	1.0	No data			Tail
	3	3	2.4	0	sand	1.0	No data			Tail
Greyell Slough	1	3	2.5	4.1	sand/gravel	0.19	4.8	4-5		Head
	2	5	5.3	12.5	sand	0.64	4.25	3-4		Tail
Carey Point	1	1	2.4	2	gravel	0.10	1.1	1		Head
	2	3	1.9	30	gravel	0.08	0.5	1-2	90-100	Head
	3	3	3.7	12	sand	0.65	0.3	1	30-35	Tail
Dyke Road	1	3	1.7	0	gravel	0	0.0	1	105-115	Head
	2	5	4.3	0	sand	0.28	1.0	1-2	35-50	Tail
	3	3	3.6	0	sand	0.52	0.5	1	75-90	Tail
Queen's Island	1	1	1.5	0	gravel	0	No data			Head
	2	3	1.1	0	gravel	0	1.8	1-3	20-30	Head
	3	3	2.2	0	sand/gravel	0.61	0.2	1	55-65	Head

Table 8

Summary of Field Data

Developing Forest Stands

Site	Stand	Age (years)	Density (trees/ha	Mean Basal area/ha (M^2)	Mean Number of Understory	Mean Percent Cover of Moss	Mean Sand depth (m)	Mean Silt depth (m)	Mean Organic depth (m)	Relative Elevation (m)	Recurrence Interval of Submergence (years)	Geographical Location on Bar
Peter's Island	4	20	706	1322	5.6	7.5	1.0	0.02	0	No data		Head
Greyell Slough	3	55+	1344	6192	2.4	2	2.0	0.30	0.01	5.25	5-15	Head
	4	55+	1765	8030	2.6	8	3.0	0.21	0.12	5.25	5-15	Tail
Carey Point	4	22	2822	4654	6.6	5	3.0	0.05	0.07	1.8	3-5	Tail
	5	18	2343	1631	2.1	8.9	0.10	0.01	0.01	2.4	4-5	Head
Queen's Island	4	42+	3858	5568	4.4	0	2.0	0.10	0.03	0.8	3-5	Head
	5	21	4044	2402	4.2	0	3.0	0.20	0.03	0.8	3-5	Tail

4.1. Colonisation

4.1. (a) Habitats

The habitats where colonisation is occuring are generally recent alluvial deposits. They consist of sediments at the margins of established mid-channel bars as well as those of newly emergent bar surfaces.

The relative elevation of the sites is generally low with bar tail surfaces being lower than bar heads (Figure 11). An exception is the surface of pioneer stands at Greyell Slough. The relatively high elevation at this site is attributed to rapid accretion at the slough head. The frequency and duration of inundation is dependent upon site elevation. Most of the habitats are inundated annually, and the duration of submergence varies from 3 to 115 days (Table 7, Figures 12 and 13). Younger stands are inundated for longer periods than the older ones, and bar head sites are less frequently submerged than tails.

The alluvial substrate in these habitats is either gravel or sand. Figure 14 shows that sand depth ranges from 0 to 3 metres in pioneer stands, and is related to the geographical location of a stand on a bar. Bar heads are mostly gravel with minimal amounts of sand/gravel, while bar tails are generally sand, the depth of which varies from 1 to 3 metres.

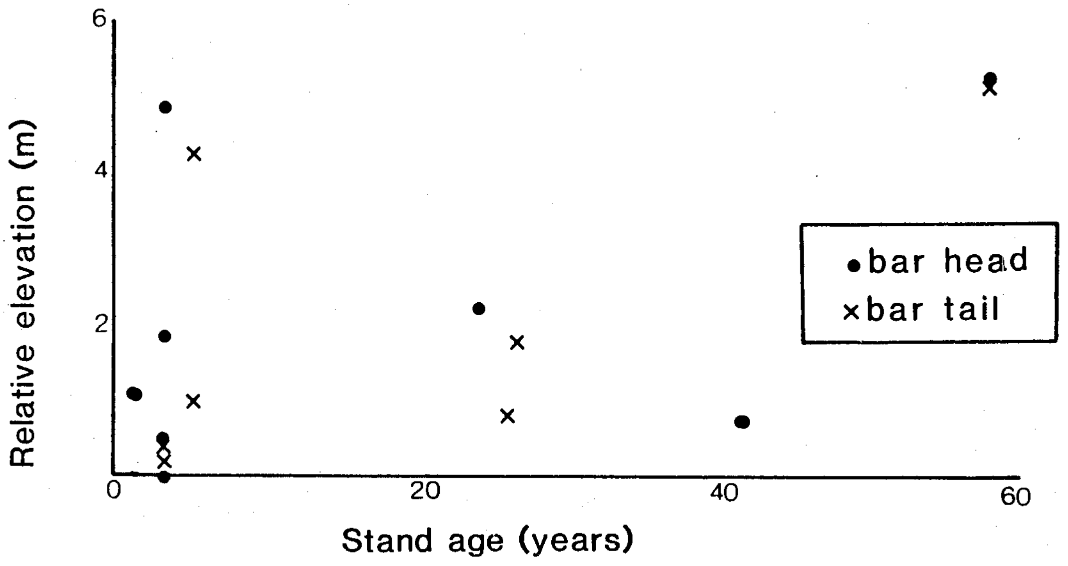


Figure 11. Relative elevation of stands.

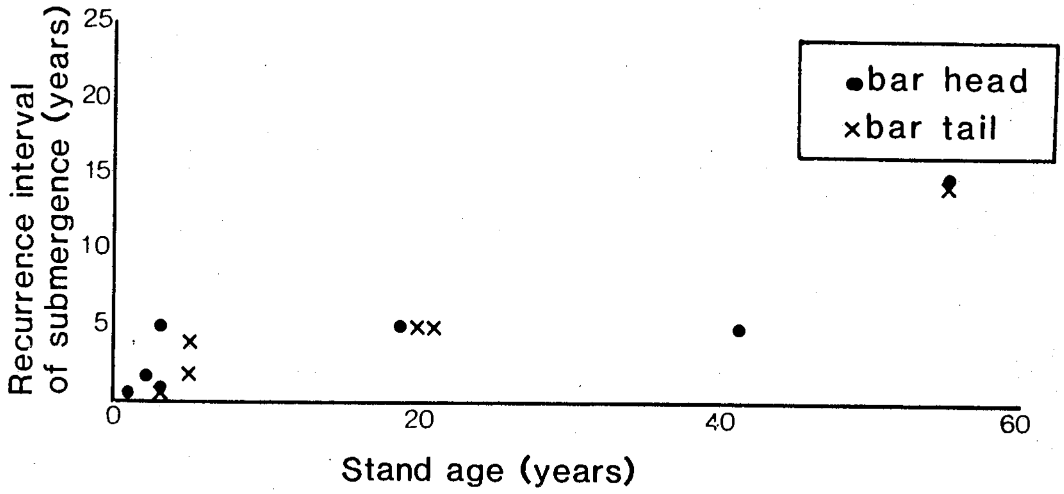


Figure 12. Recurrence interval of submergence of stands.

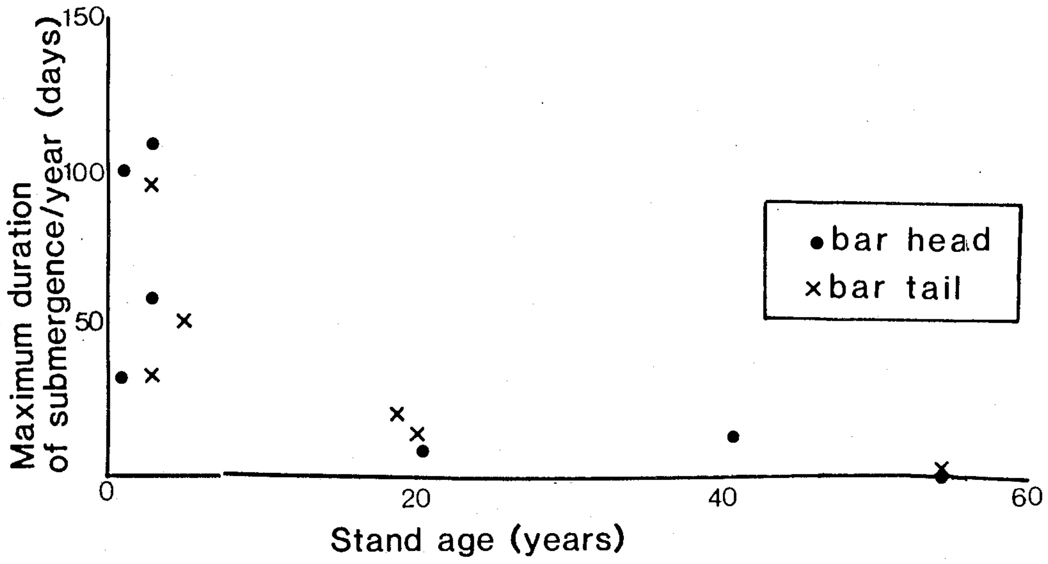


Figure 13. Maximum duration of submergence of stands.

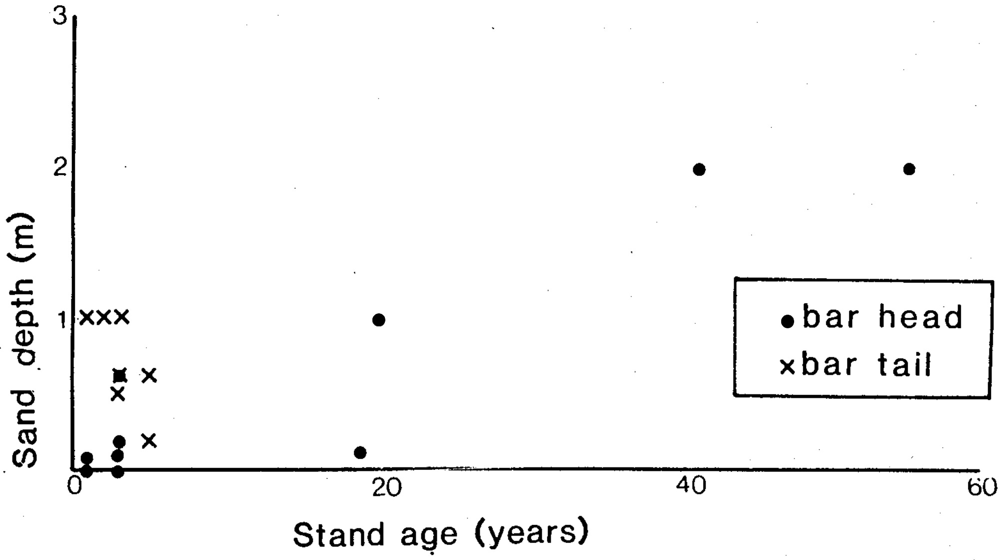


Figure 14. Stand mean sand depth.

4.1. (b) Processes

There are three distinct processes within the colonisation stage of vegetation succession, and these are examined in the context of field evidence. The processes are :

(i) Seed dispersal and species immigration

(ii) Species establishment

(iii) Growth

(i) Seed dispersal and species immigration

The initial process in the colonisation of a new alluvial substrate on a mid-channel bar is species immigration. Seed may be available from floodplain species, and from those species already established on mid-channel bars, and is dispersed by a variety of mechanisms. Several of the indigenous tree species, including black cottonwood, species of willow and red alder, release large amounts of seed during the freshet,and the seed is dispersed by wind and by water. The absence of any species from the interior of British Columbia, may be evidence of the overwhelming importance of local seed transport. Seed carried by the river is left stranded on the moist sediments of bar banks as flood waters recede. The seed of black cottonwood is particularly light and bouyant, and may be transported long distances without loss of viability (Fowells, 1965). Seed from annual and perennial herbs, and grasses may also be dispersed by the river and by wind.

Seed of local coniferous species, such as western red cedar and western hemlock is wind dispersed and travels short distances. These species commonly disseminate seed in the fall, and due to the time of seed release and the limitations of the environment on species establishment, the seed of coniferous species is not significant in bar colonisation.

(ii) Species establishment

Of the seed that reaches potential habitats on the bars not all will germinate. The number of species which become established in any phase of colonisation is very low (Figure 15). The high mortality rate is typical of pioneer species. Species occurrence varies from an average of 1 to 6 species per site, with the number of species found in older stands, and bar tail habitats being highest. The percentage cover of Bryophytes ranges from 0 to 30%, and shows comparable trends (Figure 16).

The most commonly occuring species, and usually the only species in the first vegetation class are black cottonwood and willow. Seedlings generally become established at the high water line and this is evidence of the importance of water transport of seed. Seedlings may also be rafted onto bar surfaces during flooding, and may form a nucleus for colonisation. Under favourable climatic and edaphic conditions, and in the absence

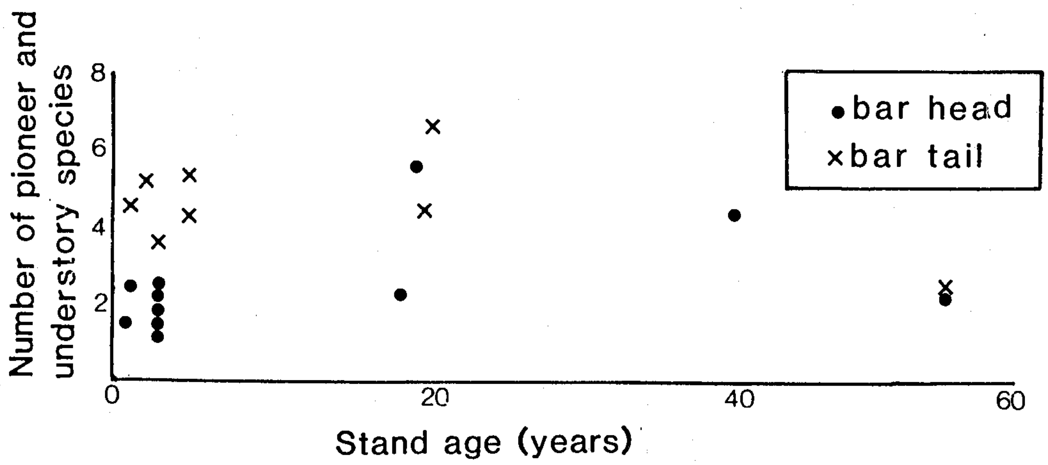


Figure 15. Mean number of species in stands.

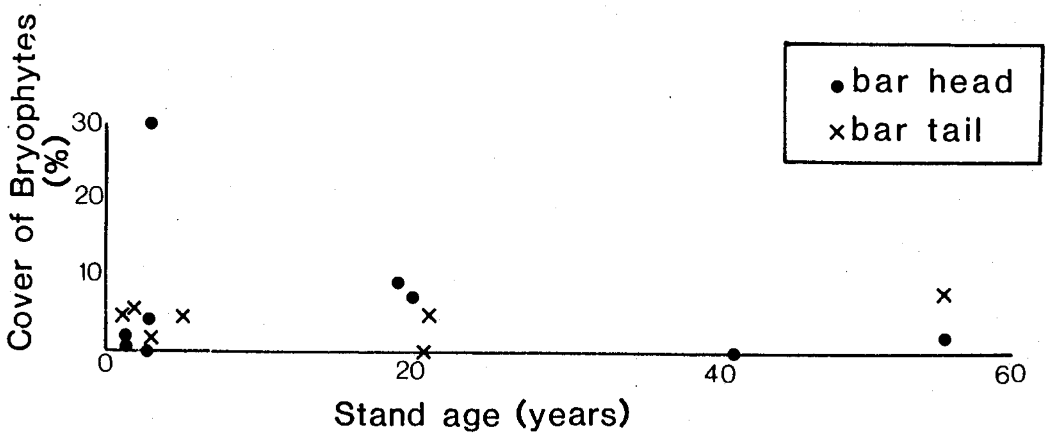


Figure 16 . Mean cover of Bryophytes in stands.

of disturbance by flooding, the germination of both black cottonwood and willow seed is very high.

Other species found during colonisation include *Aster conspicuus*, *Solidago canadensis*, *Melilotus alba*, *Equisetum hyemale*, *Equisetum arvense*, *Plantago major*, *Crepis capillaris*, *Agrostis tenuis* (Sibth.) and *Poa pratensis* (L.).

There are two major environmental limitations on species establishment; flooding, and the nature of the substrate.

(a) Flooding

Flooding can prohibit establishment by eroding or deeply burying seed on bar surfaces. It can also inhibit germination by waterlogging sediments. Black cottonwood and willows are both able to germinate on anoxic sediment, but neither species will germinate under conditions of prolonged inundation. Cottonwood seedlings are particularly susceptible to mortality if they are submerged by stagnant water. Apart from black cottonwood and willow, the only species present in the initial stage of colonisation were *Juncus vaseyii* and *Equisetum hyemale*. Red alder and other trees, shrubs and herbs were absent in the lowest elevation sites, presumably as a result of their failure to establish under conditions of frequent and prolonged flooding.

Once seedlings of cottonwood and willow are established they help to increase the surface elevation by trapping sediment, and other species may then become established.

(b). Substrate

Figure 15 shows that the number of species established at bar tails is greater than that at bar heads. Deposits of sand are significantly deeper at bar tails, and this suggests that substrate conditions influence species establishment.

The results of the chi-square test (Table 9) indicate that species presence is influenced by the interactive effects of sediment texture, sediment depth and the vegetation class. Deeper, finer sediments are associated with the upper vegetation classes (2 and 3). The presence of many species is influenced by the interactive effects of sediment texture and sediment depth (Table 9). The species are Crepis capillaris, Leersia oryzoides, Lolium perenne, Melilotus alba, Agrostis tenuis, Equisetum arvense , Plantago major and species of Bryophytes. These species are established where significant deposits of sand overlie gravel.

No significant influence of substrate is associated with the presence of either Equisetum hyemale or species of willow. Equisetum hyemale is apparently sufficiently opportunistic as to colonise any substrate, and is found in all vegetation classes. The influence of flooding, or the absence of cottonwood, may have more effect on the establishment of willow than the depth or type of sediment.

Table 9.

Analysis of Multiway Frequency Tables for Pioneer Species

SPECIES	LEVEL	MODEL	SIGNIFICANCE G2	X2
P. trichocarpa	2 way	NA,DA	.69	.68
C. capillaris	2 way	ND,TD,DA	.25	.26
L. oryzoides	2 way	TD,DA	.29	.27
P. pratensis	2 way	TD,DA	.60	.61
E. hyemale	2 way	ND,NA,DA	.02	.00
L. perenne	2 way	TD,DA	.68	.48
Salix sp.	2 way	ND	.00	.00
M. alba	2 way	TD,DA	.61	.58
A. tenuis	2 way	ND,TD,DA	.38	.24
S. canadensis	2 way	DA	.58	.35
E. arvense	2 way	ND,TD,DA	.15	.05
P. major	2 way	TD,DA	.61	.54
Moss	2 way	NA,TD,DA	.15	.11
J. vaseyi	2 way	DA	.58	.24
A. margaritacea	2 way	DA	.15	.26

N=species, A=vegetation class,
T=sediment texture, D=sediment depth

A primary observation is that cottonwood is more often found on gravel than willow, while on finer substrates stands of mixed cottonwood and willow seedlings are often established. For example, at the Dyke Road site, cottonwood seedlings are present on the gravel substrate, while on fine sediment an even-aged, mixed cottonwood and willow stand is established.

McBride and Strachan (1984) similarly determined that on gravel bars of an intermittent stream in California willows occupy sites with fine substrate and Populus Freemontii grows on coarser substrate. Seedlings of willow are very susceptible to mortality if the water table drops. This is more probable in coarse rather than fine sediments. Cottonwood, however, has deeply penetrating roots and can survive lowering of the water table in gravel.

Other hazards which may prohibit the establishment of species on mid-channel bar surfaces include shifting of the substrate by the wind. This is particularly common during the winter on the mid-channel bars of the Fraser River. Similarly during the winter seedlings may suffer ice damage. In general species establishment is limited to those species which are adapted to the environmental conditions on the bars, and other species are excluded.

(iii) Growth

If germination and establishment are successful rapid seedling growth may follow to fill the available space. Within five years, in the absence of disturbance, a dense cottonwood, or mixed cottonwood and willow stand, 4-5 metres in height, may be established (Plate 4). Species growth during colonisation is not limited by competition, because there is usually sufficient space, light, and a good supply of nutrients from the river, but it may be limited by both inundation, and the substrate. The survival of seedlings depends on the adaptability of the species to the harsh environmental conditions on the bars.

(a) Flooding

Flooding limits species growth, and maintains a sparse vegetation cover on many surfaces (Plate 6). Tolerance of inundation is critical and determines which species survive the annual freshet. Cottonwood is particularly well adapted, and has evolved several mechanisms for withstanding flooding (Plate 6). It exhibits floodtraining, whereby prostrate stems, aligned in the direction of water flow, produce new vertical shoots, and continue to grow. This facet of cottonwood growth is described by Lindsey et. al. (1961), Sigafoos (1964) and Everitt (1968). Cottonwood sprouting was observed by Barnes (1985) on a disturbed river island in the Chippewa River, Wisconsin. He

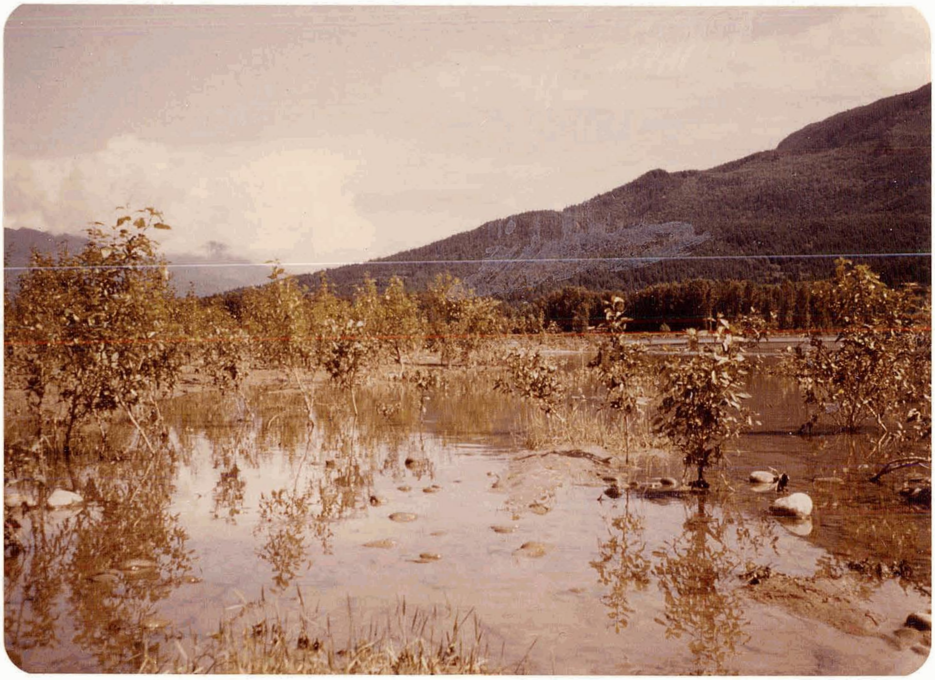


Plate 6

Cottonwood seedlings inundated by flood waters, Queen's Island describes this as a survival strategy, suggesting that where inundation is frequent or severe, growth is lateral rather than vertical.

Cottonwood stems are very resistant and can survive abrasion and the breakage of bark. The species is also able to withstand siltation by putting out a large number of adventitious roots from a buried stem. Seedlings of willow likewise have tough stems which are resistant to abrasion by flooding, and heavy siltation. At the Dyke road site the root collar on willow seedlings was buried beneath 0.10 - 0.20 m of sand, and the species puts out adventitious roots following burial.

Inhibition of seedling cambial development by frequent and prolonged flooding is demonstrated by the supressed ring structure of seedlings' annual growth rings, particularly on their upstream side. This was observed at several bar head sites, particularly at Queen's Island and Dyke Road, both of which are of low elevation, and are frequently inundated.

Seedlings may be destroyed by floods if abrasion is severe, inundation is prolonged, or if the substrate is eroded. Although species on the mid-channel bars can tolerate regular submergence they are not usually able to survive episodic severe floods. The large numbers of dead seedlings found in the first vegetation class, and at bar heads are evidence of this. Mortality is apparently due to siltation and suffocation in the case of smaller seedlings, and abrasion, stem breakage, and uprooting of saplings. Substrate erosion is the most common cause of mortality. Although the roots of seedlings and young trees increase the cohesive properties of alluvial deposits (Smith, 1976), fast moving flood waters are an efficient erosional agent. Erosion is apparently particularly severe at bar head sites, where any fines deposited are readily moved. Bar tail sites may experience less severe erosion, and consequently less seedling mortality.

The unstable nature of the flow regime of the Fraser River means that disturbance by flooding often disrupts species growth, and the development of a pioneer stand, and this suggests that there may well be several unsuccessful periods of colonisation of gravel bar surfaces prior to successful establishment.

(b) Substrate

Substrate conditions on the bars may inhibit the growth and development of established seedlings. The abundance of black cottonwood, *Equisetum hyemale*, and species of willow are all influenced by the synergistic effects of sediment texture and sediment depth, while for species of Bryophytes sediment texture alone is a significant control (Table 10). As in the establishment phase species growth is best where sediment is sand rather than gravel, and where the sand is over 1 metre deep, that is at bar tail sites, and in the upper vegetation

Table 10.

The Analysis of Variance for Pioneer Species

SPECIES	SEDIMENT TEXTURE	SEDIMENT DEPTH	INTERACTION	LEVEL
P. trichocarpa			significant	0.0026
E. hyemale			significant	0.0001
Salix sp.			significant	0.0121
Moss	significant			0.009

SPECIES	VEGETATION CLASS	SEDIMENT TEXTURE	INTERACTION	LEVEL
P. trichocarpa	significant			0.0000
E. hyemale			significant	0.0000
Salix sp.			significant	0.0031
Moss				

SPECIES	VEGETATION CLASS	SEDIMENT DEPTH	INTERACTION	LEVEL
P. trichocarpa			significant	0.0000
E. hyemale	significant			0.0024
Salix sp.		significant		0.0389
Moss			significant	0.0092

class (class 3). Abundance on gravel is very low, with high percentages of bare ground recorded, black cottonwood is the only species that grows well. Poor growth is particularly associated with bar head sites, and with the first vegetation class. No organic matter was recorded at any of the sites, and this implies that there is no significant modification of the substrate by the plants themselves during colonisation, except in the trapping of sediment.

4.2. Stand Development

4.2 (a) Habitats

The relative elevation of the bar surface in developing stands is up to a metre higher than in areas of colonisation (Figure 11). The oldest stands which are at the head of Greyell Slough have the highest relative elevation while the forest stand at Queen's Island has an anomalously low elevation in view of its age. In general bar head sites are higher than bar tail sites, for example at Carey point the head of the bar is 0.5 m above the tail.

Corresponding with stand elevation, the recurrence interval of discharges which submerge the bar surfaces are less in the developing stands than in pioneer stands. In general the older the stand, the less frequently inundation occurs. Figure 12 shows a 1-5 year submergence interval for the stands in the age range 18 to 24 years, and a 5 to 15 year recurrence interval for the submergence of stands with a minimum age of 55 years. The bar at Queen's Island is again an exceptional site. It is inundated every 1-3 years, due to its low relative elevation.

Substrate conditions show little variation throughout the sites. Sand depth is over 1 metre in all habitats except at the bar head at Carey Point, where gravel and shallow sand on gravel are found (Figure 14). At other bar head sites 2-3 metres of sand have been deposited, while at bar tails 3-4 metres of sand are exposed. Silt depth is greater at bar tail than bar head sites (Figure 17), reaching a maximum of 0.30 m deep on top of sand. Silt deposits are also slightly deeper on the oldest stand surfaces at Greyell Slough.

In most of the habitats some organic matter is recorded in the topsoil, but amounts are low, particularly in stands at bar heads (Figure 18). It is possible that organic layers have been buried by the subsequent deposition of silt and sand, and are no longer discernable in the soil profile. This would account for the low amounts of organic matter in the topsoil of the mixed stand at Greyell Slough. The soil reaction reflects the lack of soil development at the sites. Table 5 shows that pH is slightly more acidic in the older stands at Greyell Slough, particularly beneath cedar trees.

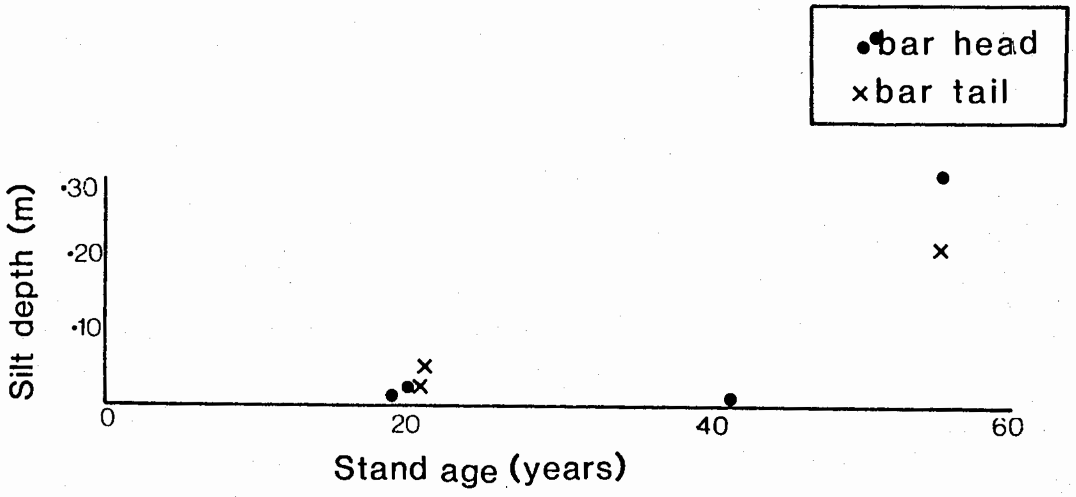


Figure 17. Stand mean silt depth.

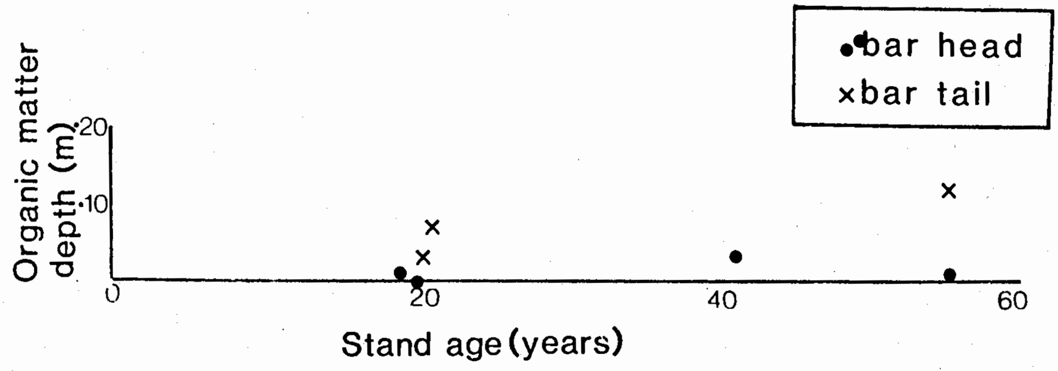


Figure 18. Stand mean organic matter depth.

4.2 (b) Processes

The processes which operate during stand development are less easily categorised than those occurring during bar colonisation. Changes in the species composition and substrate conditions of the stands occur in response to several processes, as shown by the variable character of stands of approximately equivalent age. Stand development is examined in the context of both the autogenic and allogenic processes which control

(i) changes in canopy cover

(ii) changes in the understory

(iii) changes in the substrate

(i) Changes in canopy cover

Development of a mature forest stand from a pioneer stand of cottonwood or cottonwood and willow saplings involves changes in the species composition, density and mean basal area/hectare of the canopy. In all the forest stands sampled black cottonwood is the dominant species (Table 1). However pure stands are exceptional, and cottonwood occurs with species of willow, red alder, western red cedar and western hemlock. Stands of approximately equivalent age show variable density (Figure 19 and mean basal area/hectare (Figure 20), and few of them are even-aged. They form a complex mosaic which suggests that a

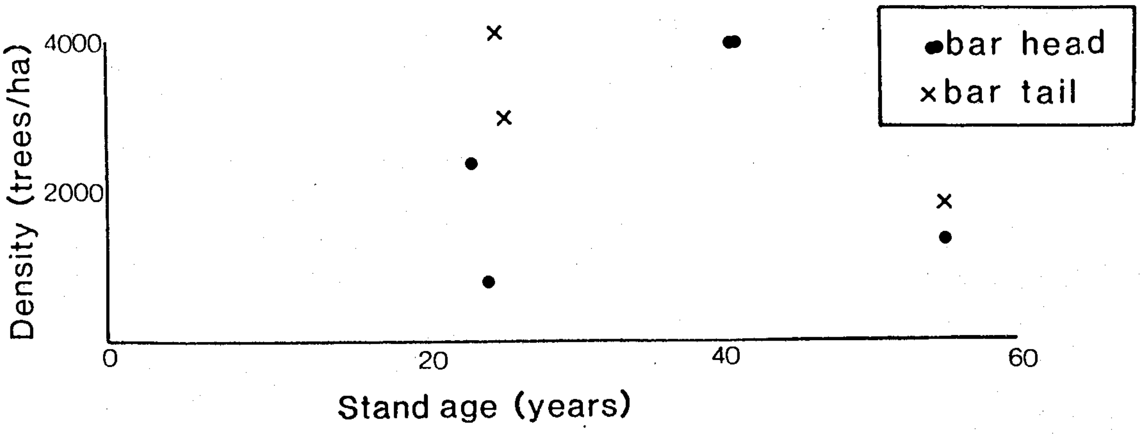


Figure 19. Stand density.

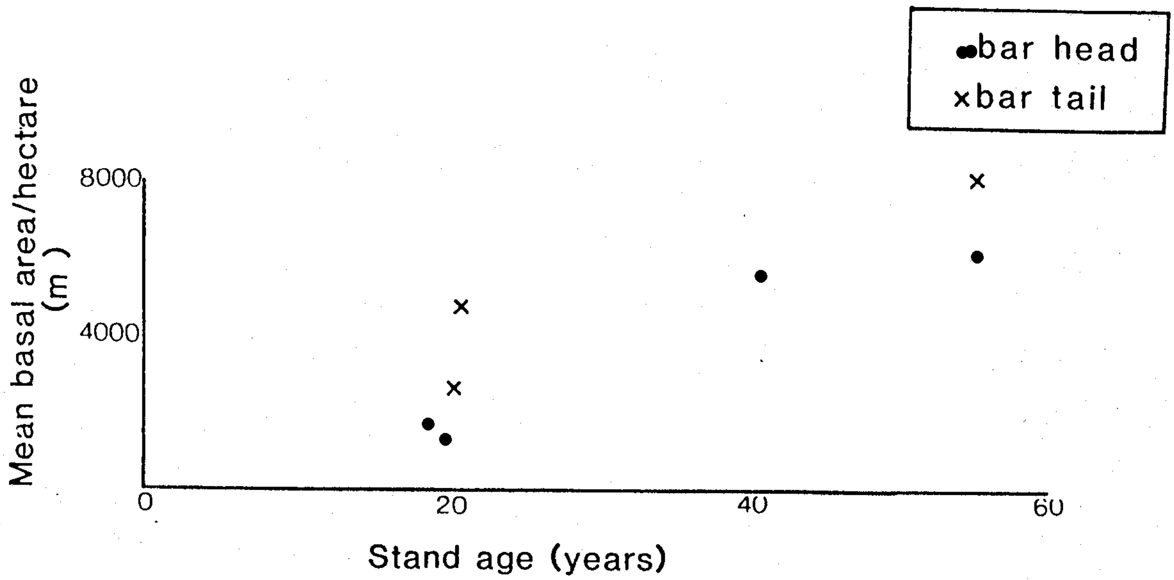


Figure 20. Stand mean basal area/hectare.

variety of developmental processes are operating. The processes are both autogenic and allogenic, with the most significant external influences being disturbance by flooding, and by human activities on the bars. As the processes do not operate in isolation they cannot be treated separately in this discussion, and for this reason changes in canopy cover are examined on a species by species basis.

In the absence of disturbance the canopy of pioneer saplings closes after approximately five years. At this stage cottonwood attains dominance within the stand canopy by growing vigorously and outcompeting any willow present. Willow has a high natural mortality after about eight years (Fowells, 1965), and its intolerance of shade probably leads to its decay. Self thinning of cottonwood stems also occurs, and new stems are potentially excluded from the stand.

The cottonwood trees reach 20 metres in height and 0.90 metres in circumference in 20 years at Carey Point, where a pure cottonwood stand is growing. This stand is dense, with a relatively low mean basal area/hectare (Table 8), as trees increase in height rather than volume in competition with neighbours for light. At the bar head at this site the stand is significantly less dense (Table 8), probably due to flood damage.

In the forest stands at Queen's Island and Greyell Slough willow is found in patches in the stand. It is significantly younger than the canopy dominants. The re-establishment of willow in a stand is dependent upon canopy mortality, the most probable cause of which is disturbance by flooding. Regular flooding has little effect on canopy cover in the forest stands because inundation is infrequent and for short duration (Figures 12 and 13), and even severe flooding may cause little canopy mortality. Brink (1954) noted good survival of tree species on the mid-channel bars of the Fraser River following the 1948 flood. Black cottonwood suffered little damage, although older willow trees and red alder were more susceptible to mortality.

Flooding causes most serious damage to stand canopies where chute channels dissect bar surfaces, eroding the substrate and opening a large gap in the canopy by uprooting trees. Chute channels were found at all the study sites. Some were bare of vegetation, while others were being revegetated. The vegetation which reoccupies a chute channel is indistinguishable from that which colonises a new gravel bar surface. Black cottonwood and willow are the only tree species able to tolerate the substrate of sand and/or gravel, and to withstand inundation. Where these young trees are found in abandoned chute channels stand density is often very high, and mean basal area/hectare is correspondingly low.

Red alder is present in the canopy of several of the forest stands sampled (Table 1). It is particularly abundant at the margins of stands, as at Peter's Island, Queen's Island and the bar head stand at Greyell Slough. Unlike black cottonwood and willow, red alder is not an efficient pioneer species on the bars, because it is not adapted to survive prolonged inundation. Brink's (op. cit.) study indicates that alder mortality was high after the 1948 flood of the Fraser River. However red alder is similar to cottonwood in that its seed requires light for germination, and its establishment within the canopy is therefore dependent on cottonwood mortality.

Smith (1957) in a study of the site quality for black cottonwood growth on the floodplain of the Fraser River, suggests that without replanting or other careful treatment following logging, cottonwood stands are replaced by brush and less valuable tree species, which include red alder. This is supported by Fowells (1965) who states that cottonwood does not grow well on logged-over ground. Large-scale logging operations on the bars usually result in the planting of cottonwoods or cottonwood regeneration from stumps through clonal growth (K. Stenersson, Scott Paper Co. Ltd., pers. comm., 1984). Red alder occupies gaps in the canopy that are formed by small scale cutting of timber from the margins of accessible mid-channel bars.

Once established red alder grows rapidly with a density and mean basal area/hectare similar to that of black cottonwood (Table 1). Vigorous alder growth may suppress the development of seedlings of other tree species, particularly coniferous species such as western red cedar and western hemlock (Stubblefield and Oliver, 1978). This may explain the absence of coniferous species in the stand following human disturbance.

The occurrence of western red cedar and western hemlock within stand canopies is restricted to the oldest sites at Greyell Slough. At both these sites a significantly lower percentage of cottonwood was recorded (Table 1), and in the oldest stand cedar approaches co-dominance with cottonwood (49% cottonwood, 47% cedar). Coniferous seedlings are not found in pioneer stands, and they are rare beneath closed cottonwood canopies, therefore it is speculated that conifer establishment follows the senescence and natural decay of black cottonwood. Cottonwood cannot reproduce beneath a closed canopy, and its shade intolerance leads to an eventual loss of dominance.

Fowells (1965) suggests that cottonwood decay may occur after 60 to 80 years, although Thomas and Podmore (1953) found that the average age of black cottonwood was 136 years in the Fraser Valley near Quesnell. At Greyell Slough the remains of a small, even-aged cottonwood population are found, and most of the trees are in a state of decay. The trees are 55 years old; an indication of the life-span of this species. The onset of decay may be a function of habitat, as conditions are less suitable for cottonwood growth at some mid-channel bar sites than others (Smith, 1957). A later age of decay may correspond with good growth in favourable habitat conditions.

Disturbance along the reach limited the sample size for older stands, and makes distinguishing between biotic and allogenic processes difficult. For this reason the exact mechanism of establishment of coniferous species is uncertain.

The patchy, mixed species stand at Greyell Slough suggests that small gaps in the cottonwood canopy are occupied by shade tolerant coniferous seedlings, the most successful of which are western red cedar.

Cedar is a very tolerant species which can reproduce, germinate and grow in the shade. The species is slow growing, but individual trees can become very large. At Greyell Slough cedar trees 2 metres in circumference are at least 55 years old. A similar size-age relationship is reported by Nystrom et al. (1980) for cedar in Washington State. The high mean basal area/hectare of stands containing western red cedar (Table 8, Figure 20), reflects the large stem size of the trees, while stand density is significantly reduced where cedar is abundant (Figure 19).

Cedar seed is dispersed by wind and travels short distances because of its small wing span (Fowells, 1965), and for this reason cedar seedlings are common beneath established trees. Cedar rarely occurs in pure stands however (Fowells, op. cit.), and is present in the study reach in association with western hemlock, as well as with black cottonwood. Western hemlock is probably less well adapted to the soil and moisture conditions on the bars than cedar. Within these cedar stands the presence of willow and red alder indicate that both disturbance by flooding and by human activities have occurred. Western red cedar suffers little damage from severe flooding, other than infrequent orange chlorosis, while hemlock mortality following the 1948 flood of the Fraser River was significant (Brink, 1954). Chute channels at the sites indicate that flooding can disrupt stand development in any stage, even though these oldest stands are only inundated every 5 to 15 years.

Cedar stands along the reach have suffered considerable disturbance due to the selective logging of cottonwoods. Although the sampled stands remain unlogged human disturbance in the Greyell Slough area has been extensive, and timber cutting at stand margins may have occurred.

(ii) Changes in the understory

Changes in the understory of developing stands are related to changes in canopy cover, and are controlled by the same processes. As with changes in canopy cover the discussion focusses on the species composition of the understory, and explains variations in the understory in terms of both autogenic and allogenic developmental processes.

The number of understory species recorded beneath a developing canopy is very variable. The average number of species ranges from 1- 6, and is generally higher in the younger stands (Figure 15). The species composition of the understory can to some extent be explained in terms of biotic processes, such as increased shading as the canopy develops, and the build up of organic matter, and lower pH with increasing stand age.

Tolerance of shade is critical for species establishment and growth beneath a closed canopy. Some species of the pioneer stand, noteably *Equisetum hyemale*, remain beneath the canopy when it closes. However, most of the grasses and herbs are excluded, and beneath cottonwood or mixed species stands, the understory changes to *Rubus spectabilis*, *Rubus ursinus*, *Symphoricarpos alba* and *Cornus stolonifera*, together with some cottonwood and red alder seedlings. These species are shade tolerant and grow well in the favourable microclimate beneath the canopy. The life cycles of some of the species may be adapted to survival on the forest floor. For example *Rubus spectabilis* flowers before the leaves are fully expanded in the deciduous canopy, that is in early April.

On the forest floor at the oldest sites at Greyell Slough the number of understory species is low beneath cedar individuals, consisting of cedar seedlings, *Polystichum munitum* and species of Bryophytes, all of which are very tolerant of shade. The percent cover of Bryophytes is highest in the oldest stand (Figure 16), but is generally lower in developing stands than in pioneer stands.

The chi-square test indicates that the presence of understory species is significantly influenced by the physical characteristics of the substrate (Table 11). The interactive influence of organic matter depth and vegetation class is significant for all species in the analysis, except *Equisetum hyemale*. As stand development progresses

Table 11.

The Analysis of Multiway Frequency Tables for Understory species.

SPECIES	LEVEL	MODEL	SIGNIFICANCE G2	X2
E. hyemale	2 way	NA	.43	.07
Rubus sp.	2 way	OA,SA	.15	.17
A. circinatum	2 way	NO,OA	.83	.71
P. munitum	2 way	NA	.40	.06
P. trichocarpa	2 way	OA	.82	.74
A. rubra	2 way	OA	.91	.92
Moss	2 way	OA	.91	.91
S. canadensis	2 way	OA	.55	.33
Hieracium sp.	2 way	OA	.31	.11
R. spectabilis	2 way	OA	.39	.15
T. plicata	2 way	NA,OA	.94	.96
Grass	2 way	OA	.59	.46

N=species, A=vegetation class,
O=organic matter depth, S=silt depth

the depth of organic layers in the substrate increases, with increasing amounts of leaf litter, and dead fall. In general organic layers are deepest in the upper vegetation class, and at bar tail sites. In the oldest stand at Greyell Slough 0.12 m of organic matter were recorded, while in younger bar tail stands depth ranged from 0.03 to 0.05 m. At several bar head sites no organic matter was found, and in these habitats the occurrence of understory species was significantly reduced (Figure 15). Although the number of understory species found in the oldest stands is low (Figure 15), this is probably a response to increased shade, rather than to substrate conditions.

Equisetum hyemale is often present in abandoned chute channels in developing stands. Smith (1957) suggests that the species is indicative of the poorest site quality for cottonwood growth, being found in waterlogged areas. The species may be associated with willow that becomes established following a disturbance. It is most often present in the lower vegetation class (class 4) where disturbance is frequent. The significance of the influence of vegetation class on the presence of E. hyemale is shown by the analysis (Table 11).

For Rubus ursinus the depth of silt as well as the depth of organic layers is a significant effect in combination with the vegetation class (Table 11) . The species is found in the younger stands at bar tail sites, and in older stands, where silt depths range from 0.05 to 0.30 m. The occurrence of cedar seedlings is influenced by the vegetation type and vegetation class. Seedlings generally occur in the older stands in association with established cedar trees.

The analysis of variance does not show any significant influence of substrate or vegetation class on species abundance, except for the effect of organic matter depth on percent cover of red alder seedlings (Table 12). The data indicate that alder abundance is greatest where organic layers are deepest, supporting the idea that alder is most likely to become established and grow well where substrate erosion has not been severe. Species-species interactions, and species adaptations, particularly tolerance of shade, are probably of more significance in controlling the abundance of understory species than substrate conditions.

Although autogenic processes may to some extent explain the occurrence and abundance of understory species in a developing stand, changes must also be viewed in the context of external disruptive influences. As with changes in canopy cover the influence of flooding and cutting of timber disrupt understory development.

The number of understory species recorded at the bar head at Carey Point is particularly low when compared with that of other stands of approximately equivalent age. and it seems that the understory may have been destroyed by flooding at this site. At the bar head at Peter's Island understory species have been buried by the deposition of about a metre of sand. In the centre of this stand cedar and hemlock seedlings are growing beneath

Table 12.

The Analysis of Variance for Understory Species

SPECIES	SILT DEPTH	ORGANIC MATTER DEPTH	INTERACTION	LEVEL
P. trichocarpa				
A. rubra		significant		0.0064
E. hyemale				

SPECIES	VEGETATION CLASS	ORGANIC MATTER DEPTH	INTERACTION	LEVEL
P. trichocarpa				
A. rubra				
E. hyemale		significant		0.0303

the cottonwood canopy. The establishment of these seedlings is attributed to the low density of the cottonwoods, which in turn is probably related to flood damage. Inundation is frequent (recurrence interval = 1 year) at this site, and this may have supressed cottonwood growth.

Following human disturbance an increase in shrubs together with red alder seedlings may be found in the understory.Once a canopy cover is re-established the understory is not significantly different beneath red alder and cottonwood canopies. Disturbance accounts for many of the variations in the understory between sites of approximately equivalent age. It also complicates the interpretation of changes associated with the later stages of stand development, such as the establishment of tree seedlings in the understory beneath a decaying cottonwood canopy.

(iii) Changes in substrate conditions

The principal changes in substrate conditions occurring during stand development are due to the decreasing importance of the influence of the river in time as bar surface elevations increase, and inundation becomes less frequent. Sedimentation in forest stands may be confined to the deposition of silt on the falling stage of floods. Organic matter depth increases as the canopy and understory develop, particularly when canopy mortality occurs. Reflecting this increase in decaying plant material is an increasingly acidic pH (Table 5). However flood disturbance disrupts the process of soil development by both eroding bar surfaces and mobilising sediments, and by depositing coarse sediment on bar platforms, burying silt and organic layers. Human disturbance at the sampled sites is sufficiently small scale to have had apparently little impact on soil development, although logging will reduce the cohesive properties of the bar sediments, and may lead to increased rates of erosion at the margins of the bars.

CHAPTER 5. BOTANICAL EVIDENCE OF BAR SURFACE AGE AND STABILITY

Bar surface age on one mid-channel bar at each field site is inferred from stand age. Stand ages were determined from dendrochronological evidence of the age of the largest tree. The bars were selected to represent a range of sizes, ages and stabilities. Stand morphology is used as additional evidence of bar stability. The validity of this botanical and dendrochronological evidence is tested using the aerial photographic record (Figures 21 to 25).

5.1. Peter's Island

On the sampled bar at Peter's Island (Figure 6) the age of the largest cottonwood is 20 years, and this is taken as the age of the stand. The stand has a diverse, yet sparse understory that includes coniferous seedlings. Both cottonwood and red alder are found in the canopy, with cottonwood as the dominant species. Stand density is particularly low suggesting flood damage, and deposits of sand burying the understory at the bar head are evidence of inundation.

The aerial photographic record for the site (Figure 21) confirms the stand age of 20 years. On the 1943 air photos no bar is seen, while in 1954 a sedimentation zone is apparent, with no vegetation. Vegetation colonisation has begun by 1961, and in the period between 1961 and 1978 the stand developed its present form. Two chute channels are seen dissecting the bar on

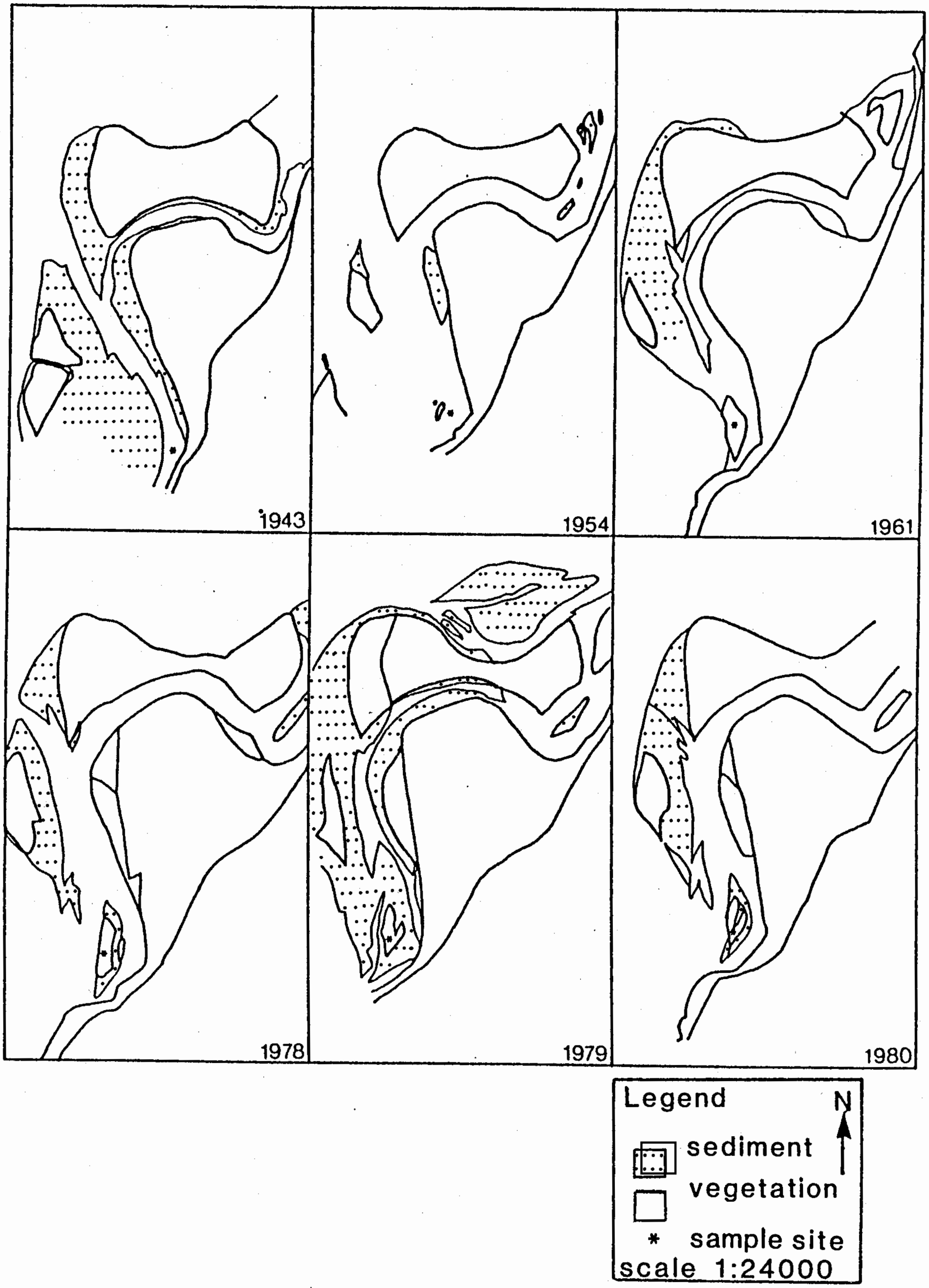


Figure 21. Bar development, Peter's Island
(source: British Columbia government air photographs)

the 1978, 1979 and 1980 photos, and are evidence of flood damage. By 1980 these channels were being revegetated, but still show the influence of erosion, and disturbance by flooding. Surface age at this site appears to be about ten years older than stand age.

5.2. Greyell Slough

The nature of the mixed stand on the selected bar at Greyell Slough (Figure 7) suggests a relatively stable substrate. A diverse understory is found beneath a canopy of cottonwood, cedar, hemlock, and red alder. The largest cottonwoods in the stand are decaying, and are 55 years old, and the largest cedar is 42 years old. The suggested stand age is at least 55 years. Younger red alder and cottonwood trees at the margins of the bar suggest that the stand has been disturbed by flooding or human activities, and indicate the mode of bar growth by successive deposition of sediments along the bar margins.

The aerial photographs confirm the stable nature of the upper bar platform (Figure 22). The 1928 photos show that the bar was much larger than at present, and was protected from erosion by surrounding bars, and mature vegetation is seen on the bar surface. Little change is apparent until 1954, when erosion at the bar head begins. By 1961 channels at the bar head, and on the north and south sides have widened. 1963 marks

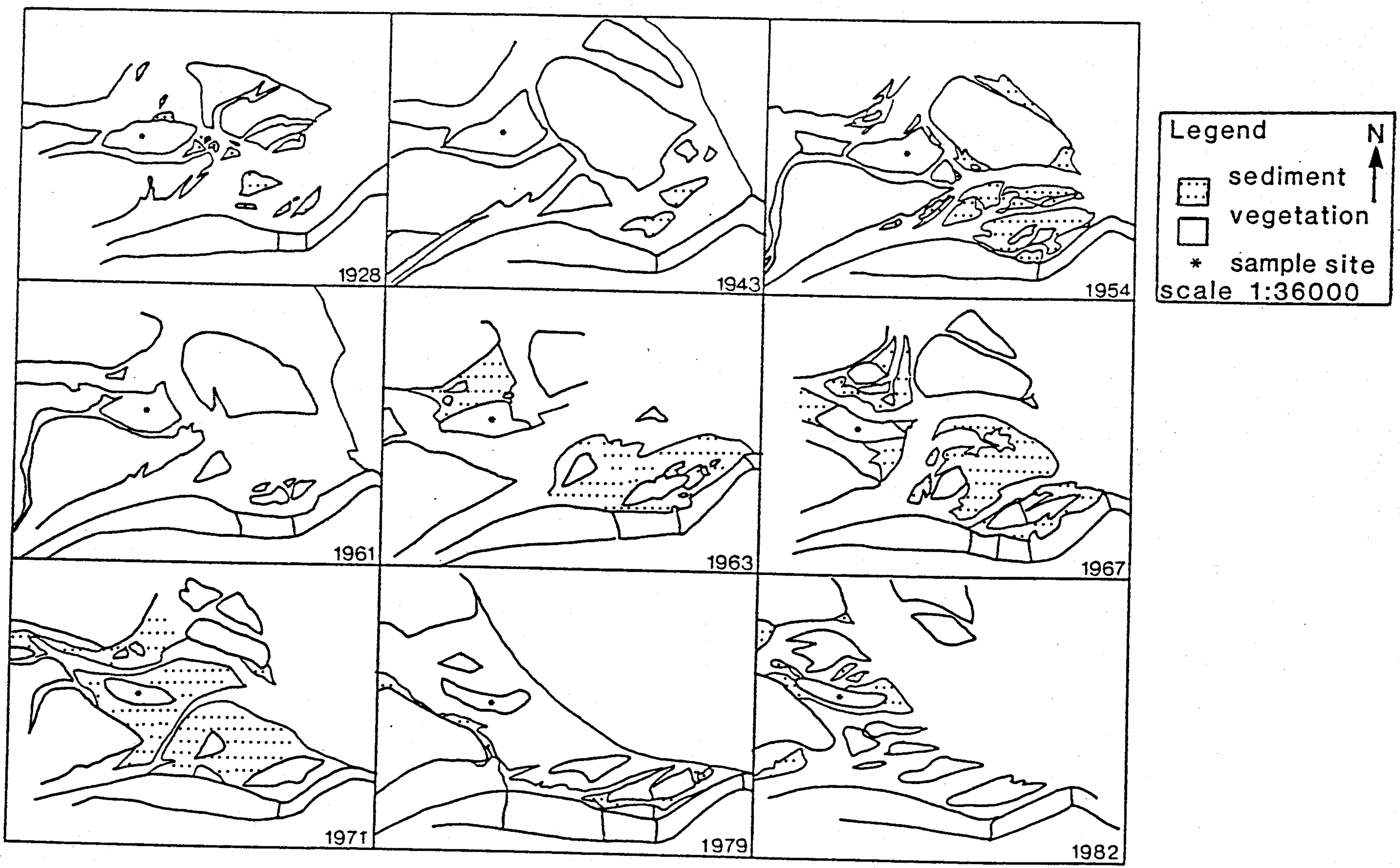


Figure 22. Bar development, Greyell Slough.
(source: British Columbia government air photographs)

the onset of logging of the main island bordering Greyell Slough, and although the stand remains unlogged some human disturbance is apparent at the field site. The 1963 photos also show that a large part of the stand has been eroded by a chute channel cutting through on the north side. Erosion continues from this time on, as channels enlarge, and is particularly severe on the northern margin, and at the bar tail.

Surface age cannot be determined from the air photos, because the bar is older than the photographs. Stand age probably underestimates surface age at this site, although it does provide a minimum age.

5.3. Carey Point

The cottonwood stands on the upper bar platform (Figure 8) are in the early stages of development. Cottonwood is the only species recorded in the canopy, and the largest trees on the bar are 22 years old.

The aerial photographs illustrate the development of this bar (Figure 23). From the beginning of the records until 1943 no bar was recorded, at which time the first trace of sediment appears on the photographs. In 1954 some young vegetation is recorded, but by 1955 the sediment is bare once more. Colonisation is seen on the 1961 photos, and a young stand has developed by 1966. The size of the bar has increased by 1973, and the young stand is evident. The 1979 photos show two stands

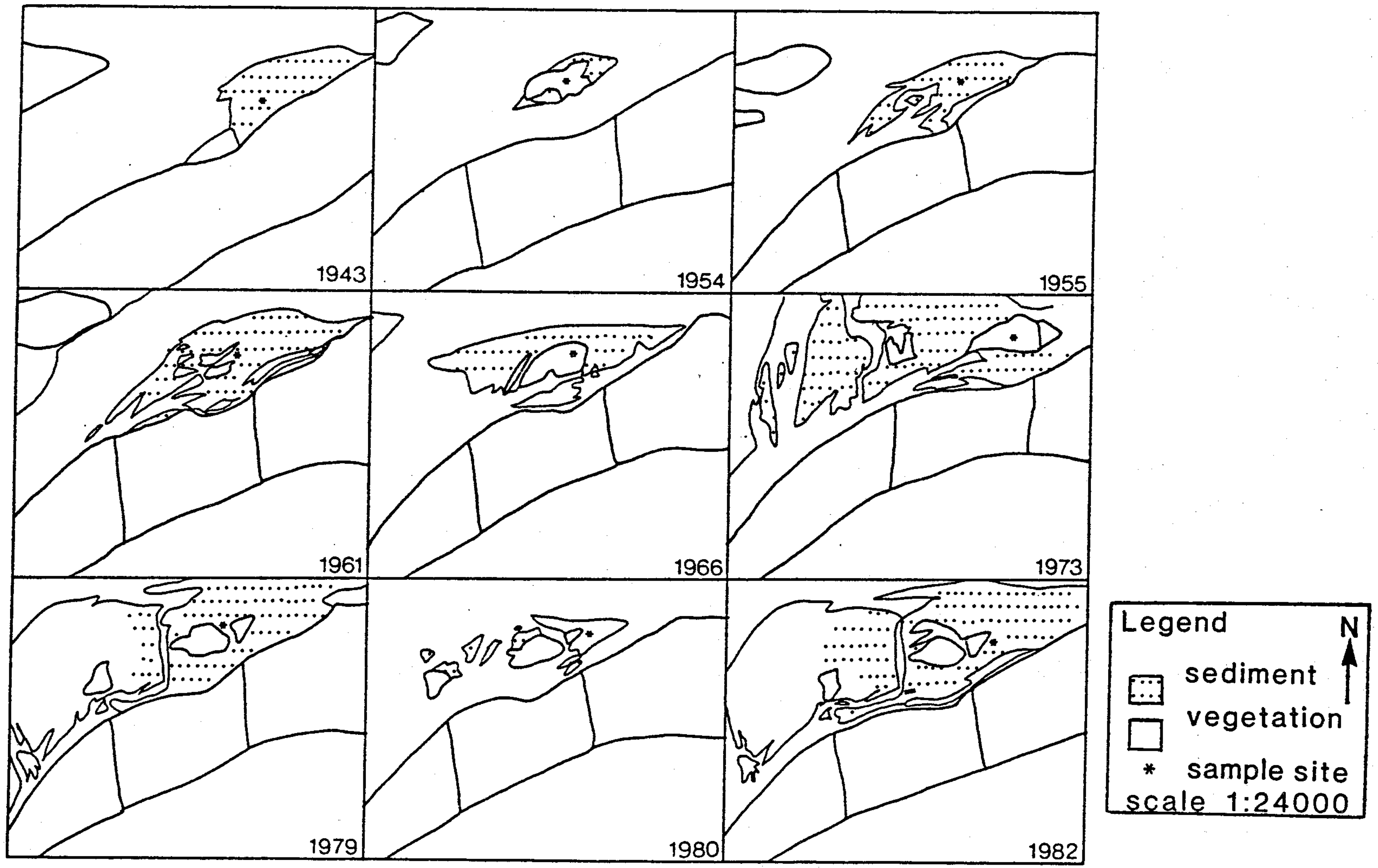


Figure 23. Bar development, Carey Point.
(source: British Columbia government air photographs)

separated by a chute channel in the centre of the bar. Dissection at the bar head is evident on the 1980 photos, and in 1982 two stands are seen, separated by a chute channel, with some colonisation taking place at the bar head and margins.

The stand age at the site provides an approximation of surface age. However, a time lag has to be allowed for the colonisation of new deposits by vegetation. If the bar surface is 22 years old, it would first appear on the 1961 photos. Stand age is shown to be accurately determined, but this provides a serious underestimate of surface age. The air photos show that the surface is at least 40 years old, and that a period of 20 years passed before vegetation successfully colonised the deposits. Establishment began in 1954, but vegetation had been destroyed by 1955. Successful re-establishment was initiated in 1961.

5.4. Dyke Road

The pioneer stands at the Dyke Road site (Figure 9) permit an assessment of the bar's stability. Pioneer vegetation on the bar is three years old. The aerial photographs (Figure 24) do not record a bar at this site until 1955. By 1966 a trace of sediment is recorded at the upstream end of the bar, but in 1967 no vegetation is seen. Scattered pioneer vegetation is seen on the 1973 photo, and similarly in 1979. Little change is recorded in 1980, and by 1982 pioneer vegetation is clearly established.

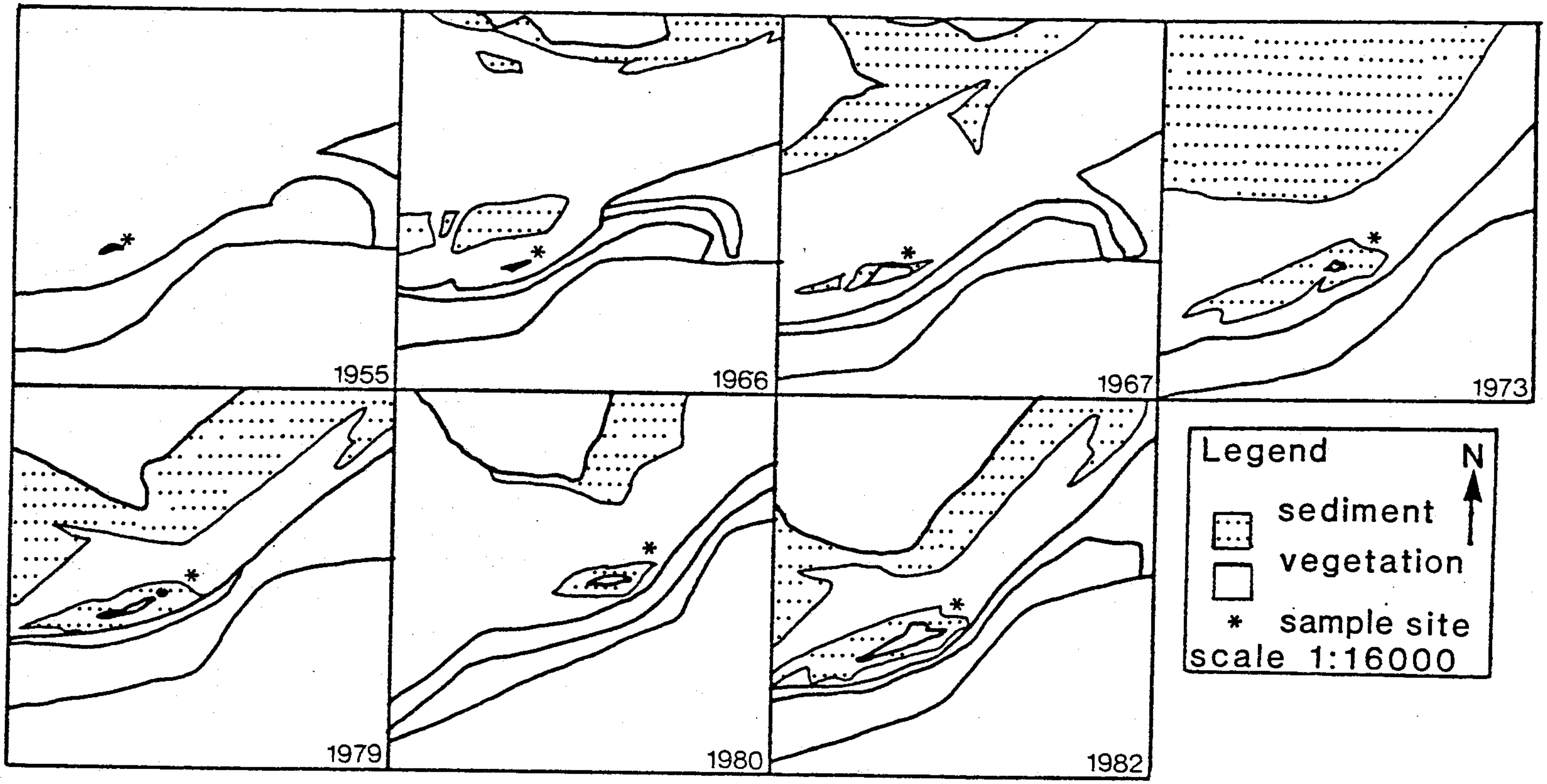


Figure 24. Bar development, Dyke Road.
(source: British Columbia government air photographs)

Vegetation ages on the bars would suggest that the bar is about 5 years old. However sedimentation began at this site 18 years ago, and there have been several periods of unsuccessful colonisation since then. The photos show that the current vegetation on the bar is correctly aged, but that this cannot give an accurate estimate of surface age.

5.5. Queen's Island

The cottonwood stands on the upper bar platform at this sample site (Figure 10) are of mixed species composition and species age. Red alder and willow are found in the canopy with cottonwood, and suggest disturbance by flooding and by human activities. The age of the oldest cottonwoods is 42 years.

The 1928 air photos (Figure 25) show the bar in its present position, with a well developed forest stand on it. The bar remained stable for up to 20 years. On the 1954 photos a chute channel has dissected part of the central bar, and the 1961 photos show that the head of the bar has been cut off by a chute channel. The 1979 photos indicate the generally stable location of the bar with new chute channels in the centre, and at the bar head.

The stand age of 42 years provides an inaccurate estimate of surface age. The bar is older than the aerial photographic records. Close examination of the vegetation reveals the influence of disturbance by flooding and logging. Flood damage

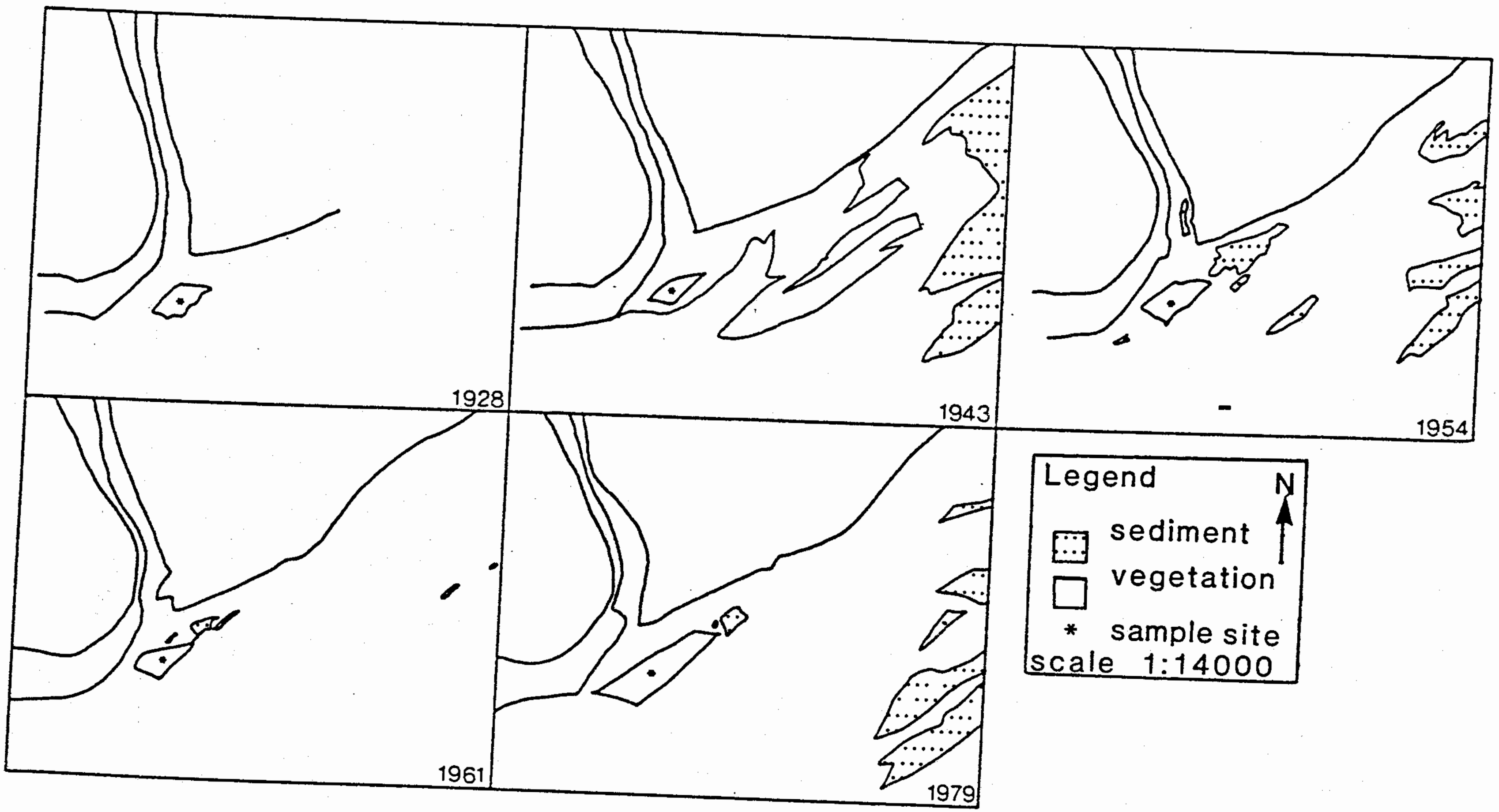


Figure 25. Bar development, Queen's Island.
(source: British Columbia government air photographs)

was apparent on the aerial photographs, but human disturbance was undetected until the stand was re-examined following sampling, by which time logs were exposed in a cut bank. This illustrates one of the problems of using botanical evidence to determine mid-channel bar development on a floodplain as easily accessible as that of the Fraser River.

5.6. Discussion

The validity of using botanical evidence to infer mid channel bar stability can be assessed from this comparison with the aerial photographs. Estimations of stand ages, including those made from the age-size relationship for cottonwood, are shown to be accurate. However it is clear that stand age does not give a direct estimate of surface age. The time lag for the colonisation of new alluvium showed great variability throughout the field sites.

Several factors influence the duration of this establishment phase. These include seed source, suitability of substrate, individual site elevation, and flood frequency and the duration of inundation. There is generally adequate seed produced by both cottonwood and willow during the freshet, and the ability of both species to survive on unfavourable substrates has already been discussed.

Elevation and its relation to flooding are the most critical determinants of successful colonisation. On several bars initial colonisation was unsuccessful due to the mobilising of substrate and vegetation. The frequency of floods of sufficient magnitude to set back succession in this way is high for the lowest elevation deposits in the Fraser River. This means that timing is critical for the establishment of seedlings. If they can reach a sufficient size in the interval between flood events, they may be able to withstand further flooding. No vegetation is free from the influence of infrequent severe floods, and this can destroy all, or part of a stand, and bar surfaces in any stage of development. The unstable regime of the Fraser River has significant influence on both bar and vegetation development, and reduces the usefulness of botanical evidence for inferring bar surface age.

Botanical evidence is of most use in determining stability subsequent to stand initiation. Stand ages permit the assignment of minimum ages to deposits, while stand composition and stand age structure allow speculation on bar development. The disruptive influence of flood events is clearly preserved in forest stands on the bars in the Fraser River, although the picture is complicated by human disturbance. Interpreted with caution botanical evidence is a valuable tool in inferring mid-channel bar stability. However in an unstable river channel it is not advisable to use stand age as direct evidence of the surface age of mid-channel bar deposits.

CHAPTER 6. SUMMARY

In this study vegetation succession on the mid-channel bars of the Lower Fraser River has been examined through a field survey of the species composition, age and environmental conditions of stands on the bars. The discussion uses the results of statistical analysis, and a summary of the field data to describe the processes operating in two developmetal stages, colonisation and stand development. A process orientated approach, rather than the traditional description of succession in terms of patterns and pathways has been used, because disturbance by flooding and logging along the reach precludes the classification of stands into discrete successional stages, and makes the identification of a predictable successional pathway unrealistic. The rate of successional change similarly is not deterministic, but depends upon the frequency and magnitude of disturbance events. The results of the study are summarised as follows.

Colonisation occurs on recent alluvial deposits of the mid-channel bars of the Fraser River. During high flows some of the stored sediments in the river channel are mobilised, transported, and redeposited to create new habitats. The habitats are usually of low relative elevation, and are inundated annually for several weeks. The substrate is usually gravel or sand.

Seed is dispersed to the bar surfaces by wind and by water. The most effective method of seed dispersal is during the freshet, and those species which disseminate seed in the spring are most successful at becoming established. Light bouyant seeds of indigenous tree species, such as black cottonwood and species of willows are left stranded on moist sediments of bar banks as flood waters recede.

Species adapted to the environmental conditions of the seed bed, that is to moist sand or gravel, germinate and become established. The results of a chi-square test indicate that the interactive effects of sediment texture and sediment depth are significant controls on species establishment. Establishment is most successful where the surficial sediment is sand rather than gravel, particularly where the sand is over 1 metre deep. Habitats with significant deposits of sand are most often bar tail sites. Many species are excluded until habitat conditions improve, and generally only seedlings of cottonwood and species of willow colonise bare sand or gravel. When surface elevation increases through continued deposition of sediment by the river, and the frequency and duration of inundation are reduced, species of herbs and grasses may become established beneath the tree seedlings.

Growth to a pioneer stand of saplings is rapid in the absence of competition. Cottonwood and willow may both reach heights of 5 metres in 5 years. Seedling growth is controlled by the river, which creates suitable habitat conditions, and supplies essential nutrients, and also by the substrate conditions. Analysis of variance indicates that species abundance is influenced by the interactive effects of sediment texture and sediment depth. Abundance is greatest on sand over a metre in depth, and in the upper vegetation class of cottonwood and willow saplings.

The processes of colonisation usually result in a pioneer stand of either black cottonwood, or mixed black cottonwood and willow saplings approximately five years after initial establishment on a mid-channel bar surface. However, both the nature and rate of colonisation are determined by the disruptive influence of floods. Pioneer species on the bars are adapted to regular flooding, which causes little mortality among seedlings that are well established.

Severe flooding however may set back colonisation in any stage. During species immigration seed may be eroded by flood waters, or surficial sediments may be waterlogged, reducing seed viability, and inhibiting germination and establishment. Seedlings may be buried by sedimentation and suffocated, or uprooted if the substrate is eroded, and once established they may be destroyed by abrasion and stem breakage, by burial or by erosion of bar surface. The vegetation which recolonises an area following flood damage is indistinguishable from that which was originally established. Due to the unstable nature of the Fraser River there may be several unsuccessful attempts before a pioneer stand is established, and can develop into a mature forest stand.

Habitat conditions within developing stands are generally more favourable than during colonisation. Surfaces may be up to a metre higher, and are consequently less frequently inundated. The probability of inundation decreases with stand age, from a 1-5 year recurrence interval for stands in the age range 18 to 24 years, to a 5 to 15 year recurrence interval for stands with a minimum age of 55 years. Such stands are submerged only for a few days at the peak of the freshet. Sand depths are generally over a metre deep, and sand may be overlain by silt and organic layers. However there is little true soil development, and the substrate pH reflects this.

The processes of stand development are not controlled by the Fraser River to the same extent as those of colonisation. Changes in canopy cover, the understory and substrate conditions are determined by autogenic processes as well as by floods and human activities. Developing stands form a complex mosaic, the nature of which is controlled by the intensity and frequency of disturbance.

In the absence of disturbance the canopy of pioneer cottonwood and willow stems closes, and species that are not adapted to shade are excluded from the stand. Willow is outcompeted by vigorously growing cottonwood, and cottonwood becomes dominant in the canopy. However pure cottonwood stands are exceptional on the bars. Willow that is significantly younger than the cottonwood canopy is often found in old chute channels. It recolonises the large gap left in the stand when the bar surface is dissected by the river, demonstrating that succession is set back by flood damage. Red alder like willow depends on cottonwood mortality for establishment, and occupies gaps left by the cutting of timber. Red alder does not become established following disturbance by flooding because it is not adapted to prolonged inundation, or the substrate conditions which prevail following severe substrate erosion. Large scale disturbance by logging is not a factor at the study sites, but replanting or cottonwood regeneration through clonal growth usually follow logging operations on the bars.

The occurrence of western red cedar and western hemlock in the canopy is restricted to the oldest stands, and it is suggested that following natural decadence of the cottonwood canopy small gaps in the stand are occupied by these species. Cottonwood cannot reproduce beneath a closed canopy, whereas the coniferous seedlings are shade tolerant. Western red cedar is the best adapted coniferous species to environmental conditions on the bars, growing well on the alluvial substrate, and suffering little damage by severe, episodic flooding. The stands are sufficiently elevated to be unaffected by most floods. Very little cedar is found on the bars along the reach, and it is found in association with hemlock, and also younger deciduous trees including cottonwood, willow and red alder. This suggests that the stands have been disturbed at some stage during their development by both flooding and human activities.

Changes in the density and mean basal area /hectare of stands reflect the changes in species composition, and the influence of disturbance. Frequent inundation may lead to suppressed development, and a low stand density, while where willows are found in the canopy following severe disurbance by flooding the stand may have a high density, and a very low mean basal area /hectare. The density of pure cottonwood stands, and those containing red alder are similar. Both species grow relatively densely, and increase in height rather than volumein competition for light. Where cedar is abundant in the canopy stand density is low, and mean basal area/hectare is high.

Changes in the understory are autogenically controlled to some extent. Tolerance of shade is critical in determining which species become established and grow beneath a canopy in different stages of development. Establishment is also associated with the substrate conditions in the stand as shown by the results of a chi-square analysis. The number of understory species is greatest where silt and organic matter layers are deepest. Although substrate conditions are most favourable in the oldest stands shade limits species establishment in the later stages of stand development. Analysis of variance indicates that factors other than the physical characteristics of the substrate influence the abundance of understory species. Species-species interactions, and species adaptations are probably of more significance. The development of the understory is also affected by external disturbances. Low occurrence is associated with flood damage, and some species may be particularly abundant in the understory in disturbed areas.

Changes in the substrate from sand and gravel, to sand overlain by silt and some organic matter, and an increasingly acidic pH occur as stands develop. However soil development on the bar surfaces is slow, and is disrupted by flooding. Silt and organic layers can be buried by the deposition of coarse sediment, and surficial deposits may be eroded. Although established trees usually prevent erosion of the bar platform except in chute channels, fine sediment on top of sand may easily be mobilised by high flows.

Stand development is disrupted by both flooding and by human activities on the bars, and sometimes it is difficult to determine which processes have been operating. The study shows that small scale cutting of timber may be more common on the bars than was at first apparent, and this illustrates one of the problems of working in an accessible area such as the floodplain of the Fraser River. Although human disturbance alters vegetation patterns on the mid-channel bars and complicates the interpretation of the processes of change, it is clear that the fluvial processes which create and destroy habitats, exert significant control on vegetation succession during both colonisation and stand development.

The magnitude and frequency of disturbance events not only disrupt the processes of vegetation succession on the mid-channel bars, but also reduce the validity of using stand ages to infer bar surface ages. The time lag between initial sediment deposition and colonisation is shown to be highly variable, due to the disruptive influence of floods in mobilising both sediment and vegetation. Disruption during the later stages of succession by flooding and human activities may lead to the mortality of the original canopy, and the establishment of younger vegetation in patches. This can provide a misleading estimate of bar surface age.

Stand composition and morphology may indicate bar stability, and provide a picture of bar development subsequent to colonisation, but detailed studies may be required to establish the exact nature of development on bars which have suffered disturbance from both flooding and logging. It is apparent from this study that on the mid-channel bars of the Fraser River stand age cannot be used as a reliable indicator of bar surface age, and that evidence of stand composition and morphology must be used with caution to infer bar stability and development.

APPENDIX I : POINT QUARTER DATA

Key
1 Black cottonwood
2 Red alder
3 Western red cedar
4 Western hemlock
5 Willow

Species				Distance (m)				Circumference (cm)			
1	2	3	4	1	2	3	4	1	2	3	4
				Peter's Island							
1	1	1	1	3.00	5.00	0.45	8.00	65.00	80.00	25.00	70.00
1	1	1	1	3.40	1.00	8.30	7.30	12.00	75.00	70.00	12.00
1	1	1	1	5.70	5.00	4.70	5.70	75.00	35.00	60.00	45.00
1	1	1	1	4.90	3.90	3.20	3.40	30.00	60.00	70.00	40.00
2	1	1	1	4.20	4.00	3.00	1.60	40.00	20.00	65.00	15.00
1	1	1	1	2.30	3.20	1.90	1.00	17.00	50.00	25.00	13.00
1	1	1	1	2.10	2.10	2.90	3.40	55.00	35.00	55.00	50.00
1	1	1	1	3.30	5.00	5.20	1.30	70.00	20.00	50.00	25.00
1	1	1	1	4.20	4.75	4.20	1.50	55.00	55.00	50.00	15.00
1	1	1	1	2.20	7.00	4.90	2.30	30.00	60.00	35.00	30.00
				Greyell Slough Stand 3							
2	2	2	2	2.80	3.20	2.40	1.60	15.00	15.00	15.00	22.00
2	2	3	1	3.50	2.50	1.50	2.60	20.00	25.00	44.00	75.00
1	2	2	2	2.00	1.95	2.00	1.50	170.00	15.00	15.00	12.00
1	1	3	1	2.60	6.00	2.00	5.50	35.00	185.00	115.00	70.00
1	4	1	1	4.20	2.50	3.00	1.20	85.00	90.00	80.00	35.00

Species				Distance (m)				Circumference (cm)			
1	2	3	4	1	2	3	4	1	2	3	4
				Greyell Slough Stand 4							
2	2	1	1	5.20	2.00	1.40	2.70	30.00	30.00	95.00	25.00
1	1	3	1	4.50	2.00	2.00	3.40	10.00	80.00	200.00	80.00
1	3	1	1	4.60	3.00	4.00	6.00	120.00	50.00	60.00	80.00
2	2	2	2	3.10	2.60	0.70	1.20	25.00	20.00	15.00	25.00
2	2	1	1	1.20	1.60	1.00	1.70	12.00	15.00	45.00	45.00
3	2	1	3	1.20	2.20	2.00	1.90	25.00	30.00	120.00	40.00
1	2	1	1	1.70	1.30	2.00	1.80	125.00	35.00	50.00	120.00
3	3	2	2	0.70	2.00	1.40	3.50	150.00	200.00	15.00	15.00
2	1	2	1	0.80	2.90	3.30	4.50	12.00	90.00	12.00	80.00
5	2	2	2	2.00	4.40	0.70	1.00	15.00	20.00	25.00	25.00
				Carey Point Stand 4							
1	1	1	1	1.60	2.65	2.85	3.10	15.00	30.00	11.00	25.00
1	1	1	1	3.60	2.10	0.95	0.40	90.00	30.00	10.00	82.00
1	1	1	1	1.00	2.40	1.90	0.60	34.00	60.00	25.00	35.00
1	1	1	1	0.30	6.00	2.90	1.00	50.00	40.00	50.00	75.00
1	1	1	1	1.00	1.30	0.80	1.20	30.00	30.00	50.00	25.00
				Carey Point Stand 5							
1	1	1	1	1.10	1.60	0.60	0.90	22.00	19.00	27.00	36.00
1	1	1	1	1.20	1.05	1.60	3.00	16.00	6.00	10.00	10.00
1	1	1	1	0.30	1.45	1.25	0.80	45.00	15.00	35.00	5.00
1	1	1	1	4.00	2.00	3.00	3.40	30.00	70.00	10.00	13.00
1	1	1	1	3.00	2.70	2.00	7.00	30.00	15.00	40.00	8.00
1	1	1	1	3.30	4.20	2.20	2.70	35.00	25.00	70.00	40.00
1	1	1	1	0.40	1.10	1.00	1.00	6.00	12.00	11.00	11.00

Species				Distance (m)				Circumference (cm)			
				Queen's Island Stand 4							
1	2	3	4	1	2	3	4	1	2	3	4
1	1	1	1	1.20	1.00	1.50	3.20	22.00	13.00	50.00	20.00
1	1	1	2	1.30	0.40	1.50	0.90	95.00	90.00	20.00	20.00
1	2	1	1	1.60	1.50	2.50	0.70	35.00	25.00	20.00	95.00
2	2	2	1	3.40	0.90	2.30	5.00	25.00	13.00	25.00	20.00
1	1	1	1	0.70	0.50	0.80	1.30	15.00	25.00	25.00	15.00
				Queen's Island Stand 5							
1	1	2	1	0.70	1.40	3.00	4.00	50.00	25.00	20.00	25.00
1	2	5	2	0.80	1.50	1.20	0.80	12.00	15.00	10.00	25.00
1	2	2	2	1.80	1.50	2.10	1.00	20.00	11.00	11.00	8.00
1	2	5	2	1.40	1.10	1.50	1.30	85.00	27.00	15.00	20.00
5	2	5	2	0.80	0.75	3.20	1.60	10.00	10.00	10.00	10.00

APPENDIX II : SPECIES PRESENCE AND ABUNDANCE

(a)

Species Presence and Abundance, and Sediment Characteristics in Pioneer Stands

Key Structural vegetation Classes

Classes	1	Bare alluvium
	2	Young pioneer stand
	3	Intermediate aged pioneer stand

Sediment texture

Classes	1	gravel
	2	sand-gravel
	3	sand
	4	silt

Species abundance is expressed as percentage cover.

Species Abundance in Pioneer Stands at Peter's Island

Species	Stand 1 Vegetation Class 1 Quadrat										Stand 2 Vegetation Class 2 Quadrat										Stand 3 Vegetation Class 3 Quadrat									
	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
Populus trichocarpa	1	3	1	3	1	20	30	20	1	20			20		20					30	3	35	75	55	30	40	50	5	50	50
Juncus vaseyi	1	3	1	3		1	2	3																						
Crepis capillaris	1	2													2			3	20	20										
Tanacetum vulgare		1																	1											
Cirsium Sp.		3												1	3	1														
Poa pratensis		3									10						20	10	2											
Lolium perenne		3																			5									
Leersia oryzoides		3			4			3	2	30																				
Salix Sp.			2		1					1	20		3	2	20					2	20	3	3		3	20	20	60	5	
Equisetum hyemale			3			1	20	20			10	5	20	10	30	20	30	80	75						2					
Plantago major						1	1		1							15	10		2	20										
Melilotus alba							1	1	1		3					2	10			5									20	20
Equisetum arvense								20	30	5		25	10	30	10	25				5					1					
Moss									50					70	90	70	40	30	10	10										
Lolium perenne											25			20											2					
Trifolium repens														25				10												
Trifolium procumbens														10																
Ranunculus acris															2															
Cerastium vulgatum																5														
Rumex acetosa																15														
Trifolium pratense																	15													
Crysanthemum leucanthemum																		3												
Aster conspicuus																												20		
Sediment texture (1-4)	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Sediment depth (cms)	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Species Abundance in Pioneer Stands at Greyell Slough

Species	Stand 1 Vegetation Class 2 Quadrat										Stand 2 Vegetation Class 3 Quadrat							
	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8
Populus trichocarpa	3	20	5	5		5	2				60	90	30	80	5	50	15	80
Solidago canadensis	1									5					2	3		
Crepis capillaris	1			1			1				2	1						
Plantago major	1														3			
Moss	1					40					20		75	5	30			
Meliolotus alba		20					20			5			1		10	5		
Poa pratensis		20	20			5	5				15				5	10		
Salix Sp.			5				20		5		3	3				10		
Juncus vaseyi								1										
Cirsium Sp.									5		3						1	
Tanacetum vulgare										1					5			
Equisetum hyemale											2	75	80	70			5	
Equisetum arvense												25	5	10				
Cerastium vulgatum												2						
Fragaria virginiana													5					
Anaphalis margaritacea															5			
Erigeron annuus															1			
Rubus ursinus															20			
Agrostis tenuis															10			
Sediment texture (1-4)	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3
Sediment depth (cms)	30	10	30	45	10	5	30	25	30	10	100	100	100	100	2	100	5	5

<u>Species Abundance in Pioneer Stands at Carey Point</u>

Species	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
Populus trichocarpa	2	3	2	3	3	3	2	3	2	2		1	1	10		5	5			10	50	10	30	10	20		50	5	5	5
Moss	20												5					5	20										60	60
Equisetum arvense		2		1						1												1	5		1	5		3	10	10
Crepis capillaris		1				1						1			1															1
Juncus vaseyi		2		2																								3	10	5
Fragaria virginiana				1																										
Leersia oryzoides						1	1		1	1																				
Agrostis tenuis						1		1		5		2	10		2	3		10	5		1			5						
Solidago canadensis													1			1														
Cerastium vulgatum																						2						2		3
Tanacetum vulgare																						1								
Salix Sp.																							3		5					5
Melilotus alba																							15				5	1		1
Equisetum hyemale																								1						5
Sediment texture (1-4)	3	3	3	3	3	3	3	3	2	3	2	2	1	1	2	1	1	2	2	2	3	4	3	3	3	3	3	3	3	4
Sediment depth (cms)	8	10	5	12	11	12	5	16	3	20	2	4			2						50	5	100	50	100	100	75	60	100	5

Species Abundance in Pioneer Stands at Dyke Road

Species	Stand 1 Vegetation Class 1 Quadrat										Stand 2 Vegetation Class 3 Quadrat				Stand 3 Vegetation Class 2 Quadrat						
	1	2	3	4	5	6	7	8	9	10	1	2	3	4	1	2	3	4	5	6	7
Populus trichocarpa	1	1	5		5	10	5			5	20	50	30	20	10	10	10	10	15	30	5
Agrostis tenuis		5					5		10												
Tanacetum vulgare					5																
Solidago canadensis									3												
Melilotus alba											50										
Equisetum hyemale											20	80	50	30	90	40	30	20	20	5	
Cornus stolonifera											10										
Rubus ursinus											5										
Lolium perenne											5										
Equisetum arvense											3	3				10	10	10	5	10	
Salix												5	5	50	20	15	10	20	10	30	20
Sediment texture (1-4)	1	1	1	1	1	1	1	1	1	1	3	3	3	3	3	3	3	3	3	3	1
Sediment depth (cms)											100	100	5	5	100	100	100	30	25	10	

Species Abundance in Pioneer Stands at Queen's Island

Species	Stand 1 Vegetation Class 1 Quadrat 1	2	3	4	5	6	7	8	9	10
Agrostis tenuis	10	5	5	5		10	20	10	5	10
Aster conspicuus			20				10			
Salix Sp.			3	5						
Populus trichocarpa									1	
Solidago canadensis										5
Leersia oryzoides										
Equisetum arvense										
Lolium perenne										
Sediment texture (1-4)	1	1	1	1	1	1	1	1	1	1
Sediment depth (cms)										

Species	Stand 2 Vegetation Class 2 Quadrat 1	2	3	4	5	6	7	8	9	10
Agrostis tenuis			3							10
Aster conspicuus										
Salix Sp.				2						
Populus trichocarpa	2	5	2	2	10	5		20	5	3
Solidago canadensis										
Leersia oryzoides										
Equisetum arvense										
Lolium perenne										
Sediment texture (1-4)	1	1	1	1	1	1	1	1	2	2
Sediment depth (cms)										

Species	Stand 3 Vegetation Class 2 Quadrat 1	2	3	4	5	6	7	8	9	10
Agrostis tenuis									10	3
Aster conspicuus						1		2	5	5
Salix Sp.	3		2	1	5		5	3	5	
Populus trichocarpa				2	5					5
Solidago canadensis									1	
Leersia oryzoides					1		1			
Equisetum arvense								5		
Lolium perenne								5	1	10
Sediment texture (1-4)	2	2	1	2	2	2	2	3	3	3
Sediment depth (cms)						5		30	18	8

(b)

Species Presence and Abundance and Substrate Characteristics in the Understory of Forest Stands

Key Structural Vegetation Classes
- 4 Mature cottonwood
- 5 Mixed cottonwood cedar
- 6 Cedar

Species abundance is expressed as percentage cover.

Species Abundance in the Understory at Peter's Island

Species	Stand 4 Vegetation Class 4/5 Quadrat									
	1	2	3	4	5	6	7	8	9	10
Equisetum hyemale	40	15	20	10	5	15	15	15	5	10
Cerastium vulgatum	5		5							
Aster conspicuus	3									
Grass	10		10	15	20		20	30	10	10
Solidago canadensis	5			1				2		
Moss	10		30	10			10	5	5	5
Alnus rubra		1		1	2					2
Centauria scabiosa		2		1	1					
Thuja plicata			2			3	1	2		
Tsuga heterophylla			1	2						
Crepis capillaris			5		3	3	3			
Hiercacium aurantiacum					2					
Populus trichocarpa						10		15	3	10
Trifolium repens						10			2	
Picea Sp.								1		
Silt depth (cm)		1	1	5	3	3	1	1		
Organic Matter depth (cm)										

Species Abundance in the Understory at Greyell Slough

Species	Stand 3 Vegetation Class 5 Quadrat					Stand 4 Vegetation Class 6 Quarat									
	1	2	3	4	5	1	2	3	4	5	6	7	8	9	10
Thuja plicata	10		30	2	20		30				50				
Rubus spectabilis		5	5		20										
Alnus rubra		2	5		5	40	20	10	20	20		20	20	50	50
Moss					10	10	20			30				20	
Populus trichocarpa					10										30
Polystichum munitum						1	2	2				10			
Acer circinatum								20	50	25				5	
Grass									5	2		5		5	
Salix Sp.														5	
Silt depth (cm)	30	30	30	30	30	10	10	30	30	30	5	30	30	20	20
Organic Matter depth (cm)	1	1	1	1	1	10	10	5	15	18	10	20	10	5	20

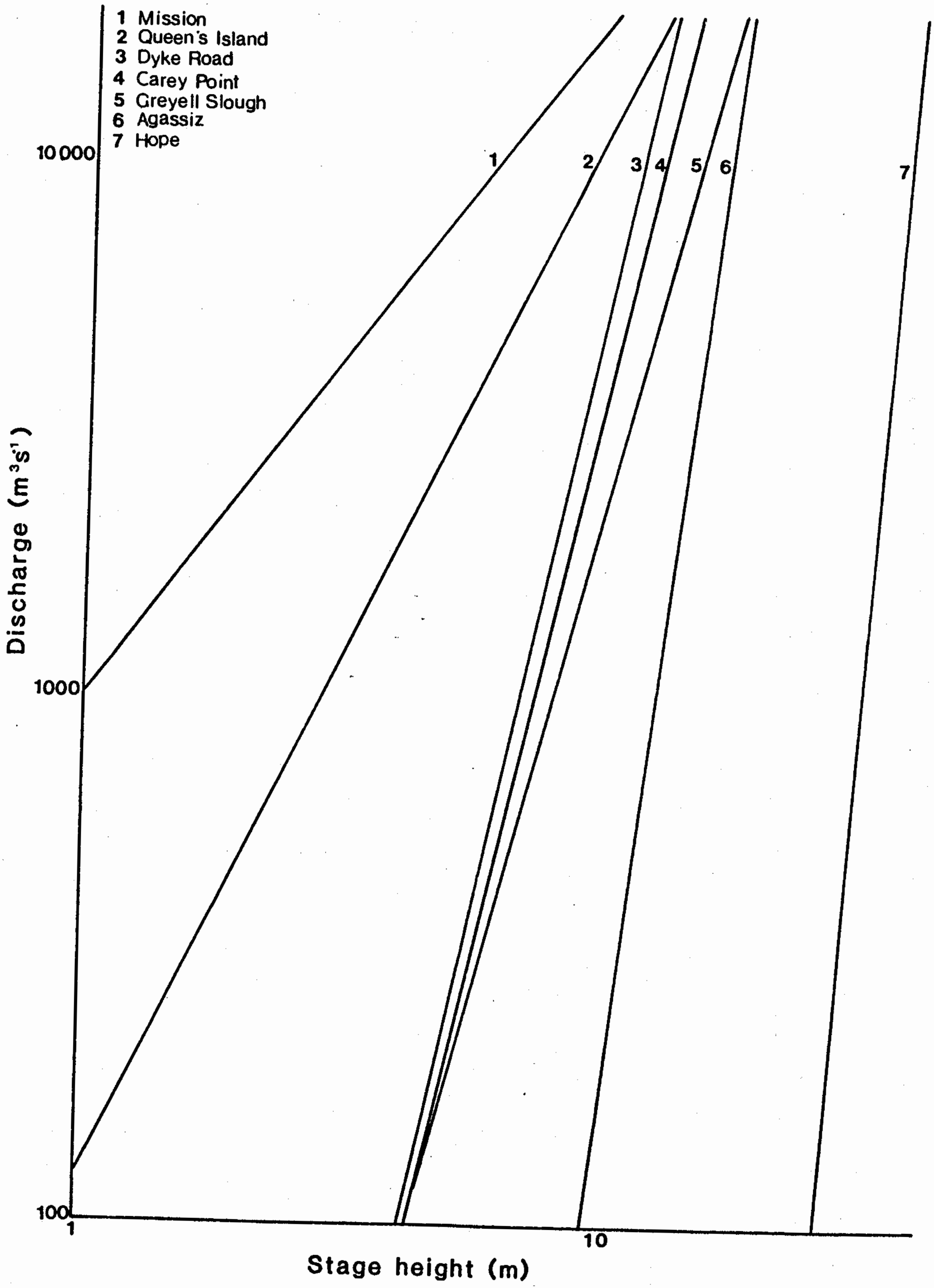
Species Abundance in the Understory at Carey Point

Species	Stand 4 Vegetation Class 4 Quadrat					Stand 5 Vegetation Class 4 Quarat						
	1	2	3	4	5	1	2	3	4	5	6	7
Equisetum hyemale	3	5	2	2	5			3				
Symphoricarpos alba	1			1								
Solidago canadensis	2				5	3		5				
Hieracium aurantiacum	2	1	1		3							
Agrostis tenuis	5				5	2	20	10		10		3
Cerastium vulgatum	2					1						
Rubus ursinus	5	10	5		2							
Populus trichocarpa	10	40	10	10	10						1	1
Moss	5	5	5	10						2	60	
Salix Sp.		5										
Galium triflorum			2									
Alnus rubra			30	10								
Melilotus alba								5				
Aster conspicuus								3				
Cirsium Sp.								1				
Plantago major										5	1	
Crepis capillaris											1	
Silt depth (cm)	10	5	10					10				
Organic Matter depth (cm)	20	3	10	1	2						1	

Species Abundance in the Understory at Queen's Island

Species	Stand 4 Vegetation Class 4 Quadrat					Stand 5 Vegetation Class 4 Quadrat				
	1	2	3	4	5	1	2	3	4	5
Alnus rubra	10		5	10	5	30			20	20
Populus trichocarpa	20	10	10	5	30	5	5	20		
Rubus spectabilis	10	5	1			5	5	5	50	30
Salix Sp.		5		10	20		40	30		20
Equisetum hyemale		3		2	2	5	3		3	2
Leersia oryzoides			10			1		3		3
Equisetum arvense			1	2						
Hieracium			10							
Grass										
Symphoricarpos alba									5	10
Vaccinium parvifolium									5	
Melilotus alba										10
Rubus ursinus										2
Silt depth (cm)			30	20		20	20	20	20	20
Organic Matter depth (cm)	2	1	10	1	2	1	4	2	2	5

APPENDIX III : FRASER RIVER FLOW DATA



(a) Stage–discharge relationships.

(b) Frequency of Occurrence of Maximum Average Daily Discharge for the Period of Record (1967-1983), Fraser River near Agassiz

Discharge (M^3S^{-1})	Average Number of days/year	Average Yearly Cumulative Frequency	Recurrence Interval (years)
3000-3999	28	111	
4000-4999	23	83	
5000-4999	21	60	1
6000-6999	15	39	1
7000-7999	13	24	1-3
8000-8999	6	11	3-4
9000-9999	2	5	4-5
10000-10999	2	3	5-10
11000-11999	1	1	5-15
12000-12999	1		
13000-13999	1		

APPENDIX IV : DENDROCHRONOLOGY

SITE (Stand)	SPECIES	CIRCUMFERENCE (m)	AGE (years)
Greyell Slough (3)	cottonwood	0.55	11
	cottonwood	0.19	5
	cottonwood	2.10	50
	cottonwood	1.10	27
	cottonwood	1.20	38
	cottonwood	0.75	27
	red alder	0.50	16
	cedar	1.75	42
	cedar	0.47	19
	cedar	0.70	20
	cedar	0.80	33
	cedar	1.17	38
	cedar	1.33	40
	cedar	1.43	41
	cedar	1.65	42
Greyell Slough (4)	cedar	1.48	34
	cedar	1.50	35
	cedar	2.00	55
	cedar	0.49	24
	cedar	1.37	40
	cedar	1.15	34
	cedar	1.38	35
	cottonwood	0.30	14
	cottonwood	0.68	17
	cottonwood	1.50	36
Carey Point (4)	cottonwood	0.90	21
	cottonwood	0.95	22
	cottonwood	0.35	5
Carey Point (3)	willow	0.16	3
	cottonwood	0.15	3
	cottonwood	1.15	25
Dyke Road (1)	cottonwood	0.13	3
Dyke Road (3)	willow	0.14	3
	willow	0.16	3
	willow	0.13	3
Queen's Island (2)	cottonwood	0.13	3
Queen's Island (4)	cottonwood	0.25	7
	cottonwood	0.55	11
	cottonwood		9
	cottonwood	1.70	42
	cottonwood	1.30	35
	red alder	0.30	5

APPENDIX V : OCCURRENCE OF SPECIES

(a)

Occurence of Pioneer Species.

SPECIES	MAXIMUM % COVER	MEAN % COVER	% OCCURENCE
Populus trichocarpa	90	11.5	67.6
Crepis capillaris	25	1.3	20.1
Juncus vaseyi	20	0.4	10.1
Tanacetum vulgare	10	0.2	5.0
Cirsium sp.	25	0.3	5.0
Poa pratensis	30	1.6	11.5
Lolium perenne	25	0.5	5.8
Leersia oryzoides	10	0.2	8.6
Salix sp.	60	3.0	16.6
Equisetum hyemale	90	6.8	22.3
Plantago major	20	4.0	6.5
Melilotus alba	50	1.8	18.0
Equisetum arvense	30	2.0	20.1
Trifolium repens	25	0.5	1.4
Trifolium procumbens	10	0.1	1.4
Moss	95	11.3	23.7
Ranunculus acris	2	0.1	0.7
Rumex acetosa	15	0.1	0.7
Crysanthemum leucanthemum	3	0.0	0.7
Aster conspicuus	20	0.5	5.8
Solidago canadensis	15	0.2	6.5
Alnus rubra	3	0.0	0.7
Centauria scabiosa	25	0.5	2.9
Cerastium vulgatum	5	0.1	3.6
Anaphalis margaritacea	40	1.3	8.6
Rubus ursinus	50	0.6	4.3
Erigeron annuus	1	0.0	0.7
Trifolium pratense	15	0.1	0.7
Fragaria virginiana	5	0.0	1.4
Agrostis tenuis	20	1.3	19.4
Cornus stolonifera	10	0.1	1.4

(b)

Occurence of Understory Species.

SPECIES	MAXIMUM %COVER	MEAN% COVER	%OCCURENCE
Equisetum hyemale	40	4.2	65.3
Cerastium vulgatum	5	0.3	8.5
Aster conspicuus	3	0.1	4.3
Solidago canadensis	5	0.5	14.9
Moss	60	6.0	40.4
Alnus rubra	50	9.4	56.5
Centauria scabiosa	2	0.1	4.3
Grass	30	4.9	40.4
Tsuga heterophylla	2	0.1	4.3
Thuja plicata	50	3.2	23.4
Hieracium aurantiacum	10	0.5	12.8
Trifolium repens	10	0.3	4.3
Crepis capillaris	3	0.1	2.1
Picea sp.	1	0.0	2.1
Populus trichocarpa	40	5.0	46.8
Rubus spectabilis	30	2.4	23.4
Polystichum munitum	50	1.8	12.8
Acer circinatum	20	0.8	10.6
Salix sp.	50	6.0	23.4
Symphoricarpos alba	10	0.3	4.3
Rubus ursinus	10	0.5	10.6
Galium triflorum	2	0.0	2.1
Meliolotus alba	10	0.2	2.1
Vaccinium parvifolium	5	0.1	2.1

APPENDIX VI : STATISTICAL ANALYSES

(a) Variables for Chi-square Analysis for Pioneer Species

Variable Name	Category Code	Category Name	Interval Range Greater than	Interval Range Less than or equal to
Vegetation class	1	Bare		
	2	Seedlings		
	3	Saplings		
Sediment texture	1	gravel		
	2	sand/gravel		
	3	sand		
	4	silt		
Sediment depth		Zero		1.0
		1-99	1.0	99.0
		100	99.0	
Species		Absent		1.0
		Present	1.0	

Variables for Chi-square Analysis for Understory Species

Variable Name	Category Code	Category Name	Interval Range Greater than	Interval Range Less than or equal to
Vegetation class	4	Cottonwood		
	5	Mixed species		
	6	Cedar		
Silt depth		Zero		1.0
		1-10	1.0	10.0
		10-30	10.0	
Organic matter		Zero		1.0
		1-5	1.0	5.0
		5-20	5.0	
Species		Absent		1.0
		Present	1.0	

(b)

Variables for Analysis of Variance for Pioneer Species

Variable Name	Category Code	Category Name	Interval Range Greater than	Less than or equal to
Vegetation class	1	Base/seedlings		
	2	Saplings		
Sediment texture	1	gravel/sand		
	2	sand/silt		
Sediment depth		present		1.0
		absent	1.0	
Species		abundance	0	100
		% cover		

Variables for Analysis of Variance for Understory Species

Variable Name	Category Code	Category Name	Interval Range Greater than	Less than or equal to
Vegetation class	4	Cottonwood		
	5	Mixed species/ cedar		
Silt depth		present		1.0
		absent	1.0	
Organic matter depth		present		1.0
		absent	1.0	
Species		abundance	0	
		% cover		100

APPENDIX VII : MAPS

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Plans of the Fraser River, Barnston Island to Yale.
1 in. = 400 ft.

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1 in. = 10 miles.

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Lower Fraser Valley.
1 in. = 1000 ft.

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British Columbia.
1 : 50000, 1 : 25000

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