Changes in Land Cover and Subsequent Effects on Lower Fraser Basin Ecosystems from 1827 to 1990

C. A. BOYLE
Civil and Resource Engineering
University of Auckland
Private Bag 92019
Auckland, New Zealand

L. LAVKULICH*
H. SCHREIER
E. KISS
Resource Management and Environmental Studies
436E 2206 East Mall
University of British Columbia
Vancouver, British Columbia, Canada V6T 1Z3

ABSTRACT / European settlement began in the Lower Fraser Basin (LFB) in western British Columbia in 1827 and has impacted the basin ecosystem in a number of ways, especially affecting the vegetation. Using previously published data, air photos, and other historical material for the area, estimates of land cover were made for the years prior to 1827 and for 1930 and 1990. The area of coniferous forest changed from 71% prior to 1827 to 50% in 1930 to 54% in 1990. However, prior to 1827, only 27% of the forest would have been immature (<120 years old), while 40% would have been immature in 1930 and 73% of the forest was immature in 1990. The amount of wetland area decreased from 10% to 1% of the study area while urban and agricultural area increased to 26% of the study area by 1990. The changes in land cover have had adverse effects on soil, water, and air quality; aquatic life; and plant and animal populations. Estimates of changes in net primary production and organic soil carbon suggest a decline over the past 170 years, although the latter rate of decrease has slowed since 1930. As human populations in the Lower Fraser Basin continue to increase, the quality of air, water, and soil will continue to decline unless measures are taken.

As part of the three year interdisciplinary research project on the ecosystem of the Lower Fraser Basin (LFB) at the University of British Columbia, one of the fundamental questions lay in defining the ecosystem structure and function as it existed historically and as it operates today. Human activity has had a significant impact on the land cover and has changed forest composition and age and wetland areas in many parts of the world. Our ability to change land cover has increased markedly in recent decades. Meyer and Turner (1992) indicate that between 1700 and 1980 there has been a 400% increase in cropland and an approximate 30% decrease of forestland, globally. The rate of conversion of land capable of producing biomass to urban development is also increasing. In a report edited by Turner and others (1993) on the topic of land use and global land-cover change, they state that, although land-cover changes occur on relatively small spatial scales of fields or small regions, these discrete changes have resulted in what they term as globally cumulative changes. Cumulative land-use changes have considerable impact on both the local or regional setting and linkages to the global systemic environmental changes. The relationships between deforestation, afforestation, agricultural development and the role of the terrestrial biosphere as a CO_2 regulator are poorly understood, yet of common usage in modeling alternative futures of global change. The significance of land-use cover changes as it relates to ecosystem composition and structure, nutrient cycling, and the distribution of nutrients, water, and contaminants between soil, air, and water has been the focus of several studies as reported by Houghton and Skole (1990) and Turner and others (1993).

As forest ecosystems are replaced with farms and urban landscapes, water, soil, and air quality usually degrade. Organic debris is no longer as abundant and, consequently, the organic and nutrient content of the soil begins to drop (Sedell 1990). Moreover, forest mammals, reptiles, and avians are displaced by species that thrive in open grassland conditions (Crow 1990). Streams are affected by the increase of eroded soil, causing the suspended solids level to increase, increasing the amount of silt on the streambed and affecting fish habitat (Schreier and others 1991). The loss of woody debris in the stream also reduces the amount of fish habitat and allows the stream to flow faster, increasing its erosion of banks (Sedell 1990). Loss of leafy debris affects the nutrient content of the water and,

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*Author to whom correspondence should be addressed.

consequently, the growth of aquatic organisms (Sedell 1990). Loss of shading also affects the stream temperature and, consequently, fish habitat (Schreier and others 1991).

With continued logging of forests, the forest ecosystem is also affected. The loss of old-growth forest decreases the mass of woody debris left on the forest floor and the amount of carbon stored by the ecosystem as well as the carbon in soil (Harmon and others 1990). Reducing woody debris, especially in size, also reduces the habitat available for vertebrates (Triska and Cromack 1979). Nutrients in the soil also decrease with continued logging activity (Boyle and others 1973, Aber and others 1979, Swank and Waide 1979). The large trees also store large amounts of water and nutrients internally, thus providing a buffer against environmental stress (Waring and Franklin 1979). The decrease of woody debris in forest streams also reduces the habitat available for aquatic organisms and directly influences the size of fish populations (Triska and Cromack 1979). Overall, continual logging has significant effects upon the forest ecosystem. Moreover, in areas where old-growth forest flourished, as in the LFB, hundreds of years are often required to regrow the forest. It is therefore important to consider forest age as a factor when examining human impact.

Although there is ongoing research to examine the state of ecosystems in the LFB, there has been no effort to link changes in land cover to present ecosystem conditions. Moreover, it is essential to understand what changes are occurring overall to ecosystems and ecosystem components (air, water, soil, biota) in order to understand possible future consequences of current human activities in the LFB. This paper will, therefore, examine changes in land cover (including forest age) due to human activity, and assess the effects of changes in land cover on water, soil, air, and biotic components of ecosystems in the LFB.

Methods

Study Area

The LFB lies in southwestern British Columbia, encompassing the Fraser Valley from Hope to Vancouver. The study area covers a region of approximately 828,000 ha along the LFB, from Vancouver to Hope, British Columbia (Figure 1) Population and industrial growth in the basin is among the most rapid in North America (Hutton and Davis 1991). However, growth is limited geographically due to the surrounding mountains and ocean and, consequently, the quality of the environment and the current way of life in the basin are threatened. The boundary of the area was selected to encompass the basin and the major towns and communities that comprise the lower mainland, excluding lands north of Lions Bay, Stave Lake, and Pitt Lake, since there are few communities in these mountainous regions. Those portions of the lower mainland watersheds that drain into the Fraser River were also included. It is recognized that the study area is influenced by and influences the surrounding areas by other factors such as atmospheric processes.

The elevation of the study area ranges from sea level to 1500 m, but the population is centered along the Fraser river floodplain where the elevation ranges from 1 to 175 m above sea level. The area consists of a low floodplain running west–east, bounded by mountains on the north and extending to the US border on the south. East of Chilliwack, mountains also limit the valley to the south. A total of 30 watersheds are contained in the region, five of which are larger than 100,000 ha. All have been extensively logged, developed, or cleared for agriculture and none are pristine (Moore 1991).

The majority of the study area is classified as lying within the Coastal Western Hemlock Biogeoclimatic Zone (BC Ministry of Forests 1988). Lower forested areas are classified as coastal temperate forest (Moore 1991) and include western hemlock (*Tsuga heterphylla*), western red cedar (*Thuya plicata*), Douglas fir (*Pseudotsuga menziessi*), balsam fir (*Abies balsamea*), Sitka spruce (*Picea stichensis*), and yellow cypress (*Chamaecyparis nootkatensis*), with black cottonwood (*Populus balsamifera*), alder (*Alnus rubra*), and willow (*Salix* spp.) growing in forested swamps.

Europeans first arrived in the Lower Fraser Basin in 1827, building and settling near Fort Langley. Although some clearing and planting of land took place near the fort, it was not until the 1850s and the gold rush that settlers began moving into the area. Dense forest, swampy lands, and hoards of mosquitoes slowed the settlement and development in the basin (Borden 1968, Perry 1984). Commercial logging was initiated in the early 1800s with the cutting of spars for ships (McCombs and Chittenden 1990), and the Vancouver area was logged until the 1880s, when the focus of the logging industry shifted to the east and north. Diking of the river banks, initiated in the 1860s, reduced flooding and allowed for agricultural development of the wet lowland areas, but it was not until the railway was built in 1885 that settlement increased dramatically in the basin (Roy 1966). Subsequent railways also provided transportation for logs and lumber to the Fraser and tidewater ports, enabling the logging industry to flourish in the basin (Porter and others 1995). A forest fire swept the area from the east of Langley to Matsqui Prairie in 1868

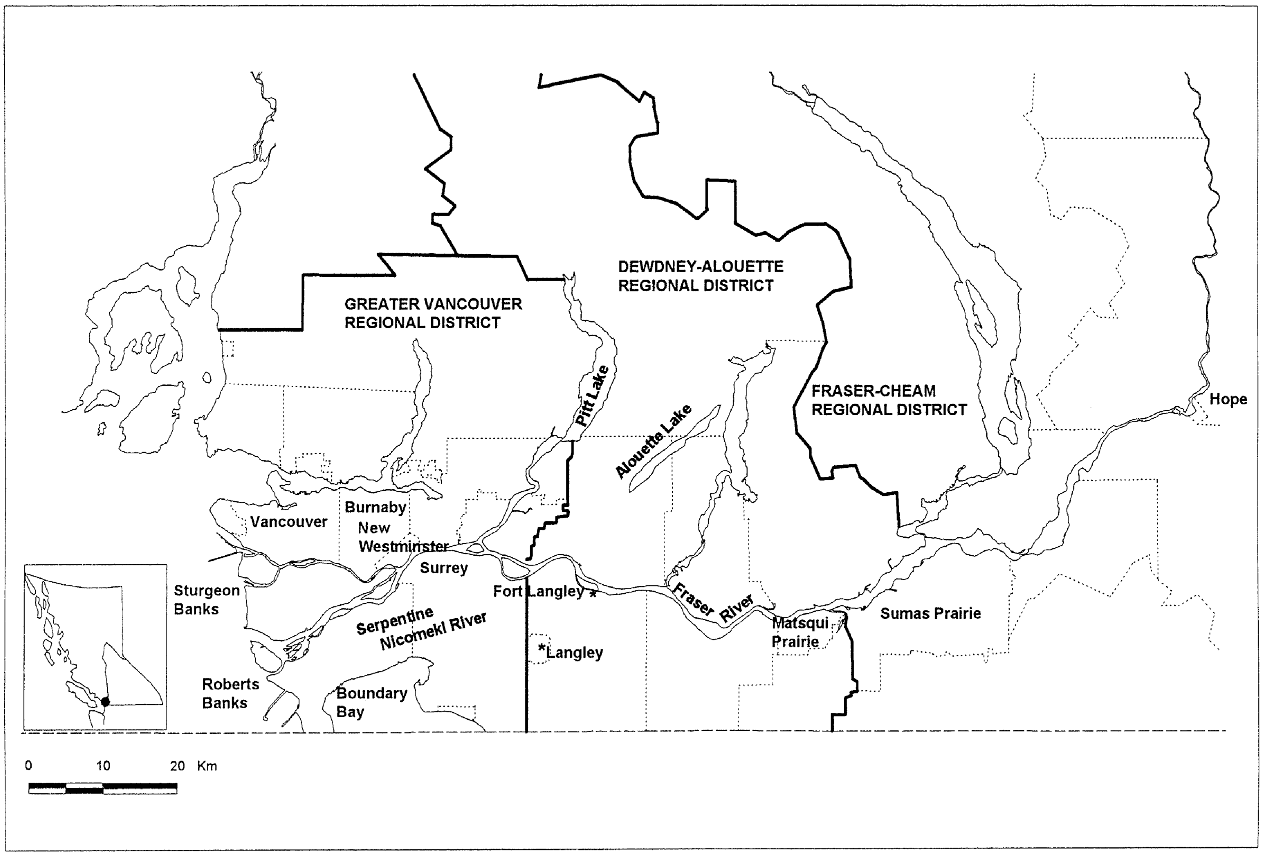

Figure 1. The study area, which covers the Lower Fraser Basin from Vancouver to Hope, south to the Canada–US border and north of Pitt Lake.

(Perry 1984), wiping out the old forest and resulting in the growth of a luxuriant, mixed forest. By 1930, logging was still continuing in the mountains in the north and east sections of the study area, and some large trees were still being found (McCombs and Chittenden 1990). A number of towns and small communities had been established, together with a flourishing agricultural industry. By 1990, urbanization had increased significantly as had agricultural activity in the Lower Fraser Basin, but logging still continued and stands of old-growth forest were rare.

Table 1. Land cover and descriptions

Land cover	Description
Coniferous forest	Primarily conifers with underbrush of deciduous brush
Deciduous/mixed	Deciduous species with some conifers
Fen	Sedges, growing in primarily or seasonally wet soils
Swamp/bog/marsh	Wet swamp, marsh or bog areas, including willows
Cleared	Cleared areas with no obvious subsequent use
Agricultural	Crop or pasture land
Urban	Buildings, urban areas

Estimates of Land Cover

The primary cover on land was defined as land cover and was classified into 10 types (Table 1). Land cover was determined for three time periods—prior to 1827, 1930, and 1990, which were examples of three important time periods for which information was also available. Since Europeans first settled in Vancouver in 1827, land cover prior to that year was considered to be primarily native. By 1930, much of the initial logging and settling of the area had been completed; moreover, sufficient information was available to determine the extent of land cover for that year. The final year, 1990, provided a view of the changes wrought by a modern society on the ecosystems of the area.

To reconstruct the pre-1827 land cover of the basin, Snell's method (1987) of examining current soil types to determine past land cover was used. A detailed, current soil survey of the area (Luttmerding 1980) was

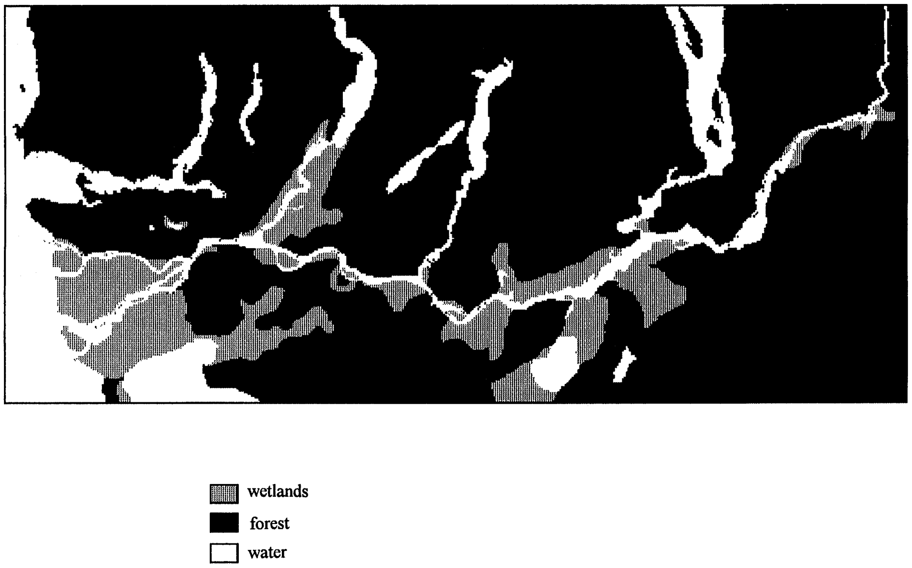

Figure 2. Approximate land cover for the Lower Fraser Basin prior to 1827.

correlated with descriptions and data from historical and other accounts. For example, soils classified as gleysols and organics were assigned to fens and swamps/marsh/bog according to their nearest equivalence as could be determined from data of North and others (1979), North and Teversham (1984), and Kelley and Spilsbury (1939). The Canadian Wetland Classification System was not used since wetland descriptions were insufficient to distinguish among classifications. Better drained podzolic, regosolic, and brunisolic soils were assigned to the various forest communities as described by Kelley and Spilsbury (1939), North and others (1979), North and Teversham (1984), and McCombs and Chittenden (1990). There were insufficient data to determine the forest types and changes with elevation; hence, only two forested communities were identified, coniferous forest and deciduous/mixed forest. Although extrapolation errors are inevitable, considering the geographical scale of the analysis and the accuracy of the historical data, reasonable estimates have resulted. The original configurations of Pitt Lake, Aloutte Lake, Stave Lake, Coquitlam Lake, and Sumas Lake were determined using maps of the New Westminster District (1905). Forest inventory data (Ministry of Forests personal communication 1994) also provided details on the percent of rock and alpine, river, and lake for the basin. These numbers were then extrapolated to the pre-1827 data. Any change in the rock and alpine area in the Basin since the 1820s due to climatic warming was considered to be insignificant.

An aerial photo mosaic from 1930 was used as the basis for the 1930 land cover, together with information from Kelley and Spilsbury (1939), logging accounts of the time as related by McCombs and Chittenden (1990), and available forestry inventory data (Forest Branch 1930). A Landsat photograph (Figure 2) was used as the basis for the 1990 land cover, together with forestry inventory data (Ministry of Forests personal communication 1994), a land-use map of the Lower Fraser Valley (Moore 1990), and an inventory of wetlands in the basin (Ward and others 1992).

The boundary for each land cover class was transposed onto a copy of the Landsat image for each of the three time periods and then digitized using Terrasoft (GIS software). Land-cover class areas prior to 1827, for 1930, and for 1990 were calculated using the digitized data. The approximate areas of each type of land cover were then calculated for each respective period.

Forest Age Structure

The ages of coniferous and deciduous/mixed forests prior to 1927 were estimated using historical accounts of forestry practices (Whitford and Craig 1919), discussions of average tree sizes (Whitford and Craig, 1919, McCombs and Chittenden 1990), and literature information on specific species size and age correlations (Long 1982, Franklin and Waring 1979). Franklin and Waring (1979) found that old growth forest had a broad range of ages, with the mean age being 400–425 years old and the range 75–550 years old. Accounts of tree sizes by Whitford and Craig (1919) indicate that the "ordinary" size of trees being cut on the coast at that time were 1–2.4 m diameter for red cedar, 1–2 m diameter for Douglas fir and Sitka spruce, and 0.6–1.5 m diameter for western hemlock. According to Franklin and Waring (1979), these represent size ranges for trees that would be 350–750 years old. Ratios of tree age in remaining pockets of old-growth forest today were also used to determine the ratios of immature (<120 years old) to mature (>121 years old) trees.

Prior to 1827, in addition to natural mortality, forest fires played the primary role in limiting the age of trees since there were few other factors that would kill abundant quantities of trees. Fires in the Coastal Wet Hemlock Biogeoclimatic Zone ranged from low to high intensity, with an average return interval of 150–300 years and an average fire size ranging from 50 to 500 ha. Pest damage would also have been a factor in the death of trees, but forests of the LFB are highly resistant to disease (G. F. Weetman personal communication 1995) and, consequently, pests would not have played a large role in the mortality of trees. Accounts of trees 3 m in diameter (Whitford and Craig 1919, McCombs and Chittenden 1990) tend to indicate that a number of trees were well over 750 years old.

To determine the ages of forests in 1930, accounts of logging in the valley (Whitford and Craig 1919, McCombs and Chittenden 1990), forest inventories for 1930 (Forest Branch 1930), and age inventories for today (Ministry of Forests personal communication 1994) were used to determine the area of immature and mature trees for that period. The Ministry of Forests (personal communication 1994) was able to provide some data on the ages and compositions of forests in the basin for 1990 but, since these were based on leading species in a 2-km polygon, the accuracy is questionable. However, it is sufficient to provide some indication of age and species in the Basin.

Effects on Ecosystem Components

Existing literature and ongoing research were used to assess the effects of changes in land cover on water quality and volume and air quality. Sufficient research has been completed on soil carbon in the LFB to be able to calculate the change in soil carbon since 1827. It is well known that soil organic matter (largely carbon) is one of the largest near-surface stores of carbon on earth and much of this is labile, as a result of soil processes, with a mean residence time of 32 years in contrast to a mean residence time of about three years for atmospheric carbon (Schlesinger 1995). Goldin and Lavkulich (1990), in a study of the effects of land clearing on soil organic matter in the central portion of the Lower Fraser Valley and adjacent Washington State, estimated a decrease in soil organic matter (58% carbon) of about 20% (about 12% carbon) after a mere 35 years of cultivation.

One can estimate conservatively the amount of carbon lost from the soil in the basin as a result of change in land cover, assuming a mean value of 125 g/kg of organic matter or 72.5 g/kg organic carbon for forested soils (Goldin and Lavkulich 1990), a loss of 20% organic carbon for agricultural soils, a further loss of 32% for urban soils (Anderson 1995), 600 g/kg organic carbon for wetland soils (Luttmerding 1980), and a mass of 3 million kg/ha of the 0.2-m depth of soil. Soils in areas that had been recently cleared were assumed to have lost no carbon.

Effects on Biota

One of the effects of changing land cover is the possibility of changes in net primary production (NPP). NPP provides some indication of the activity of an ecosystem and of the uptake of carbon by the system, important when considering local contributions to global warming.

No data on net primary productivity (NPP) could be found for ecosystems in the LFB, so values from similar ecosystems were used to provide estimates of NPP. According to Weetman (personal communication 1995) such measures had not been made for LFB forest ecosystems, so data quoted by Franklin and Waring (1979) and Long (1982) for forest communities similar to those found in the LFB were used. For five community types similar to those found in the LFB, NPP values ranged from 9.3 to 13.0, with a median of 11 mt/ha/yr (Franklin and Waring 1979). There appeared to be little difference between immature and mature trees once the canopy has closed (Long 1982), and Long (1982) points out that NPP in immature stands is accumulated as standing biomass while, in mature forests, an amount equal to the NPP is converted to detritus. Turner and Long (1975) found that NPP for young stands (<40 years old), prior to canopy closure, was almost twice the NPP of mature trees, with the peak NPP occurring just before closure at approximately 40 years. A value of 11 mt/ha/yr NPP was used for coniferous forest older than 40 years and 22 mt/ha/yr for those less than 40 years old. Deciduous forest NPP was estimated at 20 mt/ha/yr (Long 1982). Swamp and marsh NPP was estimated using data quoted by Bradbury and Grace (1983) at 6 mt/ha/yr (to include both above- and belowground biomass), while estimates of 3.7 mt/ha/yr for agricultural land and 0.5 mt/ha/yr for urban land (Klien-Goldewijk and Vloedbed, 1995) were used.

Changes in plant populations and aquatic life were assessed through existing literature and ongoing research. Discussions with BC Ministry of Environment, Lands and Parks wildlife biologist Bob Forbes (personal communication 1995) indicated that little is known about the size of the animal populations prior to European arrival in the basin, although species' presence and relative abundance could be identified through archeological evidence. Using the estimates of land cover prior to 1827 and a knowledge of specific animal species' behaviors, an estimate of the number of each animal species that would have occupied the valley were made.

Results and Discussion

Land Cover

Prior to 1827, the forests in the Lower Fraser Basin consisted primarily of coniferous stands on uplands and lowlands in the eastern portion of the basin with some stands of deciduous forest just west of the delta (Figure 2). Significant areas of fen would have existed in the delta and along the river, as would marshes, bogs, and swamp forests. Maple (*Acer macrophyllum*), alder (*Alnus rubra*), hardhack (*Spiraea douglasii*), willow (*Salix* spp.), rose (*Rosa* spp.), and crabapple (*Malus fusca*) trees grew in the drier sections of the fens (North and Teversham 1984). The major tree species found at that time would have been Douglas fir (*Pseudotsuga menziessi*), western red cedar (*Thuya plicata*), and western hemlock (*Tsuga heterphylla*) (Whitford and Craig 1919). Douglas fir would have predominated on the lower-elevation, drier soils, regenerating when forest fire swept through the area (Slaymaker and others 1992). Red cedar and western hemlock would have thrived in the wetter sites and on the lower slopes of the mountains. At higher elevations, mountain hemlock (*Tsuga mertensiana*) would have been able to withstand the cooler temperatures and coastal alpine tundra covered the tops of the North Shore Mountains and the Eastern Pacific Ranges. Approximately 7% of the study area was ocean, 6% was lake and river, and 5% was rock and alpine (Ministry of Forests personal communication 1994) (Table 2).

Table 2. Land cover for pre-1827, 1930, and 1990

Land cover	Pre-1820 Area (ha)	Pre-1820 Percent	1930 Area (ha)	1930 Percent	1990 Area (ha)	1990 Percent
Coniferous	590,800	71	412,000	50	445,800	54
Deciduous/mixed	8,200	1	71,800	8	4,000	0
Fen	56,000	7	5,500	1	2,400	0
Swamp/bog/marsh	27,100	3	10,800	1	9,700	1
Agriculture	0	0	81,100	9	132,100	16
Urban	0	0	25,000	3	86,300	10
Cleared	0	0	79,200	10	8,600	1
Rock/alpine	37,800	5	37,800	5	37,800	5
Lake/river	50,800	6	47,500	6	46,600	6
Ocean	57,500	7	57,500	7	54,900	7

Flooding along the Fraser River occurred during the spring freshet and resulted in large tracts of swampy or marshy land (North and Teversham 1984, Perry 1984). As a result, mosquitoes thrived, sufficient to discourage permanent human settlement even in the drier sections of the area (Borden 1968). According to early settlers, much of the forest was dense, making travel difficult (Perry 1984).

By 1930, much of the area had been diked, including Sumas Lake, and urbanization and agriculture had taken over much of the delta area and lowland near the Fraser River (Figure 3). The area from Langley to Matsqui Prairie was primarily mixed forest with about 10% agricultural activity. Agricultural activity in this area was otherwise located on the richer soils of the Serpentine and Nicomekl riverbanks and the diked fens of Matsqui Prairie and Sumas Prairie. Between Langley and the Fraser River about 50% of the area appeared to have been cleared for agricultural purposes. Most of Surrey was under agriculture, while Richmond and Vancouver had already been urbanized (Figure 3). Dams had been placed on Pitt Lake, Coquitlam Lake, and Stave Lake, affecting the area of open water.

Most of the Sitka spruce and yellow cypress had been removed from the basin by 1930 (McCombs and Chittenden 1990). Douglas fir, red cedar, and western hemlock still constituted the majority of the timber left but the predominantly Douglas fir forest of the low-lying areas had been almost completely cleared. Large clear-cut strips existed in the valleys to the north of the lowland. Sixty percent of the fires in the Vancouver area were now man-induced, although these caused only 40% of the damage (Forest Branch 1930).

By 1990, the amount of coniferous forest had increased and cleared area decreased as a result of reforestation polices implemented since 1930 (Ministry of Forests personal communication 1994), but forested area was still significantly lower than before 1827. The remaining forest was primarily located at higher elevations or in rugged territories (McCombs and Chittenden 1990), although some second-growth logging was being undertaken. Man-induced fires were still causing 60% of the fires in the area (Ministry of Forests 1991). The volume of wood of the major species of tree found in the merchantable (trees suitable for commercial harvesting) forests of the Lower Fraser Basin are listed in Table 3. Percentages of Sitka spruce and western red cedar were significantly less than before 1827, while the percentages of balsam fir and deciduous trees had increased from Whitford and Craig's estimations (1919). Much of this was due to the decrease in volume of other species, notably Sitka spruce. By 1990, 99.5% of the

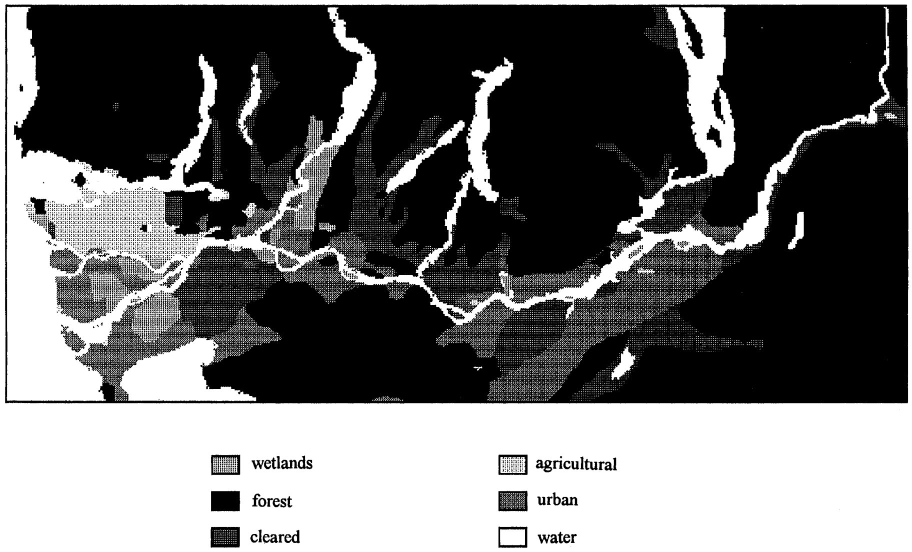

Figure 3. Approximate land cover in the Lower Fraser Basin in 1930.

Table 3. Estimates of percentages of tree species in lower mainland[a]

Species	Percent Pre-1827	1930	1990
Douglas fir	30	39	32
Western red cedar	28	33	8
Sitka spruce	6	0.6	0.01
Western hemlock	24	15	32
Balsam fir	9	8	15
Western white pine	0.5	2	0
Yellow cypress	2	0.7	0
Black cottonwood	0.2	0.5	—[b]
Lodgepole pine	—[b]	0.02	0.1
Other	0.7	0.1	12

[a]The estimates are based on merchantable volume data from Whitford and Craig (1919), Forest Branch (1930) and Ministry of Forests (personal communication 1994).

[b]Not reported individually so incorporated with "other."

Sitka spruce in the study area was less than 40 years old but the older 0.5% constituted all of the merchantable volume of Sitka timber.

Agricultural and urban land had increased to 26% of the study area by 1990 (Table 2)—almost all of the lowland along the Fraser River. The areas of fen and swamp/bog/marsh had decreased to 1% from 10% of the area.

Forest Age

In general, there has been a decline in mean tree age and forest age structure between 1827 and 1990 (Figure 4). In 1855 in the LFB (prior to logging activities), approximately 20% of the forest would have been less than 120 years old. Without human influence, mortality of trees from fire and disease (G. F. Weetman personal communication 1995) is low; thus it is likely that less than 5% were less than 40 years old prior to 1827. Approximately 40% of the forest in the study area in 1930 would have been less than 120 years old and 20% less than 40 years old.

In 1990, approximately 19% of the current forest in the basin was over 250 years old, with only 27% over 120 years old and 20% less than 40 years old. Many of the mountain tops were not logged and there were still areas of old-growth forest throughout the basin (Figure 5).

Soil

Approximately 125 $\times$ 10^6 tonnes of organic carbon (43%), mostly as CO_2, has been lost from the soils of the basin as a result of the changes in land cover (Figure 5). The rate of loss has slowed since 1930, however, as 88% of the loss (113 $\times$ 10^6 tonnes carbon) occurred prior to 1930.

Water Flow and Quality

Changes in water quality and volume from forestry practices have been reported, inducing increased flooding (Moore 1991); the loss or conversion of streams (Fisheries and Oceans Canada 1995); increased water temperature in summer months due to logging, clearcutting, and slash burning (Slaney and others 1977a,b, Brownlee and others 1988); and increased sedimentation of streams due to construction of logging roads (Slaney and others 1977b). No effects of land-cover changes on water nutrient levels have been detected

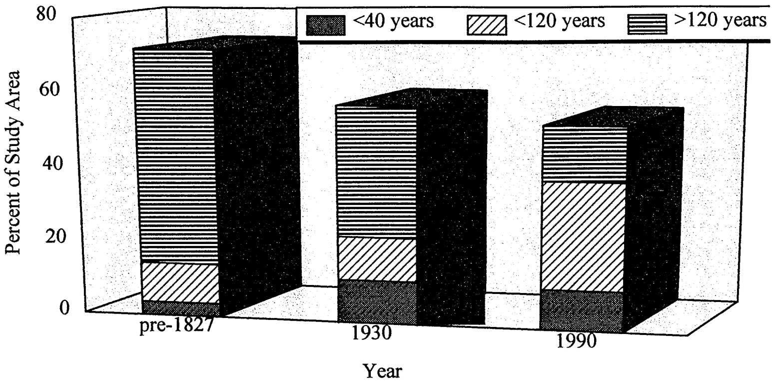

Figure 4. Changes in forest age and area in the study area.

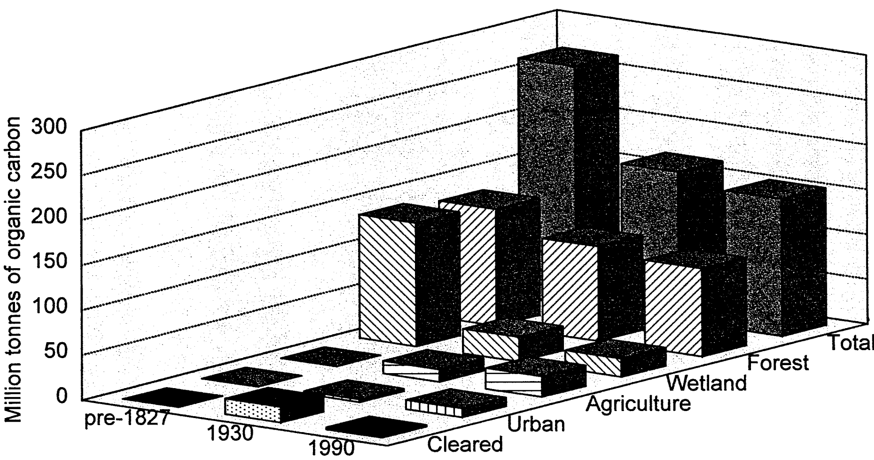

Figure 5. Estimated organic carbon in soils in the Lower Fraser Basin, pre-1827, 1930, and 1990.

from application of fertilizer to forests (Brownlee and others 1988).

Changes in water quality have also been documented with the development of forest and fen land for agricultural or urban purposes. Research on tributaries of the Lower Fraser River have indicated that application of chemical fertilizer and manure to agricultural land has resulted in contamination of ground- and surface water with nitrates (Lavkulich and others 1995, Ames and others 1995) above acceptable (10 ppm) levels. Nutrient loadings have resulted in fish kills in the Serpentine, Nicomekl, and Sumas rivers (Ames and others 1995), and applications of pesticides have caused several bird kill incidents (Environment Canada 1992). Diking of fens and marshes has resulted in the filling of back channels and vegetative encroachment, resulting in the loss of those streams (Slaymaker 1991) and their aquatic habitat.

Concentrations of cadmium, chromium, copper, nickel, lead, and zinc are high in sediments of the Lower Fraser River (Ames and others 1995). Discharges of liquid wastes from sewage treatment plants and industries in the Lower Fraser Basin have resulted in polycyclic aromatic hydrocarbons being found in sediments of the Fraser River, although in low concentrations due to the high flushing action of the river (Hall and others 1991). Metals have been found in high concentrations in sediments in tributaries to the Fraser River (Berka and others 1995, Hall and others 1991).

In addition to changes in water flow and quality, as much as 59% of the land surface may become impervious to water infiltration as a result of urbanization (McCallum 1995) in an urban watershed. A more conservative figure of 32% was estimated by Anderson (1995) for a typical urban–suburban development in the Lower Fraser Valley. Given an average 1500 mm of precipitation per year (Environment Canada 1992), with higher amounts at higher elevations, and assuming that 11% of the basin is now urbanized (Table 2), of which 30% is impervious to precipitation, an estimated 3.79×10^8 m^3 of water per year no longer recharges the soil or the underlying aquifers. Assuming water consumption in the Lower Fraser Basin at approximately 555 liters/capita/day (Environment Canada 1992), this would supply 1,900,000 people, more than the population of the LFB (Environment Canada 1992), with water

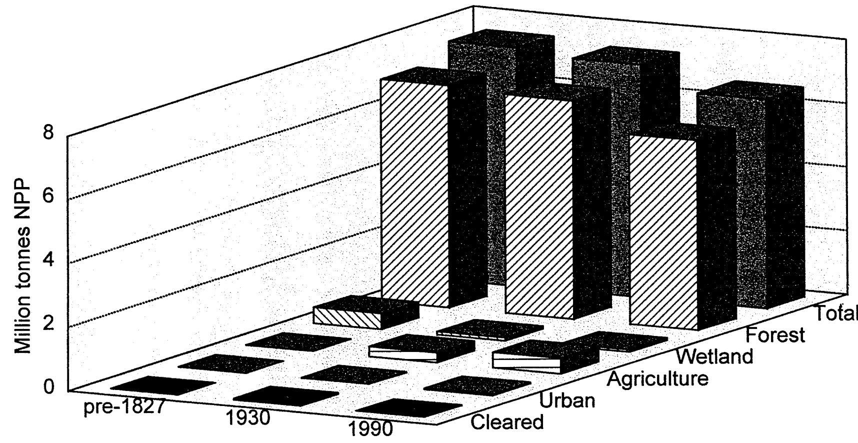

Figure 6. Estimated net primary productivity (NPP) of the Lower Fraser Basin, pre-1827, 1930, and 1990. NPP / ha for pre-1827 is 11.0 tonnes C / yr; for 1930 it is 10.7 tonnes C / yr, while for 1990, it is 9.5 tonnes C / yr.

for a year. Moreover, the excess water affects the discharge profiles of water courses in the basin, causing an increase in erosion of stream banks and increased sedimentation.

Air Quality

Little research has been done on changes in air quality due to changes in vegetation in the Lower Fraser Basin. The major changes in air quality have been due to urbanization, with higher levels of ozone, particulate metals, particulates, nitrogen oxides, sulphur dioxide, and carbon monoxide (Environment Canada 1992). Anthropogenic emission of carbon dioxide (Bovard-Concord Environmental 1994) and hydrocarbons (Bhattacharyya 1993) have also increased with increased burning of fossil fuels.

Effects on Biota

Net primary productivity. NPP / ha of the study area has decreased from about 11.0 to 10.7 mt / ha / yr over a hundred year period (0.03 tonnes C / ha decrease per decade) and to 9.5 mt / ha / yr over the past 60 years (0.2 tonnes C / ha decrease per decade), a loss since 1827 of 15% (Figure 6). This indicates a decrease in net primary productivity and, hence, CO_2 sequestering by the land cover from the atmosphere. The greater decrease in NPP / ha since 1930 is a result of the increase in urban area and agricultural land and the decrease in forested area.

Plant Species

In addition to the loss of plant communities, over the past 100 years approximately 5% of the native plant species have become locally extinct in the Lower Fraser Basin, primarily due to urbanization and clearing for agricultural purposes (Boyle and others 1995). Provincial parks and other protected areas have prevented the extinction of other rare species. Over the same period,

Table 4. Estimated populations of wildlife in valley in 1820 and today

	Estimated population	
Wildlife	1820	1995
Roosevelt elk	1000	0
Black-tailed deer	1000	6000–7000
Black bear	2000	500–600
Grizzly bear	200–300	0
Rodents / rabbits	thousands	thousands
Waterfowl	billions	506,600[a]

[a]Butler and Campbell (1987) as quoted in Environment Canada (1992).

the introduction of alien species has resulted in the replacement of native vegetation, with the result that 41% of all plant species in the Fraser Valley are now nonnative (Boyle and others 1995).

Animal Species

According to Forbes (personal communication 1995), with the loss of forested areas that are prime black bear habitat, the population of black bears decreased significantly (Table 4). Conversely, the population of black-tail deer has increased as areas were drained and cleared for agriculture and pasture. Both Roosevelt elk and grizzly bear have been extirpated from the basin due to ecosystem changes, and the waterfowl population has diminished as wetlands have been lost. Rodents and rabbits that thrive in both wild and urban settings have probably not significantly changed their numbers. Other species such as the spotted owl are also dependent upon old-growth forest, but there are few data to determine the actual numbers lost of these uncommon species.

Aquatic Species

The change in water quality and volume in the LFB has also affected aquatic biota. Slaney and others

(1977b) found that sedimentation of salmonid spawning gravel beds from logging road construction resulted in a 30% decrease in fry emergence, although increases in stream temperature from clear-cutting can have beneficial effects for salmonid fish habitat at higher elevations unless they exceed fish tolerance levels (Brownlee and others 1988). Reductions in wetland areas due to diking and riparian habitat have also significantly reduced salmonid fish habitat, and the decline in water quality has had a lethal or sublethal effect on salmonid fish and fish fry in the Lower Fraser Basin (Northcote and Burwash 1991). However, the effects of these changes on total salmonid population numbers in the LFB have not been determined.

High fecal coliform levels, reflecting the increased urban and agricultural land use, have resulted in the closure of Boundary Bay and Sturgeon and Roberts banks to bivalve harvesting since 1962 (Environment Canada 1992). In addition, heavy metals and organic contaminants, including chlorinated phenols, have been found in aquatic organisms in the Fraser River and its tributaries (Hall and others 1991). Sources of these contaminants include industrial effluents, sewage discharges, and storm sewer runoff. The effects of these contaminants on the viability of aquatic organisms have not yet been determined.

Conclusions

Land cover in the Lower Fraser Basin has changed significantly since Europeans arrived in 1827. Forested areas have declined, and there have been changes in species composition and stand age as a consequence of logging, an increase in fires, agricultural development, and urbanization. Diking the extensive wetlands and fens of the Fraser lowlands and clearing land for agricultural purposes have reduced both wetlands and lowland forests. Consequently, agricultural and urban areas have increased in the basin. The effect of these changes has been a decline in net primary productivity, soil organic carbon, and air and water quality with concomitant declines in terrestrial and aquatic biota. A number of native plant species are now extinct in the Lower Fraser Basin, while alien species have increased. Animal populations have also been affected, with some species becoming extinct locally.

The rate for most changes was greatest prior to 1930. However, as the human population in the Lower Fraser Basin continues to increase, human effects on the ecosystems will also increase, further degrading water and soil quality and affecting both aquatic and terrestrial life, unless measures are taken to further offset adverse effects on the environment and native species.

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