Cottonwoods in British Columbia Problem Analysis
Cottonwoods in British Columbia
Problem Analysis

by
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1 INTRODUCTION

1.1 Background

Black cottonwood and balsam poplar are the fastest growing trees in British Columbia and interest in their management has recently been renewed. In the 1950s and early 1960s, European success in managing hybrid poplars on short rotations drew considerable attention in the province; and several coastal forest products companies established hybrid poplar plantations, primarily at wide spacing to produce peeler logs for veneer and plywood (Smith 1957; Mahon 1966; Smith and Blom 1966, 1970; Smith and DeBell 1973; Smith 1980). However, abundant sources of relatively inexpensive softwood fibre for pulp, combined with low utilization and an abundance of native cottonwood, have kept demand down and hardwood prices low.

More recently, interest in cottonwood has arisen once again. This problem analysis was initiated by the Ministry of Forests in response to a number of proposals it received for cottonwood research. The overall objective of the analysis was to summarize our current state of knowledge of cottonwood and hybrid poplar management, identify knowledge gaps, and recommend and prioritize research to acquire this information. According to the terms of reference for the contract, the specific objectives of the problem analysis are:

1. to assemble resource data on the amount, quality, distribution, and potential economic importance of cottonwood in British Columbia;
2. to describe the range of management regimes currently used and provide a summary of management options available;
3. to describe the potential impacts of cottonwood harvesting and management on other resource values; and, based on this information,
4. to summarize current cottonwood knowledge gaps and management problems, and recommend and prioritize research to be undertaken to address them.

1.2 Approach

We visited all Forest Regions in British Columbia to get direct input from operational personnel about cottonwoods and their management. We were particularly interested in surveying opinions about the potential for cottonwood management in the different Forest Regions, and in identifying the regional research requirements and priorities envisioned by operational foresters and managers. A questionnaire was circulated to interested parties before the meetings to give us a basis for discussion and to seek opinions relevant to the objectives of the project. The final stage of all these meetings was to ask each participant to identify the most important information gaps for cottonwood management, and to prioritize research requirements. Local information on cottonwood inventory, utilization, distribution, management, and integrated resource concerns was acquired at all these meetings and is included throughout this report. Where specific opinions or facts are put forward, personal communications are cited. Where statements are made without personal citation or published reference, they are the opinions of the authors. Through field trips in many of the Forest Regions, we familiarized ourselves with issues and ecosystems of local interest. A summary of meeting dates and locations and a list of all meeting participants and written submissions are included in Appendix 1. Written submissions of local management knowledge or priorities for research were also solicited, and a list of all written submissions received is in Appendix 2.

1.3 Cottonwood Literature Search

The second major area of work was a literature search of black cottonwood (Populus trichocarpa Torrey and Gray = Populus balsamifera ssp. trichocarpa) and balsam poplar (Populus balsamifera ssp. balsamifera). This literature compilation is included in a separate volume (McLennan and Marmias 1992). References relevant solely to the management of cottonwoods and hybrid poplars in British Columbia were acquired and are included, with personal communications and the authors’ experience with cottonwood, in this volume.
2 THE GENUS POPULUS

2.1 Evolution and Taxonomy

The genus *Populus*, with the willows (*Salix*), together make up the family of ament-bearing plants known as Salicaceae. *Populus* is believed to have originated in southeast Asia (Khosla and Khurana 1982) as are many temperate forest species. *Populus* leaf fossils are commonly found in geological strata representing what is termed the Arcto-tertiary Geoflora, which represents forests that dominated North America from coast to coast at a latitude of 70° north in the Cretaceous period and afterwards (Campbell 1926). Over 50 species of *Populus* have been described from leaf characters in continental shelf Eocene deposits (Berry 1917). The genus is now common throughout temperate latitudes and taxonomically is divided into several sections (Table 1). The two British Columbia cottonwoods, black cottonwood and balsam poplar, are both members of the section *Tacamahaca*, or "balsam poplars" (Weisgerber 1979). Trembling aspen, the other important member of the genus in British Columbia, belongs to the section *Leuce*.

<table>
<thead>
<tr>
<th>Section</th>
<th>Species</th>
<th>Geographic distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Algerios Duby</td>
<td>deltoides Bartr. ex Marsh</td>
<td>North America</td>
</tr>
<tr>
<td></td>
<td>deltoides var. occidentalis Rydb. (=sargentii Dode)</td>
<td>North America</td>
</tr>
<tr>
<td></td>
<td>fremontii Wats.</td>
<td>North America</td>
</tr>
<tr>
<td></td>
<td>fremontii var. wislizenii Wats. (=wislizenii Wats.)</td>
<td>North America</td>
</tr>
<tr>
<td></td>
<td>nigra L.</td>
<td>Europe, Asia, North Africa</td>
</tr>
<tr>
<td>Leuce Duby</td>
<td>adenopoda Maxim.</td>
<td>China</td>
</tr>
<tr>
<td></td>
<td>alba L.</td>
<td>Europe, Asia, North Africa</td>
</tr>
<tr>
<td></td>
<td>davidiana (Dode) Schneid.</td>
<td>northeast Asia</td>
</tr>
<tr>
<td></td>
<td>grandidentata Michx.</td>
<td>North America</td>
</tr>
<tr>
<td></td>
<td>sieboldii Miq.</td>
<td>Japan, Korea</td>
</tr>
<tr>
<td></td>
<td>tomentosa Carr.</td>
<td>Asia</td>
</tr>
<tr>
<td></td>
<td>tremula L.</td>
<td>Europe, Asia</td>
</tr>
<tr>
<td></td>
<td>tremuloides Michx.</td>
<td>North America</td>
</tr>
<tr>
<td>Leucoideas Spach</td>
<td>ciliata Wall</td>
<td>central Asia</td>
</tr>
<tr>
<td></td>
<td>heterophylla L.</td>
<td>southeast USA</td>
</tr>
<tr>
<td></td>
<td>lasiocarpa Oliv.</td>
<td>China</td>
</tr>
<tr>
<td></td>
<td>wilsonii Schneid.</td>
<td>China</td>
</tr>
<tr>
<td>Tacamahaca Spach</td>
<td>angustifolia James</td>
<td>North America</td>
</tr>
<tr>
<td></td>
<td>balsamifera L.</td>
<td>North America</td>
</tr>
<tr>
<td></td>
<td>cathayana Rehd.</td>
<td>northeast Asia</td>
</tr>
<tr>
<td></td>
<td>koreana Rehd.</td>
<td>Korea</td>
</tr>
<tr>
<td></td>
<td>laurifolia Ledeb.</td>
<td>Siberia</td>
</tr>
<tr>
<td></td>
<td>maximowiczii Henry</td>
<td>northeast Asia, Japan</td>
</tr>
<tr>
<td></td>
<td>simoni Carr.</td>
<td>Asia</td>
</tr>
<tr>
<td></td>
<td>suaveolens Fisch.</td>
<td>Asia</td>
</tr>
<tr>
<td></td>
<td>szechuanica Schneid.</td>
<td>China</td>
</tr>
<tr>
<td></td>
<td>balsamifera L. ssp. trichocarpa (Torr. and Gray) Brayshaw (= P.trichocarpa Torr. and Gray)</td>
<td>North America</td>
</tr>
<tr>
<td></td>
<td>yunnanensis Dode</td>
<td>China</td>
</tr>
<tr>
<td>Turanga Bge.</td>
<td>euphratica Olivier (= pruinosa Shrenk)</td>
<td>west and central Asia, North Africa</td>
</tr>
</tbody>
</table>
There is some confusion over the taxonomic status of black cottonwood and balsam poplar, and the following account is based on the work of Brayshaw (1965). During the most recent glaciation, *Populus balsamifera* retreated into two geographically disjoint populations, one south of the ice and west of the Cascades, and the other south of the ice but east of the Rocky Mountains. This geographic separation led to the slight morphological differences that now exist between black cottonwood and balsam poplar, but the separation was not long enough to evolve effective sterility barriers. Where the two groups came together in northeastern British Columbia, Yukon, and Alaska, they have interbred freely. They thus should not be considered as two species, but as one large, interbreeding species complex. Vierock and Foote (1970) reached the same conclusion after examining material from Alaska and Yukon. Looman and Best (1979) and Hulten (1974) also consider the two cottonwoods as members of one species. Hosie (1973) describes the two cottonwoods as separate species: balsam poplar as *P. balsamifera* L. and black cottonwood as *P. trichocarpa* Torr. and Gray. Hitchcock and Cronquist (1973), dealing only with black cottonwood, use the name *Populus trichocarpa* Torr. and Gray. This species status has been used throughout the literature for black cottonwood and, according to Brayshaw (1965), is based on specimens from widely separated geographic populations.

From the detailed local work of Brayshaw (1965) and Vierock and Foote (1970), black cottonwood and balsam poplar are now considered as subspecies of *P. balsamifera*, with four variants as described by Brayshaw (1978) and shown in Table 2.

**TABLE 2. Geographic ranges of subspecies and variants of *P. balsamifera* as described by Brayshaw (1978)**

<table>
<thead>
<tr>
<th>Cottonwood variety</th>
<th>Geographic range</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>P. balsamifera</em> ssp. <em>balsamifera</em> var. <em>balsamifera</em></td>
<td>NE B.C. to Atlantic coast</td>
</tr>
<tr>
<td><em>P. balsamifera</em> ssp. <em>balsamifera</em> var. <em>subcordata</em></td>
<td>across Canada but most common in west</td>
</tr>
<tr>
<td><em>P. balsamifera</em> ssp. <em>trichocarpa</em> var. <em>trichocarpa</em></td>
<td>central and coastal B.C.</td>
</tr>
<tr>
<td><em>P. balsamifera</em> ssp. <em>trichocarpa</em> var. <em>hastata</em></td>
<td>Rocky Mountains and central B.C.</td>
</tr>
</tbody>
</table>

Brayshaw (1965) states that ssp. *balsamifera* var. *subcordata* and ssp. *trichocarpa* var. *hastata* are intermediate forms between the extremes expressed by typical varieties of the subspecies. In this report, the name “black cottonwood” is used to refer to the two varieties of the subspecies *trichocarpa*, and “balsam poplar” to the two varieties of the subspecies *balsamifera*. The geographic ranges of black cottonwood and balsam poplar are shown in Figure 1. In most cases, the two subspecies are considered together as “cottonwoods” throughout the report.

### 2.2 Hybrid Poplars

The creation of hybrid poplars within the genus *Populus* has been the focus of research efforts in many areas of the world. Hybrids are produced when plants of different species are cross-fertilized. Hybrids may occur naturally where ranges of two species overlap, or they can be induced artificially when pollen is introduced from one species onto the receptive flowers of the other. The objective of planned hybridization is (1) the creation of hybrid vigour, a term that describes offspring that grow larger and faster than either parent or (2) the recombination of desirable parental traits into hybrid offspring. Exceptional hybrid vigour has been demonstrated when certain *Populus* species are crossed (Stettler and Heilman 1984; Heilman and Stettler 1985a, 1990; Weber *et al.* 1985). Because cottonwoods are very easy to regenerate vegetatively, the promising genotypes created (often after a large number of crosses and selection within cross-offspring arrays) are easily cloned and used. Another positive aspect of the potential of hybrid poplars in forestry is short rotations, so that new silvicultural and genetic developments can be incorporated relatively rapidly. Furthermore, many traits of commercial importance (e.g., growth rate, susceptibility to pests and pathogens, branching habit, and desirable wood characteristics) are under strong genetic control, and can therefore be manipulated by selection and breeding techniques.
FIGURE 1. Geographic distribution of black cottonwood and balsam poplar in British Columbia. The dashed line represents the approximate boundary between the two distributions—balsam poplar to the northeast and black cottonwood to the southwest (adapted from Krajina et al. 1982).

Poplar breeding has a long history in Canada and hybrids have been created for shelterbelts, plywood and match stock, and pulp (Heimberger 1958). More recently, a very active program breeding poplar hybrids for the production of poplar pulp on abandoned farmland has taken place in eastern Ontario (Zsufta et al. 1977; Barkley 1983; Ontario Ministry of Natural Resources 1983; Boyson and Strobl 1991). The United States also has a long history of hybrid poplar breeding, especially in the southern and north central regions, using hybrids between P. deltoides and other species. Most relevant to British Columbia forestry is recent work carried out on black cottonwood crosses with eastern cottonwood in Washington (Heilman and Stettler 1985a; Weber et al. 1985). Because of its rapid juvenile growth and relatively low nutrient demands, crosses involving black
cottonwood have received a good deal of attention in Europe as well, and have resulted in the establishment of the International *P. trichocarpa* Provenance Trial (Weisgerber 1979). In fact, the first attempts to cross different *Populus* species to capture hybrid vigour involved black cottonwood in Ireland in 1910 (Henry 1914). At this time there are several commercially available black cottonwood—*P. deltoides* hybrids that have been developed in Holland and Belgium. Thus there has been keen interest in black cottonwood as a source of genetic material for hybrid poplar programs in many areas of the world. No breeding of hybrid poplars has been carried out in British Columbia, although Scott Paper Ltd. currently plants hybrids developed by the Washington program on its operational plantations. Preliminary screening trials of some of these hybrids have been carried out by Carlson.1,2

Another aspect of hybrid poplar breeding beginning to receive attention in British Columbia is the genetic engineering of “specialty trees.” The following summary is based on a submission forwarded by C. Douglas of the UBC Botany Department. The general process is to isolate the genes that possess the desired trait, transfer these genes to an already desirable genotype, regenerate the “transgenic” trees, and propagate them for testing. Cottonwood is better suited to this type of research than many conifers for several reasons: genetic maps for poplars have already been well researched by H. Bradshaw at the University of Washington (also discussed by Abelson 1991); transfer of genes using *Agrobacterium* has been shown to work in poplars; poplar tissue culture permits the regeneration of *Agrobacterium*-transformed cells (a process not yet possible for conifers); and easy vegetative propagation makes duplication and testing of desired genotypes much easier.

2.3 Information Gaps and Research Needs

A major portion of the range of black cottonwood is within British Columbia and, to date, very little of this genetic potential has been collected to create hybrid poplars. Limited collections have been made in south coastal British Columbia, primarily in accessible areas such as the Fraser Valley, and some of these have been tested in the Washington program (Heilman and Stettler 1985a; Weber et al. 1985) and in Europe (Weisgerber 1979). Weisgerber (1979) emphasized the small number of black cottonwood clones now used in Germany, and pointed out that a wider genetic base would provide greater long-term security for the hybrid poplar program there. Heilman and Stettler (1985a) made the same point: “With the demonstration of wide genetic variation in natural populations of black cottonwood, and with only a modest number of clones tested around the world, it seems unlikely that the growth potential of the species has been adequately evaluated.” In addition, balsam poplar has potential for creating promising hybrids that would be adapted to colder, more continental climates. The preliminary tests carried out by Carlson (pers. comm.) demonstrated that hybrid poplars now available are generally unsuitable for climates of all but a few of interior British Columbia environments.

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3 DISTRIBUTION AND INVENTORY

3.1 Assessment of Inventory Estimates

According to a 1991 estimate carried out for this analysis by Inventory Branch, over 96% of the mature volume of cottonwood in British Columbia occurs on Timber Supply Areas (TSAs) in the Prince George (78%) and Prince Rupert (18%) Forest Regions (Tables 3a, b). The unevenness of the distribution can be further seen in that 73% of the total volume for the province is located in TSAs 8 (Fort Nelson), 41 (Dawson Creek), and 40 (Fort St. John). As well, TSAs 4, 10, and 12 in the Prince Rupert Forest Region make a significant contribution to the provincial total, and much of this volume occurs on the alluvial floodplains of the Skeena and Nass rivers. Thus, the Cariboo (1.6%), Vancouver (1.2%), Nelson (0.76%), and Kamloops (0.75%) Forest Regions contain only a small part of the mature cottonwood volume in the province. The high proportions of cottonwood in the Prince George and Prince Rupert Forest Regions can be attributed largely to the fact that, in those Forest Regions, cottonwoods are common components of upland as well as alluvial landforms, whereas in other Forest Regions, cottonwoods are more or less restricted to alluvial sites.

The data compiled in Tables 3a and 3b for TSA lands represent mature volume only, and not the total volume of the cottonwood resource in the province. Table 3c is a compilation of 1974 data that show there were about 10 million m$^3$ of additional mature volume in other tenures. Assuming this volume has remained essentially constant (i.e., that harvesting on these tenures is low, and that succession from immature to mature stands balances mature cottonwood stands that change through succession into conifer types), it can then be estimated that there are about 50 million m$^3$ of mature cottonwood volume in British Columbia at this time.

TABLE 3a. Summary of mature (> 80 years) cottonwood merchantable (17.5 cm less decay, waste, and breakage to a 10-cm top) volume by TSA in the Prince George, Prince Rupert, and Cariboo Forest Regions

<table>
<thead>
<tr>
<th>TSA</th>
<th>Volume</th>
<th>TSA</th>
<th>Volume</th>
<th>TSA</th>
<th>Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>14 218 890</td>
<td>4</td>
<td>5 492 920</td>
<td>26</td>
<td>462 500</td>
</tr>
<tr>
<td>41</td>
<td>11 197 300</td>
<td>12</td>
<td>740 530</td>
<td>29</td>
<td>174 390</td>
</tr>
<tr>
<td>40</td>
<td>4 622 340</td>
<td>10</td>
<td>598 540</td>
<td>23</td>
<td>26 610</td>
</tr>
<tr>
<td>24</td>
<td>927 500</td>
<td>20</td>
<td>219 200</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>124 470</td>
<td>3</td>
<td>185 870</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>790 360</td>
<td>14</td>
<td>74 370</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>21</td>
<td>71 790</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>31 880 860</td>
<td></td>
<td>7 383 220</td>
<td>663 500</td>
<td></td>
</tr>
</tbody>
</table>

TABLE 3b. Summary of mature (> 80 years) cottonwood merchantable (17.5 cm less decay, waste, and breakage to a 10-cm top) volume by TSA in the Vancouver, Nelson, and Kamloops Forest Regions

<table>
<thead>
<tr>
<th>TSA</th>
<th>Volume</th>
<th>TSA</th>
<th>Volume</th>
<th>TSA</th>
<th>Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>33</td>
<td>174 920</td>
<td>5</td>
<td>144 110</td>
<td>22</td>
<td>133 710</td>
</tr>
<tr>
<td>19</td>
<td>146 670</td>
<td>2</td>
<td>56 050</td>
<td>11</td>
<td>114 690</td>
</tr>
<tr>
<td>31</td>
<td>68 530</td>
<td>13</td>
<td>42 350</td>
<td>18</td>
<td>52 740</td>
</tr>
<tr>
<td>39</td>
<td>57 810</td>
<td>7</td>
<td>26 560</td>
<td>15</td>
<td>25 660</td>
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<tr>
<td>30</td>
<td>25 930</td>
<td>9</td>
<td>19 720</td>
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<td>1 660</td>
<td>1</td>
<td>17 610</td>
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<td>38</td>
<td>920</td>
<td>27</td>
<td>6 900</td>
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</tr>
<tr>
<td>26</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>476 440</td>
<td></td>
<td>313 300</td>
<td>306 800</td>
<td></td>
</tr>
</tbody>
</table>
TABLE 3c. Summary (1974) of mature cottonwood (black cottonwood and balsam poplar) volume (thousands of cubic metres) by Forest Region and ownership/tenure status (Simons Strategic Services 1991)

<table>
<thead>
<tr>
<th>Forest Region</th>
<th>Crown land</th>
<th>Private land</th>
<th>Parks</th>
<th>Federal land</th>
<th>Region total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TSA</td>
<td>TFL</td>
<td>Temp.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cariboo</td>
<td>1 394</td>
<td>0</td>
<td>21</td>
<td>98</td>
<td>175</td>
</tr>
<tr>
<td>Kamloops</td>
<td>281</td>
<td>3</td>
<td>36</td>
<td>294</td>
<td>202</td>
</tr>
<tr>
<td>Nelson</td>
<td>566</td>
<td>22</td>
<td>67</td>
<td>333</td>
<td>11</td>
</tr>
<tr>
<td>Prince George</td>
<td>28 507</td>
<td>198</td>
<td>77</td>
<td>1 195</td>
<td>55</td>
</tr>
<tr>
<td>Prince Rupert</td>
<td>15 207</td>
<td>3 965</td>
<td>714</td>
<td>1 089</td>
<td>242</td>
</tr>
<tr>
<td>Vancouver</td>
<td>1 034</td>
<td>43</td>
<td>153</td>
<td>214</td>
<td>7</td>
</tr>
<tr>
<td>Totals</td>
<td>46 989</td>
<td>4 231</td>
<td>1 068</td>
<td>3 223</td>
<td>692</td>
</tr>
</tbody>
</table>

Taking mature volume as an estimate of the utilizable resource underestimates the cottonwood resource because cottonwood can be used at younger ages due to its rapid growth. Cottonwood for pulp and oriented strand board can be economically utilized on a 30-year rotation on the coast, and after about 40–50 years in the Interior. Tables 4a and 4b, using the same breakdown by TSA and Forest Region as Tables 3a and 3b, summarize the number of hectares of immature stands where cottonwood is the leading species. The data

TABLE 4a. Summary of area (ha) of immature (< 80 years) cottonwood (cottonwood is the leading species in the stand) by TSA in the Prince Rupert, Prince George, and Cariboo Forest Regions (B.C. Ministry of Forests 1991)

<table>
<thead>
<tr>
<th>Prince George</th>
<th>Prince Rupert</th>
<th>Cariboo</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSA</td>
<td>Area</td>
<td>TSA</td>
</tr>
<tr>
<td>8</td>
<td>54 373</td>
<td>4</td>
</tr>
<tr>
<td>24</td>
<td>6 022</td>
<td>10</td>
</tr>
<tr>
<td>40</td>
<td>5 488</td>
<td>12</td>
</tr>
<tr>
<td>41</td>
<td>4 455</td>
<td>21</td>
</tr>
<tr>
<td>10</td>
<td>6 643</td>
<td>20</td>
</tr>
<tr>
<td>17</td>
<td>182</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>14</td>
</tr>
<tr>
<td>Total</td>
<td>71 173</td>
<td></td>
</tr>
</tbody>
</table>

TABLE 4b. Summary of area (ha) of immature (< 80 years) cottonwood (cottonwood is the leading species in the stand) by TSA in the Vancouver, Nelson, and Kamloops Forest Regions (B.C. Ministry of Forests 1991)

<table>
<thead>
<tr>
<th>Vancouver</th>
<th>Nelson</th>
<th>Kamloops</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSA</td>
<td>Area</td>
<td>TSA</td>
</tr>
<tr>
<td>31</td>
<td>1 879</td>
<td>5</td>
</tr>
<tr>
<td>30</td>
<td>1 665</td>
<td>2</td>
</tr>
<tr>
<td>39</td>
<td>1 305</td>
<td>7</td>
</tr>
<tr>
<td>19</td>
<td>1 215</td>
<td>13</td>
</tr>
<tr>
<td>33</td>
<td>955</td>
<td>1</td>
</tr>
<tr>
<td>37</td>
<td>62</td>
<td>27</td>
</tr>
<tr>
<td>36</td>
<td>27</td>
<td>9</td>
</tr>
<tr>
<td>25</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>7 108</td>
<td>1 248</td>
</tr>
</tbody>
</table>
on immature area show approximately the same pattern as for the mature volume of cottonwood—that is, the majority is located in the Prince George (76%) and Prince Rupert (13%) Forest Regions. Given the low mature volume in the Vancouver Forest Region, there appears to be a relatively high (7.6%) coverage of immature cottonwood and this may reflect the higher utilization of cottonwood in that Forest Region than in the others.

It is difficult to estimate the volume contribution of the immature types from the data presented since volumes of cottonwood will vary with age and its contribution to the stand. If we assume that there are between 50 and 100 m³/ha of utilizable cottonwood in these immature types, and given a total immature area of 93 287 ha, then we can add between 4.5 and 9 million m³ to the provincial total. This would be a total 55–60 million m³ of utilizable cottonwood volume for the entire province.

From the comments we received in the meetings held in the Forest Regions, and during discussions with operational personnel, we to believe that the volumes of cottonwood listed in Tables 3a and 3b grossly underestimate the actual volumes that exist in the different Forest Regions in the province. For example, based on the data for the Vancouver Forest Region, there are about 500 000 m³ of mature cottonwood volume. Assuming there is at least this much again as immature volume, then there is an estimated total of about 1 million m³ of merchantable cottonwood volume in this region. However, Scott Paper calculates that there are about 500 000 m³ of utilizable cottonwood volume on the 5000 ha operating area of their Tree Farm Licence (TFL) alone (P. McAuliffe, pers. comm.). Much of this discrepancy can be attributed to a combination of unreliable decay, waste, and breakage factors, different utilization standards, poor information on per-hectare yields, and the inaccuracy associated with volume estimates when cottonwood is a minor component of the stands included. It appears, therefore, that Tables 3a and 3b should be interpreted as absolute minimum estimates. We would not expect the relative amounts of cottonwood to change, however, given a more precise estimate. Thus the data remain useful for determining the geographic distribution of the resource in British Columbia.

Even if accurate estimates of gross cottonwood volumes were available, much more detail about the resource is required for planning utilization facilities and rates of cut. In relation to a given utilization, it is important to know where the volume is located, what its diameter and age classes are, and the costs of delivering the wood to an existing or planned processing facility. Often these considerations are unique to a given geographic area. For example, most logging areas in the Fort Nelson Forest District can be accessed only in the winter, so transport is on ice roads and harvesting is restricted to a relatively short period from freeze-up to break-up. From various costs associated with cottonwood logging in the Fort Nelson area, a delivered wood cost of $17.74/m³ for peeler utilization has been estimated (Industrial Forest Services Ltd. 1991). (This assumes an economic hauling distance of 64 km, an operable area of 15,026 ha, and a total net cottonwood volume of 5 050 496 m³. These figures are under revision [G. Dolynchuk, pers. comm.].)

The age class distribution of the available volume is also an important consideration because of increased volume of decay with age, especially in cottonwoods. A deciduous timber supply analysis was carried out in the Dawson Creek TSA to plan long-term harvesting in the area (B.C. Ministry of Forests 1989). Based on industrial experience in Alberta, the 61–80 age class (age class 4) was determined to be the optimal age for pulp and oriented strandboard (OSB) utilization, with 90 years (midpoint of age class 5) being a maximum before decay percentage (> 20%) made harvesting uneconomical. After netting down, it was determined that there are about 300 000 ha of economically accessible area in the TSA, and of this total about 20–25% is in cottonwood cover types. The deciduous age class distribution in the Dawson Creek TSA is shown in Figure 2a, and it is evident from this figure that about half of the present volume is in age classes 4 and 5. Using growth and yield equations for the species, and assuming timber will be harvested at the long run sustained yield (LRSY), the analysis calculated a deciduous allowable annual cut (AAC) of 529 000 m³/yr (non- accelerated/ all; Figure 2b). However, if the resource is harvested at the LRSY, much of it will become unmerchantable due to overmaturity. For this reason, the analysis proposes changing the age class structure by cutting at a deciduous AAC of 1 000 000 m³/yr, declining to a projected higher LRSY of 728 000 m³/yr after about 70–90 years (accelerated/ all; Figure 2b). From these estimates, it is predicted that the utilization of cottonwood in the Dawson Creek TSA could increase to about 200 000–250 000 m³/yr for the next 70–90 years, and then decline to a LRSY of 150 000–180 000 m³/yr (accelerated/ Ac; Figure 2b).
FIGURE 2a. Age class distribution of deciduous volume in the Dawson Creek Timber Supply Area.

FIGURE 2b. Projected long-term cutting plans for all deciduous species ("all") and cottonwood ("Ac") in the Dawson Creek Timber Supply Area (B.C. Ministry of Forests 1989).
3.2 Information Gaps and Research Requirements

Given this analysis of the existing inventory of cottonwood, we believe that the present assessment of cottonwood inventory probably seriously underestimates the gross volume of utilizable cottonwood available in the various Forest Regions. The major reason for this inaccuracy is an historical lack of emphasis on the deciduous resource base, which is not surprising considering the size of the coniferous resource and the lack of markets or processing facilities for hardwoods. During the inventory process, few ground plots were located in deciduous cover types. This in turn led to the use of inaccurate decay, waste, and breakage factors, an underestimate of cottonwood yield (especially in those stands where it is only a minor component), and an underestimate of cottonwood growth, especially in the juvenile phase. Underestimates are also the result of cottonwood being included in not satisfactorily restocked (NSR) and non-commercial cover (NCC) inventory categories, and of the mature category used for conifers (80 years) excluding a large component of cottonwood volume that is merchantable before that time.

Although the actual amounts are largely unknown, it is evident from the data available that the Prince Rupert and Prince George Forest Regions have most of the cottonwood volume in British Columbia. It is therefore in these two regions that the potential for utilization and management of the species is greatest. The accuracy and usefulness of cottonwood inventory in all the Forest Regions is very much a function of regional interest in the potential utilization of cottonwood and other deciduous species.

The Prince George Forest Region has the best grasp of utilizable volumes of cottonwood within an economic distance of its major processing facilities. It should be noted, however, that the baseline information on which AAC planning in the Dawson Creek TSA is based comes from decay estimates in Alberta. It is assumed that these same relationships apply to the TSAs in British Columbia, but there is no evidence to support this. As discussed in Section 5.2.2, decay characteristics can vary appreciably in different geographic areas. This has important implications since major planning decisions on rates of deciduous cut depend on the accuracy of the information.

A more detailed cottonwood inventory is not technically a research requirement for cottonwood, but more reliable estimates must be acquired before the detailed planning needed to establish new utilization facilities can be carried out. Accurate decay and waste data for the different regions are a definite research requirement. This is discussed in Section 5.2.2.

4 WOOD PROPERTIES AND UTILIZATION

4.1 Physical and Chemical Wood Properties

Cottonwood is a low density, diffuse porous hardwood species and cannot be reliably differentiated from other Populus species according to wood properties (Kennedy 1968; Barker 1974; Kellogg and Swan 1986). Cottonwood heartwood has high water content and surrounds a continuous column of olive green, saturated “watwood” (van der Kamp and Gokhale 1979). Cottonwood fibres respond to sweep or other lateral stress by producing a special kind of tension wood where a gelatinous layer is laid down next to the cell lumen (Panning and Gertjejansen 1985; Karaim et al. 1990). Tension wood in cottonwood results in the wood having higher specific gravity and cellulose content, lower specific strength properties (except toughness), higher longitudinal shrinkage, and “fuzzy” surfaces when machined (Kennedy 1968). In general, for machining and processing, cottonwood cuts roughly with a heavy surface because of its low specific gravity and porous structure. Increasing amounts of tension wood increase roughness and create “woolliness,” which may cause pinching, clogging, or overheating of saw blades or chipping teeth (Kennedy 1968). Tension wood also affects cottonwood’s use for veneer since plies may warp easily and require significantly more glue (Kennedy 1968; Karaim et al. 1990).

Balsam poplar has traditionally been included in a “Northern Aspen Species Group” (Canadian Lumber Standards Administration Board 1970; Littleford and Roff 1975) that also includes trembling aspen and bigtooth aspen. Black cottonwood is excluded from the group because of its lower modulus of rupture, specific gravity, and modulus of elasticity, as measured by Jessome (1977). As a result, black cottonwood cannot technically be used for structural lumber or as core material in certain plywood groups. This separation
appears anomalous given the taxonomic, and apparent morphological similarity of balsam poplar and black cottonwood (Kellogg and Swan 1986). Kellogg and Swan (1986) and Swan and Kellogg (1986) compared physical and chemical properties of black cottonwood and balsam poplar to determine whether the exclusion of black cottonwood from this group was justified. Their results are summarized in Tables 5 and 6. Contrary to what Jessome (1977) found, the modulus of elasticity and modulus of rupture were significantly higher in black cottonwood than in balsam poplar, while specific gravity was the same. Fibre length was significantly longer in black cottonwood, but this probably related to rate of growth of sample trees. These comparisons showed that there is no justification for the discrimination against black cottonwood based on its physical wood properties (Kellogg and Swan 1986).

<table>
<thead>
<tr>
<th>Wood property</th>
<th>Black cottonwood</th>
<th>Balsam poplar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture content (%)</td>
<td>160.5</td>
<td>120.6</td>
</tr>
<tr>
<td>Specific gravity</td>
<td>0.338</td>
<td>0.337</td>
</tr>
<tr>
<td>Fibre length (mm)</td>
<td>1.271</td>
<td>1.023</td>
</tr>
<tr>
<td>Modulus of elasticity (MPa)</td>
<td>11 200</td>
<td>9 650</td>
</tr>
<tr>
<td>Modulus of rupture (MPa)</td>
<td>66.3</td>
<td>60.7</td>
</tr>
</tbody>
</table>

TABLE 5. Summary of physical wood properties of black cottonwood and balsam poplar. Values are for breast height bolts (Kellogg and Swan 1986).

<table>
<thead>
<tr>
<th>Wood property</th>
<th>Populus species\textsuperscript{a}</th>
<th>Other species\textsuperscript{b}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum crushing stress – green\textsuperscript{**}</td>
<td>6 181</td>
<td>7 238</td>
</tr>
<tr>
<td>Maximum crushing stress – air-dry\textsuperscript{**}</td>
<td>13 218</td>
<td>14 968</td>
</tr>
<tr>
<td>Modulus of rupture – green\textsuperscript{*}</td>
<td>14 108</td>
<td>14 962</td>
</tr>
<tr>
<td>Modulus of rupture – air-dry</td>
<td>24 481</td>
<td>25 807</td>
</tr>
<tr>
<td>Modulus of elasticity – green (\times10^3)</td>
<td>2 936</td>
<td>3 077</td>
</tr>
<tr>
<td>Modulus of elasticity – air-dry (\times10^3)</td>
<td>3 841</td>
<td>3 882</td>
</tr>
<tr>
<td>Volumetric shrinkage (%)\textsuperscript{**}</td>
<td>34.4</td>
<td>29.8</td>
</tr>
</tbody>
</table>

\textsuperscript{a} Asterisks indicate statistically significant differences at: p < .001 (**), p < .01 (**), and p < .05 (*).
\textsuperscript{b} Species include black cottonwood, balsam poplar, trembling aspen, larch/aspen, and eastern cottonwood.
\textsuperscript{a} Species include red alder, basswood, butternut, eastern white cedar, western redcedar, amabilis fir, balsam fir, eastern white pine, western white pine, red pine, Engelmann spruce, red spruce, Sitka spruce, and white spruce.

Cottonwood utilization for structural or dimension lumber in British Columbia is very rare and no commercial operations use it for these purposes. This is primarily the result of the availability of competitively priced softwood fibre, which is superior in many strength categories (Table 6), although the difference is smaller than is widely appreciated. In Europe, poplar is used for structural lumber (C. van Oosten, pers. comm.), and points out the fact that the low utilization for this purpose in British Columbia is largely historical. The nail-holding capacity is somewhat low, but the wood does not split easily and is thus excellent for crates and pallets (Harris 1968; Keays et al. 1974; Karaim et al. 1990). The combination of high water content and an excess of tension wood in cottonwood can present problems, as drying times can be longer than in other wood groups, and lumber may warp (Kennedy 1968). The low specific gravity of cottonwood is a benefit for making particle board, since for a given pressure, lower density chips form a more compact board of greater
strength because of better bonding between individual chips (Keays et al. 1974). Cottonwood has a history of use in plywood manufacture in British Columbia, both as core material for softwood outer plies and as cottonwood plywood (Harris 1968).

The chemical wood characteristics of balsam poplar and black cottonwood are compared in Table 7 (Swan and Kellogg 1986). Although the total extractive contents are higher in balsam poplar, analysis using thin layer chromatography has shown that the chemistry of the extractives is very similar. Mean lignin content is the same in both cottonwoods. For pH and titratable acidity, differences between heartwood and sapwood are apparent, but there are few differences between balsam poplar and black cottonwood. These observations suggest that pulping characteristics of black cottonwood and balsam poplar are similar, and that the two species can be used interchangeably for pulping as well.

**TABLE 7.** Summary of chemical wood properties of black cottonwood and balsam poplar. Values are means for breast height bolts (Swan and Kellogg 1986).

<table>
<thead>
<tr>
<th>Property</th>
<th>Black cottonwood</th>
<th>Balsam poplar</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sapwood Heartwood</td>
<td>Sapwood Heartwood</td>
</tr>
<tr>
<td>Total extractive content</td>
<td>3.20 3.18</td>
<td>5.68 4.67</td>
</tr>
<tr>
<td>Mean lignin content</td>
<td>21.04 22.74</td>
<td>21.19 22.18</td>
</tr>
<tr>
<td>Titratable acidity</td>
<td>42.60 32.60</td>
<td>48.90 24.20</td>
</tr>
<tr>
<td>pH</td>
<td>5.72 8.21</td>
<td>5.40 8.12</td>
</tr>
</tbody>
</table>

*a* Total of benzene-alcohol and hot water extraction.  
*b* Measured as % of extractive-free, oven dry weight.  
*c* Measured as mg/gram.

As is the case for structural lumber, cottonwood has been little used for pulp production in British Columbia, mainly because of the abundance of softwood which, for many purposes, makes stronger pulp. Cottonwood fibre length for all British Columbia poplars (including trembling aspen) is about 1.3 mm, compared to about 3.5 mm for softwood species (Keays et al. 1974). This fact, along with cell wall thickness and fibre strength, are reflected in the physical properties of the pulps produced by different pulping processes. Table 8 compares the physical properties of cottonwood and softwood pulps. In general, cottonwoods produce pulps of lower tensile strength, except in the chemi-mechanical process where burst and tear are about the same as a mixture of spruce and western hemlock. This lower strength factor has made it hard to use high concentrations of cottonwood in pulping mixtures, mainly because of the difficulty in keeping paper sheets together over the rollers during the pulping process (Kennedy 1968; Keays et al. 1974). Although cottonwood fibre has been little used in making newsprint in British Columbia, it has been used to produce household tissue products.

**TABLE 8.** Comparisons of the relative strength of poplar pulps (including trembling aspen) with pulp made by the same process using softwood species. Values are the percentage strength of poplar pulps compared to the listed softwood pulps (from Keays et al. 1974).

<table>
<thead>
<tr>
<th>Species</th>
<th>Method</th>
<th>Burst (%)</th>
<th>Tear (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Picea glauca</em></td>
<td>Kraft</td>
<td>55</td>
<td>80</td>
</tr>
<tr>
<td><em>Picea glauca</em></td>
<td>Groundwood</td>
<td>80</td>
<td>60</td>
</tr>
<tr>
<td><em>Picea abies</em></td>
<td>Sulphite</td>
<td>70</td>
<td>55</td>
</tr>
<tr>
<td><em>spruce</em> + <em>T. heterophylla</em></td>
<td>Chami-mechanical</td>
<td>100</td>
<td>90</td>
</tr>
</tbody>
</table>
4.2 Present Utilization

Given the low level of cottonwood use in British Columbia, some details about all companies are presented here to show how the fibre is being used. The following short descriptions of the companies are based on information we received from R. Publicover, Tackama Forest Products Ltd., D. Swaffield, Louisiana-Pacific Canada Ltd., P. McAuliffe, Scott Paper Ltd., and S. Thorsteinson, West Coast Plywood Ltd. A summary of cottonwood utilization by these companies is presented in Table 9.

### TABLE 9. Summary of companies presently using cottonwoods as a major source of raw material.
(Source: compiled from personal contacts within the companies listed.)

<table>
<thead>
<tr>
<th>Forest Region</th>
<th>Company</th>
<th>Amount</th>
<th>Utilization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prince George</td>
<td>Tackama F.P.</td>
<td>40 000 m³/yr</td>
<td>peel cottonwood used as core material in softwood plywood and panelling</td>
</tr>
<tr>
<td>Prince George</td>
<td>Louisiana-Pacific</td>
<td>120 000 m³/yr</td>
<td>20–25% cottonwood mixture with aspen in oriented strandboard mill</td>
</tr>
<tr>
<td>Vancouver</td>
<td>Scott Paper Ltd.</td>
<td>100 000 m³/yr</td>
<td>33% cottonwood mixture mixed with kraft pulp to make household paper products</td>
</tr>
<tr>
<td>Vancouver</td>
<td>West Coast Plywood</td>
<td>40 000 m³/yr</td>
<td>peel cottonwood to make plywood</td>
</tr>
</tbody>
</table>

The largest licence-holder for cottonwood in British Columbia is Tackama Forest Products Ltd., located in Fort Nelson. Tackama has a 15-year, non-replaceable forest licence with an AAC of 150 000 m³. Since 1987, it has harvested an average of 40 000 m³/yr, ranging from 72 000 m³ in 1987 and 52 000 m³ in 1990/91 to 3300 m³ in 1989 (S. Lindsey, pers. comm.). Tackama peels cottonwood to make core material for spruce plywood and for panelling. Almost all of this volume is harvested from the alluvial floodplains of rivers in the area of Fort Nelson.

Louisiana-Pacific Canada Ltd. operates an OSB mill in Dawson Creek and has recently completed a chemical-thermal mechanical pulping (CTMP) pulp mill in Chetwynd. The Chetwynd mill uses trembling aspen exclusively, since the company feels that cottonwood does not meet the required brightness criteria for its pulping process. The OSB plant in Dawson Creek has a deciduous AAC (pulpwood agreement) of 520 000 m³/yr, of which 20–25% is cottonwood. Cottonwood is less preferable than trembling aspen for OSB utilization because of its tendency to "feather" when chipped (a tension wood problem), and this can create problems at the gluing stage.

Scott Paper Ltd. of New Westminster uses a blend of 30–40% cottonwood in its pulp to produce household tissue products. Scott operates the only deciduous TFL in British Columbia, made up of about 10 000 ha on the floodplains of the Fraser, Homathko, and Kingcome rivers. Of this total, about 5000 ha accounts for the operable land base after netting down factors are included. The company purchases logs on the open market and harvests about 30 000 m³ itself to make up the 100 000 m³ it uses annually. Through in-house product processing and marketing, Scott enjoys a $800/m³ value-added factor on the cottonwood fibre it uses. Scott is the only company to have purposefully managed cottonwood in British Columbia, and much of our knowledge of cottonwood management is based on the company's experience and the information it has made available.

West Coast Plywood, located in Vancouver, peels cottonwood logs to produce two types of cottonwood plywood. Its cross-grained plywood is sold to a local processor who faces it with a hardwood veneer for wall panelling, and the long-grained plywood is used locally for finished products such as kitchen cupboards and counters. The company buys logs on the open market and, although utilization is variable, it can process a maximum of about 40 000 m³/yr. West Coast Plywood originated from Wekwood of Canada, whose plywood division sprang from Western Plywoods Ltd., a company started by John bene in 1945 (Harris 1968). The original product, cottonwood plywood with a softwood core, was preferred by local cabinet and furniture makers over the heavier-grained fir plywood (Harris 1968).
Another utilization category for cottonwood is whole logs to be sold on the export market. Chinese markets have predominated in the past, with minor consumption by buyers in Japan, Korea, and Taiwan. The market is highly sporadic (Table 10) and reflects the availability and cost of competing fibre from other Pacific Rim source areas. Whole log exports are permitted where in-province utilization requirements either do not exist, or where local requirements have been met. Except for small amounts of cottonwood added to pulp mixtures, the log export market is the only utilization for cottonwood in the Prince Rupert Forest Region.


<table>
<thead>
<tr>
<th>Year</th>
<th>Volume exported (m$^3$)</th>
<th>Year</th>
<th>Volume exported (m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1971</td>
<td>26 000</td>
<td>1979</td>
<td>11</td>
</tr>
<tr>
<td>1972</td>
<td>17 000</td>
<td>1980</td>
<td>41 000</td>
</tr>
<tr>
<td>1973</td>
<td>0</td>
<td>1981</td>
<td>13 000</td>
</tr>
<tr>
<td>1974</td>
<td>14 000</td>
<td>1982</td>
<td>74 000</td>
</tr>
<tr>
<td>1975</td>
<td>0</td>
<td>1983</td>
<td>178 000</td>
</tr>
<tr>
<td>1976</td>
<td>0</td>
<td>1984</td>
<td>109 000</td>
</tr>
<tr>
<td>1977</td>
<td>0</td>
<td>1985</td>
<td>32 000</td>
</tr>
<tr>
<td>1978</td>
<td>0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total utilization by companies now using cottonwood as a major source of raw material in British Columbia is about 400 000 m$^3$/yr (Table 9). In addition to this total, some pulp mills will accept a low percentage of cottonwood in mixture with softwood species, although an estimate of the amount is unavailable. In addition, there is a sporadic market for log exports (Table 10) which, on an annual basis, ranges from 0 to close to 200 000 m$^3$/yr. If we use the estimates that 50 000 m$^3$/yr go into export logs and 100 000 m$^3$/yr go into pulp mixtures, then we can assume that about 500 000–600 000 m$^3$/yr of cottonwood fibre are currently being utilized in British Columbia. Given the size of the provincial cottonwood inventory, it is obvious that considerable potential exists for increased utilization of cottonwood, especially in some Forest Districts in the Prince Rupert Forest Region, where no processing facilities exist.

4.3 Utilization Specifications

Cottonwood utilization standards vary widely depending on the product being produced (Table 11). Minimum top diameters range from 8 cm for OSB and 10 cm for pulp, to 20–30 cm for peelers and export logs. Maximum butt diameter specifications also vary widely, and are dictated by both the utilization and the type of processing machinery being operated. The low maximum butt diameter for the Fort Nelson and Dawson Creek operations presents a utilization problem since, in many cases, cottonwood being harvested exceeds these specifications. As a result, logs of usable specifications are cut from the upper parts of boles and the large and often sound butts are left on the site. We saw this type of utilization in the Fort Nelson Forest District, where even fairly old cottonwoods are often sound at the butt.

TABLE 11. Summary of cottonwood utilization standards for present utilization facilities

<table>
<thead>
<tr>
<th>Utilization</th>
<th>Tecksm F.P.</th>
<th>Louisiana-Pacific</th>
<th>Scott Paper</th>
<th>West Coast Plywood</th>
<th>Export logs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Plywood/</td>
<td>Oriented</td>
<td>Pulp furnish</td>
<td>Plywood</td>
<td>Variable</td>
</tr>
<tr>
<td>Min. top diam.</td>
<td>20 cm</td>
<td>8 cm</td>
<td>10 cm</td>
<td>30 cm</td>
<td>30 cm</td>
</tr>
<tr>
<td>Max. butt diam.</td>
<td>30 cm</td>
<td>50 cm</td>
<td>123 cm</td>
<td>127 cm</td>
<td>na</td>
</tr>
<tr>
<td>Defect</td>
<td>&lt; 50% ring shake;</td>
<td>&gt; 50% firm wood;</td>
<td>Limited rot, sweep, and lean</td>
<td>Very low defect allowed</td>
<td>No top rot, rotten knots, or conks; no shake; one-way sweep only</td>
</tr>
</tbody>
</table>

14
4.4 Future Trends in Cottonwood Utilization

In northeastern British Columbia, cottonwood is included as part of a deciduous resource component for which more intensive utilization is planned. Louisiana-Pacific Canada Ltd. has proposed a new OSB plant at Chetwynd; this would help increase utilization of cottonwood up to the harvest level outlined in the Timber Supply Analysis for the Dawson Creek TSA (Section 3.1). However, OSB prices are somewhat depressed now and these plans are on hold (D. Robb, pers. comm.). A CTMP pulp mill is planned for Vanderhoof but is stalled by the environmental review process for Kemano II. Cottonwood apparently does not meet the brightness requirement for CTMP plants, so further development of these mills will not influence cottonwood utilization. (They will likely be residuals or trees harvested and left on the site, along with trembling aspen which also does not meet the brightness criteria for that process.) The future of cottonwood utilization would be radically changed if a process could be developed to permit the utilization of cottonwood in CTMP plants.

Although there is a considerable cottonwood resource in the Prince Rupert Forest Region (Section 3.1), no utilization is planned at the present time, even though extensively managed cottonwood plantations are actively being established by both industry and Ministry of Forests on alluvial sites throughout the region. A CTMP pulp mill using trembling aspen is planned for the Terrace area, but, as stated above, cottonwood fibre may be unsuitable for this purpose. Other areas of interior British Columbia have no plans for establishing cottonwood utilization facilities in the near future.

Considerable interest in the management of black cottonwood exists in coastal British Columbia, but only Scott Paper now uses the species in any quantity. There are some indications that this may change in the future if a reliable supply can be ensured. MacMillan Bloedel has undertaken an extensive internal analysis of the potential for growing and using hybrid poplar fibre in pulp mixtures. Cottonwood pulp has high opacity and good bulk and printability, and it blends with softwood kraft pulp containing 10–50% poplar fibre. It is well suited to book papers, computer paper, offset printing papers, and a range of other fine papers (Clayton 1968). Utilization as pulp furnish has the largest potential for increasing cottonwood utilization in coastal British Columbia (C. van Oosten, pers. comm).

4.5 Information Gaps and Research Requirements

From our review of the literature and discussions with forestry personnel, we believe that the basic physical and chemical wood characteristics of cottonwood, as they relate to different utilization processes, are relatively well researched and do not limit cottonwood utilization at present. The possibility of using cottonwood fibre in CTMP mills is a subject that deserves immediate attention, because this would radically alter its future utilization potential. What is lacking is the development of integrated utilization systems for cottonwood in conjunction with trembling aspen. As a result, both resources have been very poorly used in some areas of northeastern British Columbia. Some authors have proposed an integrated and hierarchical poplar utilization complex, so that more efficient use is made of the cottonwood resource (Maini and Cayford 1968; Keays et al. 1974). Following this reasoning in the present types of utilization in British Columbia, chopstick production requires the brightest fibre, followed by CTMP pulping, after which unsuitable aspen and cottonwood can be used for OSB. Peeler-quality logs for plywood and paneling could also be integrated into this complex.

In addition to these existing uses of cottonwood, Karaim et al. (1990) evaluated a number of potential uses for balsam poplar in Alberta. The most promising they found were 4 x 4 utility lumber, furniture blanks and parts, children's furniture, shingles, pallets, animal feed and bedding, and a range of different pulping methods. Clearly, then, considerable potential exists for using cottonwood fibre and the key for doing so profitably will be to develop manufacturing complexes that are economically sound and designed to use the range of poplar resource qualities in a given area. There is also an obvious need to develop reliable, long-term markets for new cottonwood products, to drive the integrated approach to cottonwood utilization as described above.
5 COTTONWOOD MANAGEMENT

5.1 Silvics, Range, and Site Selection

Black cottonwood is distributed throughout British Columbia and extends primarily west of the Cascade Mountains and south into Washington and Oregon (Figure 1). Balsam poplar, on the other hand, occurs only in the northeastern area of the province, and extends from there across the continent to eastern Canada. Balsam poplar extends farther north than any other tree in Alaska (Viereck and Foote 1970). The two subspecies meet in the northeastern area of the province where hybridization is common (Brayshaw 1965, 1978). Black cottonwood is commonly believed to be the common variant on alluvial floodplains in northern British Columbia, while balsam poplar occurs primarily on upland sites (Brayshaw 1965; McLennan 1990).

In most of British Columbia, cottonwood occurs on alluvial floodplains, often creating relatively pure and extensive stands. The species also occurs on suitably moist upland sites, usually as scattered individuals, although relatively pure upland balsam poplar stands may occur in landscape depressions in northeastern areas of the province. In the northern Interior, cottonwoods are common up to mesic hygrotopes, but growth and vigour are reduced considerably (DeLong 1988; D.S. McLennan, unpublished data). On coastal floodplains, red alder and bigleaf maple are associates of cottonwood, as are Sitka spruce and western redcedar. In the Interior, paper birch and trembling aspen are the most common deciduous associates, with white and various hybrid spruce being the most common conifers.

Cottonwood is highly shade-intolerant and aggressively colonizes moist, mineral soils along rivers or wherever disturbance creates appropriate conditions. The species exhibits very rapid juvenile growth rates and soon comes to dominate any substrate that it colonizes. It is common to see cottonwood growing above the general canopy level of associated deciduous and coniferous trees. On the best sites, height increases rapidly to about 30 m after which the rate of height growth decreases but considerable diameter growth continues (D.S. McLennan, unpublished data). Canopies begin to break up after 70–90 years, at which time suppressed, shade-tolerant conifers are released and slowly come to dominate the stands.

Cottonwoods are dioecious and flowers develop annually from late March on the coast to early or mid-June in the northeast. Seeds ripen quickly and are released from late May to July, depending on the regional climate (Haeussler and Coates 1986; DeBell 1990; Zasada and Phipps 1990). Cottonwood releases its seeds during late spring and early summer and this allows the seeds to colonize mineral soil left after the May to July flooding which is common on alluvial floodplains in British Columbia (McLennan 1990). Large crops of light, downy seeds are produced and can be wind- or water-dispersed over long distances. Seed viability is high but of short duration, and seedling development requires mineral seedbeds that must remain moist for at least a month after germination (Scheir and Campbell 1976). Cottonwoods also regenerate vegetatively from cut stumps and from branch and twig fragments partially buried in the soil following logging or flooding (Haeussler and Coates 1986; DeBell 1990; Zasada and Phipps 1990). Cottonwood is the most shade-intolerant tree in British Columbia and rapidly expires at all ages if shaded (Minore 1979; Krajina et al. 1982; Haeussler and Coates 1986; DeBell 1990; Zasada and Phipps 1990).

Given the proper growing conditions, cottonwoods are the fastest growing trees in British Columbia. They thrive on nutrient-rich soils with fresh to very moist soil moisture regimes, and are poorly adapted to soil drought (Smith 1957; Roe 1958a, 1958b; Fowells 1965; DeLong 1988; DeBell 1990; Zasada and Phipps 1990; McLennan 1991). Figure 3 shows correlations between black cottonwood site index and the range of site associations on which it grows in subzones of the CDF and CWH biogeoclimatic zones in coastal British Columbia (taken from McLennan 1991). In McLennan (1991) the fastest growing cottonwoods were found on nutrient very rich, moist to very moist upland sites, with height growth decreasing as soils became drier. Height growth was rapid on the high bench of alluvial floodplains, although height growth decreased as alluvial bench height decreased and growing season flooding increased. Site associations with gleysoilic soils were found to range from medium to low productivity, depending on the depth of well-aerated soil above the gleyed horizon (Figure 3). This agrees with the general observation that cottonwood tolerates rooting zone flooding and soil waterlogging during the dormant season, but prolonged flooding in the rooting zone during the growing period reduces productivity (Smith 1957; DeBell 1990). Thus, although much has been said about the
impressive growth rates of black cottonwood, it is important to realize that a greater than fourfold increase in height growth occurs across its range in coastal British Columbia (Figure 3). The results of the study demonstrate the importance of careful site selection for optimum growth of black cottonwood.

5.2 Pests and Pathogens

5.2.1 Insects, diseases, and other damage

Although a wide range of insects and diseases affect cottonwoods and hybrid poplars in British Columbia (Table 12), few appear to seriously affect thriving stands of cottonwood. Some defoliators such as tent caterpillars and satin moths can be locally important, but they seldom cause widespread damage. Poplar leaf rust (*Melampsora* spp.) is common on foliage of native cottonwoods, although there are few data available on its effects on the productivity of wild stands (Wang and van der Kamp, in press). The poplar borer reportedly attacks young stands of balsam poplar regularly in Alberta, especially on poorer sites (Drouin and Wong 1975).
TABLE 12. Summary of common pests that attack cottonwood and hybrid poplars in British Columbia (DeBell 1990; Fowells 1965; and Heilman et al. 1990)

<table>
<thead>
<tr>
<th>Pest category</th>
<th>Pest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deloters</td>
<td>Gray willow leaf beetle (<em>Galerucella decorata</em>)</td>
</tr>
<tr>
<td></td>
<td>Tent caterpillar (<em>Malacosoma disstria</em>)</td>
</tr>
<tr>
<td></td>
<td>Dark brown poplar aphid (<em>Pterocoma populifoliae</em>)</td>
</tr>
<tr>
<td></td>
<td>Bud midges (<em>Contarinia</em> spp.)</td>
</tr>
<tr>
<td></td>
<td>Leaf-folding sawfly (<em>Phyllocopra bozemanii</em>)</td>
</tr>
<tr>
<td></td>
<td>Poplar leaf beetle (<em>Chrysomela scripta</em>)</td>
</tr>
<tr>
<td></td>
<td>Poplar leaf skeletonizer (<em>Chrysomela aeneicollis</em>)</td>
</tr>
<tr>
<td></td>
<td>Satin moth (<em>Leucoma salicina</em>)</td>
</tr>
<tr>
<td></td>
<td>Thrips (<em>Thysanoptera</em> spp.)</td>
</tr>
<tr>
<td>Borers</td>
<td>Poplar and willow borer (<em>Cryptorhynchus lepather</em>)</td>
</tr>
<tr>
<td></td>
<td>Bronze poplar borer (<em>Agrius liragus</em>)</td>
</tr>
<tr>
<td></td>
<td>Poplar borer (<em>Saperda calcarata</em>)</td>
</tr>
<tr>
<td></td>
<td>Clear wing borer (<em>Sesiidae</em> spp.)</td>
</tr>
<tr>
<td>Galls</td>
<td>Poplar bud gall mite (<em>Aceria parapopulii</em>)</td>
</tr>
<tr>
<td>Foliage diseases</td>
<td><em>Shepherd’s crook</em> (<em>Venturia populina</em>)</td>
</tr>
<tr>
<td></td>
<td><em>Poplar rust</em> (<em>Melampsora occidentalis</em>)</td>
</tr>
<tr>
<td></td>
<td><em>Septoria leaf spot</em> (<em>Septoria musiva</em>)</td>
</tr>
<tr>
<td>Cankers</td>
<td>Blackstem (<em>Cytospora</em> sp.)</td>
</tr>
<tr>
<td>Animals</td>
<td>Vole (<em>Microtus</em> spp.)</td>
</tr>
<tr>
<td></td>
<td>Beaver (<em>Castor canadensis</em>)</td>
</tr>
<tr>
<td></td>
<td>Roosevelt elk (<em>Cervus canadensis</em>)</td>
</tr>
</tbody>
</table>

Much more widespread is the observed susceptibility of many hybrid poplars to attack by several of these pests. Poplar borer damage has been reported from 3-year-old coastal hybrid poplar plantations, although the seriousness of the damage is not known at the time (C. van Oosten, pers. comm.). Whereas insect attack has so far been relatively minor, foliage diseases and cankers are probably the greatest threat to hybrid poplar culture (Heilman et al. 1990). *Septoria* leaf spot and Shepherd’s crook (*Venturia* spp.) are common on certain clones in both Washington (Heilman et al. 1990) and in British Columbia (C. van Oosten, pers. comm.). Shepherd’s crook is emerging as the most troublesome problem for hybrid poplar plantations in Washington, especially in moist coastal climates (Heilman et al. 1990).

Poplar leaf rust (*Melampsora* spp.) has been shown to diminish significantly the productivity of native black cottonwood (Wang and van der Kamp, in press), although its effects on productivity of hybrid poplars is not well known. One important aspect of poplar leaf rust is that conifers such as Douglas-fir, grand fir, and Sitka spruce are the alternate hosts, and infections from susceptible hybrid poplars to adjacent Douglas-fir plantations have been reported (Heilman et al. 1991). In almost all cases, susceptibility to these diseases has been shown to have a strong genetic component, so that hybrid poplars can be selected for resistance to the various diseases (Heilman et al. 1990; Wang and van der Kamp, in press). However, recent serious attacks of *Melampsora* on hybrid poplars in Washington, previously believed to be resistant, emphasize the inherent risk in developing hybrid plantations from too narrow a genetic base (B.J. van der Kamp, pers. comm.).
Several animal pests can also severely damage both cottonwood and hybrid poplar plantations. Voles girdle the bark, especially in plantations with high grass coverage and under and above snow. Of all animal pests listed here, voles probably create the largest potential impediment to plantation establishment, for both native cottonwoods and hybrid poplars. Protective collars are often required to protect young planted whips from vole damage. In areas directly adjacent to rivers and backchannels, beavers may harvest small patches of plantation trees. Black-tailed deer are a relatively minor problem, but Roosevelt elk can cause severe damage to plantations (C. van Oosten, pers. comm.). Although few plantations exist in the interior, winter browsing by moose and Rocky Mountain elk may create a problem where overwintering populations are high.

Mechanical damage to alluvial cottonwood stands by wind and ice storms is another considerable problem in many coastal valleys. Often older stands have recognizable frost cracks and top damage followed by resprouting, and stem form can be seriously affected. Broken tops and branches create wounds that permit the entry of decay fungi and accelerate the onset of heart and butt rots. Mechanical damage to stems of whips can occur in young plantations where whips protrude through crusted snow and wind causes abrasion of bark (C. Ripley, pers. comm.).

5.2.2 Fungal attack and decay

Although many decay fungi have been observed on balsam poplar (Table 13) and black cottonwood (Table 14), only a few species cause most of the damage. Also, although the incidence of decay is high, the volume of decay in trees affected is quite low (Thomas and Podmore 1953). This information coincides with the suggestion (B.J. van der Kamp, pers. comm.) that anaerobic conditions in cottonwood wetwood often limit fungal attack to relatively small, oxygenated regions of the trunk where wounding has occurred. _Phellinus tremulae_ and _Pholiota destructans_ accounted for almost all of the pathogens identified in a study of decay in balsam poplar in Alberta (Table 13). A similar situation was found in a black cottonwood stand near Quesnel, except that the two decay species were _Polyporus delectans_ and _Pholiota destructans_ (Table 14). Thomas and Podmore (1953) considered _Pholiota destructans_ to be the most important species economically, because this fungus occurred primarily in the butt and thus had the most impact on utilization for peeler logs. Using visible indicators of decay (basal scars, branch stubs, broken tops, bunch knots, butt swell, crook and trunk scars), they could account for 67% of the measured decay in living trees.

Decay has been cited as the major problem limiting the widespread utilization of poplars in western Canada (Bailey and Dobie 1977; Hiratsuka and Loman 1984). Decay limits cottonwood suitability for plywood veneers, reduces its utilization for dimension lumber, and reduces the quality of chips for OSB and kraft pulping (Keays _et al._ 1974). Decay also results in high rates of waste at processing centres and

<table>
<thead>
<tr>
<th>Species</th>
<th>Trunk</th>
<th>Butt</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Phellinus tremulae</em> (= <em>Fomes ignarius</em>)</td>
<td>26.8</td>
<td>-</td>
</tr>
<tr>
<td><em>Bjerkandrea adusta</em> (= <em>Polyporus adusta</em>)</td>
<td>2.5</td>
<td>0.1</td>
</tr>
<tr>
<td><em>Armillaria mellea</em> (= <em>Armillariella mellea</em>)</td>
<td>trace</td>
<td>1.6</td>
</tr>
<tr>
<td><em>Gymnopilus spectabilis</em> (= <em>Pholiota spectabilis</em>)</td>
<td>1.3</td>
<td>4.2</td>
</tr>
<tr>
<td><em>Pholiota destructans</em></td>
<td>17.7</td>
<td>0.4</td>
</tr>
<tr>
<td><em>Corticum expallens</em></td>
<td>5.2</td>
<td>0.4</td>
</tr>
<tr>
<td><em>Tremellispora raduloides</em></td>
<td>0.8</td>
<td>0.1</td>
</tr>
<tr>
<td><em>Corticum veilerum</em></td>
<td>0.3</td>
<td>0.1</td>
</tr>
<tr>
<td>Unknown</td>
<td>34.7</td>
<td>3.5</td>
</tr>
<tr>
<td>Total</td>
<td>89.5</td>
<td>10.5</td>
</tr>
</tbody>
</table>

TABLE 13. Major decay-causing fungi on balsam poplar in the Slave Lake area of Alberta (Hiratsuka and Loman 1984). Numbers are percentages of all decay-causing sources in tree trunks and butts.
TABLE 14. The relative importance of fungi responsible for decay on black cottonwood at Quesnel, B.C. (Thomas and Podmore 1953). Values are percentages of total decay volume for living trees.

<table>
<thead>
<tr>
<th>Species</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyporus delectans</td>
<td>49.9</td>
</tr>
<tr>
<td>Pholiota destructans</td>
<td>41.8</td>
</tr>
<tr>
<td>Polyporus adustus</td>
<td>2.3</td>
</tr>
<tr>
<td>Armillaria mellea</td>
<td>3.1</td>
</tr>
<tr>
<td>Pholiota spectabilis</td>
<td>2.3</td>
</tr>
</tbody>
</table>

can create low utilization and more expensive harvesting of cottonwood stands (Hiratsuka and Loman 1984). Accelerated rates of harvesting have been justified in the Dawson Creek TSA based on expectations of advanced decay in balsam poplar older than 90 years (B.C. Ministry of Forests 1989).

Paul and Etheridge (1958) showed a gradual progression of decay with age in balsam poplar (Table 15). The 10% decay at the 81–90 year age class corresponds with data presented for the Dawson TSA (B.C. Ministry of Forests 1989). The data presented by Bailey and Dobie (1977), however, did not show this pattern of increasing decay with age in balsam poplar (Table 16).

TABLE 15. Percentage of decay by age class for balsam poplar in Alberta (Paul and Etheridge 1958). Data are for merchantable logs with less than 50% decay and top diameter of 9 cm.

<table>
<thead>
<tr>
<th>Age class</th>
<th>Percent decay</th>
<th>Age class</th>
<th>Percent decay</th>
</tr>
</thead>
<tbody>
<tr>
<td>31–40</td>
<td>2.9</td>
<td>101–110</td>
<td>13.3</td>
</tr>
<tr>
<td>41–50</td>
<td>8.7</td>
<td>111–120</td>
<td>15.2</td>
</tr>
<tr>
<td>51–60</td>
<td>8.2</td>
<td>121–130</td>
<td>17.3</td>
</tr>
<tr>
<td>61–70</td>
<td>7.4</td>
<td>131–140</td>
<td>19.4</td>
</tr>
<tr>
<td>71–80</td>
<td>8.4</td>
<td>141–150</td>
<td>21.3</td>
</tr>
<tr>
<td>81–90</td>
<td>10.1</td>
<td>151–160</td>
<td>22.9</td>
</tr>
<tr>
<td>91–100</td>
<td>11.4</td>
<td>161–170</td>
<td>24.5</td>
</tr>
</tbody>
</table>

TABLE 16. Decay percentages in three balsam poplar age classes in Alberta (Bailey and Dobie 1977)

<table>
<thead>
<tr>
<th>Age class</th>
<th>Percent decay</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 60 years</td>
<td>5.5</td>
</tr>
<tr>
<td>60–90 years</td>
<td>5.0</td>
</tr>
<tr>
<td>&gt; 90 years</td>
<td>5.5</td>
</tr>
<tr>
<td>all age classes</td>
<td>5.5</td>
</tr>
</tbody>
</table>

Thomas and Podmore (1953) showed in their study of black cottonwood that decay increased with age in black cottonwood, but at a much slower rate than for balsam poplar (Table 17). They concluded that their study needed to be conducted over a wider range of sites to determine the general applicability of these results. Observations during field trips in the course of the present study support the idea that the amount of decay in black cottonwood varies significantly by region. Black cottonwood that we observed in the Fort Nelson area appeared sound to the core, even in trees older than 150 years. In many areas of coastal British Columbia, trees of this age class typically have significant butt and heart rot. The effects of site on the degree of rot and decay were observed in the Cranberry River drainage (ICHmc2), where black cottonwood on very wet sites had decay up to 60% in trees only 20 years old. On well-drained, productive sites in the same area, black cottonwood stands 85–100 years old had little detectable decay (KDM Forest Services Ltd. 1989). The effects of local climatic and site conditions on the ecology of the fungi concerned are probably important in determining this regional variation.
TABLE 17. The relationship between age class and actual and peeler-utilizable decay volume in black cottonwood at Quesnel, B.C. (Thomas and Podmore 1953)

<table>
<thead>
<tr>
<th>Age class</th>
<th>Actual decay volume (%)</th>
<th>Peeler decay volume(%)</th>
<th>Age class</th>
<th>Actual decay volume (%)</th>
<th>Peeler decay volume(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>80–90</td>
<td>trace</td>
<td>trace</td>
<td>141–150</td>
<td>8.6</td>
<td>18.7</td>
</tr>
<tr>
<td>91–100</td>
<td>0.9</td>
<td>2.0</td>
<td>151–160</td>
<td>9.4</td>
<td>19.9</td>
</tr>
<tr>
<td>101–110</td>
<td>2.1</td>
<td>4.5</td>
<td>161–170</td>
<td>10.1</td>
<td>20.8</td>
</tr>
<tr>
<td>111–120</td>
<td>3.4</td>
<td>7.5</td>
<td>171–180</td>
<td>10.6</td>
<td>21.6</td>
</tr>
<tr>
<td>121–130</td>
<td>4.7</td>
<td>10.8</td>
<td>181–190</td>
<td>11.1</td>
<td>22.2</td>
</tr>
<tr>
<td>131–140</td>
<td>6.2</td>
<td>14.4</td>
<td>191–200</td>
<td>11.1</td>
<td>22.6</td>
</tr>
</tbody>
</table>

\(^a\) Based on gross measurement of wood volume.
\(^b\) Actual decay volumes plus the sound-wood volumes lost to peeler-grade recovery due to the location of decay.

Although decay is an important factor for the utilization of existing stands of mature cottonwood, it will probably not be significant for future management systems, which are projected to have rotations of 25–35 years for pulp on the coast and 60–80 years for OSB and pulp in the Interior (Section 5.3). Low incidence of rot and decay over relatively short rotations has implications for wildlife, since heart rot necessary for cavity nesting animals and associated species will be severely curtailed in these plantations. The implications of this are discussed in Section 5.4.

5.2.3 Information gaps and research requirements

As for all other commercial species, the amount of butt and trunk decay in cottonwood is an important determinant of the amount of usable volume for a given utilization. For example, Table 16 shows, for black cottonwood, both the total amount of percent decay and the amount of decay if the end use is peeler logs for plywood. Decay, waste, and breakage factors attempt to account for this loss, given different utilization standards.

The present decay, waste, and breakage factors for cottonwood are inaccurate (J. Vivian, pers. comm.) and require resampling to arrive at more realistic numbers. This we showed in Section 3.1 as one of the major factors limiting the accurate estimation of usable cottonwood volume in a given area. Such information is critical if accurate timber supply analyses are to be carried out and realistic long-term cutting plans developed, especially where cottonwood resources are in older age classes. Considerable variation in the degree of rot and decay occurs on both a regional (climatic) and local (site) scale and this variation needs to be incorporated into a decay, waste, and breakage sampling program. Decay factors published outside a particular area of interest should be used cautiously, and supplemented with local information as soon as possible. Within a given area, decay, waste, and breakage factor sampling should concentrate on sites where management of cottonwood is planned, and should provide information relevant to the particular utilization (Table 16).

5.3 Stand Management

5.3.1 Stand establishment

Cottonwood stands can be established after logging by natural regeneration or by the planting of unrooted or rooted cuttings. The following account is summarized from McLennan (1990). Natural regeneration is most successful in areas where cottonwood formed a major component of the stand being harvested, because cottonwood sprouts vigorously from stump sprouts and from branch and limb fragments in logging debris. Stump sprouts are generally considered unreliable due to the poor connection between the sprouts and the stump (Zasada and Phipps 1990), although successful regeneration can be achieved if stumps are cut to less than 10 cm in height (P. McAuliffe, pers. comm.). Balsam poplar appears to produce many more root sprouts following logging than does black cottonwood.
Suckers made up 80% of the post-logging stocking in winter-logged balsam poplar stands, but the percentage of trees established from root suckers in fall-harvested stands was only 27% (Zasada et al. 1981). Natural regeneration from seed can also occur when sufficient areas of mineral soil are exposed during the May to June flowering season, and when soil water conditions are conducive to survival of the fragile seedlings. In most cases, natural regeneration is from both sources, although in the first year vegetative sprouts grow much more rapidly than seedlings and will shade out more slowly growing individuals. One major drawback with reliance on natural regeneration is the unevenness of the spacing of the regeneration. It is often discontinuous, resulting in less than full site utilization.

Cottonwood plantations can also be established by planting long (1- to 2-m “whips”) or short (20- to 30-cm “cuttings”) ramets of cottonwood, a technique that takes advantage of the reliable vegetative sprouting of the species (Bloomfield 1959; Scheir and Campbell 1976; Radwan et al. 1987). Research on *P. trichocarpa* and *P. deltoides* shows that rooting success increases with depth of planting, length of whip, caliper of the cutting, moisture content of the whip, and soil moisture at the time of planting and for the first weeks afterwards (Allen and McComb 1956; Smith et al. 1956; Farmer 1966; Bowersox 1970; Heilman and Ekuan 1979; Krinar and Randall 1979; Dickman et al. 1980; Hansen 1983). Cuttings can be rooted in 615 styrofoam blocks and rooted sets planted by boring or shovel planting (M. Carlson, pers. comm.). Rooted cuttings of *P. deltoides* have been shown to have higher survival rates and more rapid initial growth (McKnight 1970; Phipps 1976), which may justify the extra expense if plantation soils become temporarily droughty following planting.

Whips can be cut from young cottonwoods using the first-year wood of terminal leaders or lateral branches (McLennan 1991). Trees up to about 15 years old, cut during the dormant season, will provide an economical source of stump sprouts and will continue to sprout for several years. Although caliper will be variable for wildling stock, a diameter of 1.5–2.5 cm is desirable. Wildling whips have the advantages of lower cost, accessibility to remote sites, and adaptability to local ecological conditions. An approximate cost of $0.55/whip to collect 90 000 wildling whips was estimated for an inexperienced crew in the Prince Rupert Forest Region (C. Ripley, pers. comm.). In balsam poplar stands in Ontario, wild cuttings collected after December had a higher rooting percentage, more roots per cutting, and a higher percentage of cuttings with bud activity than those collected before December (Cunningham and Farmer 1984). Nursery-grown whips are often of larger caliper, have fewer lateral branches (which interfere with planting in dibble holes), and can take advantage of rapid growth characteristics of superior clones where local climates permit. Limited amounts of whip stock can be purchased from the Pacific Regeneration Technologies nurseries at Red Rock and Thornhill, the Ministry of Forests Kalamalka Forestry Center in Vernon, and Scott Paper Ltd. (for coastal sites).

Wildling or nursery-grown whips can be harvested in the fall and winter, sealed in plastic bags, and stored at -2 to 5°C (Phipps and Netzer 1981; Fege 1983; P. McAuliffe, pers. comm.). This treatment delays flushing of leaf buds, prevents desiccation, and initiates the formation of root primordia. All cuttings and whips produced at Kalamalka Forestry Center are sealed in waxed or plastic bags and stored at about -2°C to help reduce respiration losses during storage (M. Carlson, pers. comm.). Before planting, cooled whips should be soaked in water to maximize whip moisture content and planted before bud-burst (Peterson and Phipps 1976; Krinar and Randall 1979; Fege 1983; M. Carlson, pers. comm.). At this time, whips can be sectioned into various lengths depending on expected planting conditions. The length of ramet to plant depends on the management system and the amount of site preparation used to establish the plantation. The important consideration is the high shade intolerance of cottonwood, so that ramet length should increase as competition from other vegetation increases or planned vegetation control decreases.

### 5.3.2 Management systems

Cottonwood responds well to increased levels of management, and the systems used to manage the species in British Columbia and elsewhere reflect this (DeBell et al. 1977; Armonson and Smith 1978; Heilman et al. 1990). Cottonwood management is new to British Columbia and, until very recently, Scott Paper Ltd. was the only organization to manage the species purposefully. This situation is changing and cottonwood whips are being planted in increasing numbers as the species becomes a more acceptable
alternative to both government and industrial foresters. Much of the interest in the species is the result of the difficulty in regenerating conifers on alluvial and other high brush hazard sites where cottonwood demonstrates impressive growth.

5.3.2.1 Extensive management using natural regeneration

Cottonwood is well adapted to low levels of management because of its ability to show impressive growth rates with relatively low establishment costs. In coastal British Columbia where stands have a significant component of cottonwood—more than 300 well-spaced stems per hectare is a rule of thumb (P. McAuliffe, pers. comm.)—the species will usually regenerate at adequate stocking levels without the need for site preparation. Ground-based harvesting systems work twig and stem fragments into the mineral substrate and promote their survival and rapid development. Where stems in the harvested stands are less than about 300 stems per hectare, deliberate working of tops and branches into the soil and over the site will help establish a well-stocked stand. Under these conditions it is usually necessary to fill-plant in the year following harvest, as regeneration is seldom evenly distributed over the site. Whips for fill planting can be collected from the site and “hot planted,” or they can be planted using stock collected the previous fall and winter and maintained in cold storage as described in Section 5.3.1. Hot planting must be carefully timed so that whips or cuttings are dormant at the time of planting. Fall logging has been shown to be effective in promoting sprouting from balsam poplar fragments on floodplains in Alaska (Zasada et al. 1981). A percentage of stocking from root sprouts can also be expected in balsam poplar stands, although the contribution of this component is highly variable (Kabzems et al. 1976; Zasada et al. 1981).

Stocking targets for naturally regenerated plantations are not well established. At the present time, Scott Paper aims at establishing 800–900 stems per hectare so that about 400 stems are left after 25 years for a pulpwood rotation. Evenness of stocking is often a problem, and stocking surveys must be carried out and fill planting completed after not longer than 1 year because of the high shade intolerance of the species. Overstocking is a common problem, especially where seedling survival is high, and initial establishment often ranges from 5000 to 30 000 stems per hectare. Cottonwood is strongly self-thinning, but high stocking levels at early stages reduce height and diameter growth (Smith 1980). Research in British Columbia (Smith and Blom 1966, 1970; Smith 1980) and elsewhere (Krinard and Johnson 1975, 1980, 1984) shows clearly that larger tree size is well correlated with lower stocking levels. Where conditions warrant it, a sanitation thinning carried out before the 4th year will increase productivity on overstocked plantations, although it appears that little or no response will occur if spacing occurs after the 4th year (Krinard and Johnson 1980, 1984). Further discussion of spacing on growth and yield is included in Section 5.3.3.

Given the low cost and ease of establishing of cottonwoods, along with the severe conifer regeneration problems and integrated resource management concerns on alluvial floodplains, use of this cottonwood management system will probably increase considerably in the near future, especially as foresters become more aware of its potential benefits. Although the principles of controlling and manipulating natural regeneration of cottonwood are reasonably well understood on the coast because of the experience of Scott Paper, many questions arise when these approaches are applied to interior situations. It is not known, for example, how well stem sprouting can be promoted when logging is carried out on snow, which greatly decreases ground disturbance. Reliable procedures that promote natural regeneration of cottonwood without degrading site quality or affecting other resources on alluvial floodplains are required. Concerns have also been expressed over the establishment of meaningful regulations to govern the regeneration of sites with cottonwood. Free growing standards, initial stocking levels, regeneration delays, and timing of regeneration surveys are all unknowns.
5.3.2.2 Extensive management using whip planting

Where stands being harvested contain fewer than 100 well-spaced cottonwood stems per hectare, or no cottonwood at all, stands will have to be established by whip planting. This has disadvantages and advantages over natural regeneration. Higher costs are the major drawback associated with this method, since many managers are reluctant to pay high planting costs given the present low product value of cottonwood. On the other hand, planting whips allows the final spacing of the plantation to be more carefully controlled, and this means that plantations can be established to meet final product objectives (e.g., pulp log or veneer spacing). Whips are planted directly after harvesting and, under extensive management systems, no site preparation or stand tending is needed. In the Prince Rupert Forest Region, bids to plant whips on helicopter-accessible, alluvial “rehab” sites ranged from $0.27 to $0.64 per whip, plus an additional $0.18–0.28 per whip to apply collars to protect against voe damage (C. Ripley, pers. comm.). Scott Paper currently plants 800–900 whips per hectare for a pulp log final product. Mortality can occur in dry springs or if whips are not properly handled before planting. Regeneration surveys should therefore be carried out after the first growing season, followed by fill planting the next spring. Projected pulp log rotations are 25–30 years on the coast and 30–40 years in the Interior, with final stocking of about 400 stems per hectare.

Hybrid poplars developed at the University of Washington–Washington State University (UW/WSU) poplar breeding program are considered to be suited to climates in south coastal British Columbia. They are planted operationally by Scott Paper. Productivity for hybrid poplars is much higher than for native cottonwoods, and growth and yield data for this management system are summarized in Section 5.3.3. As for extensive management of native cottonwoods, no stand tending—other than regeneration surveys and fill planting—is conducted after whip planting.

Given the relatively low cost and ease of establishing cottonwood (compared to conifers), and the promise of high yields of usable fibre over short rotations, this management system holds considerable promise for forest managers in British Columbia. As for naturally regenerated stands, whip plantations can be established on high brush hazard sites without herbicides, which reduces conflicts with integrated resource management concerns (see Section 5.4). Since spacing can be controlled, the potential for manipulating stands to enhance foraging habitat for ungulates and bears also has potential (Section 5.4). The system can be applied in all areas of the province using wildling whips or nursery stock collected locally and thus it can be adapted to local growing conditions. There is also considerable potential for increasing productivity of whip plantations if hybrid poplars adapted to the range of climatic and soil conditions of British Columbia can be developed.

5.3.2.3 Intensive management using hybrid poplars

The highest growth potential of hybrid poplar plantations can only be realized using agricultural-style management regimes that completely prepare sites, totally control competing vegetation, and control nutrient status through fertilization programs. In recently logged sites, all logging debris must be cleared, all stumps removed to facilitate mechanical stand tending, and the ground prepared as necessary (e.g., with ploughing, discing, subsoiling, ditching, or the installation of drainage pipes). With the high cost of site preparation, intensive hybrid poplar management is well suited to available agricultural lands. Where browsing ungulates such as Roosevelt elk are a potential problem, plantations may also have to be fenced (C. van Oosten, pers. comm.). Pre-emergent herbicides are often used and cuttings are planted in spacings that facilitate movement of machinery for vegetation control (Bey et al. 1975; Shipman 1975; Akinyemiju et al. 1982). Cunningham and Sowers (1965) demonstrated that pre-emergent herbicides are less effective than pre-planting cultivation for promoting early rapid growth of hybrid poplars. All competing vegetation is removed until canopy closure (usually about 3 years), through the use of either shielded herbicide applicators that protect vulnerable hybrid poplars or mechanical cultivators (Akinyemiju 1982; Hansen et al. 1984). Fertilizers are applied at the time of planting to aid in the establishment of roots, and again after 2 or 3 years, once roots are established (Aird 1962; Menetrier 1979; Menetrier and Vallée 1980; Hansen and
Cover crops of legumes or other plants have been used effectively as an alternative to herbicides and mechanical cultivation (McLaughlin et al. 1985). Ford and Williamson (1952) determined that cultivation was more effective than mulching for weed control and early poplar growth. Black polyethylene mulch is also an alternative (Bowersox and Ward 1976a) to herbicides or cultivation. After canopy closure, little management is required although fertilization may be carried out.

In the United States, considerable research has looked into using fibre from short rotation intensive silviculture (SRIC) with hybrid poplars and other species to produce fuel for generating electrical energy (Bowersox and Ward 1976a, 1976b; Ek and Dawson 1976; Hansen and Baker 1979). A considerable amount of this research has been carried out in the Pacific Northwest, initially using black cottonwood, and then hybrids between black and eastern cottonwood (Heilman et al. 1972; Heilman and Peabody 1981; Heilman and Stettler 1983; Harrington and DeBell 1984; Heilman and Stettler 1985a, 1985b, 1986; Stettler et al. 1988). In early work, black cottonwood clones were used and fresh weight yields after 2 years ranged from 13.4 tons/ha-yr⁻¹ in the first harvest to 20.9 tons/ha for the second harvest (Heilman et al. 1972). Harrington and DeBell (1984) measured yields of 13.8 tons/ha-yr⁻¹ in black cottonwood plantations amended with pulp mill sludge on a 2-year rotation. In another trial reported by Heilman and Stettler (1985a), total dry weight production of the two best P. deltoides x P. trichocarpa clones were about double the average for black cottonwood clones, and suggested the potential of hybrid poplars in short rotation culture. On a 6-year rotation, dry weight yields of 150–180 metric tons/ha for hybrid poplar plantations from hybrids developed in the UW/WSU program are reported in Abelson (1991). The most promising potential for utilization is to convert this biomass into fuels such as methanol, although the conversion process still needs to be refined (Abelson 1991).

Today the product focus for SRIC and the hybrids that have been developed is to provide fibre on slightly longer rotations for mixing with softwoods in pulp mills (Heilman et al. 1990; Abelson 1991). Using hybrids developed from this program, the James River Corporation has established about 4000 ha of intensively managed hybrid poplar plantations on farmland along the Columbia River to produce pulp as a final product. The company plants cuttings on a 2.13 × 3.05 m (7 × 10 ft) spacing, controls all competing vegetation, applies fertilizers based on foliar deficiency analysis, and mechanically harvests 60–90 dry tons/ha (about 200 m³) after 6 years. This results in a mean annual increment of about 34 m³/ha-yr⁻¹. The high productivity potential per unit land area using intensive cultivation of hybrid poplars is also shown by the James River data. Using its management system and hybrid stock, that 4000 ha produces 140 000–160 000 m³ of usable fibre annually.

No long-term experiments on how spacing affects productivity have been completed for black cottonwood or its hybrids in British Columbia. The data of Krinard and Johnson (1984) for a 20-year spacing experiment on P. deltoides do provide some insights, however, into spacing and productivity (Figure 4).

The experiment compared four spacings that ranged from a very tight biomass spacing at 1.22 × 2.72 m (2992 stems per hectare), through a pulpwod spacing of 2.44 × 2.74 m (1486 stems per hectare), to two decreasing densities of a pulpwod-sawlog spacing: 3.66 × 3.66 m (747 stems per hectare) and 4.88 × 5.49 m (373 stems per hectare). Krinard and Johnson (1984) concluded that the 3.66 × 3.66 m and 2.44 × 2.74 m spacings were the best alternatives because of their high merchantable yield on a relatively low number of planted trees. Of the two, the 2.44 × 2.74 m spacing (with the biomass spacing) reached the highest mean annual increment, but did so on 52% more trees (many more for the biomass spacing). Planting costs were therefore considerably higher. An interesting observation from this research is that the very dense spacing resulted in only slightly less merchantable volume after 20 years than did the two densities below it. Although the volume was in more stems, this result does suggest that cottonwood stands that regenerate naturally at very dense spacing (common in northeastern British Columbia) will still produce a considerable volume of usable fibre. The data should be interpreted cautiously, however, because the self-thinning or release response of black cottonwood, balsam poplar, or their hybrids may be quite different from that observed for eastern cottonwood in this experiment.
FIGURE 4. Results of a 20-year-old spacing study in a *P. deltoides* plantation in the Mississippi River. (Source: adapted from Krinar and Johnson 1984.)

The increase in juvenile growth rate that is captured by intensive management of hybrid poplars compared to extensive management of black cottonwood is evident from Figure 5. Height and DBH information are based on measurements made by Scott Paper in different plantations initiated at different times, but on similar sites on alluvial islands in the company’s TFL in the Fraser River. The black cottonwood plantation was planted from whips in 1977 and spaced to about 650 stems per hectare in 1983 (year 7). The NE41 (=OP41; *P. maximowiczii x P. trichocarpa*) and the Hybrid 11 (*P. trichocarpa x P. deltoides*) were planted with 25-cm cuttings at a square spacing of 3.6 m (770 stems per hectare). The NE41 plantation was started in March 1984 and the Hybrid 11 in March 1986. The sites were established on agricultural land in primarily grass cover, which was heavily ploughed, cross-disced, and rototilled before planting. Plantations were mechanically cultivated three times in the first year, twice in the second, and once in the third year, by which time canopies had closed and no further control was carried out. At age 7, NE41s are almost twice as tall, with more
FIGURE 5. Comparisons of black cottonwood growth and yield under extensive management with two hybrid poplars (Hybrid 11 = *P. trichocarpa* x *P. deltoides*; NE41 = OP41 = *P. maximowiczii* x *P. trichocarpa*) under intensive management on alluvial islands in the Fraser River. (Source: Scott Paper data.)

than double the mean DBH, compared to the black cottonwoods. At these densities, the NE41 has an almost 10-fold increase in volume per hectare and mean annual increment. Although the plantation is younger, the growth pattern for the Hybrid 11 is about the same as for the NE41. The volume data from this comparison should be interpreted cautiously, because plantations are still very young, and because the volume equation used was developed for hybrids in Ontario and may not accurately describe the trees in the trial. Also, mean annual increments would have been much higher in the black cottonwood plantation if the spacing had not been carried out in 1983. The mean annual increments calculated for the hybrid poplars in the Scott Paper plantations are very similar to those at the same spacing and age in the Mississippi plantations of *P. deltoides* (Figure 4).
MacMillan Bloedel has also considered using intensive management of hybrid poplars to provide usable pulp fibre over short rotations in coastal British Columbia (C. van Oosten, pers. comm.). For the last 4 years it has been evaluating the potential of different hybrid poplars developed by the UW/WSU program on experimental plantations, and will soon decide whether to embark on a major program.

Hybrid poplars developed in the UW/WSU breeding program are also being grown under irrigation from urban sewage effluent in Vernon (Carlson 1992). In addition to comparing fibre production under the various regimes, the objective is to compare the efficiency of hybrid poplar with that of grasslands in removing and assimilating wastewater nutrients. Hypothesized advantages of hybrid poplars for this purpose are that poplars can be established on ground topographically unsuited to grass management, deeper root systems may improve percolation and decrease escape to groundwater, evapo-transpiration rates will be higher per unit area, and some hybrids with a longer growing season may allow a longer irrigation period. Sites were prepared by herbiciding, ploughing, and disking, and planting was carried out in 1986 and 1988. Five-year averages for all trees in the older plantation are 13.8 m tall and 10.6 cm DBH. The best hybrids average 15 m in height and a DBH of 12.5 cm. These values are similar to those shown for hybrid poplar under intensive management in coastal British Columbia (Figure 5).

Given the shrinking forest land base and the increasing demand for fibre to process, and considering the high yields of cottonwood over short rotation lengths, we believe the intensive management of hybrid poplars should be aggressively developed in British Columbia. Prime areas for application of the management system would be those where farmland is available close to a utilization facility. The Fraser Valley is a prime example, with abundant, under-utilized farmland and with the Scott Paper mill close by in New Westminster. Eastern Vancouver Island is another possibility, as is the Prince George area. Participants at meetings in the Kamloops and Nelson Forest Regions suggested that integrated resource management issues were predominant in these areas and that the only opportunity for intensive cottonwood management would be on a localized basis (J. Pollack, pers. comm.; S. Simard, pers. comm.). The SRIC hybrid poplar plantations grown under sewage effluent and sludge applications provide a double advantage, in producing usable fibre over short rotations while disposing of a major environmental pollution problem. Use of these systems will probably increase in the future as the motivation to find solutions to sewage disposal problems becomes more focussed. The major work that needs to be done to successfully apply intensive systems on a provincial level is the development of hybrid poplars using local cottonwood clonal sources in combination with genetically superior clones of other species. This recommendation is discussed further in Section 2.3. Information on details of plantation management and yield values on different sites is also a major requirement. From this information, reliable economic models to predict revenues from this type of silviculture can be developed.

5.3.2.4 Mixed species management

Cottonwoods are early successional species that occupy sites rapidly and die out at a relatively young age. Most stands have a coniferous component that will eventually replace cottonwood, although coniferous stocking is often poor and several replacement events are necessary before full coniferous stocking is achieved in natural successions. The use of cottonwood as a nurse species to regenerate shade-tolerant conifers on high brush hazard sites mimics this natural successional process (McLennan and Klinka 1990). Cottonwood whips are interplanted with shade-tolerant conifers right after harvesting or site preparation. The cottonwoods develop rapidly and form a closed canopy after 10–20 years, depending on the site and original stocking. The closed canopy shades out light-requiring brush species, but permits the survival and slow development of the shade-tolerant conifers. Regeneration surveys and fill planting will have to be carried out so that stocking of subcanopy conifers is assured. The survival rates of subcanopy conifers in nurse tree shelterwoods are highly variable and depend in large part on the development of competing vegetation at the time of planting. Extra effort (e.g., fill planting and localized manual brushing) may be required to ensure the survival of the conifers in some situations.
Several options are possible once the two species are well established. Conifers can be released by girdling or hack and squirt as soon as 10 years after planting on some coastal sites (McLennan and Klika 1990), or the cottonwood component can be left until it is a merchantable size and then removed. For some integrated resource management applications it may be desirable to accept much longer rotations and wait for the cottonwood canopy to break up naturally (see Section 5.4).

On many upland sites in interior British Columbia, cottonwoods occur with other hardwoods, especially paper birch and trembling aspen, and form a hardwood complex that interferes with productivity of coniferous species. Until recently, the management strategy has been to remove all hardwood competition from these stands. This point of view is changing as the role of hardwoods in these stands is reconsidered in light of questions about the actual degree of interference they create, how to know when a hardwood individual needs to be removed, and the benefits hardwoods provide in terms of biodiversity and soil amelioration. Although not directly related to this problem analysis, the role of cottonwood and other hardwoods in upland coniferous plantations in interior British Columbia is a subject on which reliable information needs to be collected.

5.3.3 Growth and yield

5.3.3.1 Growth and yield of cottonwood under extensive management

Height growth for different species of cottonwood on different sites in North America and Europe is shown in Table 18. The data of McLennan (1991) have been averaged for each site association (see Figure 3) and indexed to height at 25 years for comparison with data in other published reports. The range of heights summarized for coastal black cottonwood sites in British Columbia is about the

<table>
<thead>
<tr>
<th>Species</th>
<th>Source</th>
<th>Location</th>
<th>Site</th>
<th>Height (m at 25 yrs) (m³/ha at 25 yrs)</th>
<th>Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>P. balsamifera</em> ssp. <em>trichocarpa</em></td>
<td>McLennan (unpublished data)</td>
<td>southwest B.C.</td>
<td>Cw–Ladyfern</td>
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<td></td>
<td></td>
<td>Ss–Salmonberry</td>
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<td></td>
<td></td>
<td>Ac–Willow</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Ac–Red-osier dogwood</td>
<td>31.0A</td>
<td>no data</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cw–Foamflower</td>
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<td></td>
<td>&quot;Gleysolic&quot;</td>
<td>22.3A</td>
<td>no data</td>
</tr>
<tr>
<td><em>P. balsamifera</em> ssp. <em>trichocarpa</em></td>
<td>Bunce (1990)</td>
<td>Skoena River</td>
<td>floodplain</td>
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<td>255D</td>
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<tr>
<td><em>P. deltoides</em></td>
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<td>Mississippi</td>
<td>unknown</td>
<td>32.9</td>
<td>380d</td>
</tr>
<tr>
<td><em>P. nigra</em></td>
<td>cited in Smith (1957)</td>
<td>Germany</td>
<td>Site Class I</td>
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<td>no data</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td>Site Class II</td>
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<tr>
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<td></td>
<td></td>
<td>Site Class III</td>
<td>22.8</td>
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</tr>
</tbody>
</table>

a Breast height age.
b Height and yield at 24 years.
c Height and yield at 20 years.
d To 10-cm top.
e Range from total to merchantable (to 10.2-cm top) volume at 2.44 x 2.74 m spacing.
same range as that reported in Germany for *P. nigra* (cited in Smith 1957). The best sites in British Columbia are also comparable in height growth with *P. deltoides* plantations in the Mississippi valley. The height growth reported by Murray and Harrington (1983) for a black cottonwood plantation on an alluvial site in Washington is higher than the mean for any of the site associations reported in Table 18, but two sites used to calculate the means were as high as or higher than 36 m at 25 years. Furthermore, the data of McLennan (1991) are based on unmanaged stands and are breast height age, whereas all compared stands from Washington and Europe are total age for managed stands. The data in Table 18 show clearly that black cottonwood growth in coastal British Columbia, even under unmanaged conditions, is equal to or surpasses that in other areas of North America and Europe.

Yield at 25 years is also shown in Table 17, but the figures are more difficult to compare. The studies of Mahon (1966) and Bunce (1990) were carried out in naturally regenerated stands. Average yield at 25 years in those studies is comparable to yields at 20 years in the study by Kinnard and Johnson (1984) for managed plantations of *P. deltoides* on the Mississippi River. The estimates available for British Columbia are considerably less than those shown for the Murray and Harrington (1983) study from western Washington, and for the Mississippi River study cited by Bunce (1990). Data for black cottonwood in British Columbia for the Skeena River (Bunce 1990) and Fraser River (Mahon 1966) are probably Ac–Red-osier dogwood sites that have medium productivity compared to Ss–Salmonberry or Cw–Ladyfern sites (Figure 3). The description of the study site described in the Murray and Harrington (1983) study would appear to be a Ss–Salmonberry site association. Correlating height growth for the British Columbia and Washington data supports this conclusion. If we use this assumption, we can estimate yields approaching 500 m³/ha, as reported by Murray and Harrington (1983), for black cottonwood over a 25-year rotation on the best sites in coastal British Columbia.

Yield estimates for black cottonwood under three management regimes employed by Scott Paper are shown in Table 19. The estimates for natural stands are similar to those shown in Table 18 by Mahon (1966) and Bunce (1990) for similar site associations (Ac–Red-osier dogwood) on the Fraser and Skeena rivers. Extensive management increases these yields to the 300–500 m³/ha range, depending on final stocking and variations in site quality. The estimates calculated for the Scott Paper TFL shown in Table 19 support suggestions made above—that yields approaching 500 m³/ha over a 25-year rotation can be expected with extensive management systems on the best sites in coastal British Columbia. From these figures, mean annual increments ranging from 10 to 20 m³/ha·yr⁻¹ can be expected from coastal sites under extensive management regimes (Table 19).

**TABLE 19.** Yield estimates for black cottonwood under three management regimes used by Scott Paper Ltd.

<table>
<thead>
<tr>
<th></th>
<th>Natural stands</th>
<th>Extensively managed pulpwood stands</th>
<th>Intensively managed pulpwood stands</th>
<th>&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotation age (yr)</td>
<td>30–50</td>
<td>25–30</td>
<td></td>
<td>15–20</td>
</tr>
<tr>
<td>Target tree size (m ht/cm dbh)</td>
<td>35/45</td>
<td>34/40</td>
<td></td>
<td>30/30</td>
</tr>
<tr>
<td>Target tree volume (m³/tree)</td>
<td>1.5</td>
<td>1.2</td>
<td></td>
<td>0.7</td>
</tr>
<tr>
<td>Net stand volume (m³/ha)</td>
<td>250</td>
<td>300–500</td>
<td></td>
<td>300–500</td>
</tr>
<tr>
<td>Final stocking (trees/ha)</td>
<td>325</td>
<td>350–400</td>
<td></td>
<td>700</td>
</tr>
<tr>
<td>Fraser R. MAI (m³/ha·yr⁻¹)</td>
<td>7.9&lt;sup&gt;b&lt;/sup&gt;</td>
<td>10–20</td>
<td></td>
<td>15–30+</td>
</tr>
<tr>
<td>Upcoast MAI (m³/ha·yr⁻¹)</td>
<td>5.4&lt;sup&gt;b&lt;/sup&gt;</td>
<td>10–15</td>
<td></td>
<td>15–20</td>
</tr>
</tbody>
</table>

<sup>a</sup> Projections based on current growth rates and yield data from other areas.

<sup>b</sup> Based on B.C. Forest Service inventory data and currently being updated.
5.3.3.2 Growth and yield for hybrid poplar under intensive management

Considerably higher annual increments can be expected from the intensive management of hybrid poplars, and this means that marketable specifications can be attained over a much shorter rotation. As shown in Table 19, the same final volumes of 300–500 m$^3$/ha can be expected in 15–20 years, which is just over half the time required to grow the same volume under extensive management systems. This implies a mean annual increment of 15 to over 30 m$^3$/ha-yr$^{-1}$, depending on the site and clone used. It is generally believed that annual increments from 25 to 35 m$^3$/ha-yr$^{-1}$ can be expected in south coastal British Columbia, where hybrid poplars are brought under intensive management regimes on suitable sites (P. McAuliffe and C. van Oosten, pers. comm.). Estimates in Table 19 are based on growth projections for the hybrids grown in similar climatic areas and under similar management regimes. Recent data for these plantations (Figure 5) support these projections for hybrid poplar growth and yield under intensive management regimes.

5.3.3.3 Data gaps and research recommendations

One major conclusion we can draw from summarizing information on cottonwood growth and yield is that, although much has been said about the high productivity of the species, very few studies have measured cottonwood productivity in British Columbia. Some studies have been carried out on black cottonwood growth and yield because of a historical interest in the species, but very little useful information has been collected for balsam poplar. From the information that is available, it is clear that cottonwoods and their hybrids have the potential to grow very rapidly if their moisture and nutrient requirements can be met. It is evident from the work of McLennan (1991) that cottonwood productivity varies considerably across the range of sites on which it grows. Height-age curves now in use (Hegyi et al. 1979) are inappropriate because they do not accurately describe the pattern of cottonwood height growth with age. Proper height-age curves are important for estimating cottonwood growth and yield because they are used to derive site index curves and yield tables. To provide a more realistic estimate of height growth, curves derived from stem analysis of trembling aspen are currently used (R. Drummond, pers. comm.).

In the short term, the most urgent research requirement is for accurate height-age and site index curves that can be used to develop realistic growth and yield data for cottonwood. This was seen as an important research need in all Forest Regions where managers are involved with establishing cottonwood plantations. The curves should be derived from stem analysis data collected from stands across the productivity gradient of the species. The stem analysis samples should be related to the recently correlated ecosystem classification of the Ministry of Forests so that forest managers can estimate the potential productivity of cottonwoods, whether the species is occupying the site at present or not. Some stem analysis work on cottonwood is presently under way in Inventory Branch (J. Vivian, pers. comm.) and is beginning with coastal British Columbia. This work should be expanded to focus on the Prince George and Prince Rupert Forest Regions, where the potential for managing cottonwood is high.

In the long term, more permanent sample plots (PSPs) for cottonwood should be set up across the same ecological spectrum recommended for the stem analysis. At present there are 15 cottonwood PSPs, all on alluvial floodplains and all in the Vancouver Forest Region (P. McAuliffe, pers. comm.). This network should be expanded to include the range of potential sites in coastal areas, as well as sites identified as suitable for cottonwood management in the Interior. Extensively and intensively managed hybrid poplar plantations have the potential to provide high yields of usable fibre over relatively short rotations. Permanent trials should be established to evaluate how productive these management systems can be in those areas across the province with potential for establishing such plantations.
5.4 Integrated Resource Management

5.4.1 Considerations for cottonwood management on alluvial floodplains

Cottonwoods show excellent growth and often dominate alluvial floodplains throughout British Columbia. Given their high productivity and ease of establishment on floodplains, and because of the serious competition they create for the establishment of freely growing coniferous plantations, many managers are beginning to consider cottonwoods as a preferred crop species in alluvial areas. In many Forest Regions of the province, cottonwoods are now considered to be acceptable species to regenerate on alluvial floodplain sites. In the future, alluvial floodplains will be considered as prime sites to manage cottonwood. This has serious implications for integrated resource management use, because wildlife and fish habitat values are high. This means that integrated resource management impacts must be carefully considered before cottonwood management is implemented in a given area.

Those animal species that may be affected by cottonwood management on alluvial floodplains are shown in Table 20. The list has been adapted from information presented in Enns et al. (1991), who discussed impacts of hardwood management on wildlife in British Columbia. Cottonwood stands on alluvial floodplains provide important habitat for both primary cavity nesters, who excavate nests in the decaying trunks and branches of dying and dead trees (snags), and secondary cavity nesting birds, who use the abandoned nest holes (Kelleher 1963; Carey 1983; Peterson and Gauthier 1985; Sedgwick and Knopf 1986, 1990).

TABLE 20. List of species potentially affected by cottonwood harvesting and regeneration in British Columbia. (Source: adapted from Enns et al. (1991), and Meidinger and Pojar (compilers) (1991).)

<table>
<thead>
<tr>
<th>Category</th>
<th>Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary cavity nesters</td>
<td>Lewis' Woodpecker; Pileated Woodpecker; Hairy Woodpecker; Northern Flicker; Yellow-bellied Sapsucker; Red-naped Sapsucker; Red-breasted Sapsucker; Downy Woodpecker</td>
</tr>
<tr>
<td>Secondary cavity nesters</td>
<td>Barrow's Goldeneye; Bufflehead; Common Goldeneye; Common Merganser; Hooded Merganser; Wood Duck; Western Screech-owl; Boreal Owl; Northern Saw-whet Owl; Tree Swallow</td>
</tr>
<tr>
<td>Common nesters</td>
<td>Great Horned Owl; Bald Eagle; Great Blue Heron; Osprey; Mourning Dove; Ruffed Grouse; Cooper's Hawk; Red-eyed Vireo</td>
</tr>
<tr>
<td>Small mammals</td>
<td>Northern long-eared myotis; Pacific water shrew; Southern red bat; Pacific jumping mouse</td>
</tr>
<tr>
<td>Large mammals</td>
<td>Grizzly bear; Black bear; Moose; Roosevelt elk; Mule deer; White-tailed deer</td>
</tr>
<tr>
<td>Furbearers</td>
<td>Bobcat; Mink; Ermine; River otter</td>
</tr>
<tr>
<td>Reptiles and amphibians</td>
<td>Clouded salamander; Giant salamander; Painted turtle; Western toad; Long-toed salamander; Canadian toad; Striped chorus frog; Wood frog; Tailed frog</td>
</tr>
</tbody>
</table>

Work by Sedgwick and Knopf (1990) determined that large snag density (>69 cm), total length of dead limbs over 10 cm, and cavity density were the most important habitat variables; that dead limb length, DBH, and snag species were the most important tree variables; and that cavity height and entrance diameter determined species preferences for the different cavities on cottonwood floodplains in Colorado. Their observations point out the complexity of the relationship between the various cavity nesters and their habitat requirements. Cottonwood stands also provide important nesting habitat for a variety of raptors and other birds (Table 20). Cottonwood management has the potential to affect cavity nesting species severely on alluvial floodplains because rotations planned are 25–35 years on the coast and 40–60 years in the Interior. Given that the incidence of heart rot in cottonwood under 90 years old is less than 10%, and clearcut management systems are mandatory for cottonwood regeneration, there will be very little opportunity for primary cavity nesters to excavate nests in these stands before they are harvested.
The importance of alluvial cottonwood stands to grizzly bears in coastal British Columbia is well documented by Banner et al. (1986) and Hamilton and Archibald (1986). The bears forage on the herbs and berries that abound under cottonwood canopies and are adjacent to fishing streams. Cottonwood stands on alluvial floodplains are also important foraging areas for black bear, Roosevelt elk, and black-tailed deer on the coast (Nyberg et al. 1990) and for moose and mule deer in the Interior (Meldinger and Pojar 1991). The use of shrub associates such as red-osier dogwood and willows are particularly important for the winter range of moose in the Interior (Enns et al. 1991; Sumanek3). Cottonwood management has the potential to affect all of these species as well.

Small mammals also inhabit cottonwood stands on alluvial floodplains (Table 20), including different kinds of mice, shrews, and furbearers. Population dynamics of these animals determine the prey available for the more high-profile raptors and predators that feed on them. A number of reptiles and amphibians are also common, and their habitat requirements include an abundance of downed woody material such as decaying logs and slash. The intense site preparation and close utilization that accompany some types of cottonwood management could have implications for populations of these species.

An obvious implication for hardwood management on alluvial floodplains is the potential impact of forest operations on fish populations and water quality. Fisheries-forestry guidelines have been published (British Columbia Coastal Fisheries-Forestry Guidelines 1988) and are being updated. These guidelines outline the steps to be taken to prevent damage to stream environments and fish habitats in alluvial areas. Maintenance of vegetation buffers and pesticide-free zones along watercourses are included in these recommendations. More recently, the provision of large woody debris in streamside buffers has been considered important, since large trees fall into streams and create complex pool and riffle habitats, slow down water movement, and provide important cover in rearing areas. Allowing for all these recommendations contributes to the complexity of cottonwood management on alluvial floodplains.

5.4.2 Cottonwoods as an alternative to conifer management on alluvial floodplains

Conifer regeneration is particularly difficult on alluvial floodplains because of the competition for light and nutrients by broadleaved trees and shrubs following logging, and because of social, ecological, and economic restrictions in the use of herbicides or manual brushing to control brush until conifer plantations are free growing. Cottonwood management is rapidly being seen as a desirable alternative because stands can be established rapidly, at a much lower ecologic and economic cost. At the extensive level of cottonwood management, no herbicides are required and, if stocking is controlled, regenerating stands will provide good foraging habitat for a considerable time. The rapid site occupation reduces the potential of surface erosion entering fish-bearing streams, and hardwood canopies offer shade to regulate stream temperatures and provide allochthonous nutrients to stream ecosystems. On the product side, extensive management of cottonwood provides usable fibre over relatively short rotations. The short rotations are another desirable characteristic for management on alluvial floodplains. Because surfaces are prone to erosion, returns on the expensive silvicultural investment required to establish conifers decrease as rotation lengths increase.

Nurse tree shelterwood systems described by McLennan and Klinka (1990) provide a possible method of regenerating conifers without using herbicides or affecting too severely other resource users on alluvial floodplains. Nurse tree shelterwood plantations enjoy many of the benefits mentioned above for cottonwood plantations and, where the productivity of the coniferous component is not the major management objective, the cottonwood overstory can be left to break up naturally and the subcanopy conifers released on an irregular, long-term basis. This accomplishes two objectives. First, it permits the cottonwood component to die out naturally and thus provide habitat for cavity nesters and other snag-dependent species; and it provides abundant downed woody material on the forest floor. Second, it re-

establishes a coniferous component on alluvial floodplains that might be lost if only cottonwood were managed. The method is suitable on a patch basis to rehabilitate portions of floodplains where conifers have been lost and cannot be regenerated, and to manage streamside buffer strips that contribute coniferous, large organic debris in the long term.

It may also be possible to use cottonwood to ameliorate or enhance wildlife values. Stocking density affects the productivity of forage species in important foraging areas and is an important component of habitat suitability (A. Hamilton, pers. comm.). It has been suggested, for example, that planting could be carried out so that some areas of a site were planted in relatively tightly stocked "islands" of regeneration, and other areas planted at a very wide spacing. This would create productive patches of berry-producing shrubs, interspersed with cover areas where canopy closure would be rapid and brush would be shaded out. It would also be possible to intersperse some mixed plantings into the setting to add an extra component of vegetation complexity.

As mentioned above, cottonwood management can have some serious effects on non-timber values on alluvial floodplains. The most important of these are declining sites for cavity nesters and associated species complexes, potential reduction of foraging areas for bears and ungulates, reduction in biodiversity by the alteration of small mammal, reptile and amphibian habitat, and changes to fish habitat and water quality if management is not carried out according to fisheries-forestry guidelines. Although careful research needs to be done to identify at-risk populations on a local level, some general recommendations are to:

1. maintain buffers around special wildlife habitat features such as eagle or osprey nests;
2. retain patches of live trees (conifers and hardwoods) within the block and along the edge of the block;
3. retain hard and soft snags on green retention sites and along cutting boundaries where they do not endanger the work area;
4. retain single live trees that are windfirm and may later become snags; and
5. leave unmerchantable pieces in block for down woody debris.

By trying to implement these recommendations, forest managers might be able to maintain habitat values while growing productive cottonwood crops over the majority of the area of the floodplain being managed.

Another requirement for forest operations in alluvial areas will be the netting down that must occur to ensure that fish and wildlife values are preserved. The procedure followed by Scott Paper for the dedication of its TFL lands on three alluvial floodplains in coastal British Columbia was seen by regional wildlife managers as a big step in the direction of proper management of alluvial floodplains (Enns et al. 1991). In that case, the TFL land base was netted down about 50% to allow for inoperable areas, unstable banks, and fish and wildlife concerns. This magnitude of netting down may represent a rule of thumb for managing alluvial floodplains for usable forest products.

5.4.3 Information gaps and research requirements

Managing cottonwood in British Columbia means practicing forestry on alluvial floodplains, and concern for non-timber values in these areas was repeatedly put forward as an important concern in regional meetings. Clearly, the successful integration of cottonwood management into the timber supply system across the province can only be achieved if strategies are developed to capture the productive potential of the species while not degrading other values on alluvial floodplains. The potential impacts of cottonwood management on fish and wildlife habitat on alluvial floodplains have been outlined and some ideas put forward, but most of these are based on speculation about what might be possible. Research to test the feasibility of these and other suggestions is needed.

4 Klenner, W. 1991. Pre-harvest silvicultural prescriptions to protect and maintain wildlife habitat. B.C. Min. For., Vancouver Forest Region, Burnaby, B.C.
6 SUMMARY OF COTTONWOOD MANAGEMENT AND REQUIRED RESEARCH

6.1 Rationale for Cottonwood Management in British Columbia

This problem analysis points out a growing interest in cottonwood management in British Columbia, and reflects an increased awareness of the potential of the deciduous resource throughout Canada and the United States. The managers we interviewed were interested in cottonwood management in British Columbia for several reasons:

- Regenerating conifers on high brush hazard sites, especially with the loss of herbicides as a forest management tool, is difficult and costly.
- There is a growing awareness of the potential to manage cottonwoods to produce usable fibre in proximity to important fish and wildlife areas, while at the same time protecting non-timber resource values.
- Forest managers are under pressure to increase forest production on a decreasing land base.
- New, rapidly growing hybrid poplar clones, developed using black cottonwood stock, are available and well suited to south coastal climates.
- New processing centres in northeastern British Columbia are being established that use both trembling aspen and cottonwoods.
- Cottonwood has a variety of potential new forest roles, including: to help establish conifers on high brush hazard sites; to stabilize riparian areas and provide cover and nutrients for stream ecosystems; to help replenish nutrient-depleted soils; to help stabilize unstable slopes; to reclaim denuded land and mine spoils; and to reforest root rot areas.

6.2 Cottonwood Research Requirements

The diverse aspects of cottonwood management discussed in this analysis are grouped into the following management roles to organize the discussion and ranking of knowledge gaps and research requirements. We have also identified those Forest Regions where the management system will be applied, and hence where the particular research area should be focussed. Research discussed in this section is prioritized in Section 7.

- Extensive management of cottonwood on high productivity, high brush hazard sites is the most commonly applied management system for cottonwood in British Columbia. This type of management has been conducted in the Vancouver Forest Region for some years, and its application is rapidly increasing in the Prince Rupert and Prince George Forest Regions. There will probably be limited use of this type of management system in any of the other Forest Regions, primarily because of the lack of suitable sites and processing facilities within the forest land base in those areas.

i) Operational Standards: The establishment of meaningful operational standards for cottonwood regeneration is an immediate requirement in several Forest Districts. What criteria should be established for stocking standards, regeneration delays, and freely growing plantations? In terms of site regeneration, is whip planting a requirement on all sites, or will natural regeneration be sufficient to stock the stand? How can this be predicted or manipulated? How does this vary among different biogeoclimatic zones and on the various sites within those zones?

Using the literature and observations of case history data in the areas to be managed, we should be able to assist managers in arriving at some “best guesses” for operational standards relatively quickly. More informed answers would be possible after several years’ observation of different harvesting and regeneration scenarios, and research should be initiated to examine the different possibilities on the sites to be managed. Refinements could only be made after longer term observations covering a complete rotation.
ii) **Cottonwood Whips**: The planting of cottonwood whips is a new activity to most forest managers. Details on the collection, culturing, storing, and planting of cottonwood whips was commonly expressed as an immediate need. What are the caliper and length criteria for whip planting stock? What requirements should be made of planting contractors?
Most of the information already exists within British Columbia to answer these questions well enough to successfully establish cottonwood plantations. The information needs to be collected into an information pamphlet and circulated to interested managers. Useful research could be initiated to determine whether different preplanting treatments (e.g., wounding, soaking, or rooting hormones) significantly increase rooting success, or what length of whip is best for various regeneration scenarios.

iii) **Site Selection, Growth and Yield, and Decay, Waste, and Breakage Factors**: It is well known that cottonwood is the fastest growing tree in British Columbia, but high productivity is only possible when the species' demands for high soil nutrient availability and ample soil moisture can be supplied. This means that those sites with the most potential for cottonwood management within a given geographic area need to be identified. Managers in the Interior considered this a major research requirement. Some aspects of the work required have already been carried out in the Vancouver Forest Region and should be extended to the Prince Rupert and Prince George Regions. Besides highly productive sites, it may also be possible to identify sites where cottonwood is easier to manage than any other species. Areas with fluctuating water tables are examples of such sites for cottonwood management in coastal British Columbia.

The most reliable procedure to assess site index on a given plot is to conduct stem analysis of canopy dominants and co-dominants. In this way, reliable height-age curves can be generated for use by growth and yield specialists in developing site index equations on the sites to be managed for cottonwood. The collection of good growth and yield data was another research requirement identified by managers during this analysis. With data derived from stem analysis, foresters can determine whether height-age curves are polymorphic, and this information can help refine site index equations. As well, the site index classes developed from biogeoclimatic classification can be correlated with site units, and observations of cottonwood productivity can be generalized to the area. This can assist foresters in determining on which sites cottonwood should be considered an acceptable species.

Destructive sampling should also be carried out to determine decay percentages, especially in those areas where the cottonwood resource is in the older age classes. Given the potential for variation in decay percentages on different sites, this stratification will provide the basis for sampling across the range of sites within a given management area. This work should also be carried out within those Forest Regions (Vancouver, Prince Rupert, and Prince George) where production-oriented cottonwood management is to be initiated, since considerable variation appears to occur among the different climatic areas of the province.

Stem analysis will provide accurate, short-term information on the growth and yield of cottonwood in unmanaged stands. Permanent sample plots should be established immediately on a range of sites and management systems in the three Forest Regions where productive cottonwood management is planned. This is the only way that locally relevant information on the growth and yield of managed cottonwood stands can be acquired in the long term. There are 15 cottonwood PSPs at this time and the network should be expanded greatly.

iv) **Integrated Resource Management Effects**: Invariably, managing cottonwoods for fibre production means managing alluvial floodplains in the three Forest Regions and, as discussed in Section 5.4, this has the potential to harm non-timber resources in these complex management areas. Therefore, stand-level and watershed-level research should be initiated to evaluate the impact of extensive cottonwood management on these resources, and to design systems that meet the objectives of all users. Unlike conifer management, establishment of extensive plantations of cottonwood is relatively benign, but negative impacts to cavity nesters and associated species, and to reptiles, amphibians, and small mammals, should be
seriously considered in all regions. In coastal British Columbia, the impact of management on foraging values for grizzly bears, black bears, and Roosevelt elk should be an important component of all cutting plans. In the Interior, impacts on moose winter range are an important concern.

v) **Cottonwood Inventory and Utilization:** In the analysis of the existing inventory of cottonwood presented in Section 3, we concluded that the present assessment of cottonwood inventory seriously underestimates the volume of utilizable cottonwood available in the various Forest Regions. The major reasons for this inaccuracy are discussed in that section and, except for growth and yield, or decay, waste, and breakage aspects, the updating of this inventory is not strictly a research concern. We also discussed in Section 3 how, even if an accurate gross estimate were available, its relevance for utilization would only be appreciated if the location, size characteristics, and quality were known, in relation to proposed or existing utilization facilities.

The research required in this area involves the development of locally based utilization strategies that include cottonwood with other species in utilization complexes. One of the principal reasons cited in the literature for the failure of many hardwood operations is their reliance on high quality resources that become exhausted or economically unfeasible to transport to the processing centre. Hardwoods can potentially be used in the production of locally produced, value-added specialty products, given that a reliable and economically accessible supply of the resource is available and its characteristics are known. Market research into what sort of specialty products are the most promising should be encouraged. Production of specialty products should be integrated with facilities such as oriented strandboard plants, or other uses that can take wood volume at the low end of the quality spectrum should be found. The opportunity exists, especially in the Prince Rupert and Prince George Forest Regions, to develop this potential, but careful research and good planning information is required before utilization strategies are adopted.

- **Intensive management of hybrid poplars in agricultural-style plantations** is a relatively new management system that has immediate potential for coastal and southern British Columbia (Vancouver Forest Region and parts of the Kamloops Forest Region) because a few hybrid poplars suited to these climates have already been developed. The limited growth and yield data available suggest that hybrid poplar productivity in British Columbia ranks with that described in Europe and North America, where the method is widely applied and researched. This management system has long-term potential for application in the other Forest Regions, but will require the development of hybrid poplars suited to these climates.

i) **Collection and Evaluation of Cottonwood Genetic Material:** Given the importance of black cottonwood as a source of genetic material for hybrid poplar breeding both in British Columbia and all over the world, a research initiative designed to capture and develop the genetic potential of the black cottonwood and balsam poplar resource in coastal and interior British Columbia is a high priority. This was seen as a major research requirement by those attending regional meetings and making written submissions. In the short term, the objective would be to make a major collection of representative cottonwood material from a wide geographic range in British Columbia. Collected material would be preserved in at least two clone banks, one in the Interior and one on the coast. Uniform cuttings from this material could then be used to establish screening trials to identify the most promising genotypes. These would serve as the core material for a range of field trials located throughout the province, and for the provision of new genetic material to hybrid poplar breeding programs in the United States and Europe.

ii) **Hybrid Poplar Breeding Program:** The cottonwood material collected and evaluated could, in the long term, serve as the raw genetic material for a British Columbia-based hybrid poplar breeding program. The best genotypes identified by this program would be crossed to produce productive and resistant black cottonwood hybrids, and, crossed with superior genotypes of *P. deltoides*. *P. nigra*, and *P. maximowiczii*, to develop hybrids with high growth potential,
adapted to interior and north coastal growing sites. Our late start in this field could benefit from other cottonwood breeding programs that have been under way for some time, since many desirable characteristics have already been captured in promising hybrids. The long-term objective of this program would be to create hybrid poplars specifically adapted to the range of British Columbia climates and sites, and designed for local, intensive and extensive hybrid poplar management systems. A research program of this nature would provide locally adapted hybrids for our own forestry needs, and would fulfill what was expressed by several meeting participants as our responsibility to the world poplar community to collect and develop the cottonwood genetic resource that we have in British Columbia.

A potentially important component of a cottonwood breeding program in the long term is the application of biotechnology research to the development of promising hybrid poplars. As discussed in Section 2.2, cottonwood—more than conifers—is well suited to this type of research approach, and work on locally adapted hybrid poplars is ongoing, both at the University of British Columbia and the University of Washington. This work will add to our knowledge of the organization and functioning of the poplar genome, and could potentially facilitate selection testing steps in a breeding program.

iii) Ongoing Research on Existing Intensively Managed Plantations: A few intensively managed hybrid poplar plantations have been established by Scott Paper and MacMillan Bloedel, and by the Ministry of Forests on sewage effluent at the Kalamalka Research Station in Vernon. Measurements of growth and yield for the Scott Paper plantations are shown in Figure 5, but the plantations are too young for any conclusions to be drawn about final productivity. Monitoring is continuing by the agencies concerned and this research should be supported. These plantations could serve as models for future application of the approach on a broader scale and could, in the long term, be used to develop useful, local economic models and site-specific fertilization regimes.

iv) Establishment of More Intensively Managed, Hybrid Poplar Plantations: There are presently a limited number of intensively managed hybrid poplar plantations located on a relatively small cross section of the available site units. More plantations of this nature should be established across the range of sites for which they are suited in coastal British Columbia. For example, the plantations established by Scott Paper are on the Ac–Red-osier dogwood site unit and, primarily because of growing-season flooding in the rooting zone, the site index for natural stands on such sites is in the medium range for native black cottonwood. It is possible that a higher productivity potential exists for hybrid poplar in coastal British Columbia. Establishment of a range of hybrid poplar plantations would provide the basis for a more accurate assessment of the potential of this management approach.

The use of hybrid poplars as a means of fixing organic waste in sewage effluent and sludge systems is also a promising approach to helping solve a major environmental problem while creating usable fibre. The effluent irrigation system in particular seems very well suited to many interior situations because, in areas where atmospheric moisture may be low, it supplies the hybrid poplars with the water and nutrients they need for rapid growth. Such systems are currently restricted to the climatic range for which the hybrid poplars are suited, but native cottonwoods could be used until locally adapted hybrids are developed.

- **Cottonwood mixed-wood management** is largely experimental, but is an approach well received by those with experience managing high brush hazard sites throughout British Columbia. The methods are appropriate to all Forest Regions and are being considered more seriously by many of the forest managers we interviewed. A few managers said that they are preparing to establish mixed plantations at an operational level in their Forest Districts.

i) **Nurse Tree Shelterwoods:** The use of cottonwood as a nurse species to regenerate shade-tolerant conifers on high brush hazard sites was described in Section 5.3.2.4. The method has been used only on a limited scale in British Columbia, although it has seen wider application in Europe. Many managers are willing to attempt the approach because of brush problems and restrictions in using herbicides on high brush hazard sites. Experimental plantations have
been planted on a small number of sites in coastal British Columbia, but more need to be established throughout the province. Other species combinations should be tried, depending on the regional climate of the areas and the species available for management. Another option for mixed-wood management with cottonwood involves spacing plantations that have been overtopped by cottonwoods, rather than completely removing the canopy. Establishing shelterwood systems by planting the shade-tolerant conifers and then managing the hardwood component as it invades the site should also be evaluated on an experimental basis. Many scenarios exist for removing the cottonwood overstory, and different approaches should be tried.

ii) **Balsam Poplar – White Spruce Management in the Northeast:** Considerable attention is being paid in other provinces to silvicultural systems involving mixtures of trembling aspen and balsam poplar with conifers in upland situations. Although this is primarily a trembling aspen concern, balsam poplar forms a large component of these upland stands under certain site conditions. Research into balsam poplar–white spruce mixed-wood systems are thus an important future aspect of silviculture in the northeastern areas of the province.

- **The use of cottonwood as a tool for enhancing wildlife and fish habitat** is also important for all Forest Regions in British Columbia. In Section 5.4, some aspects of this potential application of cottonwood research were discussed. Suggestions included:
  i. creating optimal bear-foraging habitat using clumped spacing approaches;
  ii. leaving the cottonwood component in nurse tree shelterwood systems to die out naturally, thus creating habitat for cavity nesters and associated species; and
  iii. using nurse tree shelterwoods in riparian zones to stabilize streambanks, provide shade and energy inputs to stream ecosystems, and, in the long term, to create coniferous, large organic debris for the enhancement of stream habitats.

Research plantations attempting these procedures should be established throughout the province. Priority areas would be grizzly bear habitat manipulation on alluvial floodplains in coastal British Columbia, riparian zone management in Class 1 rivers throughout the province, and enhancement of moose browse in northern interior districts.

### 7 RANKING OF COTTONWOOD RESEARCH

Research discussed in Section 6 is prioritized by Forest Region, management system, and research topic in Table 21. "Other Forest Regions" is used to summarize the central and southern interior Forest Regions because of the relatively low level of productive cottonwood management planned for those regions, and because their cottonwood research priorities are more or less the same. The ratings are focussed primarily on perceived requirements in the Kalum Forest District in the Prince Rupert Forest Region, although awareness of the potential for cottonwood utilization is increasing in the others. Similarly, the Dawson Creek and Fort Nelson Forest Districts are the principal focus in the Prince George Forest Region, although other districts are becoming interested as well.

The ratings vary by Forest Region, based primarily on the available expertise and experience in cottonwood management, and on the perceived utilization and management of cottonwoods as communicated by forest managers in the different Forest Regions. Scott Paper has been managing cottonwoods in coastal British Columbia, so many local solutions to management problems have been achieved. Because coastal British Columbia has also developed hybrid poplars for its relatively benign climate, intensive management has a higher urgency there. The Prince George and Prince Rupert Forest Regions have a considerable cottonwood resource, but are only beginning to manage it with planning. Their requirement is therefore for more basic information on extensive management. The other Forest Regions do not have an extensive cottonwood resource and have no long-term plans for productive management of the sites that they
do have. Their principal interest is in cottonwood management as it relates to integrated resource management concerns. Some interest has also been expressed in the long-term potential of intensive management on agricultural land, once locally adapted hybrids are available.

The priorities presented in Table 21 are subjective assessments of perceived research needs based on input from forest managers throughout British Columbia, on an assessment of the published literature on cottonwoods, and on our expertise in cottonwood management. We have ranked these research requirements and put them forward here to assist Ministry research coordinators in developing an organized approach to cottonwood management in the province.

**TABLE 21. Ranking of cottonwood research by Forest Region, management system, and research topic**

<table>
<thead>
<tr>
<th>Management system</th>
<th>Research topic</th>
<th>Vancouver</th>
<th>Prince George</th>
<th>Prince Rupert</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extensive</td>
<td>Operational standards</td>
<td>medium</td>
<td>very high</td>
<td>very high</td>
<td>low</td>
</tr>
<tr>
<td></td>
<td>Whips</td>
<td>medium</td>
<td>high</td>
<td>high</td>
<td>low</td>
</tr>
<tr>
<td></td>
<td>Site selection</td>
<td>low</td>
<td>very high</td>
<td>very high</td>
<td>low</td>
</tr>
<tr>
<td></td>
<td>Stem analysis</td>
<td>medium</td>
<td>very high</td>
<td>very high</td>
<td>low</td>
</tr>
<tr>
<td></td>
<td>Decay factors</td>
<td>high</td>
<td>very high</td>
<td>very high</td>
<td>low</td>
</tr>
<tr>
<td></td>
<td>PSPs</td>
<td>high</td>
<td>high</td>
<td>high</td>
<td>low</td>
</tr>
<tr>
<td></td>
<td>IRM effects</td>
<td>very high</td>
<td>very high</td>
<td>very high</td>
<td>low</td>
</tr>
<tr>
<td>Intensive</td>
<td>Genetic collections</td>
<td>very high</td>
<td>high</td>
<td>high</td>
<td>high</td>
</tr>
<tr>
<td></td>
<td>Hybrid poplar breeding</td>
<td>very high</td>
<td>medium</td>
<td>medium</td>
<td>medium</td>
</tr>
<tr>
<td></td>
<td>Ongoing plantations</td>
<td>very high</td>
<td>low</td>
<td>low</td>
<td>medium</td>
</tr>
<tr>
<td></td>
<td>New plantations</td>
<td>very high</td>
<td>low</td>
<td>medium</td>
<td>low</td>
</tr>
<tr>
<td>Mixed-wood</td>
<td>Nurse tree</td>
<td>very high</td>
<td>very high</td>
<td>very high</td>
<td>medium</td>
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<tr>
<td>Habitat enhancement</td>
<td>Stocking manipulation</td>
<td>very high</td>
<td>medium</td>
<td>medium</td>
<td>medium</td>
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<tr>
<td></td>
<td>Buffer zone management</td>
<td>very high</td>
<td>very high</td>
<td>very high</td>
<td>high</td>
</tr>
<tr>
<td>Final products</td>
<td>Utilization complexes</td>
<td>medium</td>
<td>very high</td>
<td>very high</td>
<td>low</td>
</tr>
<tr>
<td></td>
<td>Specialty products</td>
<td>medium</td>
<td>very high</td>
<td>very high</td>
<td>low</td>
</tr>
<tr>
<td></td>
<td>Markets</td>
<td>medium</td>
<td>very high</td>
<td>very high</td>
<td>low</td>
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</table>
8 REFERENCES


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APPENDIX 1. List of meeting participants


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