B O N N E V I L L E   P O W E R   A D M I N I S T R A T I O N

Riparian Cottonwood Ecosystems and Regulated Flows in Kootenai and Yakima Subbasins

Comparison of Remote Sensing Tools for Assessing the Distribution of Riparian Cottonwood Stands in the Columbia Basin

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AN OVERVIEW OF THE KOOTENAI AND YAKIMA RIPARIAN COTTONWOOD PROJECTS.

1.0 INTRODUCTION

Riparian vegetation and especially cottonwood and willow plant communities are dependent on normative flows and especially, spring freshette, to provide conditions for recruitment. These plant communities therefore share much in common with a range of fish species that require natural flow conditions to stimulate reproduction. We applied tools and techniques developed in other areas to assess riparian vegetation in two very different sub-basins within the Columbia Basin. Our objectives were to:

- Document the historic impact of human activity on alluvial floodplain areas in both sub-basins.
- Provide an analysis of the impacts of flow regulation on riparian vegetation in two systems with very different flow regulation systems.
- Demonstrate that altered spring flows will, in fact, result in recruitment to cottonwood stands, given other land uses impacts on each river and the limitations imposed by other flow requirements.
- Assess the applicability of remote sensing tools for documenting the distribution and health of cottonwood stands and riparian vegetation that can be used in other sub-basins.

An overview of this work is presented here, more detailed information is provided in three separate reports as below.

1. The impact of flow regulation on riparian cottonwood forests along the Kootenai River in Idaho, Montana and British Columbia.
2. The impact of flow regulation on riparian cottonwood forests along the Yakima River.
3. A comparison of remote sensing tools for assessing the distribution of riparian cottonwood forests in the Columbia Basin.

Each is presented as a stand alone report and is available at the BPA website as separate document. Appendices to the major reports are included as separate files to minimize file size.

This work was funded under the innovative projects program of the NWPPC and BPA.

2.0 STUDY AREAS

Maps of the study areas are provided in the separate reports. A description of some of the essential differences between the sub-basins is provided below.

Kootenai River: The Kootenai River is an international sub-basin with one major reservoir (Libby) mid-way on the portion of the river we looked at. There are few dams, none of which have significant storage, in the headwaters of this river. Irrigation removals are minor but diking for agricultural has had major impacts on the lower portion of the river. The hydrograph below Libby dam is highly regulated. Over the last decade, flows on the downstream reaches of this river have been manipulated to create a series of artificial spring freshettes aimed at stimulating spawning in white sturgeon. This gave us the opportunity to observe the response of native cottonwoods and willows to these experimental flow releases.

Yakima River: The Yakima River has several storage reservoirs in the upper reaches of the system. The major alluvial floodplains lower on the system support extensive areas of intensive agriculture. A significant proportion of the annual flow is removed from the river for irrigation. Agriculture, settlement and regulated flows have had a significant impact in the floodplain portions of the system. Flows vary substantially over the season in a manner that is referred to locally as “flip-flop”. In this sub-basin our project benefited substantially from collaborative research activities on the alluvial floodplains of this system. A Bureau of Reclamation project, the **Yakima Reaches Project** under the direction of Dr. Jack A. Stanford of the University of Montana Flathead Biological Station has completed extensive work on the basic ecology of these alluvial floodplain areas.

3.0 METHODS

We applied six major tools is assessing riparian vegetation in these sub-basins.

1. A regional overview using Landsat and other data sources.
2. A historic assessment, using air photo interpretation comparing photos over a 50 to 80 year period, of riparian vegetation and land uses in three study reaches (5-12 km in length) along portions of the main stem rivers in each sub-basin.
3. An assessment of the present distribution of cottonwood, using a range of remote sensing tools, in these study reaches.
4. An assessment of the health of riparian vegetation and cottonwood stands, based on vegetation transect data collected at 30 to 60 sites in each sub-basin on point bars both within and outside the major study reaches.
5. An assessment of annual and seasonal flow data for each study reach.

The methods used are described in detail in the separate reports.

4.0 RESULTS

Kootenai River: We found that human impacts on the floodplain were much more extensive in the reaches below the Libby dam than in our study reaches upstream of the reservoir. Much of the lower river is diked and most of the floodplain is now farmland. Cottonwood stands do occur in the three downstream reaches however and we found recent cottonwood recruitment at three transect sites that has occurred as a result of spring flow releases for white sturgeon in the 1991 to 2000 period. The shape of these experimental releases varied widely between years and we were able to identify the years in which recruitment likely occurred.

Yakima River: We found extensive human impacts in all the alluvial reaches we studied. Unlike the Kootenai River however, there is still an active floodplain, between dikes and other constrictions, along most of the mainstem Yakima and its major tributaries. Gravel mining has had a major impact in many areas. Very little recruitment to cottonwood stands is occurring as a result of the highly modified flow regime in this sub-basin.
This work provides a good basis for more detailed future studies that will be co-ordinated with other research and restoration activities in this sub-basin, especially the Yakima Reaches Project and riparian restoration projects being carried out by the Yakima Indian Nations.

Tools Assessment: We found that Landsat data was ineffective in providing a regional overview of cottonwood distribution, due to problems in differentiating between deciduous hardwood species. Forest cover available in Canada did provide a good overview of cottonwood distribution in the Canadian portion of the Kootenai sub-basin. It appears that new hyper-spectral satellite data may allow the separation of deciduous species and could play a role in future work.

At a study reach scale we found that traditional visual typing of vegetation types from air photos, ADAR and IKONOS all could be used to document the distribution of cottonwood stands and other riparian vegetation types. Each approach had positive attributes, some limitations and varied in cost. Hymap, a new hyper-spectral data source (flown at low elevation) has been used to separate deciduous species in the Yellowstone area. This tool will be of major value in future studies of riparian vegetation.

5.0 CONCLUSIONS

Our most important conclusions are that:

- Major losses to riparian vegetation and ecological function have occurred in response to regulated flows in both river systems.
- There are major differences in the seasonal hydrograph and the impact of other land uses in each sub-basin. As a result, separate strategies for managing regulated flows to maintain riparian vegetation are required in each sub-basin.
- On the Kootenai, we found clear evidence that spring releases do in fact result in the establishment of cottonwood recruitment, as has been documented in other basins.
- This work provides the science and the conceptual tools for managers to integrate the requirements of cottonwood and riparian vegetation into the complex mix of flow demands found in each sub-basin.
- This work has also allowed us to develop tools that can be used effectively and efficiently to document the status of riparian vegetation along rivers in other parts of the Columbia Basin.

The recent report by the Independent Scientific Advisory Board on salmon recovery strategies provides an analysis of the various planning strategies in the Basin and good advice on future direction for restoration work. They note that natural disturbance events, such as flood events, have not been given sufficient consideration in past planning. They also indicate that management is moving from more artificial management strategies toward the restoration of ecological function. A move toward more normative flows on regulated rivers is a critical element of this strategy and should be an important feature of future restoration efforts. We see our work as an important element in this move toward more normative conditions that will generate important benefits in re-establishing ecological function and providing important habitat improvements for both fish and wildlife species.

A COMPARISON OF REMOTE SENSING TOOLS FOR ASSESSING THE DISTRIBUTION OF RIPARIAN COTTONWOOD STANDS IN THE COLUMBIA BASIN.

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PORTLAND, OREGON.

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Funded under the NWPPC Innovative Projects Program (Year 2000/2001)

September 30, 2001.

EXECUTIVE SUMMARY

As part of a study of the status of riparian cottonwood on the Yakima and Kootenai Rivers, we used several different forms of remote sensing. This report describes what we have learned about using these forms of imagery. In working with riparian habitats, the challenge is to measure and map the extent of habitat types that tend to be linear and sinuous. We looked at two entire watersheds at the sub-basin scale and at three study reaches (10 km long) in each sub-basin. We tested the effectiveness of Landsat 5 and 7, IKONOS, ADAR and air photo interpretation using ortho-rectified air photos for mapping the extent of riparian vegetation types at a sub-basin scale (1:100,000 to 1:250,000 scale) and at study reach scale (1:10,000 to 1:25,000 scale). We also completed a literature review to find new types of remote-sensing imagery that could be applied to the problem of mapping riparian vegetation and compared the cost effectiveness of the best available data sources.

At a sub-basin level, we found that Landsat data could effectively differentiate areas of deciduous stands, conifer stands, areas cleared for agriculture, grasslands and wetlands. However, we also found Landsat data could not be used to differentiating cottonwood from aspen or orchards of fruit trees. BC Forest Cover data provides an alternative option for sub-basin mapping in Canada. In the study reaches on the Kootenai River, we documented the extent of cottonwood stands and other habitat types using visual typing on ortho-rectified air photo mosaics. Although major land use and vegetation type were easily identified, it was difficult to separate cottonwood and aspen stands without site by site field checks. In the study reaches on the Yakima River, we tested visual typing on ortho-rectified air photo mosaics, IKONOS and ADAR data. There data sources were reasonably effective in identifying riparian vegetation types for that system.

A wide range of imagery options are now available, including digital ortho-photograph mosaics available from the USGS, Digital Elevation Models (DEM) data, multi-spectral imagery and hyper-spectral data from recent satellite platforms and from low and high elevation flights. For a regional overview of cottonwood stands, satellite based hyper-spectral data provides some options that we did not test. Hymap, which provides 128 channel hyper-spectral data flown at low elevation, is a new tool with great potential for looking at riparian vegetation at a study reach scale. Marcus et al. 20001 used this data to map riparian habitat on the Lamar River in Yellowstone National Park. They found they could separate aspen, willow and cottonwood at the 90% level based on differences in reflectance based on leaf shape and orientation. This data source is also comparatively cheap when compared to IKONOS or ADAR or other sources providing equivalent data.

A COMPARISON OF REMOTE SENSING TOOLS FOR ASSESSING THE DISTRIBUTION OF RIPARIAN COTTONWOOD STANDS IN THE COLUMBIA BASIN.

TABLE OF CONTENTS

Page

EXECUTIVE SUMMARY....1
TABLE OF CONTENTS....2
LIST OF FIGURES....3
LIST OF TABLES....3
ACKNOWLEDGEMENTS....3

1.0 INTRODUCTION....5
1.1 OBJECTIVES....7
2.0 STUDY AREA....7
3.0 METHODS....10
3.1 COMPARIONS OF THE IMAGERY SOURCES TESTED....10
3.2 OTHER IMAGERY OPTIONS....10
3.3 COST EFFECTIVENESS....10

4.0 RESULTS....11
4.1 COMPARIONS OF THE IMAGERY SOURCES TESTED....11
4.1.1 REGIONAL/SUB-BASIN SCALE....11
4.1.2 STUDY REACH SCALE....13
4.2 OTHER IMAGERY OPTIONS....18
4.2.1 REGIONAL/SUB-BASIN SCALE....18
4.2.2 STUDY REACH SCALE....19
4.3 COST EFFECTIVENESS....20
4.3.1 REGIONAL/SUB-BASIN SCALE....20
4.3.2 STUDY REACH SCALE....21

5.0 DISCUSSION....22
5.1 REGIONAL/SUB-BASIN SCALE....22
5.2 STUDY REACH SCALE....22

6.0 CONCLUSIONS/RECOMMENDATIONS....23

7.0 LITERATURE CITED....24

8.0 APPENDICIES....26

LIST OF FIGURES

Page

Figure 1. The location of our study areas in the Columbia Basin. 8
Figure 2. The Union Gap study reach. 9
Figure 3. Reflectance graph comparing the signatures of aspen and cottonwood stands. .12
Figure 4. The distribution of cottonwood stands in the Wasa study reach. 14
Figure 5. A comparison of IKONOS and ADAR mapping of the Union Gap study reach. 16

LIST OF TABLES

Page

Table 1. A comparison of the area of landform and vegetation types identified from ADAR and IKONOS mapping. 17
Table 2. Planned hyper-spectral remote sensing satellites expected to come into service in 2001-2003 (ERSC, 2001). 18
Table 3. The costs of using various imagery data sources at a regional/sub-basin scale...20
Table 4. The costs of using various imagery data sources at a study reach scale. 21

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A COMPARISON OF REMOTE SENSING TOOLS FOR ASSESSING THE DISTRIBUTION OF RIPARIAN COTTONWOOD STANDS IN THE COLUMBIA BASIN.

1.0 INTRODUCTION

As part of a study of the status of riparian cottonwood on the Yakima and Kootenai* Rivers, we used several different forms of remote sensing. This report describes what we have learned about using these forms of imagery at the scales required for work on the linear habitat types found along rivers in the Columbia Basin.**

The use of remote sensing as a tool in resource management began when the first aerial photographs were taken in the 1920's and 1930's. The use of satellite based remote sensing systems began in 1972 when ERTS-1 (now Landsat) was launched (Jensen, 1986). In recent years, a wide range of sensors have been developed. They fall into three categories:

- Low elevation aerial photography and digital imagery from aircraft flying at 610 to 1830m (2000-6,000 feet).
- High elevation aerial photography and digital imagery from aircraft (generally from 6100 to 18,300 m (20,000 to 60,000 feet).
- Satellite based digital imagery (20,000m to >400 km above the earth).

Colour imagery data, multi-spectral data (2-10 channels) and hyper-spectral data (>10 channels) are now available in all three of these categories. The development of hyper-spectral imagery was pioneered by systems such as NASA' s AVIRIS and Itres Research's *CASI* (Compact Airborne Spectrographic Imager) flown in aircraft platforms at high altitudes. Hymap is a recent hyper-spectral addition flown from aircraft at lower elevations.

The options most relevant to our work are described below.

Low elevation aerial photography and digital imagery from aircraft flying at 610 to 1830m (2000-6,000 feet): Grotefendt et al. (1996) provide several examples of color imagery from dual cameras mounted on a boom under a fixed wing aircraft or helicopter flying at 1-2000 feet. This approach provides exceptional resolution in color photographs that have been applied in several forestry applications including identifying large woody

* We have used the American name "Kootenai River" to describe the entire sub-basin. The River is called the "Kootenay" River in the Canadian portion of the sub-basin.

** This work was funded under the innovative projects program of the North West Power Planning Council (NWPPC) and Bonneville Power Authority (BPA).

debris in streams. More recently, Marcus et al. 2001 has been successful in mapping riparian habitats and separating various deciduous species using Hymap hyper-spectral data taken from an aircraft at low elevation.

High elevation aerial photography and digital imagery from aircraft (generally from 6100 to 18,300 m (20,000 to 60,000 feet): Air photographs have been available for many years and are readily available. In recent years the United States Geological Survey (USGS) has made orth-rectified mosaics of recent air photo coverage readily available on 1:31,500 map quads with a resolution of about 1 m. This provides an effective and cheap tool for many applications. Similar data is available from some state governments. There is no general program in Canada to produce ortho-rectified air photo mosiacs, however British Columbia and some other provinces have well developed mapping systems in place that identify forest types (and other habitat types such as grassland, wetland, etc.) as part of their forest inventory system (based on air photo interpretation). One recent study used this data to identify the distribution of aspen, birch and cottonwood across the Canadian portion of the Columbia Basin (Jamieson et al. 2001). (Similar USFS inventory data does not cover private land and does not consider non-commercial tree species). Customized charter aerial photography missions are available in both jurisdictions for color photography. Multi-spectral digital data is also available with ADAR (Airborne Data Acquisition and Registration) (Positive Systems, 2001) and both multi-spectral and hyper-spectral data from CASI (Compact Airborne Spectrographic Imager) (Babey and Anger, 1993).

Satellite based digital imagery (20,000m to >400 km above the earth): A wide range of satellite based imagery is now available (see Appendix I.). Resolution ranges from wide synoptic views at 1100 m (3600 ft), down to detailed small coverages at 1 m (3 ft). These tools have been applied in a range of studies around the globe. Several hyper-spectral data sources, based on satellites have been developed in recent years.

In working with riparian habitats, the challenge is to measure and map the extent of habitat types that tend to be linear and sinuous. The required resolution varies with the scale of the river studied. First order rivers (Columbia and Fraser Rivers) result in large habitat units while second order and lower rivers and streams create habitat units that are often very narrow (<5m, 16ft) in width. In this study we were concerned with mapping riparian vegetation at two scales, i.e. a regional or sub-basin scale (1:250,000) and a study reach (1:10-20:000) scale. We looked at two entire watersheds at the sub-basin scale (Yakima and Kootenai sub-basins). The study reaches were located on alluvial floodplain portions of the mainstem rivers in each sub-basin and were 10-20 km (6-12 mi) in length and 0.5 to 3 km (.3 to 1.9 mi) wide.

A variety of studies have looked at forest, wetland and grassland habitat types at a regional scale, using different forms of satellite imagery. Hewitt (1990) provides a synoptic inventory of riparian ecosystems with Landsat imagery. Higher resolution mapping of riparian vegetation and delineation of riparian buffer zones was attempted by Narumalani et al (1997) and Muller (1997). More recently, Dunno and Weber (2001)

evaluated riparian vegetation mapping and image processing techniques for a study area in Arizona. Whited et al. (2001) tested the applicability of IKONOS in identifying aquatic river habitats in northern Montana. Extensive work has also been done on coastal vegetation in Texas (Judd et al. 1998) and on riparian vegetation along the Rio Grande (Lonard et al. 1998).
Some similar work has been done of avalanche path vegetation. These montane landforms provides a similar challenge since they are linear, narrow and contain complex plant communities that vary over meters rather than over 10's to 100's of meters as occurs in adjacent forests (Jamieson et al. 1995). Korol 1994, Franklin et al. (1994), Misurak and Smith (2000), Mowat (2000) and Dickson (2000) have looked at remote sensing to identify habitat types on avalanche paths. Korol 1994 and Franklin et al. 1994 were able to discriminate gross classes of avalanche vegetation (herbaceous, deciduous and conifer) from similar surrounding vegetation types. However, Misurak and Smith 2000 and Mowat 2000 conclude that Landsat was not effective for the scale of mapping required in their work and that air photo interpretation remained the best available tool.

1.1 OBJECTIVES

In this study, our objectives were to:

OBJECTIVE 1: Test the resolution and effectiveness of Landsat 5 and 7, IKONOS, ADAR and air photo interpretation for mapping the extent of riparian vegetation types at a sub-basin scale (1:100,000 to 1:250,000 scale) and at study reach scale (1:10,000 to 1:25,000 scale).

OBJECTIVE 2: Research the availability and utility of other remote tools for mapping the extent of riparian vegetation types at a regional and study reach scale.

OBJECTIVE 2: Compare the cost effectiveness of remote sensing options of value in mapping the aerial extent of riparian vegetation types at a regional and study reach scale

The study steam, related objectives, etc. are described in the other reports associated with this project. We were interested in finding the most effective tools for further work on riparian vegetation in the Columbia Basin.

2.0 STUDY AREA

We looked at the Yakima and Kootenai sub-basins within the Columbia River basin (Figure 1). We established three study reaches within each sub-basin. An example of one of these study reaches is provided in Figure 2. Maps of the other study reaches, in various formats, can be viewed in the other reports associated with this project.

Figure 1. The Yakima and Kootenai study areas.

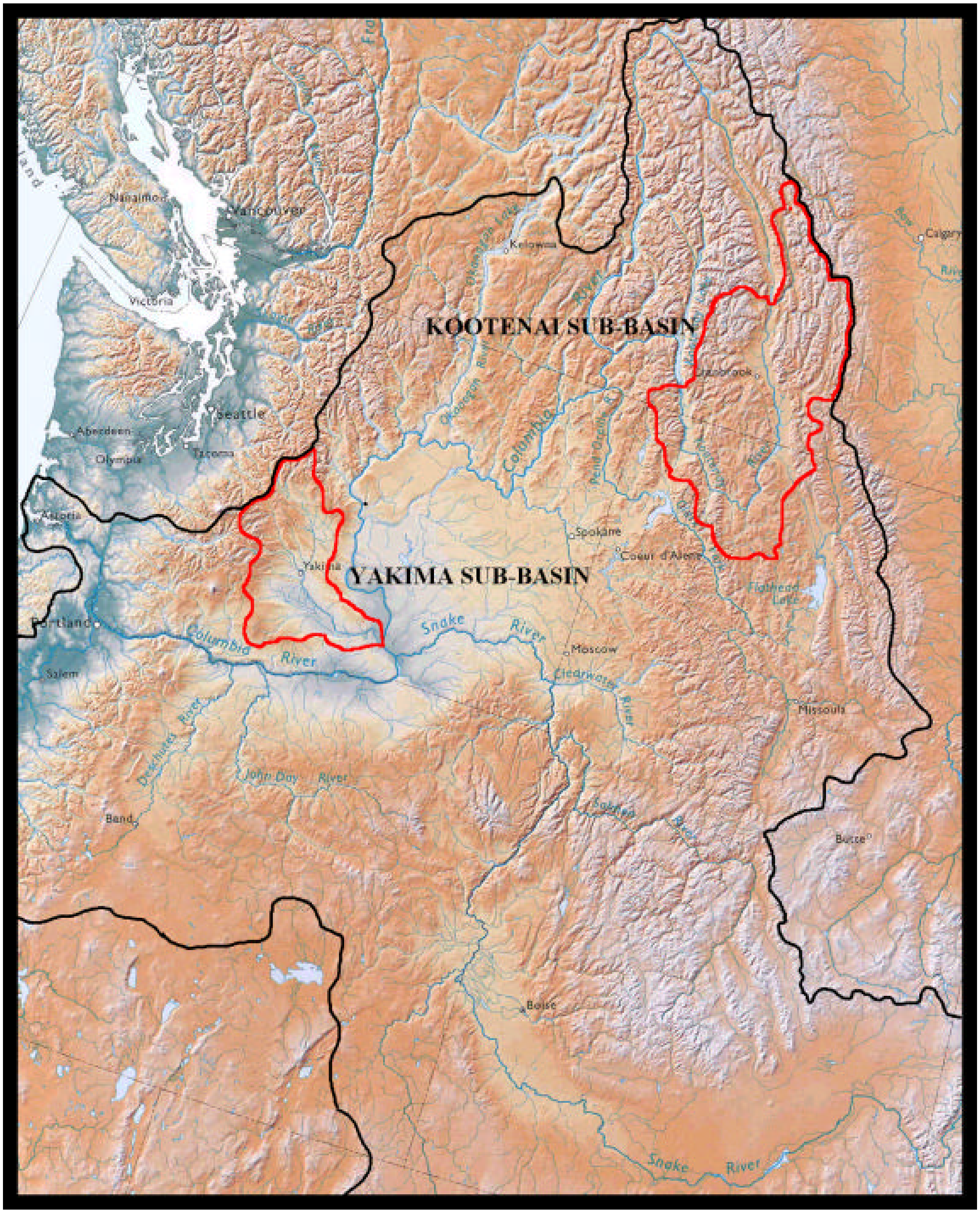
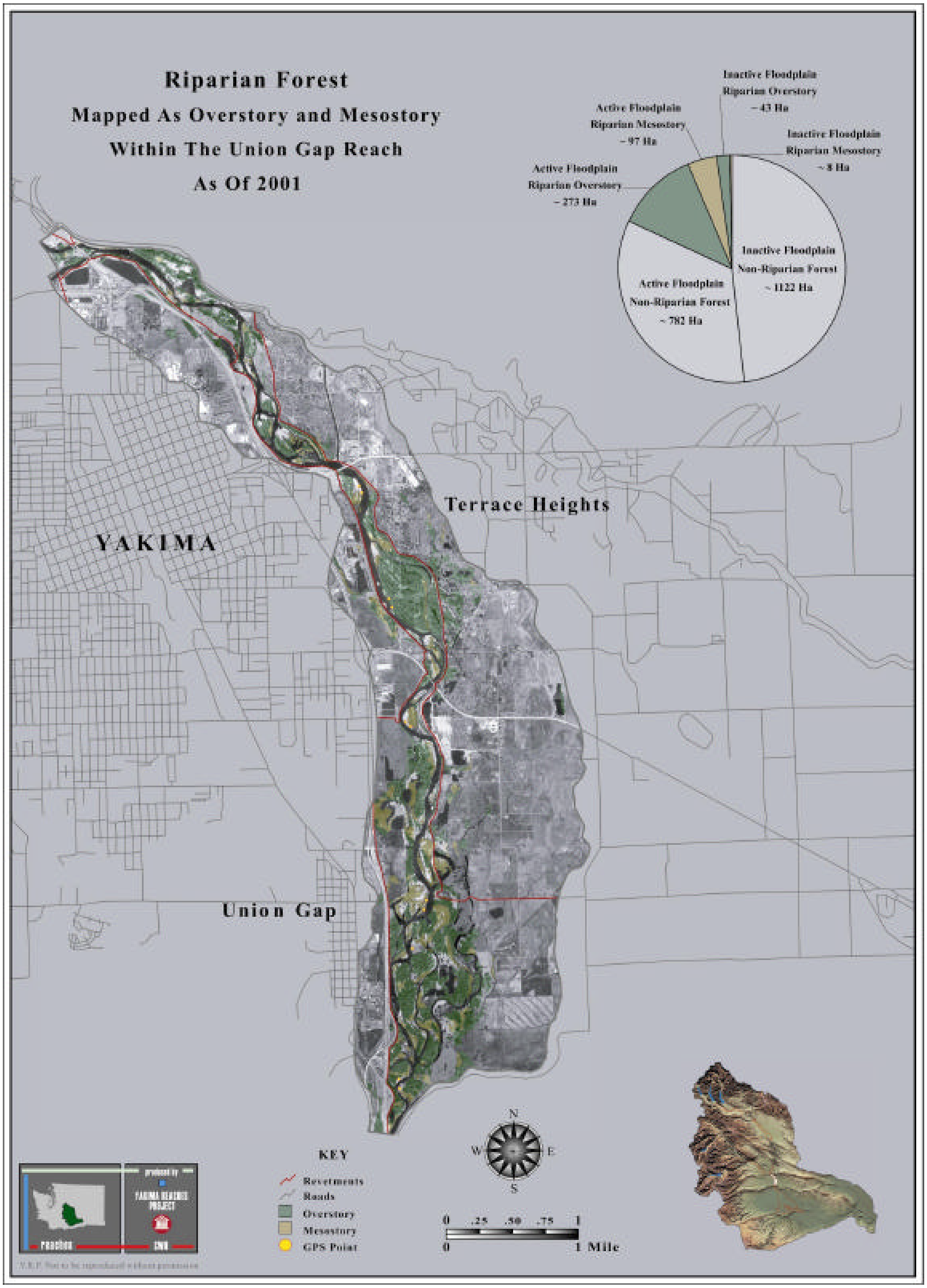


Figure 2. The Union Gap study reach.



3.0 METHODS

3.1 COMPARISON OF THE IMAGERY SOURCES TESTED

3.1.1 REGIONAL/SUB-BASIN SCALE

We tested the usefulness of Landsat 5 TM and BC Forest Service Forest Cover mapping in the Kootenai River sub-basin to determine if these digital data sources could be used to provide mapping of the regional distribution of cottonwood stands. We also tested Landsat 7 TM in the Yakima sub-basin. With both forms of Landsat, we identified training sites of pure cottonwood stands and other major vegetated and non-vegetated landform classes. The training sites were then used to separate and map the locations of cottonwood stands and other major habitat types within each Landsat image. The details on the methods used (software, etc) are included in Appendix II. BC Forest Service Forest Cover mapping was used to develop mapping for the Canadian portion of the Kootenai sub-basin as part of a separate project (Jamieson et al. 2001). The methods used (software, etc) are described in that report.

3.1.2 STUDY REACH SCALE

The utility of several data sources were tested at this sub-basin scale. Landsat 5, BC Forest Service Forest Cover mapping and visual typing on air photo ortho-mosaics were tested on three reaches of the Kootenai River. Landsat 7, ADAR, IKONOS and visual typing on ortho-mosaics was tested on 3 study reaches in the Yakima drainage. Each of these tools was used to develop maps of cottonwood stands and other habitat and land form types for each study reach. Details on the methods used are included in the other reports associated with this project (Jamieson and Braatne 2001 and Braatne and Jamieson 2001).

3.2 OTHER IMAGERY OPTIONS

A literature review was carried out using Science Indexes and Infotrieve to find new potential types of imagery and studies where various forms of remote-sensing imagery were applied to problems at similar scales.

3.3 COST EFFECTIVENESS

A literature review was also carried out to look at the costs associated with various forms of imagery. We found little data in this area. The costs associated with acquiring and processing each of the types of imagery tested in this study were documented by tracking costs within this project. The numbers provided are estimates only (+- 15%) due to challenges in tracking various study components. Field work time and costs related to mapping cottonwood stands to define a spectral image, for example, were difficult to separate from the costs of using the same data for the mapping of cottonwood stands. Marcus et al. 2001 provided cost estimates for using Hymap for similar study reaches. All costs are in US dollars.

4.0 RESULTS

4.1 COMPARISON OF THE IMAGERY SOURCES TESTED

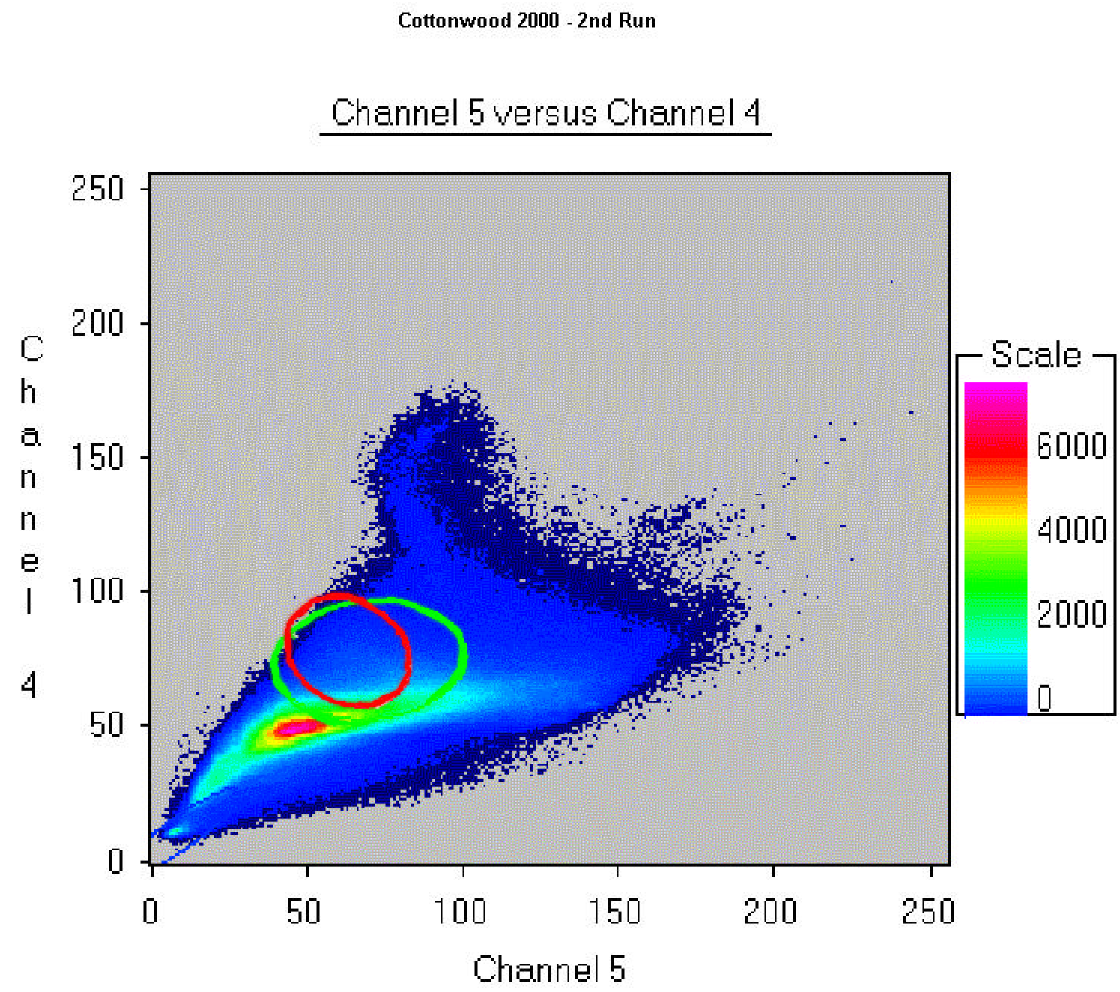
4.1.1 REGIONAL/SUB-BASIN SCALE

Landsat 5: We found that this data source could effectively differentiate areas of deciduous stands, conifer stands, areas cleared for agriculture, grasslands and wetlands. However, we also found significant problems in differentiating aspen and cottonwood stands. The reflectance of the foliage of these two species is very similar when captured with the wide bandwidths (100 nm) and moderate spatial resolution (30 m) of Landsat TM data. Figure 3. indicates the reflectance of these two species. The overlap of the two ellipses indicates the degree to which the reflectance of the two species is similar. We also used a separability measure and confusion matrix to test this data. These tests lead to the same conclusion. As a result, this form of imagery was not pursued further since separating cottonwood stands from other hardwood stands was a crucial aspect of this project.

Landsat 7: Landsat 7 data was tested in the Yakima sub-basin. In this area we found a similar problem, in this case in differentiating between cottonwood stands and nearby fruit tree orchards. Many of the pixels meant to represent cottonwood sites were located in farming areas, indicating cottonwood or other deciduous species along irrigation canals or apple and other fruit trees in orchards. We did not test this data to see if separate spectral signatures could be developed for these two types, but we would expect that would be difficult, given the problems with aspen and cottonwood. We therefore did not pursue this portion of the project further.

BC Forest Service Forest Cover mapping: This data source was tested as part of a separate project (Jamieson et al. 2001). This work provides mapping of the distribution in both upland and riparian cottonwood stands areas (also birch and aspen) for the Canadian portion of the sub-basin and the upper mainstem Columbia in Canada. An example of this mapping is available at www.cbfishwildlife.org (page 25). This mapping is useful at a sub-basin scale but has limitations at higher resolution, as is described in the next section.

Figure 3. Reflectance graph comparing the signatures of aspen and cottonwood stands.



4.1.2 STUDY REACH SCALE

In the study reaches on the Kootenai River, the following were tested:

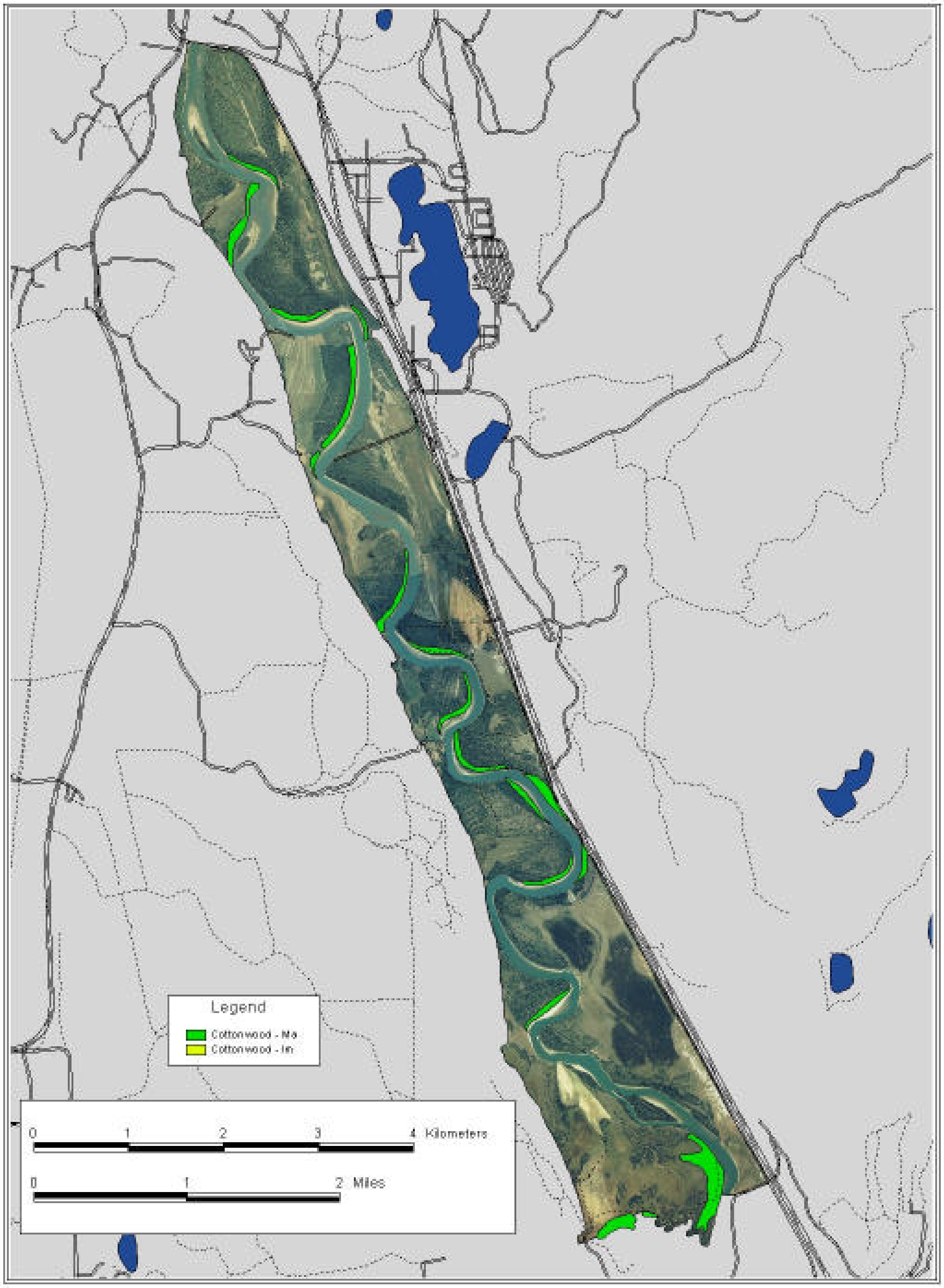
Visual typing on ortho-rectified air photo mosaics: We documented the extent of cottonwood stands and other habitat types using this tool. Although major land use changes were easily identified, it was difficult to separate cottonwood and aspen stands on the air photos. Separating the two species required field checking of any sites where aspen and cottonwood stands were adjacent to one another. Figure 4 is an example of this mapping.

Landsat 5: This source was not pursued since it lacked the resolution required for work at this scale. It is further limited by the problem of differentiating between aspen and cottonwood.

BC Forest Service Forest Cover mapping: This source was of minimal value at this scale. This data has serious limitations when applied to riparian cottonwood stands, as below:

1. The primary interest in forest cover mapping was in documenting conifer distribution and volumes. We found some stands with a 20-30% spruce component typed as spruce dominant stands, even though deciduous species, based on field checks, made up 60-80% of the stand.
2. Most stands were typed as “CtAt”, describing a mix of cottonwood and aspen due to the difficulty in differentiating these species on aerial photographs.
3. Narrow, linear stands of cottonwood (<20m) along river banks were not documented.
4. Young deciduous stands were not well documented.

Figure 4. The distribution of cottonwood stands in the Wasa study reach.



In the study reaches on the Yakima River, the following were tested:

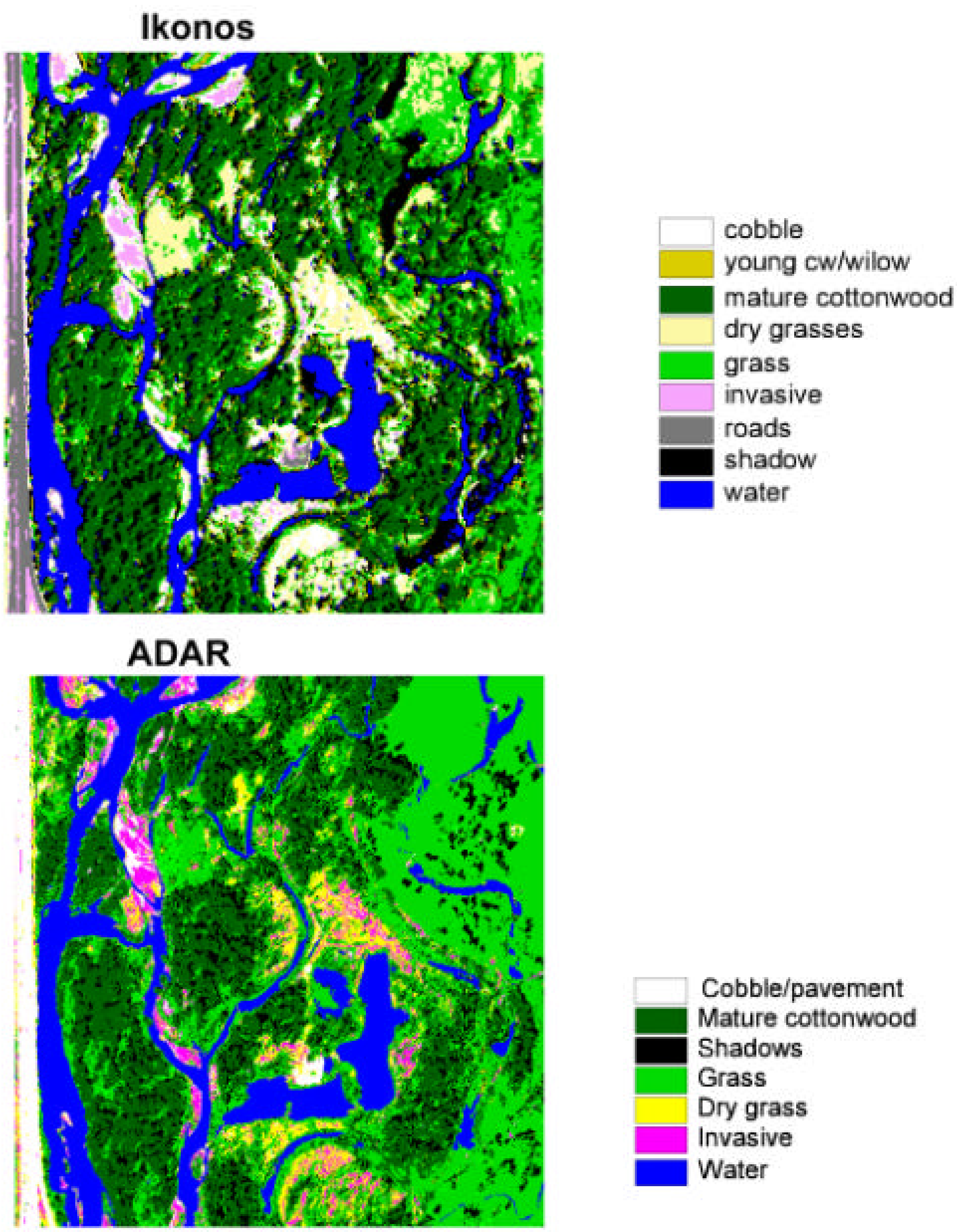
Visual typing on ortho-rectified air photo mosaics: Staff at the Central Washington University in Ellensburg documented the extent of cottonwood stands in three reaches of the Yakima River as a sub-contract to this project. Given the absence of aspen within these study reaches, they did not have the problems similar to those we identified for the Kootenai River. These reaches are dominated by cottonwood, with mino occurrences of exotic trees such as European willow and silver maple. Figure 2 provides an example of this mapping.

Landsat 7: This data source was tested in the Union and CleElum reaches. It provided a gross level of assessment (30 m resolution) but was not useful for the level of precision required for detailed work in study reaches.

IKONOS: Staff at the Flathead Biological Station, under contract, carried out an assessment of cottonwood stands in two of the three study reaches in the Yakima, using IKONOS data. Resolution for this data was 4 m. An example is provided in Figure 5.

ADAR: Staff at the Flathead Biological Station also carried out an assessment of cottonwood stands in two of the three study reaches in the Yakima, using ADAR data flown as part of other projects in the Yakima. Resolution for this data was 1 m. An example is provided in Figure 5.

Figure 5. A comparison of IKONOS and ADAR mapping of the Union Gap study reach.



The area of each landforms and vegetation types identified from IKONOS and ADAR data are compared in Table 1 below.

Table 1. A comparison of the area (ha) of landform and vegetation types identified with ADAR and IKONOS mapping.

Vegetation and landform type	Union Gap Study Reach		Cle Elum Study Reach	
	ADAR	**IKONOS**	**ADAR**	**IKONOS**
Cottonwood	120.0	151.3	211.7	200.9
Immature cottonwood*	nd	29.3	nd	nd
Conifer	0.0	0.0	57.4	52.9
Riparian meadow	280.2	172.1	154.7	86.7
Dry grass	102.6	151.8	33.6	99.0
Invasive	60.3	56.8	nd	nd
Water	102.3	105.6	63.98	66.2
Cobble	129.8	73.6	31.78	57.8
Shaded	53.2	79.6	44.8	57.0
Roads	nd	29.2	22.33	nd
TOTAL	848.4	849.3	620.34	620.5

* Sapling size cottonwood, generally mixed with willow species.

There are substantial differences in the areas calculated for several categories. Differences in resolution and the ability of the two data types to pick up variation in the canopy and in detail along the edge of stands probably introduced some error. The timing of the flights (ADAR in mid August and IKONOS in October) may also have resulted in some of the variation observed. The time of day of the flights may have affected the size of the shaded category.

The cobble category would vary depending on the day the photographs were taken, however the water category should have varied also, which it doesn't.
The riparian meadow and dry grass categories vary substantially, probably as a result of the point in the growing season on which the photos were taken.

4.2 OTHER IMAGERY OPTIONS

4.2.1 REGIONAL/SUB-BASIN SCALE

There is a wide range of imagery options available (see Appendix I.) with the level of resolution required to approach regional scale problems. We found the following options of interest to this project.

Digital orthophotograph mosaics: Because of the low cost and availability of this form of data, it is possible to acquire mosaics (as 1:31,500 map quads) for the river reaches of an entire sub-basin. This data could be used as a base for visual mapping of cottonwood stands and other riparian habitat types. The 82.5 km Bonner's Ferry to Kootenay Lake reach, for example, could be habitat typed relatively easily, since there are few other deciduous species in this reach. Visual typing on air photo mosaics introduces some human error, but this approach is still an effective way of describing the distribution patterns of riparian cottonwood forests across a sub-basin.

Digital elevation models (DEM): Digital Elevation Models (DEM data) has been used to identify floodplain areas based on terrain variables (R. Redmann, pers. comm.) This would be of some value in identifying those areas where cottonwood are likely to occur but would not provide information on the actual extent of cottonwood stands.

Hyper-spectral data: It may be possible to use hyper-spectral data from recent satellite platforms to identify riparian habitats, and different deciduous species, at a regional or sub-basin scale. Potential options are listed in Table 2.

Table 2. Planned hyper-spectral remote sensing satellites expected to come into service in 2001-2003 (ERSC, 2001).

Satellite Name	Source	Expected Launch	Sensors	Types	No. of Channels	Resolution (meters)
ARIES	Australia	2002	ARIES-1	Hyperspectral	96	30
NEMO (HRST)	US	2001	AVIRIS	Hyperspectral	210	30
OrbView-4	Orbimage	2001	OrbView-4	Hyperspectral	200	8

4.1.2 STUDY REACH SCALE

CASI**:** This source can provide multi-spectral or hyper-spectral imagery in different bands, bands widths and resolutions. Several studies have used this data source in recent years (Babey and Anger 1993). Given the hyper-spectral nature of this data (with narrow bandwidths and high spatial resolution), it could potentially be used to discriminate cottonwood from aspen and other forms of deciduous vegetation.

Hymap: Hymap provides 128 channel hyper-spectral data flown at low elevation. Resolution is 3 m, but effective resolution within a pixil with a single spectral signature was 1 m. It can be flown at different elevations to provide different coverage and resolution. A 1.5 km strip (.93 mi) flown at 1000m (3000 ft) provides 3 m (9.8 ft) resolution, while a 3.0 km strip (1.86 mi) flown at 2000m (6000 ft) provides 6 m (19.6 ft) resolution). Marcu et al. 2001 used this data to map riparian habitat on the Lamar River in Yellowstone National Park. They found they could separate aspen, willow and cottonwood at the 90% level based on differences in reflectance based on leaf shape and orientation. They could not effectively differentiate "long leave cottonwood" (P. angustifolia) from long-leaf willow (70% separation). Hymap can be flown with AIG anywhere in North America. Analysis of Hymap data is available through the Yellowstone Institute under contract.

Low elevation air photos: Grohfeldt et al. 1996 demonstrates that this option can be used effectively to estimate the volume and density of forest stands and to identify standing/down snags and large woody debris within stream habitats. Such photography could be used to identify cottonwood stands by color and texture at high resolution (>1m).

DEM: Digital elevation data is available in a range of resolutions. With higher resolution data it may be possible to differentiate cottonwood stands by height. Lidar or laser altimetry is expensive ($30,000/US map unit (quad) but provides 20-30 cm vertical accuracy. 50 cm accuracy is available at $2-3,000/quad at www.globalterrain.com. Such data has been used to measure tree height (St. Onge et al. 2000) and could be used to identify low benches or bars where recruitment would occur. It would not be able to differentiate between cottonwood and conifer stands.

* *CASI* is the acronym for the Canadian Aeronautics and Space Institute. We originally planned to test the applicability of *CASI* data with an archived hyper-spectral 5 meter data set on the upper Kootenai River made available to use by the Ktunaxa Tribal Council. However, it was found that this older data format would be difficult and expensive to process and we did not analyze this imagery.

4.3 COST EFFECTIVENESS

4.3.1 REGIONAL/SUB-BASIN SCALE

Costs associated with using each of the data forms used in this study are shown in Table 3. DEM, multi-spectral and hyper-spectral data formats provide other options but we found no good estimates of potential costs for these sources. All estimates are rounded to thousands.

Table 3. The costs of using various imagery data sources at a regional/sub-basin scale.

SOURCE	Resol.	$ per unit	Cost for sub-basin	Processing Costs	Field Costs	Total Cost
Landsat 5	30	$500.00*	$1,000.00	$2,500.00	$2,000.00	**$5,500.00**
Landsat 7	30	$1,000.00	$2,000.00	$2,500.00	$2,000.00	**$6,500.00**
BC Forest Cover	10	$0.00**	$0.00	$3,000.00	$0.00	**$3,000.00**
IKONOS	4		$70,000.00	$20,000.00	$20,000.00	**$110,000.00**
USGS orthos	1	$60.00	$80,000.00	$40,000.00	$40,000.00	**$160,000.00**
ADAR	0.7		$200,000.00	$50,000.00	$20,000.00	**$270,000.00**

***** Costs for Landsat have declined sharply since this work was done.
****** Generally available to management agencies at minimal cost.

We found that Landsat and BC Forest Cover provide cheap alternatives, with limitations, but that other sources are very expensive by comparison.

4.3.2 STUDY REACH SCALE

Table 4 indicates the costs associated with each form of imagery used and estimates of the costs associated with other potentially useful forms of imagery (based on estimated from providers and other workers), for a 10 km study reach.

Table 4. The costs of using various imagery data sources at a study reach scale.

SOURCE	Res.	Cost per unit	Cost for study reach	Processing Costs	Field Costs	Total Cost
ADAR	0.7		$10,000.00	$8,000.00	$5,000.00	**$23,000.00**
IKONOS	4		$5,000.00	$8,000.00	$5,000.00	**$18,000.00**
USGS orthos	1	$60.00	$1,000.00	$7,000.00	$7,000.00	**$15,000.00**
Hymap**	1		$5,000.00	$20,000.00	$6,000.00	**$31,000.00**
Low elev. Photos***	0.5		$5,000.00	$20,000.00	$5,000.00	**$30,000.00**

** Marcus et al. 2000.
*** M. Grotefendt pers. com.

The prices of the effective data sources are in a similar range except for low elevation air photos. Other factors that affect price are listed below.

IKONOS is sold in bands 10 km wide. This increases the price for getting imagery for narrow linear landforms like alluvial floodplains. ADAR and other high resolution airborne imagery sources which are flown on request do not have this problem. Ortho-mosiacs and their source air photos are generally oriented north to south or east to west and therefore have similar coverage problems. This is a minor problem since the data is very cheap. The Bonner’s Ferry to US-Canada border reach, for example is oriented south-east to north-west and is about 60 km long. Mapping for that area cost $300.00.

5.0 DISCUSSION

5.1 REGIONAL/WATERSHED SCALE

We found that it was difficult to identify cottonwood stands on a regional/sub-basin scale where the imagery contained different deciduous woody species such as aspen and domestic fruit trees. The usefulness of this data source is also limited by the fact that most riparian stands of cottonwood on second and third order rivers are narrower than the pixel size (30m) of Landsat imagery. Although other forms of this imagery such as SPOT have slightly better resolution (10-30 m vs 30 m for Landsat), but do not have any added value for this kind of use. However, Landsat data could be used to identify major floodplains, major land use types and stands of deciduous trees. If a reconnaissance level map is required over a regional watershed scale that does not require the separation of individual deciduous species, then this type of data is potentially useful and inexpensive. On the Canadian side of the Basin, BC Forest Service Forest Cover mapping is both useful and readily available. It provides a cheap alternative for regional assessments on the Canadian side of the Basin. On the US side of the basin, USGS ortho-mosiacs could be acquired cheaply to cover the length of the mainstem rivers within a sub-basin of interest. The data is inexpensive, but a fair level of technician time both in the field, and in typing and transferring the data to GIS, is required. Working with these relatively large files may present some problems. Digital Elevation Models (DEM) based on topographic data, has potential value in identifying alluvial floodplains but do not provide a option for identifying cottonwood stands. IKONOS, ADAR and CASI data can be used to identify riverine habitats across a sub-basin, but is probably too expensive for most regional applications. Fieldwork to define training sites is required. Hyper-spectral data from new satellite data sources, however, may be an option in the near future (R. Crabtree, pers. com.).

5.2 STUDY REACH SCALE

Preliminary tests using Landsat 5 and 7 and BC forest cover data quickly indicated that these forms of imagery lacked the resolution required at this scale (15-30 m). Traditional visual typing on ortho-mosaics appears to be a good option in many applications, especially in the USA where low-cost, ortho-rectified air photo mosaics are now available for most of the Columbia Basin. This data source can be used to document the occurrence of riparian cottonwoods at a fine scale (1m resolution). The value of this approach is subject to potential errors due to human interpretation of site types and boundaries on air photos. (Conversely, potential errors in establishing training sites for IKONOS or other sources can also result in large errors). The cost effectiveness of this source is limited in Canada since ortho-rectified data is not readily available. DEM data could be used to estimate stand height and possibly identify low benches or bars where cottonwood recruitment is likely to occur but to our knowledge, this approach has not been tested. IKONOS and ADAR are reasonable alternatives, however we did not test the ability of this data to separate cottonwood from other deciduous tree species. Where high resolution study area data are required, low elevation Hymap is an obvious choice. It provides high resolution data at relatively low cost and allows the separation of deciduous species. It can also be flown in conjunction with DEM data for detailed work to identify recruitment areas. It can also be flown with a new high resolution color camera that provides color photography 18 cm (5 in) resolution, in digital format (Marcus et al. 2001).

6.0 CONCLUSIONS/ RECOMMENDATIONS

For future work to provide regional or sub-basin overviews of riparian vegetation we would suggest that:

- DEM can be used to identify alluvial floodplain areas on basin wide scale.
- Landsat is an option where the identification of deciduous species is all that is required.
- BC Forest Cover data is a good option in the Canadian portion of the Basin.
- Hyper-spectral satellite data should be tested to see if this data can effectively differentiate deciduous species along rivers.

For future work at a study reach scale we would suggest that:

- Air photo interpretation of ortho-mosiacs is an effective tool where cost is limiting.
- Hymap provides the best available data where higher levels of precision are required.

Assuming that the cost estimates suggested in Marcus et al. 2001 prove out in other studies, Hymap is the tool of choice for future work in mapping riparian vegetation in the Columbia Basin. Where flow regulation is an issue, this level of mapping should be done in conjunction with vegetation transects established perpendicular to the river bank, in which elevations and distance from the water's edge are recorded (See the methods sections of the other reports associated with this project). Transects remain the most effective tool for monitoring, in detail, the response of vegetation to changes in flows.

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APPENDICES

Appendix I. Available sources of satellite imagery and data.

Appendix II. Study Methods

Appendix I. Available sources of satellite imagery and data.

Table 1 lists all current remote sensing satellites. Table 2 lists planned satellites expected to be launched over the next two years.

Table 1: Current remote sensing satellites in operation: May 2001- Excludes meteorological satellites (ERSC, 2001)

Satellite Name	Source	Launch	Sensors	Types	No. of Channels	Resolution (meters)
OrbView-2 (SeaStar)	US/Orbimage	1997	SeaWiFS	Multispectral	8	1130
SPOT-4	France	1998	VI	Multispectral	4	1150
NOAA-14	US	1994	AVHRR	Multispectral	5	1100
NOAA-15 (NOAA-K)	US	1998	AVHRR	Multispectral	5	1100
NOAA-L	US	2000	AVHRR	Multispectral	5	1100
ERS-1	ESA	1991	ATSR	Multispectral	4	1000
ERS-2	ESA	1995	ATSR	Multispectral	4	1000
RESURS-O1-3	Russia	1994	MSU-SK	Multispectral	1	600
IRS-P4 (Oceansat)	India	1999	OCM	Multispectral	8	360
Terra (EOS AM-1)	US	1999	MISR	Multispectral	4	275
CBERS-1	China/Brazil	1999	WFI	Multispectral	2	260
EO-1	US	2000	LAC	Hyperspectral	256	250
Terra (EOS AM-1)	US	1999	MODIS	Multispectral	36	250,500, 1000
NOAA-14	US	1994	WiFS	Multispectral	2	188
IRS-1D	India	1997	WiFS	Multispectral	2	188
RESURS-O1-3	Russia	1994	MSU-SK	Multispectral	4	170
CBERS-1	China/Brazil	1999	IRMSS	Multispectral	1	160
Landsat-5	US	1984	TM	Multispectral	1	120
Landsat-5	US	1984	MSS	Multispectral	4	82
CBERS-1	China/Brazil	1999	IRMSS	Multispectral	3	80
IRS-1B	India	1991	LISS-I	Multispectral	4	72.5

IRS-1C	India	1995	LISS-III	Multispectral	1	70
IRS-1D	India	1997	LISS-III	Multispectral	1	70
Landsat-7	US	1999	ETM+	Multispectral	1	60
IRS-1B	India	1991	LISS-II	Multispectral	4	36.25
Landsat-5	US	1984	TM	Multispectral	6	30
Landsat-7	US	1999	ETM+	Multispectral	6	30
EO-1	US	2000	ALI	Multispectral	9	30
EO-1	US	2000	Hyperion	Hyperspectral	220	30
ERS-2	ESA	1995	AMI	Radar	1	26
ERS-1	ESA	1991	AMI	Radar	1	26
IRS-1C	India	1995	LISS-III	Multispectral	3	23
IRS-1D	India	1997	LISS-III	Multispectral	3	23
SPOT-2	France	1990	HRV		3	20
SPOT-4	France	1998	HRV	Multispectral	4	20
CBERS-1	China/Brazil	1999		Multispectral	5	20
Landsat-7	US	1999	ETM+	Panchromatic	1	15
Terra (EOS AM-1)	US	1999	ASTER	Multispectral	14	15,30,90
RADARSAT	Canada	1995	SAR	Radar	1	9-100
EO-1	US	2000	ALI	Panchromatic	1	10
SPOT-4	France	1998	HRV	Panchromatic	1	10
SPOT-2	France	1990	HRV	Panchromatic	1	10
IRS-1C	India	1995	Pan	Panchromatic	1	5.8
IRS-1D	India	1997	Pan	Panchromatic	1	5.8
IKONOS	Space Imaging	1999	IKONOS	Multispectral	4	4
IKONOS	Space Imaging	1999	IKONOS	Panchromatic	1	1
EROS-A1	ImageSat International	2000	Panchromatic	Panchromatic	1	1.5

Table 2: Planned remote sensing satellites as of May 2001 - Excludes meteorological satellites (ERSC, 2001)

Satellite Name	Source	Expected Launch	Sensors	Types	No. of Channels	Resolution (meters)
SPOT-5	France	2002	VI	Multispectral	4	1150
NOAA-M	US	2001	AVHRR	Multispectral	5	1100
NOAA-N	US	2003	AVHRR	Multispectral	5	1100
CBERS-2	China/Brazil	2001 or later?	WFI	Multispectral	2	260
Envisat-1	ESA	2001	MERIS	Multispectral	15	300,1200
ADEOS-II	Japan	2001	GLI	Multispectral	36	250-1000
CBERS-2	China/Brazil	2001 or later?	IRMSS	Multispectral	1	160
Envisat-1	ESA	2001	ASAR	Radar	1	30, 150
Aqua (EOS PM-1)	US	2001	MODIS	Multispectral	36	250-1000
Resource21	Resource21	2001 or later?	Cirrus	Multispectral	1	100+
IRS-P6	India/US	2001	AWiFS	Multispectral	3	80
CBERS-2	China/Brazil	2001 or later?	IRMSS	Multispectral	3	80
ARIES	Australia	2002	ARIES-1	Hyperspectral	96	30
Envisat-1	ESA	2001	ASAR	Radar	1	30, 150
NEMO (HRST)	US	2001	AVIRIS	Hyperspectral	210	30
Resource21	Resource21	2001 or later?	Multispectral	Multispectral	5	10, 20
CBERS-2	China/Brazil	2001 or later?	CCD	Multispectral	5	20
SPOT-5	France	2002	HRV	Multispectral	1	20
XSTAR	France/Great Britian	2001 or later?	XSTAR	Multispectral	10+	20
SPOT-5	France	2002	HRV	Multispectral	3	10
ALOS	Japan	2003	VSAR	Radar	1	10
ALOS	Japan	2003	AVNIR-2	Multispectral	4	10
ARIES	Australia	2002	ARIES-1	Panchromatic	1	10

OrbView-4	Orbimage	2001	OrbView-4	Hyperspectral	200	8
IRS-P6	India/US	2001	LISS IV	Multispectral	7	6, 23.5
NEMO (HRST)	US	2001	PIC	Panchromatic	1	5
MTI	US	2001	MTI	Multispectral	15	5
SPOT-5	France	2002	HRV	Panchromatic	1	5
OrbView-4	Orbimage	2001	OrbView-4	Multispectral	4	4
OrbView-3	Orbimage	2001	OrbView	Multispectral	4	4
Radarsat-2	Canada	2003	SAR	Radar	1	3+
IRS-P5 (Cartosat)	India/US	2001	Pan	Panchromatic	1	2.5
ALOS	Japan	2003	AVNIR-2	Panchromatic	1	2.5
EROS-A2	ImageSat International	2001	Panchromatic	Panchromatic	1	1.5
OrbView-3	Orbimage	2001	OrbView	Panchromatic	2	1-2
OrbView-4	Orbimage	2001	OrbView-4	Panchromatic	1	1
EROS-B1	ImageSat International	2001 or later?	Panchromatic	Panchromatic	1	0.82

APPENDIX II. DETAILED STUDY METHODS

REGIONAL/SUB-BASIN SCALE

Landsat 5: Landsat 5 Thematic Mapper (TM) digital imagery was tested on a portion of the Kootenai drainage to determine the utility of using this type of moderate resolution remote sensing imagery on mapping cottonwood stands in this area. The Upper Kootenai River above the Libby Reservoir in Canada was chosen as it is a reach that has had no influences by dams and it is an area were a Landsat image from the mid 1990's was available to the project from the Ktunaxa Tribal Council. The study area is known as the Wasa/Fort Steel reach. Image processing was done by Eagle Vision of Cranbrook BC using PCI's Easi/Pace image processing software on a PC computer.

The image had been previously geo-corrected with a digital elevation model and therefore was ready for information extraction using standard supervised classification techniques. Before classification began, the flood plain of the study area was digitized. This floodplain mask was used to "clip" the floodplain study area out of the image so that the classification would be applied to only this area. This was done to minimize processing time.

The first step in supervised classification is developing a classification system that reflects the different land cover/classes in the study area including the classes of interest. In this area the two very similar classes were of interest: cottonwood and aspen. Other classes in the classification included: spruce, water, non-vegetated, rangeland, wetland and agriculture.

Several training areas for each of these classes were outlined on aerial photographs. The locations of the training areas were based on field reconnaissance done in the summer of 2000. The training areas were digitized over the Landsat imagery on-screen and the statistics for each of six visible and infrared Landsat bands were extracted for each class. These statistics or class signatures were then stored and made available for the classification process. The class signatures contain the statistical information that represents each of the classes in the classification system. The cottonwood signature for example contains information that is potentially different from the other classes such as aspen or spruce. As this statistical process works on data ranges or limits based on a standard deviation, similar classes such as cottonwood and aspen will overlap and may not be distinct or statistically different from each other. Classes that are spectrally very different from each other such as cottonwood and water should not overlap and will be statistically different.

The classification technique used in this study is the standard maximum likelihood classifier where an unknown pixel is assigned "the most likely class" based on the training data statistics. In the classification process, each image pixel value is examined and compared to the class signatures. A value is assigned to the pixel that represents the class that it is most like. For example, the six bands for an unknown pixel are compared to all the class signatures. The signature class that is most like the pixel is given that label. If the most likely class signature is "cottonwood" then the pixel is labelled "cottonwood" if it is most like "spruce" then it is labelled "spruce". This process is repeated for every pixel in the image, or in this case the clipped floodplain, and a classification map is produced. The map contains information that has been extracted from the raw imagery and is displayed as different colours that represent each class.

The classification process was repeated several times to improve the classification results. Each iteration was completed after adjusting the training areas or after combining similar classes and regenerating the class signatures.

Landsat 7: Landsat 7 TM imagery was tested on the Yakima drainage. A similar supervised classification approach to the upper Kootenai Landsat 5 analysis was used where training data was used in a maximum likelihood classifier with PCI Easi/Pace software. The training data from the IKONOS/ADAR data (1-4 metre pixels) were overlaid on the smaller scale Landsat images (30 metre pixels) for the two study areas and plotted. The training areas were expanded to include enough pixels to extract training statistics from the Landsat imagery. The expanded training areas were digitized over the Landsat imagery and the class signatures extracted. The classes used in this analysis included: cottonwood, grass, dry grass, invasive, water, cobble and cultivated.

The maximum likelihood classifier was applied and several iterations were conducted before the final classification maps were produced. To compare results with the IKONOS and ADAR imagery, the area of each class was calculated and the results imported into an Excel spreadsheet.

BC Forest Service Forest Cover: See the methods section in Jamieson et al. 2001.

STUDY REACH SCALE

(see other reports associated with this project)