Indicators and Methods for Effectiveness Monitoring of Tailed Frog Wildlife Habitat Areas

March 31, 2004

Prepared for:
Kathy Paige
Ministry of Water, Land, and Air Protection
PO Box 9338
Victoria, BC, V8W 9M4

Prepared by:
Katherine Maxcy
Box 646
Telkwa, BC, VOJ 2X0
Phone: (250) 846-9601
Email: k_maxcy@telus.net

EXECUTIVE SUMMARY

The purpose of this "Indicators and methods for Tailed Frog WHA effectiveness monitoring" report is to develop a monitoring protocal that can be used to evaluate the effectiveness of tailed frog wildlife habitat areas (WHA). The general goal of tailed frog WHAs is to maintain important tailed frog streams and suitable breeding habitat (IWMS 2004). This document outlines key monitoring questions, identifies key indicators for effectiveness monitoring, outlines sampling methodology for each indicator, and discusses alternative study designs that could be used to evaluate effectiveness.

There are two species of tailed frogs in British Columbia: the coastal tailed frog (*Ascaphus truei*) and the Rocky Mountain tailed frog (*Ascaphus montanus*). Both species depend on cool, fast-flowing montane streams for breeding and rearing habitat, and they are terrestrially associated with cool, moist microclimatic conditions typically found in closed canopy forest. At larger spatial scales, tailed frogs have also been linked to underlying parent geology and watershed development (e.g. forest harvesting, road density). Therefore, landscape-scale issues must also be addressed in an effectiveness monitoring protocol for tailed frog WHAs.

Key effectiveness monitoring objectives and questions were developed at three spatial scales to focus the approach of tailed frog WHA effectiveness monitoring. At the largest spatial scale (i.e. watershed), the prime objective is establish the WHA landscape context (e.g. underlying geology, climate, topography). These factors can influence the overall habitat suitability for tailed frogs and will be important in the evaluation of effectiveness of tailed frog WHAs. At the sub-basin scale, questions focus on disturbances that may affect tailed frog aquatic habitat via impacts to sedimentation, hydrology, and temperature in streams. Questions also focus on how the managed landbase may facilitate or impede movement of juvenile and adult tailed frogs. Within WHAs, there are two main objectives. First, to determine if terrestrial and aquatic habitats are being maintained. Habitat questions focus on local-scale attributes that may affect terrestrial habitat quality for adults, and aquatic breeding and rearing habitat for eggs and larvae in streams. Second, the objective is to determine the status and/or trends of tailed frog tadpoles in WHAs.

Based on a literature review of habitat and environmental variables that affect tailed frog abundance and distribution, and using a conceptual model as a guide, 16 indicators were selected to monitor in the tailed frog WHA effectiveness monitoring program. Many of the indicators selected for in-stream monitoring have well established relationships with tailed frog tadpole occurrence and/or abundance. The indicators either characterise tailed frog tadpole habitat or characterise threats to tadpole habitat, thus acting as indirect indicators of the in-stream life stages of tailed frogs. Little is known about the terrestrial requirements of juvenile and adult tailed frogs. Therefore, based on their physiological requirements for cool, moist microclimatic conditions, terrestrial habitat indicators were selected to measure surrogate indicators of microclimate at two spatial scales. The only direct indicator of tailed frogs that is feasible to measure is tadpole relative abundance in streams. A direct measure of tailed frogs will be important in an effectiveness monitoring program for two reasons. First, predictive relationships between tailed frogs and many of the indirect indicators are too poorly understood to evaluate

effectiveness using indirect indicators alone. Second, an effectiveness monitoring program cannot measure all factors that could be influencing tailed frogs.

A detailed sampling methodology for each of the indicators is described. Possible study designs are discussed for both spatial and temporal sampling. For example, one way to evaluate tailed frog WHA effectiveness is to pair a subset of WHAs with an equivalent area in the managed landbase. The managed stands act as benchmarks against which WHAs can be assessed; indicator status and trends compared between the WHA and managed landbase provide an empirical means of assessing the effectiveness of WHAs. Ultimately, the final study design that is decided upon will depend on how effectiveness is evaluated. Further work is required to establish criteria for evaluating effectiveness based on monitoring data.

ACKNOWLEDGEMENTS

John Richardson and Martin Raphael are gratefully acknowledged for access to their tailed frog data sets. Thanks to a number of people who provided information and/or advice including: Linda Dupuis, Dave Huggard, Glenn Sutherland, Len Vanderstar, and Tanya Wahbe. Reviews by Dave Huggard, Jim Herbers, John Richardson, Kathy Paige, Len Vanderstar, Richard Thompson, and Wayne Erickson greatly improved earlier drafts.

TABLE OF CONTENTS

EXECUTIVE SUMMARY I

ACKNOWLEDGEMENTS II

TABLE OF CONTENTS III

1 DEFINITIONS AND SCOPE 4

1.1 DEFINITION OF KEY TERMS 4
1.2 SCOPE OF THIS REPORT 5

2 INTRODUCTION 7

2.1 BACKGROUND 8
2.1.1 General life history of the tailed frog 8
2.1.2 Description of tailed frog WHAs 9

3 OBJECTIVES AND KEY EFFECTIVENESS MONITORING QUESTIONS 9

3.1 CONTEXT VARIABLES 10
3.2 SUB-BASIN 10
3.3 STAND-LEVEL 11
3.4 POPULATION 11

4 RATIONALE FOR INDICATOR SELECTION 12

4.1 CONTEXT VARIABLES AND WHA PERMANENT FEATURES 12
4.2 SUB-BASIN DEVELOPMENT INDICATORS 20
4.2.1 Aquatic habitat indicators 21
4.2.2 Terrestrial habitat indicators 21
4.3 STAND-LEVEL TERRESTRIAL HABITAT INDICATORS 23
4.4 AQUATIC HABITAT INDICATORS 23
4.5 POPULATION INDICATORS 25
4.6 INDICATOR RANKING 25

5 SAMPLING METHODOLOGY 26

5.1 STAGE 1 – DEFINE WATERSHED 27
5.2 STAGE 2 – DEFINE SUB-BASIN 27
5.3 STAGE 3 – STAND-LEVEL TERRESTRIAL INDICATORS 27
5.4 STAGE 4 – AQUATIC HABITAT INDICATORS 29

6 STUDY DESIGN, ANALYSIS, AND MANAGEMENT FEEDBACK 30

6.1 COMPARATIVE SAMPLING 30
6.2 TEMPORAL SAMPLING 32

7 PILOT STUDIES, PRODUCTS, AND COSTS 33

8 SUMMARY OF GAPS/PROBLEMS/NEEDS 33

9 LITERATURE CITED 34

APPENDIX 1. CONCEPTUAL MODEL 38

APPENDIX 2. WITHIN-STREAM SAMPLING VARIATION 44

APPENDIX 3. POWER ANALYSIS 48

1 DEFINITIONS AND SCOPE

1.1 Definition of key terms

For consistency and to minimise confusion, definitions of key terms used throughout this document are provided in the following.

Indicator: a measurable attribute with known or predicted relevance to tailed frogs that could be used to measure the effectiveness of wildlife habitat areas (WHAs) and associated general wildlife measures (GWMs; *e.g.*, stream substrate composition, tailed frog tadpole relative abundance).

Effectiveness: management practices or decisions can be considered effective when they achieve the goals established for tailed frog WHAs.

Goals: specific targets, thresholds, or trends that are used to define effectiveness. For example, a specific goal for tailed frog WHAs might be to maintain stable or increasing tailed frog tadpole densities.

Status: value of an indicator in one or more locations, or management systems at a single time.

Trend: changes in an indicator across two or more time intervals.

Landscape context: The context of the landscape (e.g. underlying geology, climate, topography) can influence the local-scale tailed frog habitat suitability via processes such as sedimentation and productivity. For example, a WHA located in a watershed underlain with erosion-resistant bedrock and a long growing season will likely support higher densities of tailed frogs compared to a WHA located in an erosion-prone area with shorter growing season. The evaluation of effectiveness and management options for these two WHAs likely should not be the same; a more cautionary management approach may be required for the latter.

Watershed: the largest spatial scale considered in the development of the tailed frog effectiveness monitoring program. The watershed is the area drained by the WHA stream and its tributaries. The lower boundary of the watershed is at the confluence of the WHA stream with that of a higher order stream. Because tailed frogs typically occur in small streams, the watershed boundary will likely be a tributary of a larger watershed (Figure 1).

Sub-basin: this refers to the stream network that occurs upstream of the WHA with the lower boundary of the sub-basin at the most downstream end of WHA stream(s) (Figure 1).

Managed landbase: the managed landbase surrounding the WHA (Figure 1)

Stand: the terrestrial forested area included in the WHA (Figure 1)

Reach: a section of stream with regular channel morphology (i.e. sequence of physical processes and habitat types)

Sample unit: refers to the sample unit of a stream where tadpoles are sampled (usually 1 to 10 m stream segments)

Disturbance: events, either natural or human-induced, that cause significant effects to ecosystem processes and functions (Noon et al. 1999). While disturbances can have positive and negative effects, in this document the emphasis is on the negative consequences of disturbances to tailed frogs and their habitat because these are of greatest management concern.

Catastrophic: term to describe any disturbance (natural or human caused) that could severely reduce or eliminate the aquatic life stage of tailed frogs from a single WHA, at least in the short term. For example, slope failure upstream causing excessive sedimentation could be catastrophic to tailed frog larvae in a WHA.

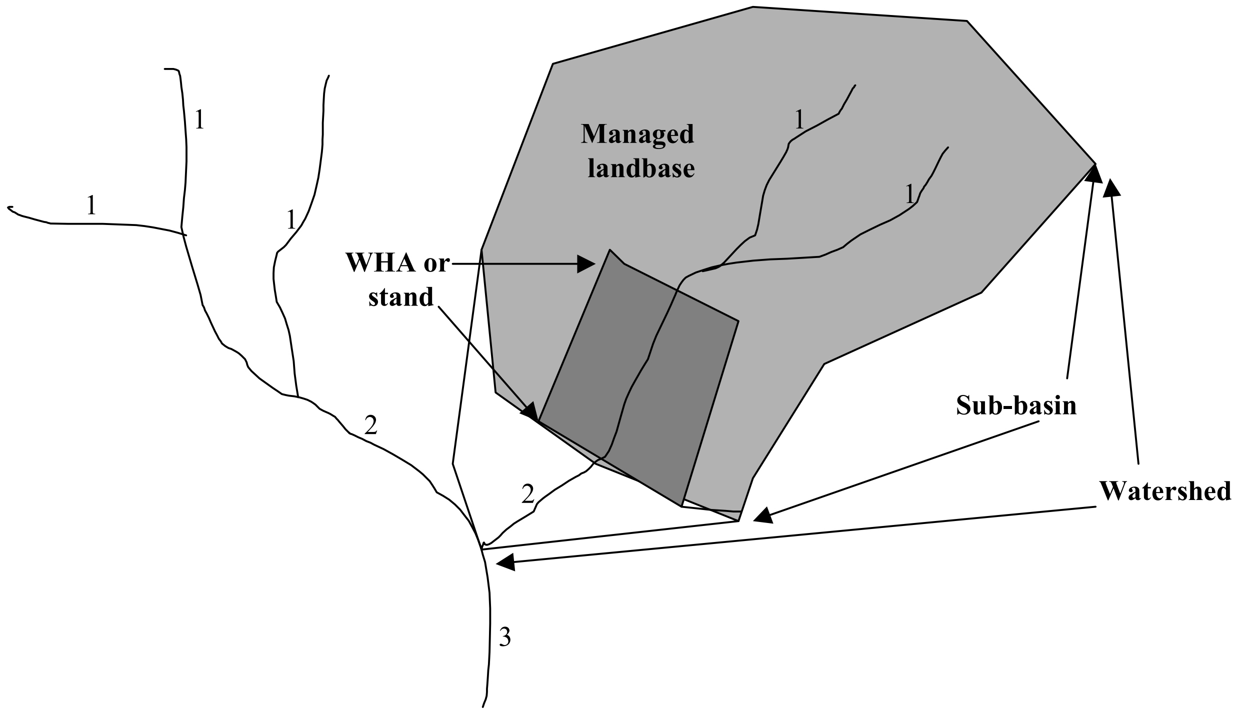

Figure 1. Scales used for effectiveness monitoring of tailed frog WHAs. Numbers refer to stream order.

1.2 Scope of this report

Effectiveness monitoring can be defined as the periodic measurement of environmental indicators that are used to assess whether management strategies are achieving their intended goal(s). There are three important concepts associated with effectiveness monitoring: measurement through time, spatial comparisons, and causation with respect to patterns in data. These three concepts are discussed briefly to provide background for effectiveness monitoring.

Monitoring programs typically require the measurement of indicators over time, thereby periodically updating trends in environmental indicators. Monitoring intervals can vary from months to decades, depending on the expected rate of change in indicators. Effectiveness monitoring programs that use inappropriate time intervals can be inefficient, ineffective, or both. Trends in indicators are important for predicting future status of environmental indicators such as species/habitat decline or recovery. The end-point for effectiveness monitoring is often indefinite if it is not tied to specific management/administrative goals such as designated species recovery or jurisdictional delisting of a listed species.

Effectiveness monitoring can also be accomplished by simultaneously comparing the status of indicators from several different management systems or landbase types; this can be one of the most powerful methods for assessing the effectiveness of WHAs. For example, comparing monitoring data between WHAs and the managed landbase is an excellent means of quantifying the effectiveness of WHAs. Similarly, comparing WHAs managed in different ways (e.g. undeveloped watershed compared to watersheds with some level of harvesting) can reduce overall costs of monitoring while facilitating the ability of managers to select between different management options. These types of comparisons advance knowledge about how to manage WHAs so overall management of WHAs can be improved.

Finally, an important concept in effectiveness monitoring programs is establishing cause-effect relationships to explain patterns. Monitoring programs can be ineffective when they are not simultaneously designed to record environmental patterns and the causes of those patterns; without cause-effect relationships, it is impossible to link monitoring programs back to management practices. As a result, managers will not know which management practices are effectively contributing to achieving monitoring goals and which need to be altered. Causation can be examined in effectiveness monitoring programs by linking disturbances to changes in the status and/or trends of indicators.

This report is essentially a tool kit that provides information on effectiveness monitoring questions, cost effective indicators, and indicator sampling protocols that are relevant to effectiveness monitoring of tailed frog WHAs. First, a comprehensive list of questions and biological indicators were identified. From this comprehensive list, a subset of relevant indicators were selected for effectiveness monitoring that could be implemented in a cost effective manner. For each cost effective indicator, the most comprehensive and conservative sampling design is described. That is, applying the entire study design described in this report to all of the WHAs is very nearly the best monitoring program that could be implemented cost effectively. However, the final monitoring program might not use all of the indicators or it might use all of the indicators but only in a portion of tailed frog WHAs.

The individual components (tools) that are ultimately implemented and to what extent will depend on financial constraints and the overall definition of WHA “effectiveness”. The implementation decision requires setting specific goals for WHAs. Goals for declaring a single or all tailed frog WHAs as "effective" can be quite diverse. For example, a tailed frog WHA may only be considered effective if:

1) tailed frog tadpole densities are stable and/or increasing
2) average percent cover of fine sediment in streams is < 25%.
3) < 25% of the sub-basin area is composed of forest < 20 years old
4) < 10% of riparian forest upstream of the WHA is composed of forest < 20 years old
5) > 50% of stream length above the WHA is buffered by forest age classes 5+
6) there are no roads within 100m of all streams that flow into the WHA
7) average canopy cover in WHAs is >25%.

Similarly, the entire provincial tailed frog WHA program might only be considered effective if:

1) at least 75% of the WHAs have stable or increasing populations of tailed frog tadpoles

2) the density of tadpoles in WHAs are greater than densities of tadpoles occurring in streams in the managed landbase[1].
3) indirect tailed frog habitat indicators in the WHAs provide more suitable habitat for tailed frogs compared to the managed landbase. For example, the average percent cover of sediment in WHA streams is 20% compared to 45% in streams in the managed landbase[2].

One, several, all, or none of these examples might be used as criteria to assess the effectiveness of tailed frog WHAs. Decisions about which monitoring questions and study designs to implement cannot be made until specific effectiveness goals are defined.

Different monitoring goals do not always provide the same level of insight or utility with respect to improving management practices. Goals based on specific habitat targets (*e.g*., substrate composition, level of disturbance upstream) are among the simplest and least expensive to monitor; however, results from monitoring habitat targets alone are limited in the extent that they can be used to evaluate and improve WHA management. Using habitat targets as the sole indicators is most effective when there is a strong understanding of the relationship between habitat structure and the species being managed (in this case tailed frogs). Currently, our understanding of the relationship between tailed frogs and their habitat as well as to forest practices is incomplete. In contrast, monitoring programs that include measuring the status or trends in species demography are more complex and more expensive. This information, however, can be used in a direct way to evaluate and improve WHA management. A cross-design in which basic monitoring is implemented in all WHAs with more intensive monitoring in a few WHAs to advance knowledge could be a useful monitoring strategy.

2 INTRODUCTION

Under the purview of the Forest and Range Practices Act, the government of British Columbia has implemented the Identified Wildlife Management Strategy. The purpose of this strategy is to "minimize the effects of forest practices on Identified Wildlife, and to maintain their critical habitats throughout their current ranges" in British Columbia (IWMS 2004). Wildlife habitat areas (WHAs) are one tool being used to implement habitat and species conservation measures for Identified Wildlife. The goal of WHAs is to "conserve those habitats considered most limiting" for Identified Wildlife. By themselves, WHAs are not designed to ensure that viable populations of Identified Wildlife are maintained throughout their current range in British Columbia. However, WHAs are being established in high quality or critical habitats and, therefore, are meant to contribute in a meaningful way toward conservation efforts.

Effectiveness monitoring of tailed frog WHAs (and WHAs generally) is important for at least four reasons. First, and most importantly, to determine if WHAs are performing the functions they were designed to maintain. Second, to serve as baseline information against which population trends from outside WHAs can be compared. Third, to help establish causal links between population trends in a species and changes in the environment, specifically forest

[1] It is assumed the managed landbase is managed with some level of consideration for environmental values otherwise WHAs may be more effective than the managed landbase but still not achieving WHA goals.
[2] Same assumption as above.

practices. That is, it is not only important to recognize that a population is increasing or declining, but to understand why these changes are occurring. Finally, effectiveness monitoring provides a way to learn and improve management of WHAs by comparing alternative management options and linking that information back to decision-making.

The purpose of this document is to outline a protocol for monitoring the effectiveness of tailed frog WHAs. Although much of the information will be relevant to a larger tailed frog monitoring program, this document is not intended as a monitoring protocol for tailed frogs throughout their current range in British Columbia. Neither is it designed to assess if the entire Identified Wildlife Management Strategy for tailed frogs is working to ensure their continued persistence throughout British Columbia. Specifically, this program is meant to determine if tailed frog WHAs, as they are currently designed, are meeting tailed frog WHA objectives as outlined in the Identified Wildlife Management Strategy (IWMS 2004). This document outlines key monitoring questions, identifies a comprehensive list of potential indicators, identifies key indicators for effectiveness monitoring, and provides a robust and cost effective sampling methodology to measure the indicators that could be used to evaluate the effectiveness of tailed frog WHAs.

2.1 Background

2.1.1 General life history of the tailed frog

There are two species of tailed frogs in British Columbia: the coastal tailed frog (*Ascaphus truei*) and the Rocky Mountain tailed frog (*Ascaphus montanus*; Nielson et al. 2001). The distribution of coastal tailed frogs in British Columbia ranges from the Lower Mainland to the Portland Canal and Nass River on the North Coast, occurring in windward and leeward drainages along the Coast Mountains (Dupuis et al. 2000). The Rocky Mountain tailed frog is located in the southeast corner of British Columbia with two disjunct populations occurring in the Columbia Ranges and the Rocky Mountain Foothills (Dupuis et al. 2000). While the coastal tailed frog and the Rocky Mountain tailed frog are considered separate species, they have similar life history characteristics and therefore, will be referred to as “tailed frogs” throughout the remainder of this document unless otherwise specified.

Tailed frogs are a stream-dwelling amphibian adapted to cool, fast-flowing, permanent mountain streams. Internal fertilization occurs by means of a “tail” that males use to internally inseminate females. Tailed frogs generally do not reach sexual maturity until 7 or 8 years of age (Daugherty and Sheldon 1982). Mating occurs in the fall with females laying eggs the following spring. Clutch sizes are relatively small with 30-70 eggs produced annually or biannually (Daugherty and Sheldon 1982; Brown 1990). Eggs hatch in the late summer and in-stream larval development takes one to four years, depending on latitude, elevation, climate, and stream productivity (Bury and Adams 1999; Sutherland 2000). Limited information is currently available on terrestrial movements or specific habitat requirements of either juvenile or adult tailed frogs. Juvenile tailed frogs are assumed to be the dispersing life stage and adults are generally assumed to be highly philopatric (Daugherty and Sheldon 1982; but see Wahbe 2003). Both juveniles and adults are physiologically restricted to cool, moist microclimates typically found in closed canopy forest (Bury and Corn 1988; Aubry and Hall 1991; Ascaphus Consulting 2002; but see Matsuda 2001; Wahbe 2003).

The development of an effective conservation strategy for tailed frogs is particularly difficult because of their complex life history. Their dependence on cool, fast-flowing montane streams as well as their terrestrial association with cool, moist microclimatic conditions necessitates the use of aquatic and terrestrial indicators within the WHA. In addition, larger spatial scales must be considered for two reasons. First, tailed frog abundance can be strongly related to landscape-level variables such as underlying parent geology (Diller and Wallace 1999; Sutherland 2000; Wilkens and Peterson 2000; Sutherland et al. 2001; Adams and Bury 2002). Second, hydrological, geomorphological, and biological processes occurring in the headwaters are strongly linked to downstream systems (Naiman et al. 2000; Gomi et al. 2002). As a result, disturbances occurring in the headwaters can also have cumulative impacts downstream. The development of an effectiveness monitoring protocol for tailed frog WHAs must, therefore, consider indicators at multiple spatial scales, and not just within the WHA itself.

2.1.2 Description of tailed frog WHAs

The general goal of tailed frog WHAs is to maintain important tailed frog streams and suitable breeding habitat (IWMS 2004). For coastal tailed frog streams, WHAs range in size from approximately 10 to 20 ha with size depending on the number and length of streams included in the WHA; at least two streams are recommended for inclusion. In the Skeena Region, proposed WHAs encompass entire watersheds ranging up to 1000 ha in size (Len Vanderstar pers. comm.). Rocky Mountain tailed frog WHAs range from 50 to 150 ha, again depending on the number and length of streams included; several streams are recommended for inclusion in Rocky Mountain tailed frog WHAs. For both species, WHAs include a core area extending 30 m to either side of the stream’s edge and a 20 m management zone extending from the core area. Currently, there are 15 approved tailed frog WHAs in the Thompson and Okanagan Regions ranging in size from 8 ha to 58.5 ha. Several more tailed frog WHAs are awaiting approval.

3 OBJECTIVES AND KEY EFFECTIVENESS MONITORING QUESTIONS

The objectives guiding the development of the tailed frog WHA effectiveness monitoring plan are based on the goals identified in the tailed frog species accounts for both the coastal and Rocky Mountain species. The WHA objective for coastal populations is to “maintain important streams and suitable breeding areas that were not addressed during landscape-level planning” (IWMS 2004). For the Rocky Mountain species, the overall objective is to “maintain and link tailed frog streams and breeding areas” (IWMS 2004). Therefore, two main questions must be addressed to determine if tailed frog WHAs are effective in meeting these objectives. First, is suitable habitat being maintained? Second, are productive tailed frog populations being maintained?

Answering these two questions not only require characterising the status and trends of tailed frog abundance and habitat conditions within the WHA, but it also requires consideration of biophysical features and management activities in the surrounding landscape. The focus of tailed frog WHAs is on breeding habitat; this requires the evaluation of in-stream tailed frog habitat within the WHA as well as potential disturbances affecting this habitat in the WHA and upstream. Further, tailed frog populations can only be successful if larvae are recruited into the adult breeding population. Consideration of stand-level structural attributes along with a larger-scale assessment of the managed landbase and its relative permeability to tailed frog movements could be important. Finally, the landscape-level context (e.g. underlying geology, topography, and climate) of tailed frog WHAs will be an important consideration in how effectiveness is actually evaluated, and has implications for management of WHAs.

Therefore, this effectiveness monitoring plan is designed to evaluate status and/or trends in tailed frog relative abundance and the suitability of tailed frog habitat. Ultimately these data will be used to determine if WHAs are successfully meeting the objectives outlined in the tailed frog species accounts. The key objectives for the monitoring plan are as follows:

1. Measure aquatic habitat characteristics in WHAs that are important for reproduction and larval development.
2. Measure habitat structure at the stand-level (i.e. within the WHA) that influence for both terrestrial and aquatic habitat quality.
3. Measure key processes and disturbances at the sub-basin level that may influence tailed frog aquatic habitat within the WHA and connectivity of tailed frog populations.
4. Determine the status and/or trends of tailed frog relative abundance within WHAs.
5. Provide context for evaluating the effectiveness of tailed frog WHAs in different geographical areas and topographical settings.

The following specific questions were developed to focus the approach of the tailed frog WHA effectiveness monitoring plan.

3.1 Context variables

1. What is the landscape context where the WHA is located? This question addresses the overall habitat suitability for tailed frogs, given that their occurrence and abundance is affected by the underlying geomorphology and productivity of streams (Sutherland 2000). The context variables will not be monitored, but are one-time measurements that will be used to evaluate the effectiveness of tailed frog WHAs, and are important considerations for WHA management.
    a. What is the underlying parent geology of the watershed where the WHA is located?
    b. What are the topographic characteristics of the WHA?
    c. What is the local climate of the WHA?

3.2 Sub-basin

2) How do disturbances at the sub-basin scale affect movement of metamorphosed tailed frogs and suitability of aquatic habitat in streams? At this level, the main concern is how disturbances surrounding the WHA influence its effectiveness by impacting aquatic habitat within the WHA, and limiting the ability of transformed tailed frogs to emigrate or immigrate into the WHA.

Connectivity

- a) What are the status and trends of key factors that might affect the connectivity of the tailed frog sub-population in the WHA to other sub-populations? That is, does the managed landbase surrounding the WHA facilitate or impede movement of dispersing tailed frogs? These questions relate to metapopulation dynamics of tailed frogs and probabilities of dispersal among streams.
    - i) What proportion of the sub-basin is < 20 years old?

ii) What proportion of the WHA boundary is bordered by forests < 20 years old?
iii) What proportion of stream length above the WHA is composed of mature (age class 5+) forest?

Aquatic processes

b) Are key processes that create and maintain suitable habitat conditions for tailed frogs in the aquatic system functioning within their natural range of variability at the sub-basin scale? Specific questions focus on threats that may impact stream sedimentation, hydrology, and temperature in streams.
   i) What proportion of the sub-basin has forests < 20 years old?
   ii) What proportion sub-basin streams are bordered by forests < 20 years old?
   iii) What proportion of the sub-basin has forests < 20 years old on slopes > 60%?
   iv) What is the road density[3] within 100 m of streams in the sub-basin?
   v) What is the stream crossing density of the sub-basin?
   vi) What is the frequency of disturbances that could affect water quality in the sub-basin (e.g. debris torrents, slope failures, mass wasting)?

3.3 Stand-level

3) Is tailed frog terrestrial and aquatic habitat being maintained in tailed frog WHAs? Questions focus on local-scale attributes that may affect terrestrial habitat quality for transformed tailed frogs, and aquatic breeding and rearing habitat for eggs and larvae in streams.

Terrestrial habitat

a. Is suitable terrestrial habitat (e.g., canopy cover, vegetation cover, CWD volume) being maintained within their natural ranges of variation in WHAs?
b. How do edges influence terrestrial habitat suitability within WHAs? For example, what proportion of forests < 20 years old[4] borders the WHA? How does habitat structure or microclimate change from the edge of the WHA to the interior?

Aquatic habitat

a. Is suitable aquatic habitat (e.g., substrate composition, pool:riffle ratio) being maintained in WHAs?
b. Is water quality (e.g. temperature, peak and/or low flows, turbidity) being maintained in WHAs?

3.4 Population

4) Will tailed frog WHAs ensure no declines of tailed frogs?
   a) What is the status and/or trend of the relative abundance of tailed frog tadpoles in WHAs? Related, what is the natural range of variability that should be expected in tailed frog tadpole relative abundance?
   b) Can status and/or trends of habitat indicators be used to predict changes in tailed frog tadpole relative abundance?

---

[3] road density within 100 m of streams was selected based on IWAP (1995) and CWAP (1995) guidebooks. Sutherland et al. (2001) also found negative associations with increasing road density within 100 m of streams and tailed frog occurrence/abundance.

[4] forests < 20 years are assumed to provide unsuitable habitat for metamorphosed tailed frogs due to frogs' physiological limitations. In addition, forests < 20 years may not recovered hydrologically, and therefore can alter flow regimes and sedimentation events in streams impacting tailed frog aquatic habitat.

4 RATIONALE FOR INDICATOR SELECTION

Using a conceptual model as a guide (see Appendix 1 for complete description), a set of indicators was selected based on a literature review of habitat and environmental variables that affect tailed frog abundance and distribution (Table 1). Many of the indicators selected for in-stream monitoring have well established relationships with tailed frog tadpole occurrence and/or abundance (see Table 2a and 2b for a qualitative summary of results). The indicators either characterise tailed frog tadpole habitat or characterise threats (e.g. forest harvesting) to tadpole habitat, thus acting as indirect indicators of the in-stream life stages of tailed frogs. Little is known about the terrestrial requirements of juvenile and adult tailed frogs. Therefore, based on their physiological requirements for cool, moist microclimatic conditions typically associated with mature seral forest, terrestrial habitat indicators were selected to measure surrogate indicators of microclimate at two spatial scales. To discuss the rationale of the indicator selection, the indicators have been grouped into different indicator types including: 1) context variables, 2) WHA permanent features, 3) sub-basin development variables, 4) stand-level terrestrial habitat indicators, 5) aquatic habitat indicators, and 6) direct population indicators.

4.1 Context variables and WHA permanent features

1. Context variables: geology, mean annual temperature, mean annual precipitation, and growing season length and

2. WHA permanent features: aspect, elevation, stream size, stream gradient.

Tailed frog populations are not equally vulnerable to disturbance (either natural or human-induced) due to the underlying influences of geology, climate, and topography on tailed frog habitat characteristics and productivity (Sutherland 2000; Sutherland et al. 2001). Therefore, several variables, defined as “Context variables” and “WHA permanent features”, were selected to provide context for the evaluation of the effectiveness of tailed frog WHAs. Rationale for their selection follows.

There are well established negative relationships between tailed frog occurrence and/or abundance with factors that promote the intrusion of fine sediment in streams (Sutherland 2000; Sutherland et al. 2001). Underlying parent lithology is an important determinant of sedimentation levels in streams; weather-resistant parent materials break down into larger substrate sizes (i.e. > 64 mm; cobbles, boulders) which is the preferred microhabitat for tailed frog tadpoles. In fact, 6 of 7 studies (and 5 geographic regions) in which parent geology was analysed, a positive relationship was found between tadpole occurrence/abundance and weather-resistant parent materials (Table 2a). WHAs located in regions with consolidated parent material are expected to support larger densities of tailed frog tadpoles that are more resilient to in-stream disturbances compared to WHAs located in areas with weaker parent materials. Therefore, underlying geology provides the context for evaluation of tailed frog WHAs and a measure of their relative sensitivity to disturbance.

Table 1. Description of indicators to evaluate the effectiveness of tailed frog WHAs including references for sampling protocols where available.

Scale	Indicator	Description	Frequency measured	Data source(s)	Reference(s)
1. Context variables – one-time measurements used to classify the sensitivity of WHAs					
Watershed	Geology	• underlying parent material	once	Geological Survey of Canada, Geological Survey Branch of BC	CWAP (1995), IWAP (1995)
	Temperature	• Mean annual temperature (^oC)	once	BEC site series guides, Meterological Service of Canada, National Climate Data Centre and Information Archive, BC MOF climate database	
	Precipitation	• Mean annual precipitation (mm)	once	BEC site series guides, Meterological Service of Canada, National Climate Data Centre and Information Archive, BC MOF climate database	
	Growing season	• Number of frost free days	once	BEC site series guides, Meterological Service of Canada, National Climate Data Centre and Information Archive, BC MOF climate database	
2. WHA permanent features - one-time measurements used to classify the sensitivity of WHAs					
	Aspect	• Aspect (degrees)	once	GIS map data layers	
	Elevation	• Elevation at the downstream end of the WHA	once	Field - GPS/map	
	Gradient	• Mean stream gradient of the watershed	once	GIS map data layers	
3. Sub-basin forest cover and roads – disturbance indicators measured periodically (e.g. 5 years) using GIS					
Sub-basin	Sub-basin forest disturbance	• Percent area of the sub-basin < 20 years old. Early seral stage may be a result of forest harvesting, wildfire, or be naturally non-forested.	5 years	GIS map data layers	

	Riparian forest disturbance	• Percent of the stream length in the sub-basin above the WHA < 20 years old . Early seral stage may be a result of forest harvesting, wildfire, or be naturally non-forested	5 years	GIS map data layers	CWAP (1995), IWAP (1995)
	Riparian buffer	• Percent of stream length in the sub-basin above the WHA with a riparian buffer > 30 m in mature/old forest (age class 5+)	5 years	GIS map data layers	CWAP (1995), IWAP (1995)
	WHA buffer	• Percent of the WHA boundary bordered by forest < 20 years old.	5 years	GIS map data layers	
	Unstable slopes[2]	• Percent area of the sub-basin < 20 years old with slopes > 60%. Early seral stage may be a result of forest harvesting, wildfire, or naturally non-forested	5 years	GIS map data layers	CWAP (1995), IWAP (1995)
	Road density within 100 m of a stream	• The total length of roads occurring within 100 m of streams in the sub-basin measured as kilometers of road near streams per unit area of the sub-basin (km/km^2)	5 years	GIS map data layers	CWAP (1995), IWAP (1995)
	Stream crossing density	• The total number of stream crossings occurring in the sub-basin measured as the density of stream crossings per square kilometer (#/km2)	5 years	GIS map data layers	CWAP (1995), IWAP (1995)
	Sub-basin disturbance record	• Evaluation of disturbance events in the sub-basin such as: avalanches, debris flows, slope failures, mass wasting	5 years	Air-photos	
4. Terrestrial habitat – indirect indicators of tailed frogs remeasured infrequently (every 20 years) or following major disturbance events					
Stand - terrestrial	Canopy closure	• A visual estimate of the percentage of sky obscured by branches and foliage > 3 m in height.	20 years or following major disturbance event (e.g. wind throw)	Field	Huggard 2001, Maxcy et al. 2001

Percent cover of vegetation layers	• Percent cover of eight vegetation layers estimated with increasing distance from the stream. Vegetation layers include: inorganic ground cover, litter, moss, herbs, shrubs (< 15 cm high), shrubs (15 cm to 2 m tall), shrubs (> 2 m), and overstory canopy cover	20 years or following major disturbance event (e.g. wind throw)	Field	Huggard 2001, Maxcy et al. 2001
CWD volume	• Volume of CWD (m^3) in different size classes and decay classes estimated with increasing distance from the stream. Estimated using the Van Wagner (1968) method.	20 years or following a major disturbance event (e.g. wind throw)	Field	Huggard 2001, Maxcy et al. 2001
5a. Aquatic habitat characteristics – indirect indicators of tailed frogs measured annually for the first 3 years and then every few years thereafter				
Substrate composition	• Visual estimate of the percent cover of substrate in four size classes: fines (< 3 mm), gravel/pebble (3-64 mm), cobbles (64-256 mm), and boulders (> 256 mm) in the sample unit	annually for first 3 years and every 2 to 3 years thereafter	Field	modified from Bury and Corn 1991
Channel morphology	• Percent cover of slow (e.g., pools and glides) to fast (e.g., riffles, cascades) is visually estimated in each sample unit. From this, pool:riffle ratio can be calculated.	annually for first 3 years and every 2 to 3 years thereafter	Field	Bury and Corn 1991
Gradient	• an upstream and downstream slope is recorded as a percent, and averaged to measure to the general gradient of each stream reach sampled.	annually for first 3 years and every 2 to 3 years thereafter	Field - clinometer	Reconnaissance (1:20,000) Fish and Fish Habitat Inventory – Site Card Field Guide (1999)
Wetted width	• Width of the water surface at the time of the survey measured perpendicular to the stream flow. Measurement is repeated three times at regular intervals in sample unit, and averaged to determine the wetted width	annually for first 3 years and every 2 to 3 years thereafter	Field	Reconnaissance (1:20,000) Fish and Fish Habitat Inventory – Site Card Field Guide (1999)

Bankful width	• The width of channel between the tops of the streambanks at approximately right angles to the orientation of the banks. Boundary of the stream is determined by changes in vegetation, sediment, texture, and topographic breaks. Measurement is repeated three times at regular intervals in the sample unit, and averaged to determine the bankful width	annually for first 3 years and every 2 to 3 years thereafter	Field	Reconnaissance (1:20,000) Fish and Fish Habitat Inventory – Site Card Field Guide (1999)
Channel disturbance intensity	• Qualitative assessment of channel disturbance intensity based on an index ranging from: • 1=extreme – evidence of debris torrent within last 3 years • 2=high – perpetual high intensity disturbances such as avalanches, high peak flows, and high bedload transport. Sidewalls may be unstable. • 3=moderate – Moderately disturbed with infrequent debris flow activity (>5 years). Channel units moderately to well developed. • 4=low - stable flooding regime with low bedload transport (large substrates stable and often mossed over). Channel units are stable and well developed.	annually for first 3 years and every 2 to 3 years thereafter	Field	Ascaphus Consulting 2003
5b. Water quality - indirect indicators of tailed frogs measured annually for the first 3 years and then every few years thereafter				
Temperature	• The ambient water temperature is recorded in each sample unit. Ideally a temperature data logger would be placed in each stream to continuously record temperature.	annually for first 3 years and every 2 to 3 years thereafter	Field	Reconnaissance (1:20,000) Fish and Fish Habitat Inventory – Site Card Field Guide (1999)
6. Population – the only direct indicator of tailed frog populations measured annually for the first 3 years and then every few years thereafter				
Tadpole density	Tadpole relative abundance (#/m^2) estimated using area-constrained searches	annually for first 3 years and every 2 to 3 years thereafter	Field	Inventory methods for Tailed Frogs and Pacific Giant Salamanders (RISC 2000)

Table 2a. Qualitative summary of tailed frog **larval** environmental and habitat associations at different spatial scales. Studies that examined specific environmental or habitat associations are shown in the Source column with significant relationships highlighted in bold.

Variable	Response of larval tailed frogs	Source[1]
Climate	5 of 5 studies found some relationship between tailed frog tadpoles and climatic variables however, results are not always consistent between studies. • **include to provide information on basic suitability of WHA for tailed frogs or incorporate in an "index of suitability"**	**10a**, **10b**, **13, 18, 19**
Geology	6 of 7 studies found a positive relationship between tadpole abundance and the presence of consolidated parent material • **include to provide information on basic suitability of WHA for tailed frogs or incorporate in an "index of suitability"**	**7**, **10a**, **10b**, **11**, **12**, **13,** 19
Elevation	9 of 13 studies found a positive relationship between elevation and tailed frog abundance, and one study found tadpoles negatively associated with elevation (Acaphus Consulting 2003) • **include to provide information on basic suitability of WHA for tailed frogs or incorporate in an "index of suitability"**	3, **5**, 7, 9, **10a**, **10b**, **11**, **12**, **13**, **15**, 17, **18**, **19**, **20**
Slope	Tailed frog tadpole abundance tends to increase with the steepness of the stream and/or the surrounding basin. • **include to provide information on basic suitability of WHA for tailed frogs or incorporate in an "index of suitability"**	**3**, **4**, 5, **7**, **10a**, 11, **12**, **13**, 14, 15, 17, 18, **19**, **20**
Sub-basin disturbance	11 studies included some measure of sub-basin disturbance. In 10 of these studies, results suggest tadpole abundances are higher in sub-basins that have lower amounts of disturbance (e.g., lower percentage of forest harvested, fewer roads, presence of uncut forest upstream) • **use % forest < 20 years in sub-basin, % stream length above WHA< 20 years, stream crossing density and significant disturbance events (e.g. landslides, debris flows) as main indicators**	**1**, **4**, **5**, **8**, **10a**, **10b**, **12**, **14**, 16, **17**, **20**
Forest age	17 studies included analysis of forest age adjacent to the stream and tadpole abundance. 9 of 17 studies found tadpole abundance was lower when streams have been logged up to the stream and riparian buffers may mitigate this negative influence (Dupuis and Steventon 1999; Stoddard 2002) but not always (Kelsey 1995). • **forest age would not be a useful indicator unless the WHA is composed of mostly young forest**	**1**, 2, **3**, 5, **7**, **8**, 9, 10a, 10b, **12**, 14, **15**, **16**, **17**, **18, 19,** 20
Substrate composition	20 studies examined the relationship between substrate composition and tailed frog abundance. In 18 of 20 studies, tadpoles were positively associated with large substrate categories (i.e., cobbles or boulders), or negatively associated with small substrates (e.g., silt, sand) • **percent cover of substrate composition size class distributions as the main indicator**	**1**, **2**, 3, **4**, **5**, **6**, **7**, **8**, 9, **10a**, **10b**, **11**, **12**, **13**, **14**, **18**, **16**, **17**, **18**, **19**, **20**
Stream channel morphology	11 studies examined the relationship between stream channel morphology (e.g., pool:riffle ratio) and tailed frog abundance. In 6 studies where significant relationships were found, tadpoles were usually	1, **2**, **3**, 4, 5, **6**, **7**, 11, 15, **17**, **20**

	associated with fast-flowing (but see Wahbe and Bunnell 2003). • **percent cover of slow-moving water (e.g. pools) and fast-moving water (riffles, runs) as main indicator.**	
Stream temperature	14 studies examined the relationship between stream temperature and tadpole abundance; 6 studies found some relationship. Tadpole abundance was negatively associated with temperature in southern parts of their range (e.g. Diller and Wallace 1999, Welsh and Lind 2002), and positively associated with temperature in northern parts of their range (e.g. Sutherland 2000, Ascaphus Consulting 2003). • **stream temperature as the main indicator**	2, 3, **5**, 6, **7**, 8, 9, **10a**, **10b**, **12**, 14, **18**, **19**, 20
Stream size	6 of 16 studies found some relationship between wetted width or stream order and tadpole abundance; however, results are inconsistent with tadpoles both increasing and decreasing in abundance with increased stream size. • **include to provide information on basic suitability of WHA for tailed frogs or incorporate in an "index of suitability"**	1, 2, 3, 4, 5, 7, **8**, 9, **10a**, **10b**, 11, 13, **14**, **17**, 17, **20**

[1] 1 - Corn and Bury 1989; 2 - Bury et al. 1991; 3 - Kelsey 1995; 4 - Bull and Carter 1996; 5 - Hunter 1998; 6 - Welsh and Ollivier 1998; 7 - Diller and Wallace 1999; 8 - Dupuis and Steventon 1999; 9 - Dupuis and Wilson 1999; 10a - Sutherland 2000, coastal populations; 10b - Sutherland 2000, interior populations; 11 - Wilkens and Peterson 2000; 12 - Sutherland et al. 2001; 13 - Adams and Bury 2002; 14 - Ascaphus Consulting 2002a; 15 - Bisson et al. 2002; 16 - Raphael et al. 2002; 17 - Stoddard 2002; 18 - Welsh and Lind 2002; 19 – Ascaphus Consulting 2003; 20 - Wahbe and Bunnell 2003

Table 2b. Qualitative summary of **metamorphosed** tailed frog habitat associations at different spatial scales. Studies that examined specific environmental or habitat associations are shown in the Source column with significant relationships highlighted in bold.

Variable	Response of metamorphosed tailed frogs	Source[1]
Elevation	In studies that examined relationships between adult tailed frog abundance and elevation, metamorphosed frogs were usually positively correlated with elevation in 3 of 5 studies • **include to provide information on basic suitability of WHA for tailed frogs or incorporate in an "index of suitability"**	**2**, 3, 5, **8**, **12**
Slope	4 of 7 studies found a positive relationship between metamorphosed frogs and the slope of the stand or of the stream. • **include to provide information on basic suitability of WHA for tailed frogs or incorporate in an "index of suitability"**	2, 3, **5**, **6**, **8**, 11, **12**
Sub-basin disturbance	In 3 of 4 studies examining the relationship between sub-basin disturbance and adult tailed frog abundance, fewer frogs were found with increasing disturbance intensity in a basin. • **use % forest < 20 years, % of WHA boundary bordered by forest < 20 years old, % stream length above WHA that is buffered by forests in age classes ≥ 5 in the sub-basin as the main indicators**	**6**, 8, **11**, **12**
Forest age	3 of 5 studies found fewer metamorphosed tailed frogs in clearcuts compared to closed canopy forest; some studies were not associated with riparian areas (e.g. Bury and Corn 1988; Corn and Bury 1991). Matsuda (2001) and Wabhe (2003) both had higher capture rates of tailed frogs in clearcuts compared to mature forest but the majority of captures were juveniles possibly due to decreased survival of juveniles in clearcut habitat. While tailed frogs tend to be positively associated with old	**1**, **3**, **7**, 10, 13

	forest, although young, unmanaged stands may also provide adequate habitat (see Gilbert and Allwine 1991) • **forest age would not be a useful indicator unless the WHA is composed of mostly young forest**	
Riparian buffers	Presence of riparian buffers mitigated the negative affects of forest harvesting on metamorphosed tailed frogs in 4 of 4 studies. • **width of WHAs (i.e. perpendicular distance from WHA streams) can be used as an indicator if WHAs are different sizes**	**6**, **9**, **11**, **12**
Terrestrial habitat structure	Only 3 studies have examined terrestrial habitat associations of metamorphosed tailed frogs. A number of correlations with vegetation characteristics have been observed; however, no consistent patterns exist across studies. • **canopy cover should be used as the main indicator** • **extra indicators could include cover of vegetation in different layers of the canopy, and volume of CWD**	**2**, **3**, **10**
Substrate composition	Similar to larval tailed frogs, in 5 of 6 studies where it was tested, metamorphosed frogs were positively associated with large substrates (e.g., cobbles and boulders) or negatively associated with small substrates (e.g., fines). • **percent cover of substrate composition size class distributions as the main indicator**	**5**, **6**, **8**, **11**, 12
Stream channel morphology	Metamorphosed tailed frogs have been positively associated with both fast-moving water and slow-moving water. • **percent cover of slow-moving water (e.g. pools) and fast-moving water (riffles, runs) as main indicator.**	**5**, 6, **8**, 12
Stream temperature	Of 3 studies that looked for an association between metamorphosed tailed frogs and stream temperature, one study found a negative relationship. • **stream temperature as the main indicator**	**5**, 8, 11

[1] 1 – Bury and Corn 1988; 2 – Aubry and Hall 1991; 3 – Corn and Bury 1991; 4 – Gilbert and Allwine 1991; 5 – Kelsey 1995; 6 – Bull and Carter 1996; 7 – Gomez and Anthony 1996; 8 – Hunter 1998; 9 – Maxcy 2000; 10 – Matsuda 2001; 11 – Ascaphus Consulting 2002; 12 – Stoddard 2002; 13 - Wahbe 2003

Also related to tailed frog aquatic habitat, is a stream's capacity to dissipate or absorb impacts of sedimentation events. Steeper and wider streams typically have a greater ability to remove fine sediment (Naiman et al. 2000) helping to maintain suitable microhabitats for tailed frog tadpoles. Both variables have been found to be positively associated with tailed frog abundance at both the micro-scale (i.e. stream reach/sample unit) to macro-scale (watershed; Table 2a and 2b). Stream gradient is generally positively related to tailed frog densities (Diller and Wallace 1999; Sutherland 2000; Sutherland et al. 2001; Adams and Bury 2002; Ascaphus Consulting 2003; Wahbe and Bunnell 2003). This may be particularly important in geological areas with intermediate erosion potential; steeper gradients may compensate for increased sedimentation into the stream by "cleaning" the substrates with fast moving water. Wider streams also have a greater capacity to flush out accumulated material. However, wetted width has shown contradictory results in association with tadpole abundance (e.g., Dupuis and Steventon 1999; Sutherland 2000; Wilkens and Peterson 2000; Table 2a). Stream size likely interacts with other factors (e.g. bedrock material, stream gradient, stream discharge, water temperature) to influence tadpole distribution and relative abundance. Presumably for both stream gradient and stream size, there is an optimal range of gradients/widths where tadpole abundance peaks and abundance generally declining outside this range. For example, in the North Coast, tadpole relative abundance was highest in streams with ranging from 30% to 70% with declines occurring above and below this range (Ascaphus Consulting 2003). It is unknown if a similar relationship applies in other areas (e.g. South Coast, SE B.C.) but determining a range of both stream gradients and stream sizes that provide optimal habitat are important factors to consider in the assessment of WHA effectiveness.

Another factor that may increase the vulnerability of tailed frog populations to disturbance is low habitat productivity (Sutherland 2000; Sutherland et al. 2001). Basic life history information (e.g., survival rate, growth rate, fecundity rate) is lacking for tailed frogs. However, in other amphibian species these vital rates can be influenced by habitat productivity (Hota 1994). Tailed frog tadpole growth rates also seem to be affected by stream productivity as larval growth rates are enhanced by the addition of nutrients (Kim and Richardson 2000; Kiffney and Richardson 2001). There are a number of consequences for tailed frog populations if their development is limited by primary productivity. Tailed frog populations living in less productive areas may take longer to metamorphose and therefore, reach reproductive maturity later. For example, the larval life stage lasts one to four years with variation in age at metamorphosis increasing with latitude (Bury and Adams 1999). This is likely the result of cooler temperatures, shorter growing seasons, and hence, lower productivity in more northerly locations. In addition, females may be only capable of bi-annual reproduction rather than annual reproduction. These factors all reduce population growth rates. A modelled population of tailed frogs that were subject to higher annual variability in habitat productivity were at greater risk of extinction compared to modelled populations in more productive, less variable habitat (Sutherland 2000). Therefore, some basic climatic variables (e.g. annual temperature, growing season length) and WHA permanent features (e.g. geographical location, aspect, elevation, slope) that influence the productivity of streams were selected to provide context for the evaluation of WHAs and a measure of population resiliency. WHAs located in more northern latitudes or at higher elevations may have lower population growth rates as a result of lower productivity; consequently, these populations may be more vulnerable to disturbances.

Taken together, “Context variables” and “WHA permanent features” serve one main purpose in tailed frog WHA effectiveness monitoring, that is to provide a sensitivity measure for each WHA which is important in the actual evaluation of effectiveness. As suggested from the above literature review, the underlying geology, local climate, and geographic position of WHAs all influence the resiliency of tailed frog populations to disturbance; populations in less productive areas, and/or in areas more prone to erosion will likely take longer to recover following disturbances. Therefore, depending on the landscape context, criteria for evaluation of effectiveness monitoring based on an index of sensitivity could be developed in which WHAs are ranked into low, medium, and high sensitivity sites. This type of designation could be used to help prioritize which WHAs to monitor for effectiveness, as well as influence the type of management activities permitted in and around WHAs of different sensitivities.

4.2 Sub-basin development indicators

3. Sub-basin development indicators: percent area of sub-basin that is < 20 years old, percent of the WHA boundary bordered by forests < 20 years old, percent of stream length in the

sub-basin bordered by forest < 20 years old, percent of stream length in the sub-basin buffered by mature/old forest, area of sub-basin with forest <20 years old on > 60% slopes, road density within 100 m of streams, stream crossing density, sub-basin disturbance record

4.2.1 Aquatic habitat indicators

Indicators selected at the sub-basin scale are all indicators of threats to in-stream tailed frog habitat. For example, increasing intensity of forest harvesting at the watershed-level was consistently found to be negatively associated with tailed frog occurrence/abundance across their range (Sutherland et al. 2001). In addition, road density has been found to be negatively associated with tailed frog occurrence and/or relative abundance of populations of tailed frogs in British Columbia (Sutherland 2000; Sutherland et al. 2001) but others have found no relationship (Bull and Carter 1996; Sutherland 2000, Rocky Mountain tailed frog; Stoddard 2002). Road networks can increase the magnitude and frequency of peak flows, debris flows, and sedimentation in streams. Consequences to aquatic tailed frog habitat may include channel rearrangement and deposition or removal of material (Jones et al. 2000); channel rearrangement can also result in direct mortality of tailed frogs. Road effects may be greatest in areas prone to erosion or high debris loads, and therefore negative impacts on tailed frogs may be related to landscape context (e.g. bedrock geology). Related to road density is stream crossing density which has not been measured in tailed frog studies to-date.

Similar to road networks, forest harvesting adjacent to streams may also have adverse impacts on aquatic habitat by destabilising streambanks, increasing peak flows, and increasing erosion. The presence of unlogged forest or buffered riparian areas along creeks up-stream of sample locations was positively associated with the presence of tailed frog tadpoles, even when sampling occurred in harvested stream reaches (Corn and Bury 1989; Stoddard 2002; Wahbe and Bunnell 2003). Forested upstream reaches may act as a source of individuals as tadpoles tend to move in a downstream direction (Wahbe and Bunnell 2001) but they may also act to minimise erosion, and sedimentation sources by maintaining stream bank and channel stability (Naiman and Decamps 1997; Benda et al. 1998), and thus suitable aquatic habitat for tailed frogs. Therefore, the length of stream bordered by recently harvested (i.e. < 20 years old) forest in the sub-basin can serve as a threat indicator of in-stream tailed frog habitat.

The final indicator of in-stream habitat at the sub-basin scale is the sub-basin disturbance record. Cumulative effects of large-scale disturbances occurring at higher elevations in a sub-basin can potentially be felt downstream. Therefore, tracking and recording large-scale disturbances in the sub-basin could be important in explaining variation in aquatic habitat variables at the stand level as well as tailed frog relative abundance.

4.2.2 Terrestrial habitat indicators

Indicators of disturbances at the sub-basin scale are not only important to consider for tailed frog aquatic habitat but also may be an important consideration for terrestrial tailed frog movement capabilities. The managed landbase can perform two vital roles for tailed frog WHAs: buffer WHAs thus increasing their effective size, and provide connectivity within the landscape to other sub-populations of tailed frogs. Therefore, at the sub-basin scale, three indicators are relevant measures of habitat quality and connectivity for juvenile and adult tailed frogs: percent area of sub-basin that is < 20 years old, percent of the WHA boundary bordered by forest < 20 years old, and percent of stream length in the sub-basin buffered by mature/old forests.

Very little is known about the terrestrial requirements of tailed frogs, or of their movement and dispersal capabilities. Evidence has suggested that adult tailed frog movements are limited to riparian areas (e.g., Wahbe et al. 2000; Matsuda 2001); dispersing metamorphs appear to move much greater distances. For example, Wahbe (2000) captured juveniles 100 m from the nearest stream all moving upslope, while Bury and Corn (1988) captured many juveniles at least 300 m from the nearest stream. However, adults in both old-growth and clearcuts can move at least 100 m from streams in some areas, including gravid females which were hypothesized to be moving between streams (Wabhe 2003). Therefore, management of the intervening matrix surrounding tailed frog WHAs may influence the effectiveness of WHAs in maintaining tailed frogs by facilitating or impeding movement between sub-population of tailed frogs. There is evidence to suggest that connectivity may be important to maintaining tailed frog populations and amphibians in general. For example, 3 of 4 studies found that low abundance of tailed frog adults was associated with increased disturbance intensity at the sub-basin scale (Table 2b); while this has not been established as a cause-effect relationship, decreased connectivity may be an implicating factor. Thresholds of connectivity do apparently exist for other amphibians such that populations can no longer be supported. For example, Gibbs (1998) found aquatic-breeding amphibians absent from landscapes with <50% canopy cover. Therefore, percent of logged areas in the sub-basin and in particular, bordering the WHA may serve as indicators of connectivity of the tailed frog sub-population in the WHA to other sub-populations of tailed frogs.

Logged areas upstream of the WHA may also be an indicator of terrestrial habitat quality for adult tailed frogs. Adult tailed frogs appear to move parallel to the stream more often than perpendicular with upstream directional movement (e.g., Wahbe et al. 2000; Matsuda 2001), and downstream directional movement (Adams and Frissell 2001) both observed. In support of upstream directional movement, higher relative abundance of adult tailed frogs are often found closer to the headwaters of streams compared to tadpoles which are more centrally located in the watershed (Bull and Carter 1996; Hunter 1998; Ascaphus Consulting 2002; Stoddard 2002). It has been suggested that adult tailed frogs may move seasonally in response to changes in environmental conditions (Adams and Frissell 2001), or for breeding purposes (Kelsey 1995; Stoddard 2002). Currently, it is unknown if these movement patterns are a common behaviour of tailed frog adults, or restricted to specific sites and/or environmental conditions. Regardless, forested riparian areas upstream of the WHA may provide optimal habitat for adult tailed frogs.

Given the network properties of streams, strong linkages can be made between disturbances occurring upstream of a tailed frog WHA and quality of tailed frog aquatic habitat in WHAs. However, the links between sub-basin disturbances and terrestrial tailed frog movements are untested. Therefore, it is unknown if these disturbances are appropriate indicators of terrestrial tailed frog movements and they should be considered working hypotheses until new information becomes available.

4.3 Stand-level terrestrial habitat indicators

4. Stand-level terrestrial habitat indicators - canopy cover, cover of vegetation layers and volume of CWD

Measures of riparian forest structure at the stand level will serve as indicators of habitat quality for transformed tailed frogs at the stand-level. Adult tailed frogs exhibit high rates of evapotranspiration and are characterized by a low thermal maximum (Claussen 1973) compared to other ranid species, placing severe physiological constraints on them. Therefore, movement and foraging are likely restricted to specific microclimatic conditions that are often found in mature forests. Seven of 9 studies found a positive relationship between adult tailed frogs and forest age or the presence of a riparian buffer (Table 2b). In two studies, there was no statistical difference in tailed frog capture rates in clearcut and mature forest (Matsuda 2001; Wahbe 2003). However, the majority of captures in clearcuts were juveniles for both studies suggesting survivorship to adulthood could be lower in clearcuts compared to mature forest. Combined, these studies indicate closed canopy forests do provide higher quality habitat for the terrestrial life stage of tailed frogs. However, the specific, stand-level factors that increase habitat quality for them remains unknown. In studies examining tailed frog terrestrial abundance and stand-level attributes, such as downed wood or understory vegetation composition, few significant correlations were found. Where correlations were observed, results are difficult to interpret in a biologically meaningful way. Therefore, the forest structure indicators (canopy cover, cover of vegetation layers and volume of CWD) were selected based on their assumed contribution to favourable microclimatic conditions rather than the actual composition of vegetation. Canopy cover is the main indicator of terrestrial habitat for tailed frogs and should be measured as a minimum. Cover of vegetation layers and volume of CWD can be measured resources permitting.

4.4 Aquatic habitat indicators

5a. Aquatic habitat characteristics: substrate composition, stream channel morphology, gradient, wetted width, bankful width, channel disturbance index.

Disturbances that influence larval attachment sites in streams have the strongest relationships with tailed frog tadpole occurrence and abundance (Sutherland 2000). In 18 of 20 studies in which some aspect of substrate composition was measured, tailed frogs tadpoles and adults were either found to be positively associated with large substrate sizes (cobbles or boulders), or negatively associated with small substrate sizes (silt or sand) (Table 2a and 2b). Coarse substrate composition is hypothesized to increase tadpole escape cover from predators and disturbances (e.g., bedload movements), provide increased foraging surface area, and provide oviposition sites (Welsh and Ollivier 1998; Dupuis and Steventon 1999; Sutherland 2000; Dupuis et al. 2000; Adams and Bury 2002). Monitoring substrate composition in streams serves as one indicator of tadpole microhabitat suitability in WHA streams, and an indirect indicator of tadpole densities.

Tailed frog habitat suitability within streams is also affected by stream channel morphology at small spatial scales. In 6 of 12 studies in which some measure of stream channel morphology was measured, tailed frog tadpoles and adults were generally positively associated with fast flowing habitat (e.g., riffles, runs; Table 2). Pools are depositional habitats often composed of fine sediment, a substrate avoided by tailed frogs. Therefore, stream channel morphology, specifically riffle and pool area, is an indicator of in-stream habitat suitability for tailed frogs, and thus is an indirect indicator of tailed frog populations.

As mentioned previously, stream size and gradient can affect the occurrence and abundance of tailed frog tadpoles at large scales (i.e. watershed) as well as at the microhabitat scale. The local distribution of tadpoles is affected by gradient and water flow as tadpoles select for specific microhabitat characteristics i.e. cobble substrates on steeper reaches with faster flowing water. Stream size can also serve as an indicator of hydrology (e.g. peak flows or flooding); tailed frog tadpoles are expected to be lower where peak flows or flooding occur frequently and are more extreme (Sutherland et al. 2001; Ascaphus Consulting 2003). Therefore, stream size and gradient also serve as indirect indicators of tailed frog populations, providing information on microhabitat suitability as well as on the larger scale process of the water flow regime.

One final indicator of in-stream tailed frog habitat is a channel disturbance index. Catastrophic disturbances could severely reduce or eliminate the aquatic life stage of tailed frogs from a single WHA, at least in the short term. For example, slope failure upstream causing excessive sedimentation could be catastrophic to tailed frog larvae in a WHA. Only one recent study (Ascaphus Consulting 2003) has examined the relationship between channel disturbance intensity and the occurrence and abundance of tailed frogs. They found both tadpole occurrence and abundance was highest in streams with a moderate disturbance intensity. Monitoring the level of disturbance the WHA provides a relative measure of in-stream habitat stability and may be used to explain variation in tailed frog tadpole abundance. Streams subject to more frequent disturbance events may have lower tadpole abundance with higher annual variation compared to streams with less frequent disturbance. A channel disturbance index can be an important indicator in the evaluation of WHA effectiveness, particularly if comparisons to references sites in the managed landbase are made.

5b. Water quality: temperature

All tailed frog life stages have a restricted thermal tolerance range. Upper and lower limits of tailed frog egg survival are 18.5^{0}C and 5^{0}C respectively (Brown 1975). Incipient lethal air temperature for adult tailed frogs is between 22^{0}C and 24^{0}C (Claussen 1973). Several studies have examined the relationship between temperature and tailed frog abundance with contradictory results (Table 2a and 2b). However, these results might be explained by geographic location of the studies. Tailed frog abundances were negatively correlated with water temperature in the southern part of their range (N. California; Diller and Wallace 1999), and positively correlated in the northern part of their range (B.C.; Sutherland 2000; Ascaphus Consulting 2003). The upper thermal limit restricts tailed frogs in warmer climates and the lower thermal limit restricts tailed frogs in cooler climates. Optimal temperatures for tailed frogs are likely intermediate between these extremes. Therefore, temperature can be a good indicator for tailed frog WHA effectiveness for two reasons. First, in the evaluation of effectiveness, productivity of WHAs located at higher elevations or at the northern extent of their range may be limited because of low temperatures, thus reducing tadpole growth rates and supporting fewer tadpoles. How these WHAs are evaluated for effectiveness could be different from WHAs at lower elevations or in more southern locales. Second, the upper thermal limit may be of concern in areas where riparian harvesting has occurred upstream of the WHA, and therefore, can be an important indicator of WHA effectiveness.

4.5 Population indicators

6. Direct population measures: tadpole density

The conceptual model includes estimates of changes to tailed frog vital rates in all life stages as a result of disturbances. Additionally, these population demographic parameters were identified as potential indicators. Clearly, population level indicators such as survival or reproduction provide the least ambiguous information as to the status of tailed frog populations in each WHA. Unfortunately there is no information on the vital rates of tailed frogs for any developmental stage (i.e., egg, larva, juvenile, or adult). Currently, tadpole relative abundance is the only reliable and cost effective indicator for tailed frog populations. Therefore, tailed frog tadpole density is the only population indicator that can be used at this time to evaluate the effectiveness of tailed frog WHAs.

4.6 Indicator Ranking

A ranking of selected tailed frog WHA effectiveness monitoring indicators is provided in Table 3. Context variables and WHA permanent features are not included in this ranking as these variables are not meant to serve as indicators of WHA effectiveness. Rather they should be used to rank WHAs according to sensitivity, prioritize WHAs for monitoring, and to provide context for evaluating the effectiveness of WHAs.

Of the response indicators, tailed frog tadpole relative abundance is the most important variable to measure. There is a lack of information on many of the indirect indicators of tailed frog abundance (e.g. terrestrial habitat). Therefore, a direct measure of tailed frog populations is the most reliable measure of effectiveness at this stage. The remaining indicators include habitat and threat indicators at all spatial scales of measurement. The habitat indicators were generally selected because of the strength of their relationship with tailed frog abundance observed in many studies (Table 2a and 2b). The threat indicators were selected for the same reason. Monitoring threat indicators will allow possible cause-effect relationships to be investigated in a monitoring program. Without these cause-effect relationships, it is difficult to improve management of WHAs.

The indicator rankings allow priorities to be set for measurement of indicators. Generally, the additional time required to measure indicators at the same scale is minimal compared to possible information gained. For example, in-stream measurements of habitat characteristics does not add significantly more time to field sampling when searching streams for tadpoles. Similarly, GIS measurements of the disturbance indicators at 5 year intervals is not a significant time investment. If prioritising indicators to measure, variables that yield the least information should be the first to be omitted from the monitoring program.

Table 3. Rankings of indicators.

Scale	Rank	Indicator	Indicator type
Stand - aquatic	1	tadpole relative abundance[1]	population
Stand - aquatic	2	substrate composition	habitat
Sub-basin	3	sub-basin forest disturbance	threat
Stand - aquatic	4	channel morphology (pool:riffle ratio, gradient, wetted width, bankful width	habitat
Sub-basin	5	road density within 100 m of streams	threat
Stand - terrestrial	6	canopy closure	habitat
Sub-basin	7	sub-basin disturbance record	threat
Sub-basin	8	riparian forest disturbance	threat
Sub-basin	9	stream crossing density	threat
Stand - aquatic	10	channel disturbance index	threat
Sub-basin	11	unstable slopes	threat
Sub-basin	12	riparian buffer	habitat
Sub-basin	13	WHA buffer	threat
Stand - aquatic	14	water temperature	habitat
Stand - terrestrial	15	percent cover of vegetation layers	habitat
Stand - terrestrial	16	CWD volume	habitat

[1] wetted width required for calculation

5 SAMPLING METHODOLOGY

The following describes the sampling methodology for tailed frog WHA effectiveness monitoring indicators. Methods are described from the broadest scale to the finest scale (i.e., watershed, sub-basin, and stand-level including terrestrial and aquatic sampling). At the watershed-scale, context variables and WHA permanent features are measured. These variables typically change over very long time scales and therefore need only be measured once. Response indicators at the sub-basin and within-WHA scales are sampled based on expected rate of change. Indicators measured at the sub-basin scale can change quite rapidly depending on rate of development in the area, and therefore should be measured at 5 year intervals. At the stand-level, changes in forest structure are not expected to change as quickly unless there are disturbances within the WHA (either natural or human-induced); these indicators can therefore be measured at 20 year intervals, or after major disturbance events. In-stream characteristics such as stream channel morphology and substrate composition are subject to annual rearrangement due to disturbance events (e.g., peak flows), and therefore should be measured more frequently. As tailed frog tadpole density is the most direct measure of WHA effectiveness, it should also be re-evaluated at regular intervals.

Watershed variables and sub-basin indicators can be measured using GIS analysis. Methods at these scales will specifically define the indicators to be measured. However, the calculation of these variables will depend on availability of map data layers in the region where the WHA is located. Field measurements will occur at the stand-level and a specific sampling protocol is described for both terrestrial and aquatic sampling. Table 1 summarizes the indicators to be measured, frequency of measurement, data source, and references with detailed sampling protocols for each indicator.

5.1 Stage 1 – Define watershed

At the largest spatial scale considered in the tailed frog effectiveness monitoring program, the watershed boundary must first be defined. The watershed is the area of the catchment that the WHA(s) is located, encompassing the entire drainage network with the downstream boundary located at the confluence of a higher order stream. The size of the area considered in effectiveness monitoring will vary depending on the size of the basin as well as the location of the WHA in the basin (e.g., high in the headwaters along a first order stream compared to a more central location on a second or third order stream).

At this spatial scale, context variables and WHA permanent features should be summarized (Table 1). The Geological Survey of Canada or the BC Geological Survey can be used to identify the underlying parent geology of the WHA and surrounding area. Aspect, elevation, stream gradient, and stream order can be estimated for the watershed where the WHA is located using available GIS map layers. General climate information can be obtained from the Biogeoclimatic zone site descriptions. Specific climate information is available from regional weather stations, the Meteorological Service of Canada, the National Climate Data Centre and Information Archive, and B.C Ministry of Forest's climate database. These variables are one-time measurements.

5.2 Stage 2 – Define sub-basin

The intermediate spatial scale of sub-basin defines the area upstream of the WHA including all the stream networks that flow into the WHA stream(s). In this way, disturbances occurring upstream of the WHA that may impact habitat quality in the WHA are included in the monitoring program. The network of streams draining into the WHA define the study area or zone of interest.

At this scale, indicators will be estimated from GIS map data layers. Existing maps such as forest cover, terrain resource inventory maps (TRIM maps), terrain maps, roads, and stream networks as well as aerial photos are possible data sources. The specific data layers that are used will likely depend on the jurisdiction where the WHA occurs. The indicators estimated at this scale include: percent area of sub-basin < 20 years old, percent of stream length above the WHA < 20 years old, percent of stream length above the WHA with a mature/old forest riparian buffer > 30 m wide, percent area of sub-basin < 20 years old on slopes > 60^0, road density of sub-basin, road density within 100 m of streams (km/km^2), stream crossing density above the WHA ($number/km^2$)(Table 1). All these indicators should be re-estimated at five year intervals.

In addition, a sub-basin disturbance record of major disturbance events (e.g. landslides, mass wasting, and debris torrents) upstream of the WHA should be recorded because these disturbances may have catastrophic consequences to aquatic habitat in the WHA.

5.3 Stage 3 – Stand-level terrestrial indicators

Canopy cover is the main indicator of terrestrial tailed frog habitat, and resources permitting, cover of other vegetation layers (e.g. shrubs, herbs) and CWD could be measured as well. The sampling design outlined below includes all three indicators. It would be useful to include tailed frog WHAs in any research/monitoring program in which riparian habitat structural sampling is already occurring for other reasons.

Given that there is minimal harvesting activity permitted in tailed frog WHAs, stand-level indicators are not expected to exhibit large annual changes. However, harvesting activities, wind-throw and other natural disturbance events can occur within the WHA, changing the forest structure through time. Therefore, terrestrial habitat structure should be re-sampled at 20 year intervals but checked every 5 years for possible disturbances; if a disturbance has occurred, structure should be re-measured.

To sample terrestrial habitat structure within the tailed frog WHAs, a transect design should be implemented to sample habitat upslope starting from the stream edge. Transects are oriented perpendicular to the stream, capturing changes in habitat structure with increasing distance from the stream (Figure 2). This type of design can determine if there are structural edge effects in the WHA and how far the edge influence might extend into the WHA. Transect locations should roughly correspond with in-stream sampling units and should generally be paired extending upslope on opposite sides of the stream. The start/end point of each transect should be permanently established so the same transects can be measured at 20 year intervals. However, this can be modified depending on individual characteristics of each WHA. The perpendicular transect length extends 50 m upslope from the stream which corresponds to the minimum width of tailed frog WHAs. Based on optimization analysis of structural elements, a minimum of 6 transects should be sampled per stream in each WHA.

Transects are divided into 10 m segments beginning from the stream edge (Figure 2). Within each 10 m segment, canopy cover should be estimated from the centre of the segment in a 5 m radius circular plot. If additional cover layers are estimated, a 2 m radius circular plot is used centred within each 10 m segment. For coarse woody debris volume, all coarse woody debris (CWD) ≥ 7.5 cm in diameter that intersects the centreline is recorded as well as along transects that run parallel to the stream located at the centre (i.e., 5 m, 15 m, 25 m, etc.) of each 10 m segment. These parallel transects extend 15 m (totalling 30 m) to either side of the centreline. For some streams, the parallel transects may be shortened because of changes in stream morphology.

Measurements of habitat attributes followed Huggard (2001). The following is a brief description of the information recorded for each of the main variables:
Canopy closure: within 5 m circular plots in each segment, a visual estimate of the percentage of sky obscured by branches and foliage > 3 m in height.
Cover layers: within 2 m circular plots in each segment, percent cover is estimated for inorganic ground cover (mineral soil, rock), litter (decaying organic matter), moss, herbs, shrubs (< 15 cm high), shrubs (15 cm to 2 m tall), shrubs (> 2 m), and overstory canopy cover. The five dominant species in each cover layer could also be recorded.
Coarse woody debris: species, diameter, decay class (following Thomas 1979), and height above ground were recorded for all CWD that intercepted transects. The volume of coarse woody debris is calculated from the diameter at point of interception using Van Wagner (1968).

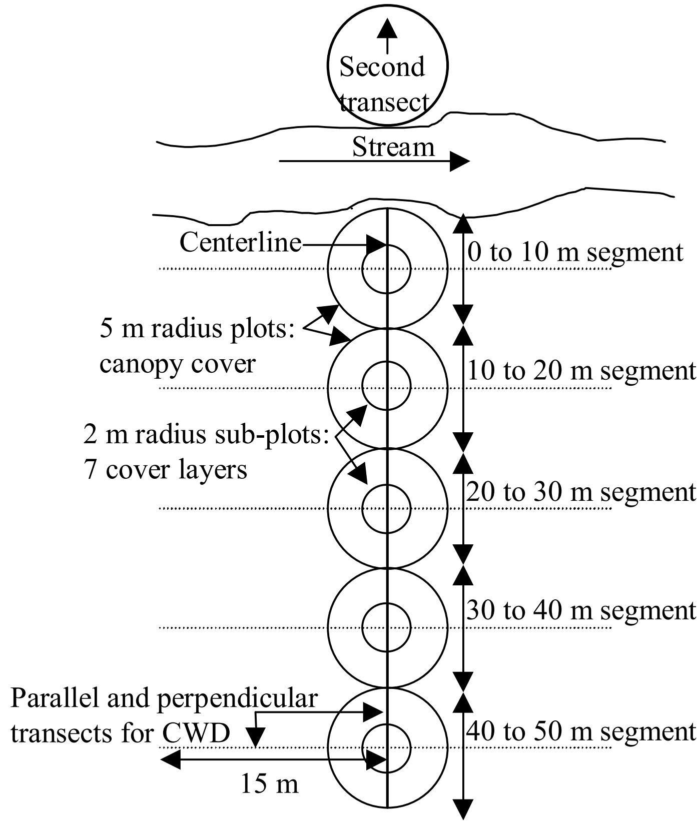

Figure 2. Habitat sampling layout across the transriparian gradient (adapted from Huggard 2000).

5.4 Stage 4 – Aquatic habitat indicators

Sampling for tailed frog tadpoles in WHAs is based on Resource Inventory Standard Procedures developed for this species (MELP 2000). Area-constrained searches (ACS) will be used to estimate the relative abundance of tailed frogs and to describe in-stream characteristics of each tailed frog WHA. However, a minimum 10 3-m sample units per stream is recommended in each WHA rather than 3 5-m sample units to maximize precision in density estimates. A comparison of the precision and accuracy of tailed frog tadpole relative abundance estimates resulting from different combinations of sample unit lengths and numbers suggest the optimal design to sample tadpoles is more, shorter sample units rather than fewer, longer units (see Appendix 2 for detailed analysis and discussion). The actual number of units sampled within each WHA may vary depending on the length of stream included in the WHA and whether more than one stream has been incorporated into the WHA.

The distribution of sample units should be systematic but again distances between sampled sections will depend on the design of the WHA (i.e. the length of stream and the number of streams included). The first sample unit in the WHA should be located at the downstream end of the WHA; starting point should be randomly selected between 25 and 50 m from the WHA downstream edge. Once the first sample unit has been established, sections to be sampled further upstream should be an equal distance apart (e.g., 25 m) with the last sample unit also at least 25 m from the upstream edge of the WHA. Locations of individual sample units may be adjusted upstream or downstream to avoid physical barriers to sampling such as waterfalls or debris dams.

Prior to surveying the creek for tadpoles, data on in-stream habitat characteristics should be collected in each 3-m sample unit. These data include: geographic position (UTM), aspect, elevation, water temperature, stream reach gradient, wetted width, bankful width, stream depth, substrate composition (percent fines, pebbles, cobbles, boulders), canopy closure, channel morphology (pool:riffle ratio), and channel disturbance index.

For each 3-m sample unit, an area constrained search is conducted (MELP 2000). Prior to each survey, a visual scan of the stream and its banks is performed to locate active tailed frogs. Each 3-m sample unit is then systematically searched in one meter increments in the upstream direction. The intensive stream survey consists of turning over all objects, hand-raking sand and gravel, and sweeping beneath large boulders to capture dislodged tadpoles in small aquarium nets held immediately downstream. A final visual scan of the area is conducted to reveal any missed animals.

All tadpoles captured are placed in buckets filled with stream water. The buckets are kept in the stream and shaded to minimize thermal stress on the captured tadpoles. The following measurements are taken on all tadpoles and/or frogs captured: snout-vent length (for tadpoles and metamorphs), total length (for tadpoles only), sex (if possible), and cohort (if possible). Following the collection of data on habitat variables, and the reconstruction of the stream unit sampled, tadpoles are released on the upstream end of the sample unit.

6 STUDY DESIGN, ANALYSIS, AND MANAGEMENT FEEDBACK

Depending on how effectiveness of tailed frog WHAs is evaluated, there are a number of potential study designs that could be used. Comparative sampling (i.e. spatial comparisons) is used to establish the status of an indicator by comparing indicator values between two or more locations, or between two different treatments (e.g. harvesting patterns). Temporal sampling is used to determine changes in indicators over time (i.e. establish trends). Effectiveness monitoring could incorporate either sampling method, or ideally, a combination of the two to evaluate effectiveness. Possible study designs for each method will be discussed in turn with considerations for data analysis, and management feedback.

6.1 Comparative Sampling

There are several options that could be used in comparative sampling to evaluate effectiveness thus feeding back to management in different ways. Here are three examples.

1) Comparisons with the managed landbase

One way to evaluate tailed frog WHA effectiveness is to pair WHA sampling with sampling in an equivalent area in the managed landbase. The “managed landbase” refers to forested stands that are managed primarily for timber values rather than wildlife conservation (*i.e.*, stands that are not being actively managed for tailed frog habitat). The primary goal of this type of monitoring is to determine if WHAs are doing better than the managed landbase at maintaining tailed frogs and their habitat. Indicators evaluating effectiveness are expected to demonstrate that tailed frog habitat suitability and/or relative abundance is higher in WHAs compared to the managed landbase. Therefore, spatial comparison will make two important contributions to the management of tailed frog WHAs. First, the effect of the WHAs will be filtered out from natural changes in the abundance of indicators. For example, if tailed frog abundance increased in WHAs without this spatial comparison, it would be difficult to determine if the cause was because of the management practices in WHAs or if increases were experienced in the landbase for other reasons. Second, the managed stands will act as a benchmark against which WHAs can be assessed. This will allow the status and trends of indicators in the WHA versus the managed landbase to be compared providing an empirical means of assessing the effectiveness of establishing the WHAs. The expectation is that if WHAs are maintaining and/or enhancing tailed frog populations and habitat then the indicators should be able to quantify their contribution. If many of the indicator measures were not different from these same measures in the managed landbase, then current WHA designs may not be effective and alternative designs should probably be considered.

In a tailed frog WHA effectiveness monitoring program, for every WHA that is being monitored there could be one stand in the managed landbase that is monitored in the same way as the WHA. This would not require sampling of all tailed frog WHAs but a subset, perhaps stratified by region (e.g. North Coast, South Coast, S.E. BC; Table 4). Priority of WHAs to sample could be selected based on region (e.g. S.E. BC WHA because of the red-listed status of Rocky Mountain tailed frog), sensitivity by region (e.g. only the most sensitive sites within each region) or some other criteria. Stands in the managed landbase should be controlled for ecosystem type (*i.e.*, biogeoclimatic subvariant and dominant site series), should be approximately the same size as the paired WHA, and should be a minimum of 2 km from the WHA. Context variables or WHA permanent features should be similar (e.g. underlying geology, aspect, elevation, stream gradient). However, managed landbase stands should **not** be controlled for habitat characteristics such as stand age, tree composition, and stand density. They are intended to be an unbiased sample of the managed landbase. The paired stand should be randomly selected from a comprehensive list of suitable stands between 2 and 3 km from the WHA. All of the WHA monitoring sampling methodology discussed above apply to stands in the managed landbase as well as the WHA.

Table 4. Example of a study design that could be used to evaluate tailed frog WHA effectiveness

Region	high sensitivity WHAs		low sensitivity WHAs[1]	
	WHA	managed	WHA	managed
North Coast	5	5	3	3
South Coast	5	5	3	3
SE B.C.	5	5	3	3

[1] sampling priority given to high sensitivity sites; low sensitivity sites sampled, resources permitting

2) Comparisons between different WHA designs

Another goal for WHA monitoring could be determine what size and/or shape of WHAs is most effective to maintain tailed frogs. Specific indicators could be selected to compare WHAs of different widths (perpendicular distance from the stream) or lengths (along the stream) to determine effectiveness. For example, the abundance of tailed frog tadpoles could be measured in WHAs with a 50 m buffer compared to WHAs with a 100m riparian buffer to determine what minimum reserve size is required to maintain tailed frogs. Alternatively, the comparison could be made between WHAs in unharvested sub-basins to WHAs in sub-basins with some level of harvesting (e.g. >50% disturbed). In either case, five WHAs in each "treatment" (design) might be sampled to examine differences in indicators. Based on results of such a comparison, the design of WHAs could be adjusted accordingly.

3) Comparisons between management alternatives in WHAs

Current management of WHAs for coastal tailed frogs permits limited harvesting in the riparian management zone of WHAs (30 to 50 m from the stream). Alternative harvesting patterns or intensities could be compared in different WHAs to determine impacts on tailed frog populations, and provide guidelines for management practices that are permitted.

6.2 Temporal Sampling

An important part of a long-term monitoring program is the ability to detect true trends in the variable(s) of interest, which requires temporal sampling. The success of tailed frog WHAs could depend on whether stable or increasing populations of tailed frogs are being maintained. But like most other amphibian (Alford and Richards 1999), annual variation in tailed frog abundance can be high, and the power to detect statistically significant population trends is low accept over very long time periods (see Appendix 3 for discussion of power). This is particularly important to consider given that variation around the mean tends to increase as tadpole relative abundance decreases. Therefore, small populations (i.e. lower tadpole relative abundance) that are likely at higher risk of extirpation from a stream, are also the populations for which significant detectable rates of change may not be possible. Therefore, evaluating the effectiveness of WHAs based on statistically significant changes in tailed frog tadpole abundance alone should not be relied upon. An alternative criteria for determining effectiveness could be the expectation that most WHAs (e.g. 75%), at any one time interval, have stable or increasing relative abundance of tailed frog tadpoles before it could be concluded WHAs are effective. Temporal sampling in combination with spatial sampling will likely be the most informative way to evaluate tailed frog WHA effectiveness.

7 PILOT STUDIES, PRODUCTS, AND COSTS

A small pilot project is recommended to incorporate into year one monitoring. The purpose of the pilot project would be to empirically determine what combinations of reach lengths and numbers achieve the most efficient sampling design in WHAs. Pilot projects are strongly recommended to evaluate sampling methodology before beginning long-term monitoring projects. Properly designed, they can provide useful, short-term information on the status of tailed frog WHAs as well as improving the long-term study design so that costs are lowered and precision increased. Pilot projects should focus on implementing a comprehensive effectiveness monitoring program in a smaller number of WHAs (*e.g*., 6 WHAs and 6 managed landbase comparisons). This approach will keep costs low, allow all the methods to be evaluated and improved before committing to a larger program. In addition information on variation between WHAs and on the current status of these WHAs would be available.

A pilot project designed to evaluate the methods discussed in this report could be completed within a year. At the end of one year, a report would be completed that: evaluated and improved the current study design, collected measures of context variables and WHA permanent features that would not have to be re-measured, collected effectiveness monitoring data on the current status of tailed frog WHAs, established baseline data in WHAs and the managed landbase, suggested future sampling methods and sampling time intervals, and detailed costs associated with a long-term monitoring project. The approximate costs of a pilot project are detailed in Table 5.

Table 5. Approximate 1-year budget for a tailed frog WHA effectiveness monitoring pilot project. Cost estimates do not factor in any in-kind contributions from industrial or governmental agencies.

Product[1]	Sampling Design[2]	Time of Year	Approximate Costs ($)
Context variables and WHA permanent features	6/6	No time restriction	3000
Sub-basin analyses	6/6	No time restriction	3000
Stand-level analyses	6/6	Summer	15000

[1] Includes all aspects of organization, field sampling, data entry, and data analysis. Does not include costs associated with report writing because redundancies and, therefore, report costs will proportionally decline with the total number of products conducted.
[2] Refers to number of replicates (WHAs/managed landbase)

8 SUMMARY OF GAPS/PROBLEMS/NEEDS

Several information gaps/problems/needs were identified in the development of the tailed frog WHA effectiveness monitoring program. Much of the information that is lacking is related to our inability to effectively measure anything other than tailed frog tadpoles in the field as well as how to actually evaluate the effectiveness of the tailed frog WHAs:

1. Before any effectiveness monitoring program is implemented for tailed frog WHAs, criteria for determining effectiveness must be established. Monitoring cannot begin without knowing the criteria for what is considered effective, and therefore, how monitoring data would be interpreted.
2. Benchmark or reference conditions of indicators are required in order to established targets or thresholds that are needed to evaluate the effectiveness of WHAs. The meta-analysis performed by Sutherland et al. (2001) may serve as a starting point for some indicators. For example, tailed frog abundance/occurrence tends to be highest in streams with > 25% boulder cover, intermediate gradients (15% to 30%), and streams in watersheds with < 3% of the area < 20 years old. Building on this work, thresholds or targets for other indicators may be established so monitoring data of each indicator can be interpreted.
3. It is likely that targets or thresholds will not be the same for all WHAs but might be specific to regions (e.g., South Coast, North Coast, and Interior tailed frog populations), or by groupings of WHAs based on similarity of landscape context (e.g., similar underlying geology), as examples. An overall risk could be useful for WHAs in different regions or landscape contexts because their relative vulnerabilities are likely different.
4. Currently, there is only one way to reliably evaluate the abundance of tailed frogs i.e. tadpole relative abundance in-streams. Information is lacking on all vital rates (e.g., survival at each stage, density estimates of the terrestrial form, dispersal capabilities etc.). As technology improves and this information becomes available, vital rates should be monitored if financially feasible because this information provides the most reliable estimates of population trends. This information also allows identification of the life history stage(s) most affected by disturbances allowing stronger cause-effect relationships to be developed. This is the least ambiguous way of determining the consequences of habitat changes on tailed frog populations.
5. A small pilot study conducted on a few WHA streams would be worthwhile to empirically determine what combination of reach lengths and numbers achieve the most efficient sampling design in WHAs.
6. One of the main assumptions of this monitoring program is that tadpole relative abundance is a good indicator of tailed frog populations as a whole. The relationship between tailed frog tadpole abundance and adult relative abundance should be evaluated to test this assumption.
7. An aggregate measure or index which combines information from population, habitat, and disturbance indicators may be useful to evaluate the effectiveness of tailed frog WHAs
8. In order for effectiveness monitoring to be useful, there needs to be a link between monitoring results (e.g., negative trend in relative abundance) and decision making.
9. Changes in habitat indicators being monitoring may not predict population responses to other stressors such as environmental toxins, climate change, and interspecific interactions that are not being monitored.
10. The indicators selected herein to monitor the effectiveness of tailed frog WHAs should evolve as new information becomes available.

9 LITERATURE CITED

Adams, M. J., and R. B. Bury. 2002. The endemic headwater stream amphibians of the American Northwest: associations with environmental gradients in a large forested preserve. Global Ecology and Biogeography 11:169-178.

Adams, S. B., and C. A. Frissell. 2001. Thermal habitat use and evidence of seasonal migration by Rocky Mountain Tailed Frogs, Ascaphus montanus, in Montana. Canadian Field-Naturalist 115:251-256.

Alford, R.A. and S.J. Richards. Global amphibian declines: a problem in applied ecology. Annual Review of Ecology and Systematics 30:133-165.

Ascaphus Consulting. 2002. Distribution of *Ascaphus montanus* in the Yahk River and neighbouring watersheds. Unpublished report prepared for Tembec Industries, Cranbrook, and Columbia Basin Fish and Wildlife Compensation Program, Nelson, BC. 35 pp.

Ascaphus Consulting. 2003. Watershed-level protection and mangagement measures for the maintenance of *Ascaphus truei* populations in the Skeena Region. Unpublished report prepared for the Ministry of Water, Land, and Air Protection, Smithers Branch.

Aubry K.B. and P.A. Hall. 1991. Wildlife and vegetation of unmanaged Douglas-fir forests. In Ruggiero, L.F., K.B. Aubry, A.B. Carey, M.H. Huff (eds) Wildlife and vegetation of unmanaged Douglas-fir forests. USDA Forest Service PNW-GTR-285. Pp 326-338.

Benda, L. E., D. J. Miller, T. Dunne, G. H. Reeves, and J. K. Agee. 1998. Dynamic landscape systems. *In* R. J. Naiman, and R. E. Bilby, eds. River ecology and management: lessons from the Pacific Coastal Ecoregion. Springer-Verlag, New York. Pp 261-288.

Bisson, P. A., M. G. Raphael, A. D. Foster, and L. L. C. Jones. 2002, Influence of site and landscape features on vertebrate assemblages in small streams. A. C. Johnson, R. W. Haynes, and R. A. Monserud, eds. Congruent management of multiple resources; Proceedings from the wood compatibility workshop PNW-GTR-563. Pp 61-72.

Brown, H.A. 1975. Temperature and development of the tailed frog, *Ascaphus truei*. Comparative Biochemistry and Physiology 50: 397-405.

Brown, H.A. 1990. Morphological variation and age-class determination in overwintering tadpoles of the tailed frog, *Ascaphus truei*. Journal of Zoolgy, London: 220:171-184.

Bull, E. L., and B. E. Carter. 1996. Tailed frogs: Distribution, ecology, and association with timber harvest in northeastern Oregon. U S Forest Service Research Paper. Pp 1-11.

Bury, R. B., and P. S. Corn. 1988. Douglas-fir forests in the Oregon and Washington Cascades: relations of the herpetofauna to stand age and moisture. *In* R. C. Szaro, K.E. Severson, and D.R. Patton, ed. Management of amphibians, reptiles and small mammals in North America. USDA Forest Service GTR. Pp 11-22

Bury, R. B., and M. J. Adams. 1999. Variation in age at metamorphosis across a latitudinal gradient for the tailed frog, Ascaphus truei. Herpetologica 55:283-291.

Bury, R.B., P.S. Corn, and K.B. Aubry. 1991. Regional patterns of terrestrial amphibian communities in Oregon and Washington. *In* L.F. Ruggiero, K.B. Aubry, A.B. Carey, and M.F. Huff, ed. Wildlife and vegetation of unmanaged Douglas-fir forests. USDA For. Serv. Gen. Tech. Rep. PNW-GTR-285, Portland, Oreg. Pp. 341-350.

Bury, R.B. and P.S. Corn. 1991. Sampling methods for amphibians in streams in the Pacific Northwest. USDA For. Serv. Gen. Tech. Rep. PNW-GTR-275, Portland, Oreg. 34 pp.

Claussen, D.L. 1973. The thermal relations of the tailed frog, Ascaphus truei, and the Pacific treefrog, Hyla regilla. Comparative Biochemistry and Physiology 44A:137-153.

Corn, P. S., and R. B. Bury. 1989. Logging in Western Oregon: responses of headwater habitats and stream amphibians. Forest Ecology & Management 29:39-57.

—. 1991. Terrestrial amphibian communities in the Oregon Coast Range. *In* L.F. Ruggiero, K.B. Aubry, A.B. Carey, and M.F. Huff, ed. Wildlife and vegetation of unmanaged Douglas-fir forests. USDA For. Serv. Gen. Tech. Rep. PNW-GTR-285, Portland, Oreg. Pp 305-317.

Daugherty, C. H., and A. L. Sheldon. 1982. Age-specific movement patterns of the frog *Ascaphus truei*. Herpetologica 38:468-474.

DeMaynadier, P. G., and J. M.L. Hunter. 1999. Forest canopy closure and juvenile emigration by pool-breeding amphibians in Maine. Journal of Wildlife Management 63:441-450.

Diller, L.V., and R.L. Wallace. 1999. Distribution and habitat of Ascaphus truei in streams on managed, young growth forests in north coastal California. Journal of Herpetology 33:71-79.

Dupuis, L. and K. Wilson. 1999. Status, distribution, and management needs of the tailed frog in the east Kootenays. B.C. Ministry of Environment, Lands and Parks. Nelson. Unpublished report. 19 pp. Available online at srmwww.gov.bc.ca/kor/wld/reports/htmlfiles/Tailed_Frog_99/Tailed_Frog_Web_Report_99.htm

Dupuis, L., F. L. Bunnell, and P. A. Friele. 2000. Determinants of the Tailed Frog's range in British Columbia, Canada. Northwest Science 74:109-115.

Dupuis, L., and D. Steventon. 1999. Riparian management and the tailed frog in northern coastal forests. Forest Ecology & Management 124:35-43.

Franklin, J. F. 1993. Preserving biodiversity: species, ecosystems, or landscapes? Ecological Applications 3:202-205.

Gibbs, J. P. 1998. Distribution of woodland amphbiians along a forest fragmentation gradient. Landscape Ecology 13:263-268.

Gilbert, F.F. and R. Allwine. 1991. Terrestrial amphibian communities in the Oregon Cascade Range. *In* L.F. Ruggiero, K.B. Aubry, A.B. Carey, and M.F. Huff, ed. Wildlife and vegetation of unmanaged Douglas-fir forests. USDA For. Serv. Gen. Tech. Rep. PNW-GTR-285, Portland, Oreg. Pp. 319-324.

Gomez, D. M., and R. G. Anthony. 1996. Amphibian and reptile abundance in riparian and upslope areas of five forest types in Western Oregon. Northwest Science 70:109-119.

Gomi, T., R. C. Sidle, and J. S. Richardson. 2002. Understanding processes and downstream linkages of headwater systems. Bioscience 52:905-916.

Hota, A.K. 1994. Growth in amphibians. Gerontology 40: 147-160.

Huggard, D. 2000. Habitat Monitoring 1999 - Summary and sample design analysis. Unpublished report prepared for Weyerhaeuser BC Variable Retention Adaptive Management Program. 57 pp.

Huggard, D. 2001. Habitat Attributes in the Arrow IFPA Non-harvestable Landbase, Unpublished report prepared for the Arrow IFPA.

Hunter, M. G. 1998. Watershed-level patterns among stream amphibians in the Blue River Watershed, West-Central Cascades of Oregon. MSc thesis, Oregon State University, Corvallis, OR.

Identified Wildlife Management Strategy. 2004. Standards for managing identified wildlife. Ministry of Forests, Ministry of Water, Land, and Air Protection, Victoria, B.C. 831 pp.

Jones, J. A., F. J. Swanson, B. C. Wemple, and K. U. Snyder. 2000. Effects of roads on hydrology, geomorphology, and disturbance patches in stream networks. Conservation Biology 14:76-85.

Kelsey, K.A. 1995. Responses of headwater stream amphibians to forest practices in Western Washington. PhD dissertation, University of Washington, Seattle, Washington, 167 pp.

Kiffney, P. M., and J. S. Richardson. 2001. Interactions among nutrients, periphyton, and invertebrate and vertebrate (Ascaphus truei) grazers in experimental channels. Copeia 2001:422-429.

Kim, M. A., and J. S. Richardson. 2000, Effects of light and nutrients on grazer-periphyton interactions. L. M. Darling, ed. At risk: proceedings of a conference on the biology and management of species and habitats at risk:497-501.

Krebs, C.J. 1989. Ecological methodology. HarperCollins*Publishers*, New York.

Marsh, D. M. 2001. Fluctuations in amphibian populations: a meta-analysis. Biological Conservation 101:327-335.

Matsuda, B. M. 2001. The effects of clear-cut timber harvest on the movement patterns of tailed frogs (*Ascaphus truei*) in southwestern British Columbia. MSc thesis, University of British Columbia, Vancouver. 104 pp.

Maxcy, K.A. 2000. The response of terrestrial salamanders to forest harvesting in Southwestern British Columbia. M.Sc. Thesis, University of British Columbia, Vancouver, BC. 92 pp.

Maxcy, K.A., R.D. Serrouya, and J.R. Herbers. 2001. Characterization of the terrestrial riparian zone in Riverside TFL 49. Unpublished report prepared for Riverside Forest Products.

Ministry of Environment, Lands, and Parks. 2000. Inventory methods for Tailed Frog and Pacific Giant Salamander. Standards for components of British Columbia's biodiversity No. 39. Resource Inventory Branch, Victoria, B.C. 37 pp. Available online at: srmwww.gov.bc.ca/risc/pubs/tebiodiv/frog/assets/tailedfrog.pdf

Ministry of Fisheries. 1999. Reconnaissance (1:20,000) and fish habitat inventory. Site card field guide. Resource Inventory Branch, Victoria, B.C. 42 pp. Available online at: srmwww.gov.bc.ca/risc/pubs/aquatic/

Ministry of Forests and B.C. Ministry of Environment, Lands, and Parks. 1995. Interior watershed assessment procedure guidebook (IWAP). Forest Practices Code of British Columiba. Victoria, B.C. 82 pp. Available online at: www.for.gov.bc.ca/tasb/legsregs/fpc/fpcguide/iwap

Ministry of Forests and B.C. Ministry of Environment, Lands, and Parks. 1995. Coastal watershed assessment procedure guidebook (CWAP). Forest Practices Code of British Columbia. Victoria, B.C. 66 pp. Available online at: www.for.gov.bc.ca/tasb/legsregs/fpc/fpcguide/coastal/cwaptoc.htm

Mulder, B.S., B.R. Noon, T.A. Spies, M.G. Raphael, C.J. Palmer, A.R. Olsen, G.H. Reeves, and H.H. Welsh 1999. The strategy and design of the effectiveness monitoring program for the Northwest forest plan. USDA Forest Service, General Technical Report. PNW-GTR-437.

Naiman, R. J., R. E. Bilby, and P. A. Bisson. 2000. Riparian ecology and management in the Pacific Coastal rain forest. Bioscience 50:996-1011.

Naiman, R. J., and H. Decamps. 1997. The ecology of interfaces: riparian zones. Annual Review of Ecology and Systematics 28:621-658.

Nielson, M., K. Lohman, and J. Sullivan. 2001. Phylogeography of the Tailed frog (Ascaphus truei): implications for the biogeography of the Pacific Northwest. Evolution 55(1): 147-160.

Noon, B.R., T.A. Spies, M.G. Raphael. 1999. Conceptual basis for designing an effectiveness monitoring program. *In* Mulder, B.S. et al. (technical coordinaters). The strategy and design of the effectiveness monitoring program for the Northwest forest plan. USDA Forest Service, General Technical Report. PNW-GTR-437. Pp 21-48.

Raphael, M. G., P. A. Bisson, L. C. Jones, and A. D. Foster. 2002, Effects of streamside forest management on the composition and abundance of stream and riparian fauna of the Olympic Peninsula. A. C. Johnson, R. W. Haynes, and R. A. Monserud, eds. Congruent management of multiple resources; Proceedings from the wood compatibility workshop PNW-GTR-563. Pp 27-40.

Reeves, G.H., D.B. Hohler, D.P. Larsen, D.E. Busch, K. Kratz, K. Reynolds, K.F. Stein, T. Atzet, P. Hays, and M. Tehan. 2003. Aquatic and riparian effectiveness monitoring plan for the Northwest Forest Plan. USDA Forest Service, General Technical Report. PNW-GTR-577.

Semlitsch, R. D. 1981. Terrestrial activity and summer home range of the mole salamander (Ambystoma talpoideum). Canadian Journal of Zoology 59:315-322.

Semlitsch, R. D., and J. R. Bodie. 1998. Are small, isolated wetlands expendable? Conservation Biology 12:1129-1133.

Stoddard, M. A. 2002. The influence of forest management on headwater stream amphibians at multiple spatial scales. MSc thesis, Oregon State University, Corvallis, OR.

Sutherland, G. D. 2000. Risk assessment for conservation under ecological uncertainty: a case study with a stream-dwelling amphibian in managed forests. PHd dissertation, University of British Columbia.

Sutherland, G.D., M.P. Hayes, T. Quinn, L.A. Dupuis, T.R. Wahbe, D.E. Runde, and J.S. Richardson. 2001. Predictive habitat models for the aoccurrence and abundance of the Olympic tailed frog (*Ascaphus truei* Stejneger) and the Rocky Mountain tailed frog (*Ascaphus montanus* Mittleman and Myers): a pilot meta-analysis. Unpublished report for the Washington State Department of Natural Resources.

Thomas, J.W., editor. 1979. Wildlife habitats in managed forest in the Blue Mountains of Oregon and Washington. U.S.D.A. Forest Service Agriculture Handbook 553.

Urban, D. L., R. V. O'Neill, and H. H. Shugart. 1987. Landscape ecology: a hierarchical perspective can help scientists understand spatial pattern. Bioscience 37:119-127.

Van Wagner, C. E. 1968. The line intersect method in forest fuel sampling. Forest Science 14:20-26.

Wahbe, T.R. 2003. Aquatic and terrestrial movements of tailed frogs in relation to timber harvest in coastal British Columbia. PHd dissertation, University of British Columbia.

Wahbe, T. R., and F. L. Bunnell. 2001. Preliminary observations on movements of tailed frog tadpoles (Ascaphus truei) in streams through harvested and natural forests. Northwest Science 75:77-83.

Wahbe, T. R., and F. L. Bunnell. 2003. Relations among larval tailed frogs, forest harvesting, stream microhabitat, and site parameters in southwestern British Columbia. Canadian Journal of Forest Research 33:1256-1266.

Wahbe, T. R., F. L. Bunnell, and R. B. Bury. 2000. Defining wildlife habitat areas for tailed frogs. L. M. Darling, ed. Proceedings of a conference on the biology and management of species and habitats at risk. University College of the Cariboo Kamloops, BC, February 15-19, 1999. Volume 2. Pp 489-496.

Welsh, H. H., Jr., and A. J. Lind. 2002. Multiscale habitat relationships of stream amphibians in the Klamath-Siskiyou Region of California and Oregon. Journal of Wildlife Management 66:581-602.

Welsh, H. H., Jr., and L. M. Ollivier. 1998. Stream amphibians as indicators of ecosystem stress: A case study from California's redwoods. Ecological Applications 8:1118-1132.

Wilkens, R. N., and N. P. Peterson. 2000. Factors related to amphibian occurrence and abundance in headwater streams draining second-growth Douglas-fir forests in southwestern Washington. Forest Ecology and Management 139:79-91.

APPENDIX 1. CONCEPTUAL MODEL

The overall objective of tailed frog WHAs for both coastal and interior species is to maintain aquatic breeding habitat as well as linkages to other sub-populations (IWMS 2004). In order to meet this objective, the natural ecological processes and functions that create and sustain suitable tailed frog habitat must be maintained. For an effectiveness monitoring program to be successful, the program should link disturbances (either natural or human-induced) to tailed frog populations or their habitat. That is, a meaningful effectiveness monitoring program will identify possible cause-effect relationships between disturbances, ecosystem responses to those disturbances, and potential impacts on tailed frogs or their habitat.

To determine a potential set of indicators to evaluate WHAs, a conceptual model was developed as outlined by Noon et al. (1999). Conceptual models are intended to aid in the selection of indicators by linking disturbances to indicators that reflect the underlying ecosystem processes and functions (Noon et al. 1999). Therefore, when changes are observed in an indicator, changes in underlying ecological processes can also be inferred. For the tailed frog conceptual model, disturbances (both natural and human-induced) that are anticipated to affect ecosystem structure and function that are relevant to tailed frogs, including both aquatic and terrestrial ecosystem components, are first identified (Table A1-1). The model then identifies potential consequences to both tailed frogs and their habitat that result from these disturbances. Finally, indicators of tailed frog populations and their habitat are identified; these indicators are anticipated to demonstrate measurable responses to alterations to specific ecosystem processes and functions. Thus, the conceptual model identifies the ecosystem processes and functions that are altered by disturbances as indicated by measurable biological and physical components (i.e., indicators) of the system; the indicators have a direct or indirect link to tailed frog populations.

To outline the conceptual model in more concrete terms, the process of in-stream sedimentation and its potential effects on tailed frogs and their habitat will be described (refer to Table A1-1). Sedimentation in streams is caused by natural disturbances such as erosion, mass wasting, and slope failures as well as human-induced disturbances such as forest harvesting and road building. Tailed frog occurrence and/or relative abundance is negatively associated with increasing levels of fine sediments, and its transport and deposition in streams (e.g., Dupuis and Steventon 1999; Sutherland 2000; Wahbe and Bunnell 2003). The effect of increased sediment on tailed frogs in streams includes reducing available escape cover from predators and disturbances (e.g., bedload movements), and reducing foraging surface area (Welsh and Ollivier 1998; Dupuis and Steventon 1999; Dupuis et al. 2000; Sutherland 2000; Adams and Bury 2002). Oviposition sites may also be reduced, which can limit the number of eggs deposited. Specific consequences to tailed frogs are reduced tailed frog relative abundance as a result of decreased habitat availability and increased mortality. Indicators of the process of sedimentation includes indicators of actual threats, such as the density of roads and number of road crossings upstream of tailed frog WHAs. In addition, direct indicators of tailed frog habitat, such as substrate composition are also identified. Therefore, the conceptual pathway in this example, identifies: 1) the process (sedimentation), 2) disturbances that may affect the process (e.g., road crossings), 3) potential consequences to tailed frogs (reduced abundance) and tailed frog habitat (smaller substrate) if the sedimentation regime is altered, and 4) potential indicators that include both indicators of threats to the sedimentation regime (e.g., road crossings) as well as a direct indicator of the sedimentation regime (substrate composition). This example provides the links between threats and indicators of tailed frog populations and their habitat. It is not enough to say there is a reduction in substrate size class distribution, it is also important to identify the possible causal factors, such as an increase in the number of road crossings upstream. This is critical, not only to evaluate the effectiveness the tailed frog WHA but also to inform future management decisions.

There are several other processes aside from sedimentation that are considered in the conceptual model, along with their consequences to tailed frogs and their habitat (Table A1-1). At the largest scale, indicators at the watershed level provide the context for tailed frog WHA effectiveness monitoring evaluation. Tailed frog populations are not equally vulnerable to disturbance (either natural or human-induced) due to the underlying influences of geology, climate, and topography on tailed frog habitat characteristics and productivity (Sutherland 2000; Sutherland et al. 2001). For example, consolidated parent materials that are resistant to weathering support higher densities of tailed frog tadpoles and therefore may be less vulnerable to disturbance compared to populations located on more erosion-prone parent material (Diller and Wallace 1999; Sutherland 2000; Wilkens and Peterson 2000; Sutherland et al. 2001; Adams and Bury 2002). In addition, WHA geographical location, with its associated climate, elevation, and aspect, influences the relative productivity of tailed frog populations and has implications for stream resiliency. Populations in less productive areas, or in areas more prone to erosion will likely take longer to recover following disturbances.

For juvenile and adult tailed frogs at the sub-basin scale, the conceptual model focuses on habitat patterns surrounding the tailed frog WHAs and how habitat changes may affect population persistence and connectivity among tailed frog sub-populations (streams). Nothing is currently known about the movement capabilities of tailed frogs. It is assumed that juveniles act as dispersers for tailed frog populations, while adults are more philopatric (Daugherty and Sheldon 1982). It is unknown what distances juveniles are capable of moving but, like other metamorphosing amphibians, they are presumably physiologically limited to appropriate microclimatic conditions (i.e. cool, moist conditions)(e.g., Semlitsch 1981; Semlitsch and Bodie 1998; DeMaynadier and Hunter 1999). Therefore, spatial pattern of landscapes structure including area of early seral stages and distances to other streams may be useful indicators to evaluate the effectiveness of tailed frog WHAs at the landscape scale; dispersal success, and thus connectivity among sub-populations assumed to be influenced by these factors.

At the stand level, riparian forest structure of tailed frog WHAs is also expected to influence the survival and reproduction of adults as well as movement and foraging behaviour. Similar to larger scales, very little is known about terrestrial habitat associations of tailed frogs at the stand level. Terrestrial life stages have been found to be positively associated with older forests (Bury and Corn 1988; Aubry and Hall 1991; Corn and Bury 1991; Gomez and Anthony 1996; Wahbe et al. 2000; Ascaphus Consulting 2002; but see Matsuda 2001). This is likely a reflection of their physiological requirements of cool, moist conditions which are typically found in closed canopy forests. Measures of forest structure and composition in riparian zones are appropriate indicators for terrestrial life stages of tailed frogs.

Regardless of spatial scale, disturbances that influence larval attachment sites in streams have the strongest relationships with tailed frog tadpole occurrence and abundance (Sutherland 2000). Hydrology, sedimentation, and disturbance all interact in complex ways at each spatial scale to shape in-stream characteristics such as substrate composition and stream channel morphology; these microhabitat characteristics are strongly linked with tadpole abundance. Therefore, the conceptual model identifies habitat indicators at all three spatial scales that affect the population dynamics of tailed frog tadpoles in streams.

The conceptual model outlined in Table A1-1 provides a model from which a core set of indicators will be selected to determine if tailed frog WHAs are meeting their objectives. Many of the indicators listed in the conceptual model, while considered ideal for measuring WHA effectiveness, cannot be readily or efficiently measured based on current tailed frog sampling techniques. For example, sampling of terrestrial life stages of tailed frogs is time-consuming, costly, and often yields low numbers. Therefore, core indicators were selected at all spatial scales to evaluate WHA effectiveness using the following five criteria (Mulder et al. 1999). First, indicators should act as early warning signals for changes to tailed frog habitat or tailed frog populations. Second, indicators should be linked to the state of the population as well as forest practices. Third, indicators can be precisely and accurately measured. Fourth, indicators should exhibit low natural variability such that any changes they exhibit can be distinguished from inherent natural variation. And finally, indicators should be simple and cost-effective to measure. Using these criteria, a subset of indicators from Table A1 were selected for a tailed frog monitoring program.

Table A1-1. Conceptual model to aid in the selection of indicators for effectiveness monitoring of tailed frog Wildlife Habitat Areas (modified from Reeves et al. 2003).

Tailed frog WHA watershed context			
	Geology	**Climate**	**Topography**
Indicators	• parent material	• temperature • precipitation • growing season length	• elevation • aspect • valley constraint

Tailed frog WHA sub-basin processes						
Ecosystem process	**Disturbances**		**Potential consequences to tailed frogs**		**Potential indicators**	
	Natural	**Human-induced**[1]	**Habitat**	**Population**[2]	**Habitat**	**Population**
Forest succession	• fire • wind-throw • insects and pathogens • senescence	• forest harvesting • road construction • range-use • mining • herbicide/pesticide	• fragmentation • habitat loss • decreased connectivity • general decline in habitat quality (e.g., decreased area in late seral stages)	• isolation of populations • decreased dispersal success • decreased gene flow • increased potential for demographic stochasticity	• area of watershed in different seral stages • index of connectivity • road density • drainage density • total length of streams logged	• population size • population distribution • juvenile survival • juvenile dispersal • adult survival • stream occupancy • reproductive success
Sedimentation	• erosion • landslides • mass wasting • debris flows	• forest harvesting • road construction • range-use • mining	• change stream channel morphology • substrate composition • productivity	• decreased carrying capacity of stream • decreased egg and tadpole survival • decreased larval growth rate	• road density • density of stream crossings • area of sub-basin harvested • stream length bordered by logged forest • area of sub-basin logged on steep slopes • area of watershed with recent landslides	• tadpole survival, density and biomass • reproductive success

Hydrology	• precipitation • flooding • drought	• forest harvesting • road construction • range-use • mining	• change timing and magnitude of peak flows and low flows • change water storage capacity • change soil moisture	• decrease egg and tadpole survival • change adult movement and foraging patterns • decrease juvenile dispersal	• change in flow regime • road density • density of stream crossings • area of sub-basin harvested • stream length bordered by logged forest • area of sub-basin logged on steep slopes • area of watershed with recent landslides	• tadpole survival, density and biomass • reproductive success • movement of juveniles and adults
Tailed frog stand-level processes						
Terrestrial						
Forest succession	• fire • wind-throw • insects and pathogens • senescence	• forest harvesting • range-use	• change structure and species composition • microclimate	• change adults movement and foraging patterns • decrease juvenile dispersal success • survival reduced in all life stages	• % cover of vegetation layers • density of trees and snags • CWD volume	• density and survival of all life stages • movement of juveniles and adults • reproductive success
Sedimentation	• erosion • landslides • mass wasting • debris flows	• forest harvesting • range-use	• change stream channel morphology • substrate composition • productivity	• decreased carrying capacity • decreased egg and tadpole survival • decreased larval growth rate	• road density • density of stream crossings • area of watershed with recent landslides	• tadpole survival, density and biomass • reproductive success
Energy exchange	• insolation • shading	• forest harvesting • range-use	• change microclimate • water temperature • primary productivty	Depending on temperature: • increase or decrease larval vital rates • increase or decrease time to metamorphosis • change adult movement and foraging patterns • decrease juvenile dispersal success	• water temperature • primary productivity	• density and survival of all life stages • time to metamorphosis • movement of juveniles and adults
Nutrient and chemical cycling	• deposition • storage • erosion • transport	• forest harvesting • range-use	• change productivity of stream	Depending on productivity: • increase or decrease tadpole vital rates • increase or decrease time to metamorphosis	• nutrient and chemical concentrations • primary productivity	• tadpole survival, density and biomass • tadpole size class distribution • time to metamorphosis

Hydrology	• precipitation • flooding • drought	• forest harvesting • road construction • range-use • mining	• change timing and magnitude of peak flows and low flows • change water storage capacity • soil moisture	• decrease egg and tadpole survival • change adult movement and foraging patterns • decrease juvenile dispersal	• changes in flow regime (e.g., peak flow, low flow)	• tadpole survival, density and survival • tadpole size class distribution • time to metamorphosis • movement of juveniles and adults
Aquatic						
Channel structure	• sedimentation • scour • deposition • debris transport • bedload movement • channel migration	• forest harvesting • range-use • mining • recreation	• change microhabitat e.g., pool:riffle ratio, substrate composition • change structural complexity • stream depth • primary productivity	• decreased carrying capacity • decreased egg and tadpole survival and density • decreased larval growth rate	• substrate composition • pool:riffle ratio • LWD volume • primary productivity	• tadpole survival, density and biomass • tadpole size class distribution • time to metamorphosis
Hydrology	• precipitation • flooding • drought	• forest harvesting • road construction • range-use • mining	• change timing and magnitude of peak flows and low flows • water storage capacity	• decreased egg and tadpole survival • decreased larval growth rate	• changes in flow regime (e.g., peak flows, low flows)	• tadpole survival, density, and biomass • size class distribution • time to metamorphosis
Energy exchange	• insolation • shading	• forest harvesting • road construction • range-use	• change microclimate • water temperature • primary productivty	<u>Depending on temperature:</u> • increase or decrease larval vital rates • increase or decrease time to metamorphosis	• water temperature • primary productivity • canopy cover	• tadpole survival, density and biomass • size class distribution • time to metamorphosis

[1] recreation and invasive species are also potential disturbances but there is no information on their impacts to tailed frogs; both disturbances are assumed to not affect tailed frog populations at this time,

[2] consequences to tailed frog populations are generally written in the negative because these population changes are of the greatest management interest in effectiveness monitoring

APPENDIX 2. WITHIN-STREAM SAMPLING VARIATION

Three 5 m reaches is the recommended number and length of reaches to sample for tailed frog tadpoles in-streams (MELP 2000). However, this may not be the most optimal reach number or reach length to sample. Krebs (1989) discusses the difficulties associated with choosing the most efficient method for estimating abundance in wildlife studies. The goal when choosing a sampling protocol is to achieve the highest level of statistical precision for the least amount of effort (or cost). For large, multi-year monitoring programs this goal is not a trivial concern. For the purpose of designing a protocol to estimate tailed frog tadpole abundance, consideration of both reach length and reach number are important decisions in the study design.

To investigate the question of what combination of reach length and number is best to maximize efficiency and precision[5] in tadpole relative abundance estimates, three stream reach lengths were investigated: 1 m, 5 m, and 10 m. Thirty 1-m sample units were used to sample streams located in the Olympic Peninsula, Washington. Ten 5-m sample units were used to sample streams in the Chilliwack River Valley, British Columbia. Five 10-m sample units were investigated by combining each successive pair of two 5-m reaches in the Chilliwack streams. Combining data in this way assumes that the number of tadpoles detected in two 5 m reaches separated by 5 m is approximately the same as the number of tadpoles detected in one continuous 10 m reach. Although imperfect, this analysis is only meant to provide a general idea about the expected level of precision using 10 m reaches. All streams included in these analyses were located in mature/old-growth forest to minimize variation. The optimal number of stream reaches and the optimal length of the sample unit was investigated by estimating the mean and 95% confidence intervals (C.I.) beginning with the first two sample units for each reach length. The mean and 95% C.I. were recalculated as sample reaches were successively added on to a maximum of 5 reaches for the 10 m sample unit, 10 reaches for the 5 m sample unit, and 30 reaches for the 1 m sample unit. The results are depicted graphically, so accuracy and precision of the estimates for different number and length of sample units could be compared (Figure A2-1A to A2-1L; Figure A2-2A to A2-2F).

Results and Discussion

Ten meter sample reaches are clearly the least cost effective means of estimating tailed frog abundance (Figure A2-1J, A2 – 1L). Both precision and accuracy[6] of the mean tadpole relative abundance were still declining even after 50 m of stream had been sampled (5 10-m reaches). In all but a single case, confidence intervals as a percent of the mean were all greater than when equivalent areas that had been sampled using 5 m reaches. The results generally suggest 10 m is not an efficient stream length to sample tailed frog tadpoles.

Results from the 5 m stream lengths indicate the precision of the tadpole relative abundance estimates levels off between 5 and 6 sample reaches (Figure A2-1I); sampling

---

[5] precision – a measure of how reliable within-year tailed frog relative abundance estimates are. In this document, it is calculated using 95% confidence intervals.

[6] accuracy – how close the estimated tailed frog relative abundance reflects the actual tadpole density

additional reaches does little to improve the precision of the estimate. Based on this information, 5 reaches is the optimal number of reaches to sample when using 5-m reach lengths.

Results from 1 m reach sample units suggest that the optimal number of 1-m sample units to use for tadpole relative abundance estimates is between 15 and 20 where precision of the estimate appears to level off (Figures A2-2E, A2-2F).

In a comparison between 1-m sample reaches and 5-m sample reaches, for the equivalent length sampled (e.g., 4 5-m reaches vs. 20 1-m reaches), the precision around the tadpole relative abundance estimate is always greater using 1-m reach lengths. This suggests that it may be more efficient to sample tailed frog tadpoles using a greater number of shorter reaches rather than fewer long reaches. The most efficient sampling design is likely a reach length between 1 and 5 m. Assuming the length of stream sampled remains constant (e.g., 30 m), it is clear from these data that using a reach size less than 5 m will improve precision. However, sampling 1 m reaches will be inefficient for 2 reasons. First, sampling efficiency declines when crews have to move between sample reaches; sampling fewer reaches is more efficient because more time is spent sampling rather than moving between reaches. Second, the probability of detecting zero tadpoles is reduced when longer stream reaches are sampled (Bury and Corn 1991); this affects the precision of the mean tadpole relative abundance. Therefore, I recommend using an intermediate reach length and reach number (10 3-m reaches per stream) to sample tailed frog tadpoles in WHAs. I strongly recommend that a small pilot study be developed to empirically determine what combination of reach lengths and numbers achieve the most efficient sampling design in WHAs. Compared to the implementation of a large tailed frog WHA monitoring program, this could be done for relatively little cost to improve data quality over the long term.

Regardless of stream reach length used to sample tadpoles, there seem to be some common patterns in precision of tadpole relative abundance estimate. In streams with high tadpole densities, (e.g., $2/m^2$) precision tends to be high (e.g., Figure A2-1G, A2-2B). In contrast, streams with low tadpole densities (e.g., $0.25\text{-}0.5/m^2$), precision is lower (Figure A2-1E, A2-2A). This is related to the patchy distribution of the tadpoles in-streams with lower population densities and the increased number of reaches sampled where zero tadpoles are captured.

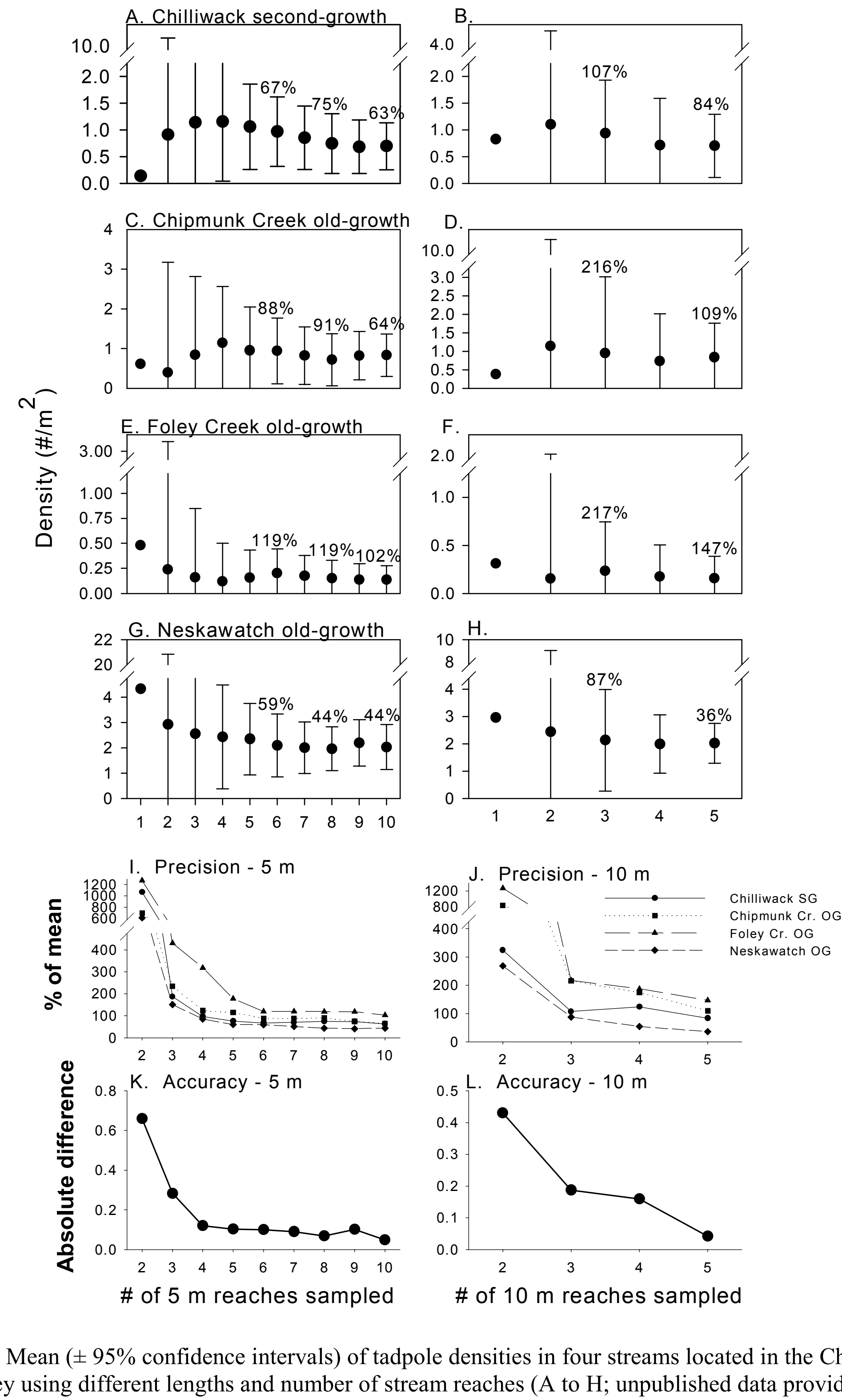

Figure A2-1. Mean (± 95% confidence intervals) of tadpole densities in four streams located in the Chilliwack river valley using different lengths and number of stream reaches (A to H; unpublished data provided by Dr. John Richardson, UBC). Percentages above certain mean estimates represent the C.I. expressed as a percent of the mean (A-H). Precision of the mean density is expressed as a percent of the mean for: I. 5 m reaches and J. 10-m reaches. Accuracy is measured as the absolute difference between the mean tadpole relative abundance estimated using a certain number of sample units (e.g. 4 sample units) compared to the mean estimate calculated sampled by adding one more sample unit (e.g. 5 sample units) .

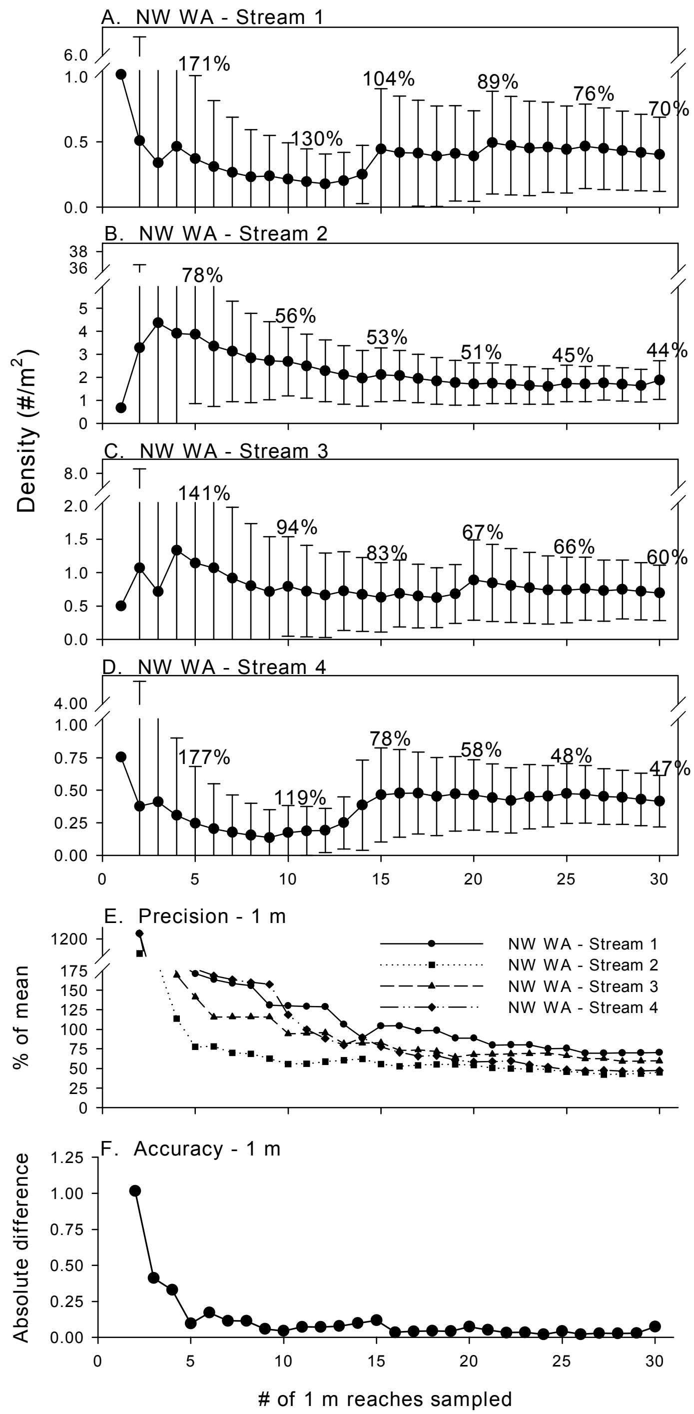

Figure A2-2. Mean (± 95% confidence intervals) of tadpole densities in four streams located in the Olympic Penisula, Washington using between 1 and 30 1-m reaches (A-D; unpublished data provided by Martin Raphael, Pacific Northwest Research Station). Percentages above certain mean estimates represent the C.I. expressed as a percent of the mean (A-H). E. Accuracy is measured as the absolute difference between the mean tadpole relative abundance estimated using a certain number of sample units (e.g. 4 sample units) compared to the mean estimate calculated sampled by adding one more sample unit (e.g. 5 sample units) .

APPENDIX 3. POWER ANALYSIS

An important part of a long-term monitoring program is the ability to detect true trends in the variable(s) of interest. In the case of effectiveness monitoring of tailed frog WHAs, a parameter of interest is the annual rate of change in tailed frog tadpole abundance in each WHA. Before any monitoring program is started, it is important to evaluate whether the sample design has the power to detect trends in the population, should they exist.

Therefore, a power analysis was conducted using the program “TRENDS”. The input of TRENDS includes five parameters:

1. n = the number of sampling occasions. In this case, it is the number of years a tailed frog population within a WHA could be monitored.
2. r = rate of change that occurs between sampling occasions (e.g., between years), or overall change (e.g., over the entire length of the sampling program).
3. CV = coefficient of variation of the first estimate of abundance in the time series.
4. α = the probability of detecting a significant trend when there is no trend
5. β = the probability of detecting a significant trend correctly

The parameter of interest in this power analysis is the minimum detectable rate of change. That is, what rate of change in tailed frog tadpoles can be detected through time at a given level of annual variation in tailed frog tadpole abundance, and at a specific α and β levels?

Using data from tailed frog populations located in the Chilliwack River valley and sampled using 10 5 m reaches as described in the “Study design and methods” section, mean annual coefficients of variation were calculated for ten streams (Table A3-1). Annual CVs for tailed frog tadpole abundance ranged from a low of 10% in one clearcut stream to a high of 110% in one second-growth stream. The average CV for all streams combined was 49%. From this range of variability, five CVs were selected that approximated the distribution of CVs for tailed frog populations in the Chilliwack River valley including: 10%, 25%, 50%, 75%, 100%. Using these levels of CV, at an $\alpha = 0.10$, and two levels of power ($1-\beta = 0.8$ and $1-\beta = 0.9$), the overall detectable rate of change in tailed frog tadpole densities was calculated for time steps of 5, 10, 20, 30, 40, and 50 years of monitoring.

Table A3-1. Mean annual coefficients of variation for 10 streams in the Chilliwack River Valley (unpublished data provided by Dr. John Richardson, UBC).

	Site	CV(%)
Clearcut	ChipCC	42
	FoleyCC	78
	NesCC	21
	Nes2[1]	10
Second growth	Prom	26
	Tam	110
	Thurs	77
	Chill	45
Old-growth	ChipOG	44
	FoleyOG	34

Combined	49

[1] This site was an old-growth site the first year of sampling, it was harvested in the second year, and was a clearcut site for the remaining three years of sampling.

Results and Discussion

Results of the power analysis which estimated detectable trends in tailed frog tadpole abundance are presented in Figure A3-1A. and 1B. For populations of tailed frogs with low levels of annual variation (CV ~ 10%, 1-β = 0.8), the minimum rate of population decline that is detectable is 8% decline per year after 5 years with smaller rates of declines detectable with increasing time monitoring is conducted. However, in populations with higher levels of annual variation (CV ≥ 25%), only relatively large declines are detectable within the first 5 years of monitoring (> 50% overall population change; 18% decline per year), with overall population change always quite large (e.g., > 20%) even after 50 years of monitoring. An overall population change of 50% were still not detectable in 50 years of monitoring for tailed frog populations with CV = 100%.

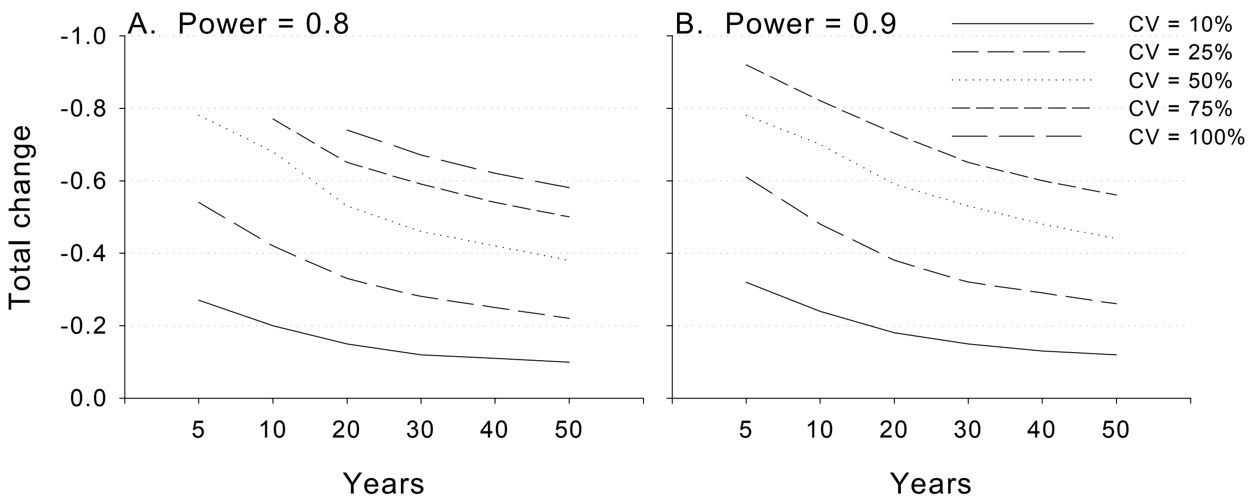

Figure A3-1A and 1B. Total change through time in tailed frog tadpole populations with different coefficients of variation.

The results of this power analysis have implications for the evaluation of the effectiveness of tailed frog WHAs in maintaining tailed frogs and their habitat. The only population indicator feasibly sampled for tailed frogs is tadpole relative abundance. If a majority of WHAs have declining densities of tailed frog tadpoles, it could be concluded WHAs, as they are currently designed, are not meeting IWMS goals and a new approach to tailed frog management might be required. The results of the power analysis suggest that for many tailed frog populations, annual variability in density may be too high to empirically detect anything but large trends in tailed frog abundance over time, with long time frames required to detect these changes. In other words, small or even moderate declines in a population may take 20 or more years to detect in some tailed frog WHAs. And while this power analysis included variability estimates of tailed frog populations in three different forest age classes, the lowest estimate of variation was found in a clearcut population; old-growth populations had CVs averaging 40%, with the overall average coefficient of variation for all streams combined equalling 50%. So like most other amphibian (Alford and Richards 1999), annual variation in tailed frog abundance is likely quite high for many populations. If CV = 50% are not unusual, twenty-five years of monitoring would be required to detect a minimum of a 50% decline tailed frog abundance. This is a big decline over a relatively long time horizon for monitoring. This level of decline may be unacceptable before changes to management occurs. Further, if tailed frog population variability tends to increase over time, also like many other amphibians (Marsh 2001), then long term estimates of power to detect trends may actually be lower than those estimated here. Therefore, evaluating the effectiveness of WHAs based on significant changes in tailed frog tadpole abundance alone should not be relied upon. An index that is an aggregate measure of the indicators should be considered to evaluate the effectiveness of tailed frog WHAs.

Assuming WHAs in general, are effective in maintaining tailed frogs, the results from this power analysis also have implications for the management of WHAs and the surrounding landscape. The results highlight the risks associated with waiting for empirical evidence of decline before taking management action. This is particularly important to consider given that variation around the mean tends to increase as tadpole abundance decreases. Therefore, those populations that are likely at higher risk of extirpation from a stream, are also the populations for which significant detectable rates of change may not be possible. Given the relationships between population size, population variation, and power to detect trends in abundance, different levels of precaution may be required in the management of tailed frog WHAs depending on it's context (e.g., location, underlying geology, productivity) and acceptable risks associated with different populations. For example, when population levels are low, a higher level of precaution may be required to not only prevent declines but to increase population size if possible. However, if population levels are high, a lower level of precaution may be required. This goes to overall regional differences in tailed frog abundance as Rocky Mountain populations, generally, have lower abundance compared to coastal populations; therefore, Rocky Mountain populations should almost always be managed with a higher level of precaution. Coastal populations could be divided into low, medium or high risk populations which could have implications for management activities surrounding the WHA and monitoring priorities.