Adaptive Management Framework for the Central and North Coast of British Columbia

Guide to the Knowledge Summary and Prioritization Procedure

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Final report
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This report was commissioned by the Ecosystem-Based Management Working Group (EBM WG) to provide information to support full implementation of EBM. The conclusions and recommendations in this report are exclusively the authors', and may not reflect the values and opinions of EBM WG members.

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1 Introduction

Monitoring and research are essential to adaptive management, providing new information about the consequences of management, leading to learning and to improved plans and practices.

Many adaptive management initiatives fall short of their potential for three reasons: indicators[1] are not explicitly linked to objectives, hindering feedback to planning; knowledge is not represented in a manner that can encourage learning and modification; and research and monitoring priorities are driven subjectively. To avoid these pitfalls, a successful adaptive management programme should link management strategies to objectives[2], summarise existing knowledge in a way that is easily updated, and easily communicated to managers and planners[3,4,5] and should prioritise monitoring and research activities across all plan objectives, based on gaps in existing knowledge[6].

The approach described in this document addresses these issues through development of a consistently formatted knowledge summary and formal prioritisation procedure that do three things:

1. link EBM policy objectives and overall goals directly to management strategies or plans;
2. summarize knowledge about these objectives and strategies in a stylized way that makes predicted effects of management strategies and their uncertainties explicit, and allows for these to be updated as additional knowledge is gained;
3. provide a transparent and replicable mechanism for prioritizing monitoring and research investments, based on gaps in existing knowledge and the potential to reduce management uncertainty and risk.

This document includes four sections and two appendices:

> Section 1 provides an introduction, context and very general procedure for setting priorities;
>
> Section 2 describes the structure of a **Knowledge Summary** that links management strategies to EBM policy objectives and summarizes knowledge in a stylised format;

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[1] See glossary at end for definitions of planning terms.

[2] Rempel, R.S., Andison, D.W., and Hannon, S.J. 2004. Guiding principles for developing an indicator and monitoring framework. For. Chron. 80: 82-90.

[3] Lee, K., 1993. Compass and Gyroscope. Island Press, Washington DC.

[4] Kinzig, A., Starrett, D., Arrow, K., Aniyar, S., Bolin, B., Dasgupta, P., Ehrlich, P., Folke, C., Hanemann, M., Heal, G., Hoel, M., Jansson, A., Jansson, B-O., Kautsky, N., Levin, S., Lubchenco, J., Mäler, K-G., Pacala, S.W., Schneider, S.H., Siniscalco, D., and Walker, B. 2003. Coping with uncertainty: a call for a new science-policy forum. Ambio 32: 330-335.

[5] Angelstam, P., Boutin, S., Schmiegelow, F., Villard, M-A., Drapeau, P., Host, G., Innes, J., Isachenko, G., Kuuluvainen, T., Mönkkönen, M., Niemelä, J., Niemi, G., Roberge, J-M., Spence, J., and Stone, D. 2004. Targets for boreal forest biodiversity conservation – a rationale for macroecological research and adaptive management. Ecol. Bull. 51: 487-509.

[6] Bunnell, F.L., and Dunsworth, B.G. 2004. Making adaptive management for biodiversity work – the example of Weyerhaeuser in coastal British Columbia. For. Chron. 80: 37-43.

Section 3 provides a formal **Prioritization Procedure** for setting research and monitoring priorities, based on information in the knowledge summary;

Section 4 describes how information gathered from projects can feed back into the adaptive management loop;

Appendix I provides a glossary of terms;

Appendix II describes how to create and update the knowledge summary.

This guiding document is intended for managers and technical specialists who will work directly with the Knowledge Summary, either to determine adaptive management investment priorities or to review and update knowledge in relation to particular objectives and strategies. Managers at the community scale can use this guide to better understand how to represent knowledge and set monitoring priorities, and to modify options for their circumstances. The first part of this guide, describing the Knowledge Summary, will also be useful to managers who wish to use the Knowledge Summary to inform management decisions. This guide assumes readers have some technical expertise and are familiar with planning concepts and terms. Using the Knowledge Summary also requires familiarity with ecological and/or socio-economic concepts, and with typical management practices.

1.1 Setting Adaptive Management Priorities

The priority-setting process differs for adaptive management related to ecology and forest policy and for adaptive management related to community development and human well-being. Because forest policy is supported by relatively clear objectives, strategies and related knowledge, existing information included in the Knowledge Summary can be formally evaluated using the Prioritisation Procedure to identify knowledge gaps and to guide decision-making. Because plans and knowledge regarding community development are less well developed, procedures will likely vary among communities.

1.1.1 Priorities related to forest policy

- Use the prioritisation procedure described in Section 3 to generate lists of high and medium priority study topics
  - There will be four lists: planning, implementation monitoring, effectiveness monitoring and validation monitoring and research
  - Topics on each list will be prioritised by the value of the information (based on both the need for information and importance of the objective)
- If necessary, meet with topic experts and/or practitioners to discuss the priority topics on each list and to describe the type of studies (experimental or not) needed in each case[7]
  - Topic experts can assist with study design

[7] If the Knowledge Summary is complete and current, information from topic experts should already be included in the Knowledge Summary. Otherwise, any information gathered at this point should be incorporated in the next update.

  - Practitioners can assist with technical and logistical feasibility of studies
- Note which of the valuable studies are most likely to succeed
  - High benefit to cost ratio
  - Achievable with current budget (if a project is highly valuable, but not currently achievable, consideration can be given to funding proposal writing or multi-agency collaboration)
- Present lists of topics to trustees (or a board that represents First Nations, BC, forest industry and ENGOs) in a manner that enables them to identify which studies should receive funding
  - Provide information on why the study is needed, benefits, costs, scope, employment/training opportunities, design, opportunities for collaboration.

1.1.2 Priorities related to human well-being

While human well-being goals, embedded in EBM, are made clear in the G2G agreements, the details of objectives and strategies are left for individual communities and their partners to initiate. Few human well-being objectives are specifically addressed in the ministerial orders. Other regional land use planning documents do not generally clarify objectives or provide specific strategies, targets and implementation indicators. As well, the management responsibility for implementation and monitoring remains unclear. Strategies, and even objectives, may vary between communities. This prioritization procedure allows for local sorting of knowledge requirements in a fashion analogous to ecological integrity (above).

Priorities for human well-being studies should be set **over the area to which the objectives apply**. When objectives, strategies and knowledge are common between several communities (as, for example, they are for shellfish aquaculture), then the priorities for those objectives can be set across multiple communities. When objectives and strategies are specific to a particular community or First Nation (as, for example, in the case of a specific tourism strategy), then priorities should be assessed at the level of that community or Nation. A community may choose to set priorities across multiple objectives that all apply at the community level (see, for example, the illustration in the spreadsheet accompanying the HWB study priorities document "HWB monitoring priorities.xls"). The greater the degree of regional collaboration on economic development and cultural heritage protection, the more the prioritization process can be applied regionally. This will provide benefits through common pursuit of studies that have high information value to all.

In general, the same prioritization approach used for ecosystem integrity applies also to human well-being. The approach prioritizes recommended studies based on the value of information that would be generated. There are some minor differences in details and categories for the human well-being prioritization (see Section 3):

- recovery period is conceptually and practically relevant for ecosystems but not for human wellbeing.

- current priority: because objectives intend to *increase* human wellbeing, rather than to *prevent damage* to ecosystems, high current uncertainty levels do not place objectives at risk for most HWB strategies, so this is not an important factor in prioritization.
- a number of factors that are important in setting priorities and assessing options for EI studies across a very wide range of objectives may not need to be evaluated for HWB studies where relatively few objectives and strategies are considered. For example, ease of collecting data or monitoring will play a role in determination of whether to proceed with a study but it may be relatively less significant in identifying priorities.

Accounting for these distinctions, the process for establishing human well-being adaptive management priorities is as follows:

- Use the Prioritization Procedure described in Section 3 to generate priorities at different scales for human well-being, across a small or large number of common objectives (four lists of priorities will result). If there are many objectives, weak planning or limited knowledge, lists may be long and may require additional criteria to sort.
- Seek funding for priority adaptive management work, through the Coast Opportunity Funds, research partnerships, or other sources. If communities apply to a regional "adaptive management fund"[8], there will not be a unified region-wide list of objectives, strategies and knowledge that can be prioritized in the same way as for ecosystem integrity. In that case, community funding applications should demonstrate that:
    - due diligence has been exercised to assemble all available knowledge about the issue in question (conclusions could be summarized)
    - proposed activities are based on value of information (i.e. assessment of uncertainty and risk in relation to planning objectives)
    - results will be widely shared

HWB adaptive management project funding decisions can be based in part on demonstrated priority (using the criteria and system provided here), but also on other criteria:

- Regional distribution of studies
- Potential contributions to local employment and capacity development
- Value of results to other communities in improving human well-being
- High benefit to cost ratio
- Opportunities for collaboration between communities, or between sectors
- Achievable with current budget (if a project is highly valuable, but not currently achievable, consideration can be given to funding proposal writing or multi-agency collaboration)

[8] There is no commitment to such funding for the Central and North Coast yet, but it is a logical dimension of EBM implementation and has been recommended as part of the proposed Institutional Design for an adaptive management framework.

2 Knowledge Summary

The Knowledge Summary is a working draft document, not a textbook. The initial version provides a starting point for further additions as new knowledge becomes available on other EBM objectives (e.g. relevant conclusions on focal species such as grizzly bear). Managers will develop new strategies and plans to meet EBM objectives, and governments will modify objectives or identify the need for new ones. Additional information from monitoring and research should lead over time to further modification of the content. So this will always be a work in progress rather than a finished product.

This version of the Knowledge Summary is intended to cover most Ecological Integrity objectives for EBM (with the exception of objectives related to individual species, as this knowledge is currently being compiled), because these have clearly articulated strategies that have been agreed by the province and First Nations governments, and a coherent body of knowledge summarized in the EBM Handbook and related studies. Human Well Being objectives are diverse and generally defined in only broad terms in G2G agreements, leaving communities to develop their own strategies and priorities. Therefore, for HWB objectives, the Knowledge Summary adopts some examples from objectives in the G2G agreements and illustrates these with strategies that reflect current community priorities. For HWB in particular, a great deal of knowledge is held at the community level, and these examples should be updated through community-based critical review. They serve as models for the refinement and development of supplementary content.

2.1 Contents of Knowledge Summary

The Knowledge Summary guides management and research and monitoring decisions. It includes three different types of information: "overview diagrams" that depict relationships among land-use planning goals, objectives and strategies[9]; graphical cause-effect relationships that explicitly connect management strategies to objectives (shown as tables in the case of human wellbeing knowledge); and text descriptions (importance ratings and uncertainty) that elaborate on relationships in the overview diagram (Table 1). In addition, the Knowledge Summary includes implementation data, when available, and estimates of the probability of achieving the objective and related uncertainty (Table 1).

Table 1. Contents of Knowledge Summary.

Section	Content
For each goal:	
Information sources and updates	records authors of section, literature and experts consulted, reviewers, and dates of revisions.
Overview of current knowledge relating to goal	general description of main factors influencing achievement of goal, including an overview diagram that depicts connections between goals, objectives and strategies
Uncertainty about achieving goal if objectives are achieved	lists objectives and their relative influence on the goal; describes uncertainty about achieving goal due to missing objectives.
Influence of goal on other	describes how the focal goal influences other goals.

[9] See glossary at end for definitions of planning terms.

*goals**	
For each objective:	
Influence of objective on goal	describes the relative influence of the objective on the goal.
Recovery period for objective	describes the recovery period for the objective if the objective is not achieved (EI only).
Relationships between objective and strategies	describes the relative influence of each strategy on the objective; depicts and describes hypothesized cause-effect relationship between implementation indicator and objective, including sources of uncertainty.
Available implementation data and targets (EI only)	describes current state (from monitoring) and future state (from target in strategy) of implementation indicator when information exists; rates the need to collect indicator data as high or medium.
Probability of achieving objective and uncertainty	describes the best-estimate probability of achieving the objective (low, medium or high) and the related uncertainty (low, medium or high) for current and future indicator states.

*italicized sections contain information used to determine importance ratings, discussed below

2.2 Overview diagram

These diagrams, also referred to as concept maps, provide an overview of the relationships between, goals (grey boxes), objectives (double-lined boxes) and strategies (single-lined boxes in Figure 1). They are based on current management plans and also on current understanding of the relationships among key factors affecting the goal. In most cases, management plans already address key factors with objectives or strategies, however, overview diagrams also identify key factors that cannot or are not currently being managed.

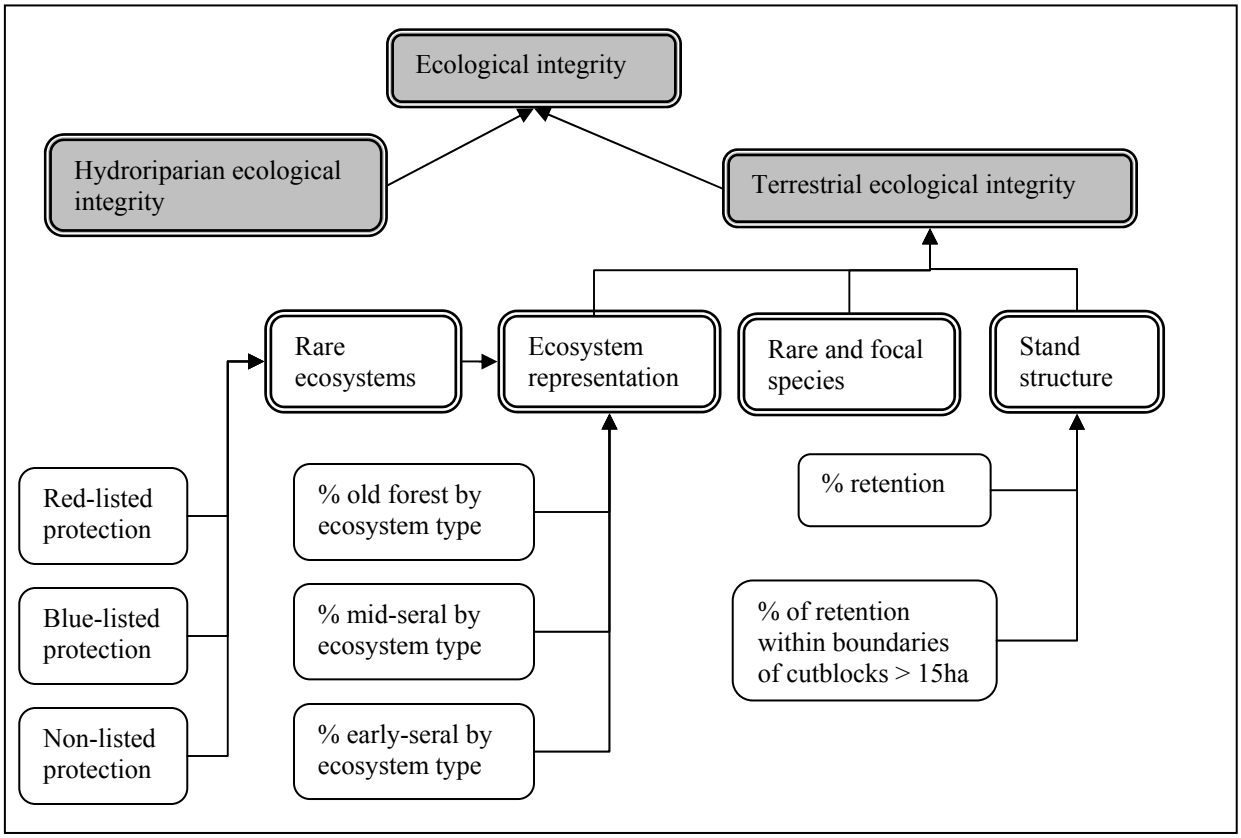


Figure 1. Example partial concept map for terrestrial ecological integrity. Within the broad goal of maintaining terrestrial ecological integrity, there are four main objectives—maintain rare

ecosystems, represent natural ecosystems, maintain rare and focal species and retain stand structure. Strategies under ecosystem representation describe the amount of each ecosystem to retain as part of a particular seral stage.

2.3 Importance ratings and uncertainty about achieving goal

The rest of the Knowledge Summary essentially provides detail on each arrow in the overview diagram (Table 2). Different sections describe the relative degree of influence of each goal on other goals, of each objective on each goal, and of each strategy on each objective: essentially, each arrow in Figure 1 is assigned a weight and a rationale is provided. Text also describes uncertainty about achieving the goal if all objectives are met (e.g., due to missing objectives or uncontrolled factors) and describes recovery period for the objective (in the case of EI objectives where ecosystem recovery is a key consideration). Influence and uncertainty are rated as low, medium or high. Recovery period is rated as short, medium or long (i.e., < 10 yrs, 10 – 100 yrs, > 100 yrs). Degree of influence and recovery period are combined to rate the relative importance of each strategy. Connections between strategies and objectives are further elaborated as cause-effect relationships (see next section).

Table 2. Text descriptions of influence, uncertainty and recovery period that elaborate on conceptual model.

Section	Example
Importance factors*	
Influence of goal on other goals	Loss of terrestrial ecological integrity carries a probability of a serious consequence for all other goals and hence has a **high influence** on other goals.
Influence of objective on goal	Ecosystem representation has a **high influence** on terrestrial ecological integrity; stand structure has a medium influence.
Influence of strategy on objective	Old forest retention has a **high influence** on ecosystem representation. Early and mid seral retention have a **low influence** because these seral stages are not threatened by forestry.
Recovery period for the objective.	Old forest has a **long recovery period**, taking centuries to recover.
Uncertainty	
Uncertainty about achieving goal if objectives are achieved**	Taken together, objectives cover most relevant factors influencing terrestrial ecological integrity. Uncertainty about achieving the goal despite achieving all objectives arises because stand structure objectives are poorly linked to natural disturbance and because global warming is altering disturbance regimes.

*used to determine relative importance of each strategy

**uncertainties may identify missing objectives

2.4 Graphical cause-effect relationships

2.4.1 Best-estimate probability of achieving objective

This section records cause-effect relationships for each listed strategy that influences a particular objective. To assess management success, strategies must be measurable, have well-defined targets, and be clearly linked to specific management objectives. Implementation indicators are the measurable subject of strategies and represent strategy options (e.g., percent old forest retained). A target level (e.g., 70%) of an indicator (e.g., old forest retained) constitutes a complete strategy. Cause-effect graphs explicitly link strategies to objectives. More specifically, they model hypothesised relationships between an implementation indicator, and the best-estimate probability of achieving an objective (Figure 2).

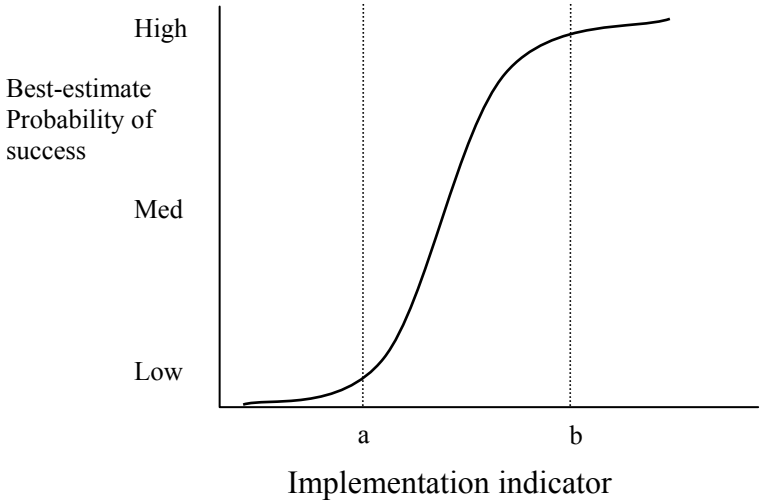


Figure 2. General, hypothesized cause-effect relationship. At indicator value "a", the probability of successfully achieving the objective is low; at "b", the probability is high.

The points on the vertical axis, represent probability of success[10, 11] and range from low to high probability. We define high probability of success as the region of implementation indicator values where even well-designed studies are unlikely to detect negative consequences to the objective (for objectives related to protection of ecological integrity), low probability as the region where most studies will detect consequences, and medium probability as the region between, where some studies will detect consequences, and others will not.

Ideally, hypothesised cause-effect relationships should be derived from peer-reviewed meta-analyses[12] of studies conducted in the region of interest. A somewhat more realistic option is to use expert workshops to discuss the applicability of studies within and

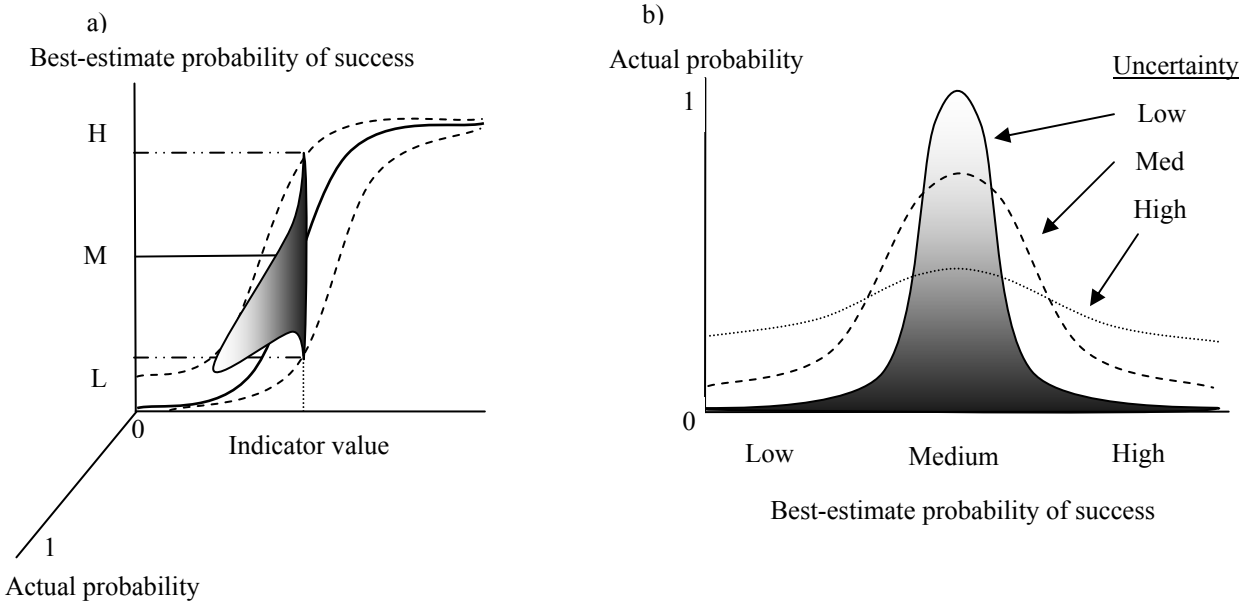
[10] the terms "probability of achieving objective" and "probability of success" are used interchangeably in this document and in the Knowledge Summary.
[11] older documents used the term risk, which was defined as the probability of failing to achieve the objective; i.e., probability of success is the opposite of risk.
[12] meta-analyses use statistical approaches to look for consistent patterns across multiple studies.

outside the region of interest. When published information is particularly sparse, expert opinion alone can be used to draft preliminary models. In the adaptive management context, the Knowledge Summary should grow and improve over time, as new information is added. Thus, weak cause-effect relationships, whether due to lack of information or lack of funding for meta-analyses, should improve over time.

2.4.2 Uncertainty about cause-effect relationships

After drawing a curve representing the best-estimate probability of success associated with a given indicator value, the next step is to describe uncertainty about this relationship. Uncertainty is represented by the distribution of actual probability around the best-estimate[13] probability for a given indicator value (Figure 3a). As uncertainty increases, the actual probability distribution becomes flatter and wider: i.e., the chance that the best-estimate probability is correct declines as uncertainty increases (Figure 3b). For practicality, uncertainty is described in three classes: low, medium and high. Uncertainty can vary from low to high along the best-estimate curve.

Uncertainty about the cause-effect function is partitioned into resolvable and irresolvable uncertainty. Resolvable uncertainty arises from lack of study. Irresolvable uncertainty may result from inherent stochasticity (e.g. fish runs can deviate substantially from predictions because of natural variation) and cannot be reduced by research (Walters 1997b). Uncertainty about the probability of success can also be partitioned into uncertainty about the appropriateness of the implementation indicator (particularly relevant in the real world, where indicators have not necessarily been chosen to match objectives), and uncertainty about the relationship between the indicator and the objective.



[13] if data existed, the best-estimate probability could be similar to the mean of the actual probability distribution (depending on distribution shape); in most cases, best-estimates reflect expert opinion.

Figure 3. A probability distribution showing the actual probability of achieving the objective at a medium best-estimate probability of achieving the objective, with low uncertainty. The two-dimensional uncertainty bands in Figure "a" are meant to imply an actual probability distribution similar to the shaded one shown in both Figures. As uncertainty increases (from low to high), uncertainty bands (dashed lines in Figure a) widen, indicating a flatter actual probability distribution (Figure b) and a lower chance of achieving the best-estimate probability.

2.4.3 Classification of cause-effect predictions

To simplify comparison and interpretation of potential outcomes and because current ecological and human well-being knowledge does not support precise estimates, the Knowledge Summary recognizes only nine distinct predictions from cause-effect curves. The best-estimate probability of achieving the objective is divided into three equally-sized classes: low, medium and high. Each of the three best-estimate probability classes can have three different levels of uncertainty (low, medium, high), leading to nine different hypothesized actual probability distributions (for achieving the objective). Another way to express this process is that if you are predicting the results from some strategy, you can label any estimated result along two dimensions: how likely is it, and how sure you are of this likelihood. With three possible options for each dimension, any predicted result will have one of nine possible combined ratings (e.g. Low likelihood with high uncertainty, low likelihood with medium uncertainty, etc.).

Best-estimate probability determines the location of the peak of the hypothesized actual probability distribution; uncertainty determines the flatness of the distribution (Figure 3b). The best-estimate probability is always the most likely outcome. If uncertainty is low, other outcomes are unlikely. As uncertainty increases, other outcomes become more likely.

2.5 Available implementation indicator data and targets

Using cause effect relationships to predict management success requires knowing the value of the X-axis variable or "implementation indicator" at two points: current status and target future status. The current value comes from implementation monitoring. The future value is usually specified as part of a strategy. Available data are recorded for relevant habitats or ecosystems and can be summarized at a variety of spatial scales, as appropriate (Table 3). Implementation data may exist, be estimable or be missing. Targets may exist or be missing.

Table 3. Hypothetical example: current and future indicator values (when known) for old forest, by landscape.

Geographic unit	Ecosystem	Current Indicator Value (% of total)	Future Indicator Value (% total)
L1	HB_Poor in CWHvh1	83	36
xx	xx	xx	xx

2.6 Probability of achieving objective and uncertainty

This section uses cause-effect relationships to translate implementation indicator values, described above, into best-estimate probabilities of achieving the objective (i.e., success) and related uncertainty, if implementation data are available (Table 4). The best-estimate

of the probability of achieving the objective is read from the Y-axis of the cause-effect relationship at specified X-values. Sometimes uncertainty can also be read directly from the graph; sometimes it is just described in categories in the text (typically text descriptions are used when many interacting sources of uncertainty are involved). Current and future probability estimates and related uncertainty provide useful information to guide adaptive management.

Table 4. Hypothetical example: current and future probability of success and uncertainty for old forest.

Geog. unit	Ecosystem	Current P(success)	Uncertainty	Future P(success)	Uncertainty
L1	HB_Poor in CWHvh1	High	High	Moderate	High
xx	xx	xx	xx	xx	xx

3 Prioritization Procedure: setting priorities for adaptive management projects

This process is designed to consider all goals and objectives across a wide range of EBM activities. Communities, however, may select a sub-set of objectives for consideration. The procedure remains the same, but may be simplified where there are fewer objectives.

3.1 Overview

Adaptive management includes steps to develop clear plans and to monitor outcomes. Setting priorities for planning and monitoring involves probing the Knowledge Summary to identify situations where information would be most useful and cost effective, based on a systematic methodology. Priorities are set based on the benefit of the information, discussed below, and then modified to account for ease of data collection, discussed in Section 3.7.

Different types of information-gathering activities are appropriate in different situations:

- Planning can address influential, unmanaged factors by developing new objectives and/or strategies and can set missing targets
- Implementation monitoring can collect implementation indicator data when information is insufficient to determine probability of achieving objectives.
- Effectiveness monitoring can detect negative consequences when the probability of achieving the objective is modest or low and therefore such consequences might be expected (for human well-being, there may just be a failure of the strategies to achieve objectives rather than negative consequences);
- Research and validation monitoring can reduce uncertainty when the probability of achieving the objective is relatively uncertain.

The Knowledge Summary identifies knowledge gaps by the activity-categories listed above. The Prioritization Procedure uses the best-estimate probability of achieving the objective and related uncertainty (Section 2.6) to set monitoring priorities within each category and then uses importance ratings (Section 2.3) to further divide topics having the same priority. The need for planning is based entirely on importance ratings. The prioritization procedure applies a scoring system to best-estimate probabilities, uncertainty and importance ratings to ease comparison and to ensure transparency and consistency over time.

In the Prioritization Procedure, all goals are treated as equal, because they reflect consensus social decisions, and all objectives are treated as being necessary to achieve the goal (although some objectives have more influence than others; see importance ratings). In general, each objective can be considered to be "limiting"—the objective with the lowest probability of being achieved has the largest influence on the goal. When two objectives have the same probability of being achieved, importance ratings determine which is most important to consider.

Table 5 summarises the possible results of the prioritisation procedure. Sections below provide details.

Table 5. High priority planning, monitoring and research activities as determined by information on objective/strategy pairs in knowledge summary.

Current state known	Target exists	Probability of success	Uncertainty	High Priority AM Activity
Yes or no	No	Not estimable	Not estimable	Planning
No	Yes or no	Not estimable	Not estimable	Implementation monitoring
Yes	Yes	Low	Low to medium	Planning; effectiveness monitoring
Yes	Yes	Low to high	High	Validation monitoring and research
Yes	Yes	High	Low to medium	None necessary; continue implementation monitoring

3.2 Planning priorities

Planning priorities arise when objectives or strategies are missing or vague. If objectives or strategies are incomplete, then targets cannot be sensibly identified. Without a planned target (either quantitative or qualitative), managers cannot tell if they have implemented the strategy. Agreed-upon targets developed through planning provide future X-axis state in probability curves or tables. If the future state is unknown (i.e., there is no target), the objective or strategy receives a high priority for planning.

3.3 Implementation monitoring priorities

Implementation (including compliance) monitoring asks whether designed strategies (specific, measurable indicators with clear targets) are being followed (e.g. what percent of trees are retained in stands). If current indicator state is unknown and not somewhat estimable[14] from existing data, an objective receives a high priority for implementation monitoring. If it is estimable, it receives a moderate priority.

In most cases, implementation monitoring will continue at periodic intervals throughout the adaptive management cycle to determine whether strategies are being implemented. The periodicity of data collection varies by indicator. Outdated indicators have exceeded their scheduled collection date by more than 50% of the specified period length. Typical re-measurement periods range from 5 to 15 years; they depend on the pace of development[15]. For human wellbeing indicators, 5 years is a typical measurement period.

Table 6. Priorities for collecting implementation data.

Status of implementation indicator data*	Priority
existing values and current (i.e., not outdated)	nil
existing values and outdated	low
estimated values	medium
no values	high

*Source: Available Implementation Data and Targets, Knowledge Summary

[14] For example, if a landscape unit has not been logged, the level of riparian retention can be easily estimated.

[15] Note that target re-measurement periods should be included in the Knowledge Summary in the Available Implementation Indicator Data Section, however, many of these sections are currently incomplete.

3.4 Effectiveness monitoring priorities

Effectiveness monitoring asks whether objectives are being met (e.g. are old-growth-dependant species maintained in stands). The Prioritization Procedure uses interpretative tables to convert estimates of (current and future[16]) best-estimate probability of achieving the objective and uncertainty into effectiveness monitoring priority scores, in a two-step process (Box 1). First, a separate score is calculated for current and future values. Then the scores are combined.

For monitoring to detect negative consequences (effectiveness monitoring), objective/strategy pairs with low probability of success (current or future) and low or medium uncertainty rank first, those with a high probability of success and low or medium uncertainty rank third, and the remainder rank second. The remaining five situations all have a mean probability of success of medium, or very close to medium (Table 7).

Table 7. Priority for detecting negative consequences (1 is highest priority), based on best-estimate probability of success and uncertainty.

		Best-estimate probability of success*		
		High	**Medium**	**Low**
Uncertainty*	**High**	2	2	2
	Medium	3	2	1
	Low	3	2	1

*Source: Probability of Achieving Objective Section of Knowledge Summary

The overall priority for detecting negative consequences (i.e., effectiveness monitoring) is a function of predicted current and future monitoring priority (Table 8). The combined priority is based more on current than future priority because negative consequences may be imminent. This process could apply to human wellbeing, although for human wellbeing the intent is typically not to avoid negative consequences but to limit the effort devoted to ineffective strategies.

Table 8. Combined priority for detecting negative consequences (1 is highest) based on current and future priorities.

		Current Priority		
		1	**2**	**3**
Future Priority	**1**	1	2	3
	2	1	2	3
	3	2	3	4

[16] Recall that current probability of achieving the objective is based on recently measured implementation indicator data; future probability is based on targets levels of implementation indicators specified in land-use plans.

Box 1. Theoretical basis for setting monitoring priorities

For effectiveness monitoring, designed to detect consequences, priority is inversely proportional to mean expected chance[1] of achieving the objective E(Y):

$E(Y) = \sum_{i=1}^{n} p_i y_i$ where n = number of probability levels specified, and p = probability that the actual chance of achieving the objective (Y) falls in a particular level y for a given best-estimate chance and uncertainty level.

Theoretically, we assume that the probability distribution for Y follows a normal distribution truncated at high and low values of y (Figure 3). Thus, for a medium best-estimate chance of achieving the objective, E(Y) = best-estimate chance of achieving the objective whether uncertainty is low or high (as errors are symmetrical). For high and low chances of achieving the objective, when uncertainty is low, E(Y) ≈ best-estimate chance of achieving the objective, and as uncertainty increases, E(Y) approaches medium levels of y.

For validation monitoring, designed to reduce uncertainty, priority is based on the breadth of possible chance-of-success levels (Figure 3). Objectives with the highest resolvable uncertainty have high priority. Priority decreases as uncertainty decreases. It also decreases as the best-estimate chance of success approaches low or high extremes (leading to a one-tailed distribution), because actual chance of success falls in a narrower band of risk levels. Objectives with low or irresolvable uncertainty, have low priority for validation monitoring.

[1]The term "chance" is used to refer to hypothesized probabilities expressed in cause-effect curves in order to avoid confusion with the term "probability" used to describe the distribution of chance.

3.5 Research and validation monitoring priorities

Validation monitoring (or monitoring to learn) investigates the relationship between implemented strategies and objectives (e.g. are the old-growth-dependant species maintained because of stand-level or landscape-level retention). Research and validation monitoring priorities are set using the same basic two step process used for effectiveness monitoring: evaluate priority based on current and future probability of achieving an objective and then combine priorities to produce an overall priority rating.

For monitoring to improve the cause-effect curve by reducing uncertainty, all objectives with high uncertainty rank first. Objectives with a medium best-estimate probability of success and medium uncertainty also rank first because actual probability of success may fall in any of the three risk categories. All objectives with low uncertainty rank third; the remaining objectives (that could fall into two categories) rank second (

Table 9).

Table 9. Priority for improving cause-effect relationships and reducing uncertainty (1 is highest priority) based on estimated risk and uncertainty.

		Best-estimate probability of success*		
		High	**Medium**	**Low**
Uncertainty*	**High**	1	1	1
	Medium	2	1	2
	Low	3	3	3

*Source: Probability of Achieving Objective Section of Knowledge Summary

The overall priority for reducing uncertainty is a function of predicted current and future monitoring priority (Table 10). Combined priority is based more on future priority than on current priority, because refining future targets allows for a potential change in strategy.

Table 10. Combined priority for improving cause-effect relationships and reducing uncertainty (1 is highest) based on current and future priorities.

		Current Priority		
		1	**2**	**3**
Future Priority	**1**	1	1	2
	2	2	2	3
	3	3	3	4

3.6 Refining priorities based on importance scores

The Prioritization Procedure results in four lists of activities: planning; implementation monitoring, effectiveness monitoring, and research/validation monitoring. Initially, the procedure assumes that all objectives are equally important. Subsequently, this step ranks objectives within high and medium priority classes by measures of importance[17] (Table 11). Importance measures are assigned a score and the score is tallied[18].

[17] Note that "uncertainty about achieving the goal if objectives are achieved" is not used as an importance measure, because the interpretation is unclear. On the one hand, higher uncertainty about achieving the goal reduces the influence of an objective. On the other hand, one can argue that irrespective of uncertainty about achieving the goal, managers should try to achieve all objectives—manage as best they can. Is it more important to improve management of tailed frog habitat, where management is the main factor that can cause extinction or to improve management of fish habitat, where poor management can cause extinction, but so can other uncontrolled factors?

[18] Technically, it is more correct to multiply the influence of the strategy on the objective by the influence of the objective on the goal to determine the net impact of the strategy on the goal, in the typical manner used in probability networks. Such an approach, however, could not include other importance measures that are not necessarily multiplicative (e.g., recovery period of objective and influence of goal on other goals). Thus the total score is simply tallied.

Table 11. Features of goals and objectives that determine secondary monitoring score (lower scores have higher priority)

Importance measure*	Range*
Influence of goal on other goals (Low = 1, Medium = 2, High = 3)	1 – 3
Influence of objective on goal (Low = 1, Medium = 2, High = 3)	1 – 3
Influence of strategy on objective (Low = 1, Medium = 2, High = 3)	1 – 3
Recovery period of objective** (Short = 1, Medium = 2, Long = 3)	1 – 3
Total = Secondary Monitoring Score (Higher scores indicate higher priority)	4 – 12

*Source: Sections of Knowledge Summary with same title, except that the influence of the strategy on the objective comes from the "List of strategies influencing objective" section.
** not relevant for HWB objectives

An important feature of our approach is that monitoring priority is determined first by risk and uncertainty and second by the importance of an objective. This approach avoids projects that—although studying important objectives—are unlikely to provide useful information for management.

3.7 Ease of collecting data

The priorities developed above are based on the relative benefit (information gained) of planning and monitoring activities. The final selection of planning and monitoring activities should consider both benefits and costs. This step calculates the relative ease or difficulty of collecting data—the "cost". The ease of planning activity is too variable to predict and not considered here. Ease of collecting data need only be calculated for high priority topics in each category:

- ease of collecting indicator data (implementation)
- ease of reducing uncertainty around the cause-effect relationship (validation)
- ease of detecting negative consequences / improvement in objective indicators (effectiveness)

The same procedure is used to rate the ease of undertaking studies in each category. First the knowledge gap is classified as resolvable or irresolvable (as recorded in Knowledge Summary). Then resolvable gaps are rated for ease of study considering several factors: the type, duration and spatial scale of the study and special skills needed for field work and analysis (Table 12). Each factor is rated and scores are tallied and divided into overall ease/difficulty ratings. Supporting rationale for ease ratings are also described. This procedure leads to a rough estimate of the ease or difficulty of undertaking studies. Ease should be re-considered more thoroughly when detailed plans for studies are developed prior to implementation.

Table 12. Relative "cost" estimates used to determine ease of monitoring: Easy: total = 3 – 6, moderate: total = 7 – 11; difficult: total = 12 – 16.

Factor	Cost score range
New data: remote sensing (none, easy to obtain, difficult to obtain)	0 – 2
New data: field study (none, easy, medium or difficult to obtain)	0 – 3
New data: study design (none, retrospective or experimental)	0 – 2
Appropriate scale: time (< 2 years, 2 – 10 years, >10 years)	1 – 3
Appropriate scale: space (watershed, landscape unit, territory, region)	1 – 3
Special skills/equipment (none, some, much)	0 – 2

Analysis of new or existing data (simple, medium or complex)	1 – 3
Total	3 – 16

3.8 Listing monitoring priorities

The Prioritization Procedure ranks planning and monitoring topics based mainly on four criteria (Table 13 [19]). It refines these ranks based on importance scores and then determines ease of monitoring for candidate topics.

Table 13. High priority planning, monitoring and research activities as determined by information on objective/strategy pairs in knowledge summary.

Current state known	Target exists	Probability of success	Uncertainty	High Priority AM Activity
Yes or no	No	Not estimable	Not estimable	Planning
No	Yes or no	Not estimable	Not estimable	Implementation monitoring
Yes	Yes	Low	Low to medium	Planning; effectiveness monitoring
Yes	Yes	Low to high	High	Validation monitoring and research
Yes	Yes	High	Low to medium	None necessary; implement strategy

This process, across all goals and objectives, will generate a list of potential monitoring activities. Depending on how many goals and objectives are prioritized, the list may be lengthy. The next section describes how to further sort this list.

To facilitate comparison of potential monitoring topics, it is useful to list potential monitoring topics in order of priority. First create a master table containing the information generated in earlier steps (Table 14). Then create four different tables, one for each different type of monitoring or planning (Table 15 to Table 17).

Table 14. List of information to include in master table of priorities.

Column Heading	Description of Heading and Contents of Column
Goal	goal stated in land-use plan.
Objective	objective stated in land use plan.
Indicator	indicator stated or indicator derived from strategy stated in land use plan.
Geographic Scope	geographic area to which objective and indicator apply (see Table of scope codes below).
Goal Uncertainty	uncertainty about achieving goal even if objectives are achieved: high uncertainty usually indicates that external factors influence goal (1=high, 2=medium, 3=low).
Importance Scores	
Goal Influence	the degree of influence that a goal has on other goals (1 influences ≥ 4 goals, 2 influences 2 or 3 goals, 3 influences ≤ 1 goal).
Objective Influence	the degree of influence of an objective on a goal (1=high influence, 2=medium, 3=low)
Strategy Influence	the degree of influence of an strategy on an objective (1=high influence, 2=medium, 3=low); influence scores are assigned so that the average score for all strategies for a given objective equals 2 (approx.), providing consistency among objectives.
Recovery Period	lag time for objective to recover after negative impacts cease (1=recovery > 100 yr, 2=recovery ranges from 10 to 100 yr, 3=recovery < 10 yr).

[19] Note that this is the same as Table 5. It is reproduced here for clarity.

Total Importance Score	Score used to rank monitoring topics within primary priority classes; calculated as the sum of goal influence, objective influence, strategy influence and recovery period; objectives with lower secondary scores have higher priority for monitoring.
Implementation monitoring priorities	
Data Priority	priority for collecting current indicator data; 1 = data do not exist and cannot be estimated, 2 = data do not exist but can be estimated, ✓ = data exist (smaller numbers indicate higher priority).
Ease of collecting data	**E**asy, **M**oderate, **D**ifficult, **V**ery **D**ifficult.
Planning priorities	
Target Priority	priority for setting indicator targets; 1 = targets do not exist and future state cannot be estimated, 2 = targets do not exist but future state can be estimated, ✓ = targets exist (smaller numbers indicate higher priority).
Probability of Success ± Uncertainty	
Current P(S) ± U	current P(S) (**L**ow, **M**edium, **H**igh) and uncertainty (**L**ow, **M**edium, **H**igh).
Future P(S) ± U	future P(S) (**L**ow, **M**edium, **H**igh) and uncertainty (**L**ow, **M**edium, **H**igh).
Research and validation monitoring priorities	
Current Priority	priority for reducing uncertainty around current risk estimate (1=high, 2=medium, 3=low), based on current R ± U (see Framework).
Future Priority	priority for reducing uncertainty around future risk estimate (1=high, 2=medium, 3=low), based on future R ± U (see Framework).
Overall Priority	combined current and future priority for reducing uncertainty around risk curve (1=high, 2=medium, 3=low, 4=very low); weights future priority more.
Ease of Monitoring	**E**asy, **M**oderate, **D**ifficult, **V**ery **D**ifficult, **N**ot **R**esolvable.
Effectiveness monitoring priorities	
Current Priority	priority for detecting consequences on current landscape (1=high, 2=medium, 3=low), based on current R ± U (see Framework).
Future Priority	priority for detecting consequences on future landscape (1=high, 2=medium, 3=low), based on future R ± U (see Framework).
Overall Priority	combined current and future priority for detecting consequences (1=high, 2=medium, 3=low, 4=very low); weights current priority more.
Ease of Monitoring	**E**asy, **M**oderate, **D**ifficult, **V**ery **D**ifficult, **N**ot **R**esolvable.

The following tables show how information generated in the previous steps can be summarised. In this example, target values exist for both % of natural old forest representation and grizzly bear Class II habitat in the geographic units listed (Table 15); hence priority for planning is low.

Table 15. Hypothetical example: Priority for setting targets.

Goal	Objective	Indicator	Geographic unit	Planning priority
Ecological integrity	Old forest representation	% of natural old	WS 3	Nil
Ecological integrity	Grizzly bear	Class II habitat	WS 23	Nil

Data have not been compiled for this example, but can be estimated; hence priority to collect data about current state is medium (

Table 16). Collecting these data is not difficult in either case (E = easy). The importance of old forest representation (based on time to recovery, and influence of objective on goal and of strategy on objective) is higher than grizzly bear habitat. Likely, other objective/strategy pairs will have higher priority for data collection.

Table 16. Hypothetical example: Priority for collecting indicator data through implementation monitoring.

Goal	Objective	Indicator	Geographic unit	Current Priority	Importance score	Ease of monitoring
Ecological integrity	Old forest representation	% of natural old	WS 3	2	4	E
Ecological integrity	Grizzly bear	Class II habitat	WS 23	2	7	E

The probability of success for old forest is high with high uncertainty (H ± H) based on current indicator values (i.e. there is currently sufficient old forest to meet the objective); the future probability of success is medium with high uncertainty (based on target values for this hypothetical ecosystem). Because of this high uncertainty, there is a high priority to complete a project to reduce this uncertainty (Table 17). Information in the Knowledge Summary lists sources of uncertainty. The grizzly bear objective/strategy pair also has high priority, but has a lower importance score and is more difficult to monitor—hence a grizzly project would have lower priority if funding was limited.

Table 17. Hypothetical example: Priority for reducing uncertainty through validation monitoring and research.

Goal	Objective	Indicator	Geographic unit	Current P(S) ± U	Future P(S) ± U	Overall Priority	Importance score	Ease of monitoring
Ecological integrity	Old forest representation	% of natural old	WS 3	H ± H	M ± H	1	4	E
Ecological integrity	Grizzly bear	Class II habitat	WS 23	H ± M	M ± M	1	7	D

Because neither grizzly bears nor old forest likely have a low probability of success (there is a small chance that they will have low probability of success due to the high uncertainty around the best estimate), neither has a high priority for effectiveness monitoring. Grizzly bear class II habitat has a low priority, and would not be listed as a topic for study; old forest would be listed as a medium priority project.

Table 18. Hypothetical example: Priority for detecting negative consequences through effectiveness monitoring.

Goal	Objective	Indicator	Geographic unit	Current P(S) ± U	Future P(S) ± U	Overall Priority	Importance score	Ease of monitoring
Ecological integrity	Old forest representation	% of natural old	WS 3	H ± H	M ± H	2	4	E to D
Ecological integrity	Grizzly bear	Class II habitat	WS 23	H ± M	M ± M	3	7	D

4 Adjusting knowledge and supporting decisions

Completed planning and monitoring projects feed back information into the adaptive management process (Figure 5). Planning projects address missing objectives, strategies or targets and feed directly into "design management strategies" in Figure 4. Completed implementation monitoring projects feed back data on current state to inform future monitoring priorities (design research and monitoring in Figure 4) and to identify implementation problems (i.e., a quality control issue). Completed projects designed to detect consequences or reduce uncertainty—investigated through monitoring, experimental management or research—update the cause-effect relationship and inform future monitoring priorities (design research and monitoring in Figure 4) and selection of management strategies (design management strategies in Figure 4).

The analysis used to prioritise monitoring provides decision support by revealing if any planned strategies are unlikely to achieve objectives based on estimated future state. For example, if analysis shows that the probability of achieving an objective is low, with low uncertainty, planning direction should be reviewed: that is, if a target is unlikely to achieve an objective, either the objective or target should be submitted for revision. If strategies are misaligned with objectives, then failure to achieve the objective cannot be attributed to lack of knowledge, but to a poor management decision. Also, if uncertainty is high but irresolvable, validation monitoring is wasted. In this case, planners may wish to select precautionary targets. Conversely, if probability of achieving the objective is high, with low uncertainty, planning direction is confirmed, and implementation monitoring is likely sufficient to achieve the objective.

Tradeoffs among objectives can also be addressed using the knowledge summary. Tradeoffs arise when different objectives depend on the same (or related) implementation indicators. For example, a timber supply objective may depend on the area available for harvesting (by productivity class) while ecological objectives may depend on area protected from harvesting. Provided that targets for each indicator adequately account for interactions between reserves and harvestable area, the Knowledge Summary provides useful information to assess the tradeoffs between the timber supply and ecological objectives: probability of achieving each objective with related uncertainty; and with importance ratings for each objective. Analysis of tradeoffs must not however be simplistic. It must consider the often multiple values related to an indicator (e.g., area protected from harvesting also influences hydrological objectives) and must consider fundamental objectives rather intermediate objectives (e.g., timber supply is an indicator or sub-objective linked to the more fundamental objective of local economic benefit). Thus, the knowledge summary identifies implementation indicators to track in simulation analyses or other calculations that project management alternatives and provides a basis for interpreting results.

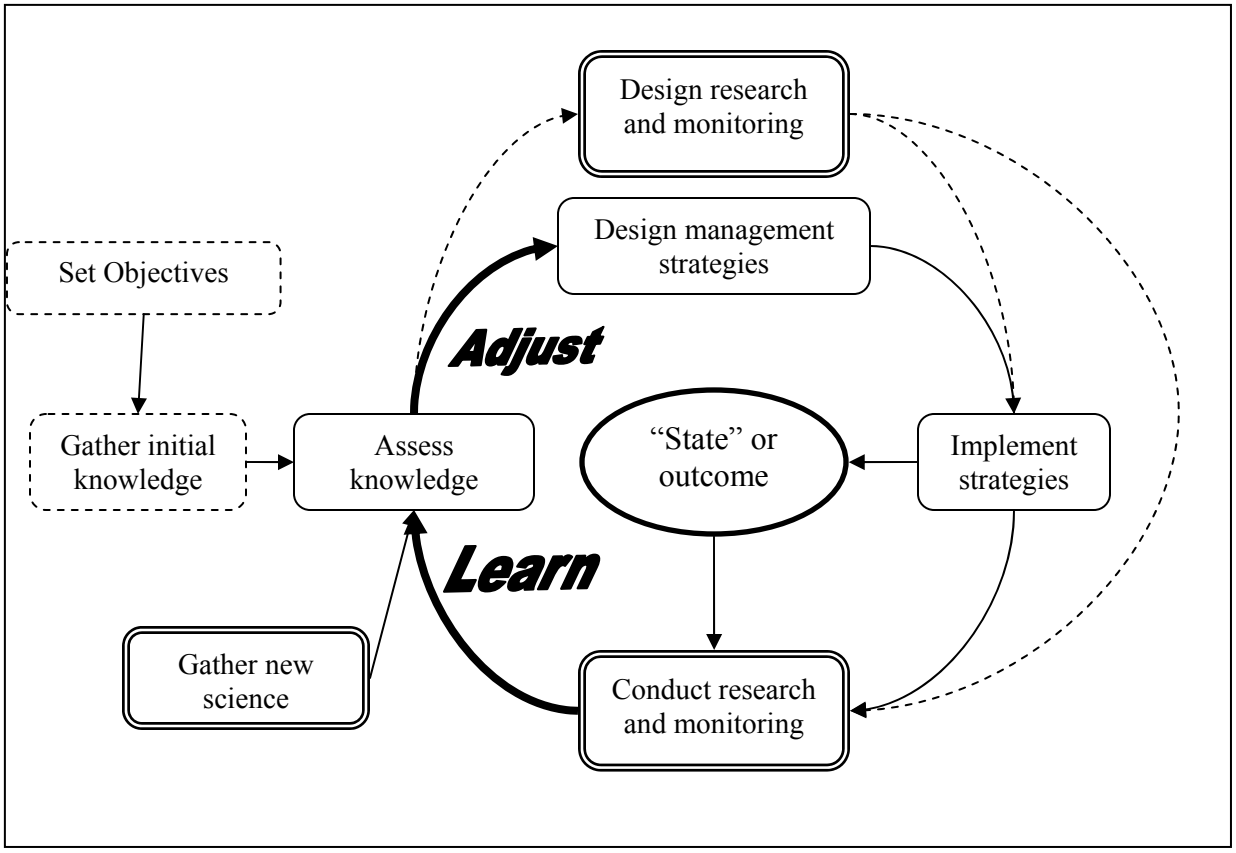


Figure 4. The adaptive management cycle, with an emphasis on monitoring and structured learning elements. The planning portion of the cycle is de-emphasized here (objectives, initial knowledge, design strategies). Over time, new scientific findings and new management-focussed monitoring and research build on existing knowledge and lead to learning and subsequent adjustment of management strategies. Current knowledge is also used to identify information gaps and priorities for future monitoring and research.

Appendix I. Glossary

Glossary of terms used in Knowledge Summary, based on EBMWG LUP Summary Terminology – Draft for Discussion – May 15, 2007.

Goal	Goals are overarching "ends". They are broadly stated, and not necessarily quantifiable or measurable. They should be clarified and supported by a set of more specific objectives. Indicators are not generally mapped directly to goals.
Objective	Objectives are specific ends that must be achieved in support of a goal. They clearly define both an end and a preferred direction, but do NOT prescribe a target. Ideally, a set of objectives will collectively describe all the components that have to be addressed in order to address a goal. Objectives are measurable via indicators and each objective should have an indicator mapped directly to it.
Sub-objective	In some cases, objectives can be further divided into components. In this case, a set of sub-objectives should collectively describe everything that's important to address with respect to a given objective, and indicators are mapped directly to the sub-objectives.
Indicator	Indicators are metrics for reporting progress toward objectives or sub-objectives. Progress can be either predicted/modeled or measured/actual.
Implementation Indicator	Indicators (metrics) that are linked to (and affected by) management strategies – they report the extent to which management strategies are implemented.
Effectiveness (Primary) Indicator	Indicators (metrics) that are linked directly to reporting change or expected change in the objectives – they report the extent to which the strategies are effective in influencing the objective. They are the primary indicators to be considered when assessing progress/performance.
Secondary (Explanatory) Indicator	Secondary indicators that report things that are not necessarily important in and of themselves, but that help to explain trends observed in other (primary) indicators. They can be useful for learning/validation but should not be used to assess performance.
Strategy	The "means" that have been adopted or are being considered for achieving the ends. That is, the actions that can be implemented to achieve or influence the objectives (as reported by the indicators). Strategies could be stated with reference to an indicator and a specified quantitative level for the indicator.
Target	A specific quantitative state of an indicator associated with a strategy that is either under consideration or has been adopted.
Threshold	A specific quantitative state of an indicator at which there is a change in rate of response.
Benchmark	A specific quantitative state of an indicator that represents a meaningful point of comparison for a true (or estimated) indicator value. Examples of benchmarks include

Appendix II. Creating and Updating the Knowledge Summary

II.1 Creating the Knowledge Summary

The Knowledge Summary stores the information—on probability of success and uncertainty and on the importance of each strategy—necessary to determine adaptive management priorities and to provide management decision support. It includes goals, objectives and strategies identified in land-use plans and summarised in the Land Use Plan Summary. Creation of the Knowledge Summary follows a simple procedure (Table 19).

Table 19. Steps to create Knowledge Summary.

1. Construct concept maps showing relationships between broad goals, objectives and management strategies. At the regional level, use information from the Land Use Plan Summary.
2. For each objective, construct and briefly explain cause-effect curves that explicitly relate each indicator (on the X-axis) to the probability of achieving the objective (on the Y-axis), using
   a. published literature,
   b. existing relationships from other areas or data for similar ecosystems (or HWB problems),
   c. expert opinion (preferably based on a workshop with several experts).

   (Note that the same information can be presented in a table, though graphs generally convey more complete information).
3. Estimate uncertainty around the cause-effect curve based on similar sources. Partition uncertainty into different sources, and estimate whether the uncertainty can be resolved. Record uncertainty for each probability-of-success class.
4. Use FREP, industry monitoring data, other available information and local knowledge to determine current indicator value. For human wellbeing indicators, these sources include HWB baselines, local knowledge, practitioners, elders
5. Use targets listed in the Land Use Plan Summary to determine probable future indicator value. (or note that targets do not yet exist)
6. Determine current and future probability of success by locating indicator values on X-axis of cause-effect curve and by reading best-estimate probability of success off the Y-axis.
7. Determine uncertainty around estimated probability of success based on step 3 above.
8. Document importance scores that modify benefits of monitoring, including
   a. influence of goal on other goals,
   b. influence of objective on goal,
   c. influence of the strategy on the objective,
   d. recovery period for objective.

   Also record uncertainty about achieving goal if all objectives are achieved.

II.2 Updating the Knowledge Summary

The Knowledge Summary and priority tables are designed to be living documents. Their usefulness depends upon regular updates to ensure that the Knowledge Summary contains the most recent information, and that adaptive management priorities are based on the most recent information. Each year, the need to revise or update the Knowledge Summary should be assessed and considered along with other funding priorities (Table 7).

Table 20. Assessing the need to update the Knowledge Summary.

1. Have the results of recent local research and monitoring studies been included in Knowledge Base (see list of updates under each goal in the Knowledge Summary and compare to summary of annual monitoring reports)
   a. if yes, proceed with prioritization
   b. if no, note that updating Knowledge Base should be considered; the priority for funding this task depends on the number of studies that need to be added
2. Has the information in Knowledge Summary been reviewed within the last five years by topic experts to incorporate relevant published results from other regions (see review dates in Knowledge Summary)?
   a. if yes, proceed with prioritization
   b. if no, note that conducting a review is high priority and proceed
3. Are the Tables of Monitoring Priorities based on the latest version of Knowledge Summary.
   a. if yes, proceed with the using priorities
   b. if no, note that revising the tables is a high priority and proceed