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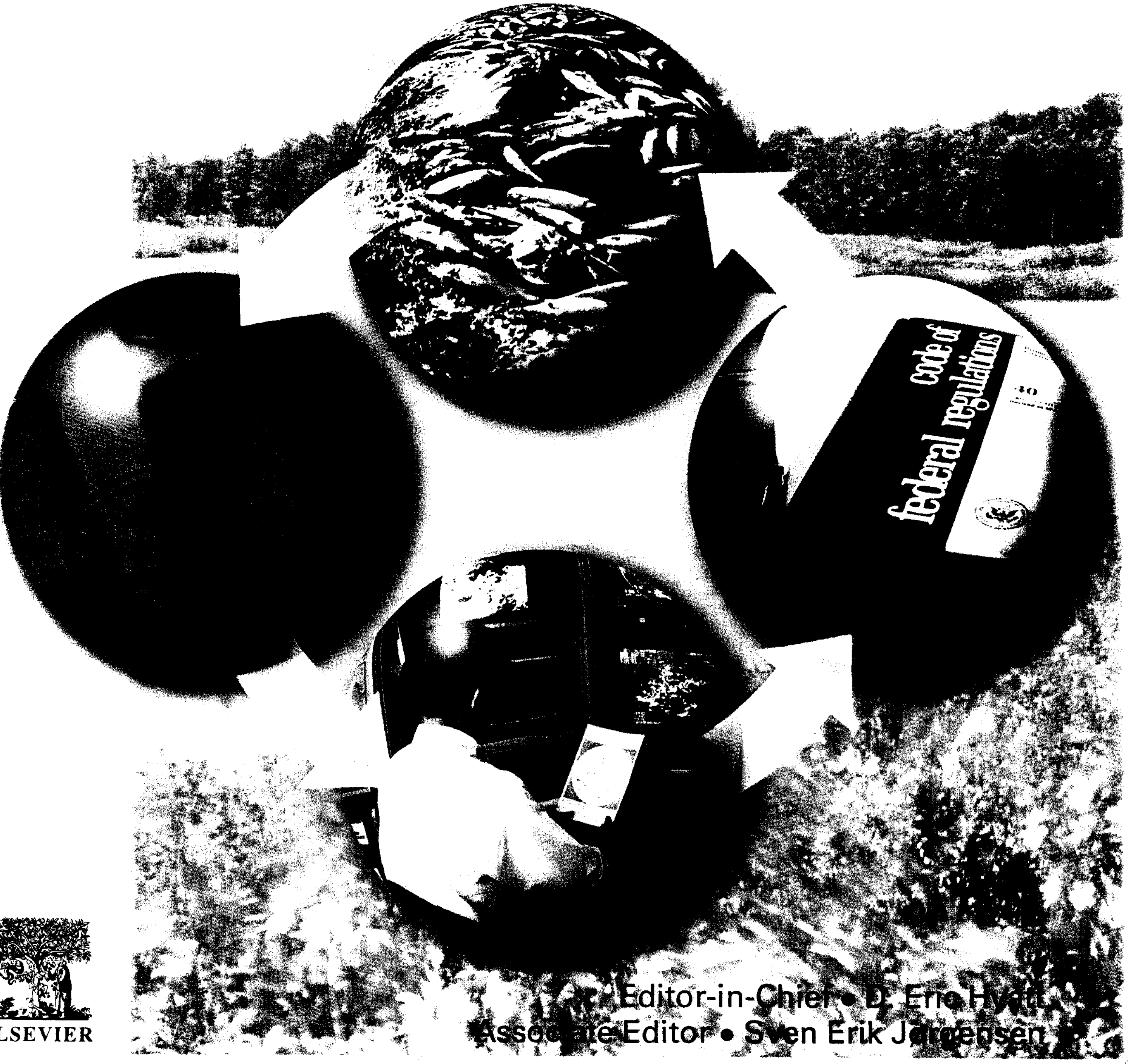

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Cost considerations for long-term ecological monitoring

Lynne Caughlan [a,*], Karen L. Oakley [b,1]

[a] US Geological Survey, Midcontinent Ecological Science Center, 4512 McMurry Ave., Fort Collins, CO 80525, USA
[b] US Geological Survey, Alaska Biological Science Center, 1011 E. Tudor Rd., Anchorage, AK 99503, USA

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Abstract

For an ecological monitoring program to be successful over the long-term, the perceived benefits of the information must justify the cost. Financial limitations will always restrict the scope of a monitoring program, hence the program's focus must be carefully prioritized. Clearly identifying the costs and benefits of a program will assist in this prioritization process, but this is easier said than done. Frequently, the true costs of monitoring are not recognized and are, therefore, underestimated. Benefits are rarely evaluated, because they are difficult to quantify. The intent of this review is to assist the designers and managers of long-term ecological monitoring programs by providing a general framework for building and operating a cost-effective program. Previous considerations of monitoring costs have focused on sampling design optimization. We present cost considerations of monitoring in a broader context. We explore monitoring costs, including both budgetary costs, what dollars are spent on, and economic costs, which include opportunity costs. Often, the largest portion of a monitoring program budget is spent on data collection, and other, critical aspects of the program, such as scientific oversight, training, data management, quality assurance, and reporting, are neglected. Recognizing and budgeting for all program costs is therefore a key factor in a program's longevity. The close relationship between statistical issues and cost is discussed, highlighting the importance of sampling design, replication and power, and comparing the costs of alternative designs through pilot studies and simulation modeling. A monitoring program development process that includes explicit checkpoints for considering costs is presented. The first checkpoint occurs during the setting of objectives and during sampling design optimization. The last checkpoint occurs once the basic shape of the program is known, and the costs and benefits, or alternatively the cost-effectiveness, of each program element can be evaluated. Moving into the implementation phase without careful evaluation of costs and benefits is risky because if costs are later found to exceed benefits, the program will fail. The costs of development, which can be quite high, will have been largely wasted. Realistic expectations of costs and benefits will help ensure that monitoring programs survive the early, turbulent stages of development and the challenges posed by fluctuating budgets during implementation.

Keywords: Assessment; Cost–benefit; Cost-effectiveness; Ecological; Environmental; Monitoring; Sampling design

1. Introduction

Hinds (1984) observed that successful ecological monitoring programs must be ecologically relevant, statistically credible, and cost-effective. Programs that neglect any one of these critical areas will face problems and likely fail. We explore the third part of Hinds (1984) tripartite requirement—cost-effectiveness. To

* Corresponding author. Fax: +1-970-226-9230.
E-mail addresses: lynne_caughlan@usgs.gov (L. Caughlan), karen_oakley@usgs.gov (K.L. Oakley).
[1] Fax: +1-907-786-3636.

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be successful over the long-term, the benefits of the information from any monitoring program must justify the cost. That is, the monitoring program should answer the questions that it was put in place to address. Financial limitations will always restrict the scope of a monitoring program, hence a monitoring program's focus must be carefully prioritized so that the most effective set of ecological indicators can be found to produce information about social concerns within a limited budget. The final choice of ecological indicators, therefore, should be guided as much by the costs to address appropriate questions about a resource as by the science of how to collect and analyze data.

While costs are clearly a central issue for long-term ecological monitoring programs, guidelines for providing a holistic treatment of the costs associated with monitoring are not available. Existing guidelines for cost-effective resource monitoring focus only on monitoring related to industrial pollution and compliance (e.g. Hanks, 1993; Sutherland et al., 1996; Ontario Ministry of the Environment, 1997; Harford, 2000). In the industrial context, the cost of a monitoring program can be readily justified because the program's costs and benefits can be weighed against the amount of a fine or other legal penalties for violations. Justifying the cost of an ecological monitoring program is more difficult because the benefits accrue over many years and are unlikely to be realized by current program managers. In addition, the benefits of monitoring may not be easily expressed in monetary terms, making comparison of costs to benefits difficult. Many ecological monitoring programs address how much a program costs in budgetary terms, but typically do not address how to make program elements more cost-effective (Shaw et al., 1993; Berg, 1995).

The intent of this review is to assist the designers and managers of long-term ecological monitoring programs by providing a general framework for building and operating a cost-effective program. We characterize types of monitoring costs, review the close relationship between statistical issues and cost, and suggest checkpoints in the monitoring program design process where costs should be explicitly considered. By including cost considerations, monitoring program managers will develop more realistic expectations of costs and benefits and will be more likely to develop programs that meet Hinds (1984) requirement of cost-effectiveness.

2. Monitoring costs

We begin by introducing two basic categories of monitoring cost. *Budgetary costs* are the actual dollars spent in the process of developing and operating a monitoring program. Identifying budgetary costs is important because costs for activities crucial to the success of monitoring that are overlooked can threaten the quality of a monitoring program. We also consider *economic costs* of monitoring, which include the opportunity costs of the dollars spent on monitoring. Economic costs are important to understand because it is these costs against which the program's benefits will ultimately be compared.

2.1. Budgetary costs: how is money spent

Budgetary costs are the out of pocket, or cash costs. They include: (1) the start-up, or development costs, and (2) the costs of regular monitoring once the program is operational. In general, the costs to develop a program are much greater than the annual costs to run the program. Start-up costs should include an objective-setting process, drafting of a conceptual design, methodological pilot studies, and development of administrative support systems. The start-up period likely will occur over several years. A failure to adequately invest in program development will likely result in a poorly planned program which will fail to meet its objectives, requiring major course changes (e.g. Oakley et al., 1999), or resulting in cancellation. The high costs of starting up a program, and the time delay in obtaining initial monitoring results, should be acknowledged so the value of the program is not judged prematurely.

Once a monitoring program is operational, budgetary costs can be divided into the following major categories: (1) scientific oversight; (2) data collection including labor, training, travel, supplies and equipment; (3) data management; (4) quality assurance (QA); (5) data analysis and reporting; (6) administration, and (7) other expenses such as depreciation.

Monitoring is a scientific activity and requires supervision by qualified scientists. The cost of designating a lead scientist responsible for the design, collection, analysis, interpretation, and reporting of data is often overlooked. The salary of the lead scientist may be paid by other portions of an agency's budget, leading to an underestimate of the true monitoring budget. Recognizing and including the costs associated with scientific oversight is important, because qualified scientists are highly paid and will need to be hired on a long-term basis to be effective. The costs of scientific oversight can therefore be a significant part of the budget but these costs are typically taken for granted and therefore ignored. Another problem can be the assignment of these scientific duties to persons without proper training or credentials.

Frequently, the largest portion of a monitoring program budget is spent on costs associated with data collection. For example, for three monitoring surveys in western Australia, data collection costs ranged from 60 to 69% of the total budget (Burbidge, 1991). In these same surveys, the amount spent on data analysis was less than 1%. This domination of project budgets by data collection costs is not atypical. Costs of proper data management and reporting systems are often underestimated or not accounted for at all. Fancy (1999), reviewing the progress of US National Parks in setting up long-term monitoring programs, found that most had encountered problems because they did not allocate enough time and funding for database development, data entry, data validation, analysis, interpretation, and reporting of monitoring data. Experience from these and other programs shows that 25–30% of the monitoring program budget should be used for data management, assessment, and reporting (Graber et al., 1993; Fancy, 1999; Mulder et al., 1999).

Another critical component of a monitoring program that should be explicitly budgeted for is quality assessment. QA is defined as all systematic actions necessary to provide adequate confidence that a product or service will satisfy given requirements of quality (Shampine, 1993; Lane, 1997). For an ecological monitoring program, QA means that the data are of known quality that is adequate to meet the program's objectives. Quality controls (QCs) are an important part of QA. QCs are aspects under an investigator's control such as instrument calibration and checklists (Clark and Whitfield, 1993). The use of a QA plan can increase the cost-effectiveness of a monitoring program by minimizing the amount of work lost or that must be repeated due to faulty measurements (Shampine, 1993).

The intensity and cost of a QA program should vary depending on the purpose of the study (Young et al., 1992). Clark and Whitfield (1993) suggested that at least 30% of the overall budget should be allocated to QA. The costs of poor management decisions based on faulty data must also be considered when budgeting for the QA aspects of a monitoring program (Geoghegan, 1996). Where there are major flaws in procedures, methods, or equipment to be corrected, over 50% of the budget can go to QA (Clark and Whitfield, 1993). Ongoing long-term monitoring program QA costs will decrease yearly as data quality increases, and the proper way to collect data becomes the only way to collect data (Geoghegan, 1996).

Turnover in personnel is a major constraint to long-term monitoring. No matter what method is used in data collection strategies, changes in the personnel collecting the data can lead to significant shifts in the mean level or variability of a measurement (Beard et al., 1999). If high personnel turnover is expected, techniques should be chosen that are as insensitive as possible to differences among observers because preventing measurement error is generally easier than correcting it (Davis, 1989; Lesser and Kalsbeek, 1999). Training of observers is an important mechanism for reducing differences among observers and should be an adequately funded part of a monitoring program budget.

Reporting of monitoring data is an especially important element of successful programs, because reporting communicates results, demonstrating the value of the program. Mechanisms of reporting are often inadequate because they are not timely or targeted to audiences whose support is essential. Monitoring program managers should recognize that monitoring data have a variety of audiences, including the public, scientists, and land and resource managers. Appropriate reporting mechanisms for each audience will vary. Establishing reporting mechanisms early in a program is also important for building awareness of and support during the critical early days.

Given the scope and magnitude of a long-term monitoring program, a stable and long-term base commitment to funding and staffing is needed for every program element (Stohlgren et al., 1995; Mulder et al., 1999). Managers reviewing budgets for monitoring programs should be aware of the need for the activities discussed here and expect to see them budgeted for. Failure to account for these costs will short-circuit the monitoring process. The most likely situation is that data will be collected, but never analyzed or reported upon, and their quality will not be known. To avoid this situation, the many activities that must occur to create a viable monitoring program must be recognized and adequately funded.

2.2. *Economic costs: what monitoring really costs*

An economic evaluation of a long-term monitoring program adds an analysis of the opportunity costs to the budgetary costs (Loomis and Walsh, 1997). The opportunity costs of a monitoring program are the benefits forgone by allocating resources to monitoring rather than to some other management activity (Noble and Norton, 1991). When measuring opportunity costs, all consequences of the monitoring program must be identified and incorporated into the measurement (Loomis and Walsh, 1997).

For a complete evaluation of the cost of a monitoring program, opportunity costs must be estimated for all program aspects, whether they are correctly or incorrectly priced by markets or not priced at all (Loomis and Walsh, 1997). Market prices exist for many of the costs associated with monitoring, including an employee's hourly time spent on monitoring, travel, equipment, and data analysis. These costs can vary with the size of study area, number or types of species surveyed, ease of species identification, type of survey design including number of site visits and time required, and distance to survey area (Burbidge, 1991). Other costs, such as depreciation, are less obvious but can still be priced in terms of market values.

Economic costs of a monitoring program include external costs. External costs are those costs that fall on others and which are not directly covered by the monitoring program budget (Loomis and Walsh, 1997). For example, some monitoring activities occur as part of research funded by other programs. These external costs are subsidized by agency activities not paid for by the monitoring budget. Other examples of subsidized costs include monitoring personnel staying overnight without cost at an agency camp instead of a hotel, the use of government vehicles not assigned to the monitoring program, or relying on scientists in another agency for oversight or analysis of monitoring data. A proposed monitoring program should not increase the costs of these other efforts, but should help refine these efforts and make better use of collected data (Mulder et al., 1999). However, there are risks to leveraging the monitoring program by relying on subsidized costs. If changes occur that result in the loss of the subsidy, the monitoring program may suffer.

Placing a dollar value on some subsidized costs is relatively easy. Some costs, however, are difficult to quantify in terms of market values. Non-market values refer to goods and services that cannot be bought or sold, but still have economic value (Green and Tunstall, 1991). Examples of non-market monitoring costs include the costs imposed on the public by using helicopters to access an area for monitoring that the public expected to be free from mechanical noise, or accounting for the cost of a Type II statistical error (failing to detect a change that has occurred). If a Type II statistical error results in irreversible ecological harm, the benefit of monitoring is high, relative to its cost. Economic valuations of non-market costs are more complex but need to be included when determining the total cost of a monitoring program. Including, for example, the cost of closing a highly visited trail to collect monitoring data may change the basic indicators that are most efficient for a monitoring program to collect.

2.3. *Statistical issues: choosing what to monitor*

Statistical considerations and cost considerations for long-term monitoring are closely related. For the data from a monitoring program to be credible, they must be collected according to a valid scientific design based on sampling. However, the ideal sampling regime can rarely be afforded. Thus begins the process of choosing a design that is within the budget but that can still produce data to meet the stated objectives.

Because it is unrealistic and cost prohibitive to monitor everything of interest to an environmental monitoring program, statistical sampling must be included as part of the program design. The statistical design stage is fundamental to ensuring cost-effective sampling programs, and is often done poorly or not at all (Maher et al., 1994). A review of the statistical designs of national long-term environmental monitoring programs in the US showed that data are not being collected in a cost-efficient manner and that all programs would benefit from being part of a collective effort (Olsen et al., 1999). The type and level of statistical analysis will depend on the purpose of monitoring.

Not every quantitative characteristic needs to be measured unless it is required to answer a specific objective (US Environmental Protection Agency, 1995). In some cases, easily measured parameters can be used as surrogates for others that are more costly (Burbidge, 1991; MacDonald et al., 1991; Silsbee and Peterson, 1993). If these data are relevant to the objectives, they should be used instead of more costly parameters.

The level of replication must be considered as a part of the statistical design. Replication in time is a critical part of an environmental sampling design (Noble and Norton, 1991). Without replication, monitoring programs run the risk of only being able to detect catastrophic events or sampling far more than is needed. Achieving the correct level of replication can reduce costs by decreasing the costs associated with detecting changes after it is too late if not enough samples are taken, or reducing the amount of money spent on over sampling. The appropriate replicate structure will vary for each sampling program and consequently, should be analyzed as part of the statistical design process. Another type of cost to consider is that of not properly reporting statistical power. Low power is an important concern for ecological monitoring programs (Fairweather, 1991). Power calculations indicate the sample size needed to detect a change. Power is inversely related to the probability of making a Type II error. For ecological monitoring, a Type II error is made when it is concluded that no change has occurred even though one has (Fairweather, 1991). A Type I error is the mistake of concluding that there is a change when one has not occurred. A low power indicates a high probability of Type II error (Fairweather, 1991).

When developing a monitoring program, statistical power should be considered during the objective-setting stage. Prospective power analysis can guide the design and determine the sampling effort needed to have a high probability of detecting change (Steidl et al., 1997). A poorly designed monitoring program can lead researchers to falsely conclude that a significant change has not been detected (Bernstein and Zalinski, 1983). To make informed management decisions, managers must not equate scientists' failure to reject some null hypothesis with the assertion that the null hypothesis is true (Peterman, 1990). Decision makers who take action assuming that the null hypothesis of "no change" is true, without considering power, are implicitly assuming that Type II errors are less costly than Type I errors. In an ecological context, Type II errors are likely to be more costly than Type I errors (Peterman, 1990; Fairweather, 1991). Fighting a false alarm (Type I error) can only continue until the mistake is discovered, thus the costs are short-term. The costs of not taking action, when action should be taken, will be immediate and long-term, as ecological damage occurs. The damage may be costly to repair or irreversible.

The easiest way to increase power is to increase the number of samples at each level of replication. Although the number of samples increases the statistical precision, cost also increases and at some point the diminishing returns in power become marginal (Fairweather, 1991). This precision to cost trade-off allows room for optimization in any sampling design (Bernstein and Zalinski, 1983; Kingston and Riddle, 1989; Fairweather, 1991).

The testing of sampling procedures in pilot studies to ensure that the best design has been chosen is a critical part of developing a monitoring program (Duffy et al., 1981; Resh and Price, 1984; Holland-Bartels et al., 1995; Heidelbaugh and Nelson, 1996; MacNally, 1997; Bartsch et al., 1998; Schreuder et al., 1999). Modeling can be also be used to simulate monitoring designs, with their associated costs, providing confidence that the selected design can detect the type of changes the program intends to detect within the available budget (Austin and Adomeit, 1993; Belbin and Austin, 1993; Lesser and Kalsbeek, 1997; Starfield, 1997). Modeling of alternative designs is an inexpensive way to select the best design for the objectives and budget and is an indispensable complement to pilot studies.

2.4. Incorporating cost considerations

Several authors have recommended steps in monitoring procedures (Hinds, 1984; MacDonald et al., 1991; Silsbee and Peterson, 1993; Maher et al., 1994; Elzinga et al., 1998; Vos et al., 2000). We consolidated and integrated these steps to illustrate an idealized process that includes checkpoints where costs are considered (Fig. 1). This development process includes three major stages: design, testing, and implementation. Cost considerations play a critical role during the design stage when setting the objectives and optimizing the statistical design. If cost considerations are

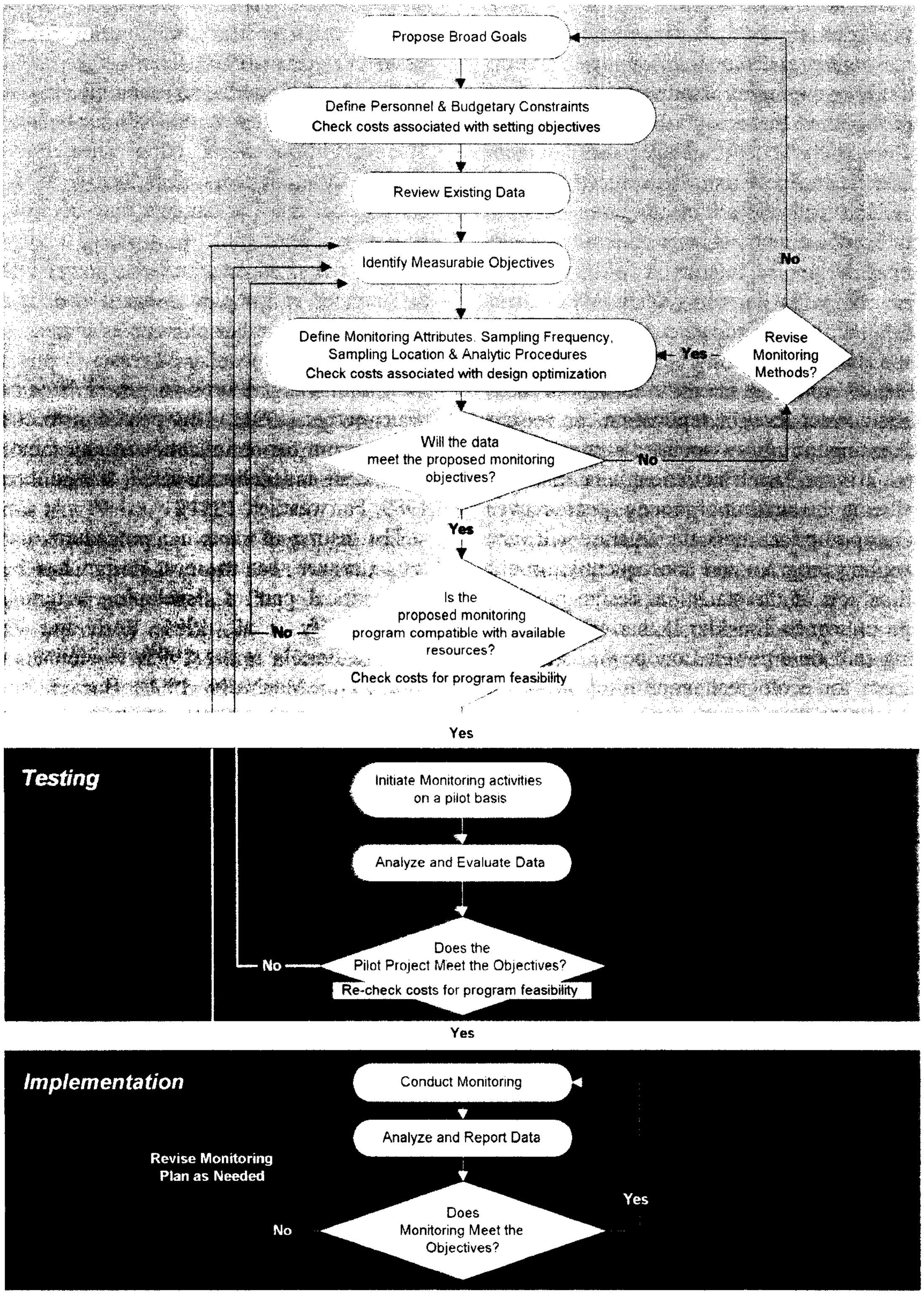

Fig. 1. Monitoring program development process.

correctly incorporated during the design stage, then cost issues in the testing and implementation stages serve as a check of the program's feasibility. Therefore, we focus on how to incorporate costs during the design stage.

2.5. Setting objectives

Carefully defining the objectives in the design stage is often the most difficult and critical element of developing a monitoring program (Garton, 1984; MacDonald et al., 1991; Silsbee and Peterson, 1993; Schmoldt et al., 1994; Pastorok et al., 1997). Frequently, the objectives of a monitoring program are not well-defined or closely tied to what the program is trying to accomplish (Noble and Norton, 1991; Olsen et al., 1999). The result is that time and money are wasted in trying to decide what to monitor and how to do it (Silsbee and Peterson, 1993). The design of a monitoring program cannot be optimized without knowing the objectives. However, it is possible to optimize the design to meet monitoring objectives that are not important to the overall goals of the organization doing the monitoring. The importance of setting appropriate and clear objectives cannot be overemphasized.

Frequently, resource managers want to simultaneously meet multiple objectives, which greatly complicates the setting of priorities. Investing in a planning process for setting clear objectives that are logically linked to the purposes of the organization doing the monitoring is probably the single most important investment the designers of a program can make. The analytic hierarchy process is one such planning method and shows great promise as a technique in this context, especially where multiple objectives are involved (Schmoldt and Peterson, 2000).

Initially, the process of setting objectives can and probably should occur without consideration of budgetary costs. Determining the most important attributes to monitor to meet management objectives is independent of the resources available to do the work. A thorough evaluation of benefits at this stage, however, is critical. In this regard, a consideration of the economic costs of not conducting the monitoring program can be extremely helpful. That is, what are the consequences of failing to detect a change that has occurred (i.e. making a Type II error)? If a Type II error results in irreversible ecological harm, the benefit of monitoring is high, relative to its cost. Thinking through the relative costs and benefits, in a broad economic sense, is an important part of the objective-setting stage—it sets the foundation for the entire program. Once that foundation is set, managers can more easily make decisions necessitated by the financial realities of limited and fluctuating budgets, as the planning process continues.

2.6. Planning for the reality of limited and fluctuating budgets

Monitoring costs are usually erroneously treated as fixed constraints, rather than as variables that can be manipulated or controlled (Silsbee and Peterson, 1993). Fixed costs are those that do not vary with changes in the monitoring program in the short-term. In this case, fixed costs include capital investment, administrative overhead, and a fixed budget for variable costs. Variable costs are those that vary directly with changes in the monitoring program. Variable costs will increase with sampling frequency and number of samples. Variable costs include operation and maintenance including labor, expendable supplies, and utilities (Loomis and Walsh, 1997). Variable costs can usually be manipulated internally to address changes in priorities. Fixed costs, however, might be changed for the better or worse, and are most often outside the monitoring program's control. Therefore, a monitoring program needs a plan that will be flexible, allowing for and being prepared for changes in the budget.

Fixed costs will restrict the scope of a monitoring program. Because budgets can fluctuate year-to-year, a monitoring program's focus of effort must be prioritized when the objectives are set. Some protocol elements under consideration could be so costly that they could easily be eliminated in the beginning before time and money are wasted.

During planning, including the objective-setting stage, we recommend keeping in mind the upper and lower bounds of financial resources available for the program. This approach to planning helps ensure that the design is robust enough to survive variations in annual funding. As with any government program subject to annual appropriations by a legislative body, it must be anticipated that the budget may decline, stay the same, or even increase, all due to factors that are outside the control of program managers. For a long-term program to be successful, however, it must be ensured that core data sets are identified and the cheapest methods of collecting those data must be known and compatible. At the same time, it is important to know what are the most critical things to do next, should additional money become available.

To help keep a monitoring program operating within realistic constraints, we recommend that managers plan for operating under three levels of funding. We call this a tiered approach.

- Tier 1 assumes a low level of funding for the monitoring program. An example of Tier 1 would be assuming that all monitoring must be paid for with existing budgets using existing staff. For the purposes of planning, Tier 1 represents the lower bound.
- Tier 2 assumes a moderate level of funding for the program. Tier 2 is the expected budget under normal circumstances.
- Tier 3 assumes that additional money becomes available. The extra funding could result from legislative appropriations aimed at expanding the program or from one-time pulses aimed at specific issues. Tier 3 represents the best-case scenario. For the purposes of planning, Tier 3 is the upper bound.

Multiple benefits arise from putting financial sideboards on the design process. First, under Tier 1, core data sets that have the highest value are identified. Planning for the worst will help identify creative ways of keeping critical data series going, even under the most dire financial circumstances. Tier 3, which represents the most optimistic view for the amount of money that could be allocated to a monitoring program, provides an upper bound to constrain planning. By establishing a plan for unplanned influxes of money, the Tier 3 situation, managers will not be as tempted to make drastic changes unlikely to be supported in the long run. For program planning to have meaning, these upper and lower bounds are critical. Any monitoring program needs to prioritize its effort, and prioritization without constraints is not possible.

The way to incorporate the tiers into the design is by having each protocol be developed to address the effort that would be made under the three tiers. Program managers will then have options when dealing with fluctuating budgets. Finding statistical designs that are compatible with these expected variations in sampling effort is challenging, but solutions are possible (e.g. Arbria and LaFratta, 1997) and advice from statisticians should be sought. Recognizing the need to incorporate variable sampling effort into the design will be vital to the program's long-term success.

2.7. *Initial protocol development*

After objectives have been defined, protocols must be developed and tested for each specific ecological attribute to be monitored. Development of monitoring protocols is dictated by project funding limitations and the intensity of sampling needed to give useful and meaningful results (Hinds, 1984). A comprehensive protocol should include detailed information about every aspect of the monitoring element including the goals and objectives, site selection, equipment description and setup, sampling frequency and intensity, analysis routines, QC procedures, and reporting (Thorsteinson and Taylor, 1997; Oakley and Boudreau, 2000).

As discussed earlier, statistical sampling costs to consider include optimization of the statistical sampling design, statistical power, and statistical replication. A statistical perspective will contribute to ensuring that information gathered is scientifically defensible and that the stated objectives have been met in a way that is cost-effective (Olsen et al., 1999). Once sampling protocols have been developed, a pilot study should be conducted to test whether the objectives can be met at a reasonable cost (Hinds, 1984). If the stated objectives cannot be met, the objectives must be changed or the methods revised before monitoring should begin (Oakley and Boudreau, 2000).

2.8. *Completing the design phase: comparing costs and benefits*

Once generally affordable monitoring program elements are determined and their costs outlined, the next step is to choose the elements that are the most cost-effective. These elements provide the most useful knowledge per dollar spent. To do this, the perceived benefits expected to result from each element should be compared to costs. Two methods of comparison are available. When benefits can be quantified, cost–benefit analysis should be used. When the value of benefits from monitoring are unknown, which is generally the case, the cost-effectiveness approach should be used.

2.8.1. Comparing costs to benefits

While economic values can be determined for market and non-market costs, the benefits of a monitoring program are more difficult to quantify because many benefits are long-term and may not yet be realized. Due to the significant time lag on benefit realization, the program manager in charge of current budget allocations may not be in position long enough to recognize the benefits associated with spending today's dollars for tomorrow's benefits. This sets long-term ecological monitoring apart from other monitoring programs such as compliance monitoring. Benefits can include identification of endangered species, resolution of land use conflicts, clarification of a species status, better management practices, and setting priorities for future studies (Burbidge, 1991). Long-term monitoring can provide beneficial information including: basic background information that is always needed by researchers, managers, and the public; providing a kind of "canary in the mine" early warning signal to warn of the effects of human activities before they are noticeable in less pristine areas; and providing a reference point to which less pristine areas can be compared (Silsbee and Peterson, 1993).

Every monitoring program element requires part of the program's budget and personnel resources. Cost–benefit analysis can sometimes be used as a selection criterion for such resource allocation problems (Saaty, 1980). Under cost–benefit analysis, projects with the best economic pay-off are most desirable. However, the goal of planning a monitoring program is to do the "most" monitoring work for the given budget and personnel limitations, where "most" is defined as the greatest total program value which may not be the same as the best economic pay-off (Schmoldt et al., 1994). This is particularly true when the program's benefits are intangible and not quantifiable in dollar terms and are thus omitted from the benefit–cost ratio (Sassone and Schaffer, 1978). If benefits are omitted, the monitoring program's best economic pay-off will be judged by the total quantity, not the quality, of monitoring for the given budget. Cost–benefit analysis should not be used to evaluate an entire program when benefits cannot be measured in dollar terms. Underestimating the value of a program's benefits in a cost–benefit ratio will inaccurately diminish the importance of the program.

2.8.2. Cost-effectiveness

Cost-effectiveness analysis provides a way to help make budgeting decisions when costs can be measured in dollar values but benefits cannot. Measures of cost are the same as for benefit–cost studies, although measures of benefits may be in units other than dollar values, such as physical units of output or a scale of effectiveness prepared by an informed manager (Loomis and Walsh, 1997). The results are usually presented as a ratio in which the non-monetary measure of effectiveness is divided by the costs. The US National Park Service (NPS) authorized the use of cost-effectiveness analysis in 1976. Since then, its main use within the NPS has been for the evaluation of alternative park management plans (Loomis and Walsh, 1997). Although cost-effectiveness has not yet been directly used to evaluate park monitoring programs, it has been used to develop an optimal cost-effective biota sampling program with approval from the Environmental Protection Agency (Duffy et al., 1981).

Cost-effectiveness analysis gives the decision-maker a way to compare alternative program elements by minimizing dollar cost subject to some required output level that is not measurable in dollar terms, or to maximize some output level of program results subject to a fixed budget constraint (Loomis and Walsh, 1997). Both cost-effectiveness techniques provide decision-makers with a way to include benefits that are intangible and not measurable in dollars. This allows for a more complete program evaluation as compared to using cost–benefit analysis where intangible benefits are omitted. Cost-effectiveness analysis may be of substantial assistance in the development of monitoring programs.

3. Discussion

Long-term ecological monitoring programs will have a much greater chance of success if cost considerations are explicitly incorporated into the program's framework. Cost issues should be considered during the setting of objectives and development of the sampling design and by frequently checking the program's feasibility with current and future financial resources. Typically, relatively too much time and money are spent on data collection and not enough consideration is given to program development, data management and analysis, interpretation, and reporting. When identifying the objectives of a monitoring program, the program's costs, including opportunity costs and external costs, should be compared to the perceived benefits. Identifying the costs and perceived benefits of a program's objectives will assist in prioritizing what is most important to include in the program now, and what the next steps should be if additional funding becomes available. Failure to properly account for how much all program aspects cost now and in the future will diminish the chances of the program's success over the long-term, especially when budgets are uncertain.

We propose the following questions as a checklist for taking cost considerations into account.

1. Have clear objectives linked to the broad goals of the organization been set?
2. Have economic costs and benefits been considered? Will the benefits of the program outweigh the costs, including opportunity costs?
3. Have the costs of a Type II error been considered?
4. Have the financial bounds (high, medium, and low) of the budgets available to operate the monitoring program been identified?
5. Has an adequate start-up phase been budgeted for?
6. Have sampling designs been optimized?
7. Have all *budgetary costs* for operational monitoring program elements been taken into account? Are scientific oversight, training, data management, quality assurance/quality control, reporting, etc. provided for in the budget?
8. Has a cost–benefit or cost-effectiveness analysis been performed?

One way to incorporate cost considerations into the design and operation of long-term monitoring programs will be to seek input and review by resource economists. Economists can help identify the economic costs and benefits of a developing program, and can guide the challenging process of comparing costs and benefits or determining cost-effectiveness. By their nature, ecological monitoring programs are developed and operated by multidisciplinary teams working closely with resource managers. We suggest that economists can make valuable contributions to such teams by providing insight into true costs of monitoring programs and by helping clarify benefits. Realistic expectations of monitoring costs and benefits will help ensure that monitoring programs survive the early, turbulent stages of development and the challenges posed by fluctuating budgets during implementation.

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