Contributed Paper

Current Trends in Plant and Animal Population Monitoring

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Abstract: *Animal and plant population monitoring programs are critical for identifying species at risk, evaluating the effects of management or harvest, and tracking invasive and pest species. Nevertheless, monitoring activities are highly decentralized, which makes it difficult for researchers or conservation planners to get a good general picture of what real-world monitoring programs actually entail. We used a Web-based survey to collect information on population monitoring programs. The survey focused on basic questions about each program, including motivations for monitoring, types of data being collected, spatiotemporal design of the program, and reasons for choosing that design. We received responses from 311 people involved in monitoring of various species and used these responses to summarize ongoing monitoring efforts. We also used responses to determine whether monitoring strategies have changed over time and whether they differed among monitoring agencies. Most commonly, monitoring entailed collection of count data at multiple sites with the primary goal of detecting trends. But we also found that goals and strategies for monitoring appeared to be diversifying, that area-occupied and presence–absence approaches appeared to be gaining in popularity, and that several other promising approaches (monitoring to reduce parameter uncertainty, risk-based monitoring, and directly linking monitoring data to management decisions) have yet to become widely established. We suggest that improved communication between researchers studying monitoring designs and those who are charged with putting these designs into practice could further improve monitoring programs and better match sampling designs to the objectives of monitoring programs.*

Keywords: biodiversity, government agencies, monitoring programs, nongovernmental organizations, population decline, population monitoring, sampling designs

Tendencias Actuales en el Monitoreo de Poblaciones de Plantas y Animales

Resumen: *Los programas de monitoreo de poblaciones de animales y plantas son críticos para la identificación de especies en riesgo, la evaluación de efectos del manejo o cosecha y el seguimiento de especies plaga e invasoras. Sin embargo, las actividades de monitoreo están muy descentralizadas, lo que dificulta que los investigadores o los planificadores de conservación tengan un buena imagen general de lo que significan los programas de monitoreo en el mundo real. Utilizamos un muestreo basado en la Red para colectar información sobre programas de monitoreo de poblaciones. El muestreo se concentró en preguntas básicas sobre cada programa, y las razones para seleccionar ese diseño. Recibimos respuesta de 311 personas involucradas en el monitoreo de varias especies, y utilizamos estas respuestas para resumir los esfuerzos de monitoreo actuales. También utilizamos las respuestas para determinar sí las estrategias de monitoreo han cambiado en el tiempo y sí difieren entre agencias de monitoreo. En general, el monitoreo implicó la colecta de datos de conteo en múltiples sitios con el objetivo primario de detectar tendencias. Pero también encontramos que las metas y estrategias de monitoreo eran diversas, y que los enfoques del área ocupada y de presencia- ausencia*

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parecen ser más populares, y que aun falta tiempo para que otros enfoques prometedores (monitoreo para reducir la incertidumbre de parámetros, monitoreo basado en riesgo y la vinculación directa de datos de monitoreo con la toma de decisiones de manejo) sean utilizados ampliamente. Sugerimos que una mejor comunicación entre quienes estudian el diseño del monitoreo y quienes los ponen en práctica podría mejorar los programas de monitoreo así como lograr que los diseños de muestreo correspondan a los objetivos de los programas de monitoreo.

Palabras Clave: agencias gubernamentales, biodiversidad, declinación poblacional, diseño de muestreo, monitoreo de poblaciones, organizaciones no gubernamentales, programas de monitoreo

Introduction

Monitoring plant and animal populations is one of the core activities of conservation biology. Monitoring data are used to identify species in decline or at risk of extinction (Gerber et al. 1999; Shea & Mangel 2001), to track the spread of invasive and pest species (Rooney et al. 2004; Campbell & Donlan 2005), to assess whether specific management strategies are working (Holling 1978; Lindley et al. 2000; Campbell et al. 2002), and to determine sustainable levels of harvest or take (Martell & Walters 2002; Hauser et al. 2006). Monitoring is also a highly de-centralized activity. In the United States alone, population monitoring falls under the purview of several federal agencies, state natural heritage organizations, nongovernmental organizations, academic scientists, volunteer groups, private contractors, and various partnerships among these entities. Although a number of recent efforts have begun to enhance coordination among monitoring agencies (e.g., the Natural Resource Monitoring Partnership, Partners in Flight, the Amphibian Research and Monitoring Initiative), monitoring programs still tend to be managed by many different groups that have little administrative overlap.

Partly because of this diverse oversight, population monitoring programs are themselves highly variable. Monitoring programs range from continent-wide, multispecies programs, such as the North American Breeding Bird Survey (Link & Sauer 1998; Sauer et al. 2003), to programs focused on a single species at a single site (e.g., Knox 1997). They include programs that integrate data with sophisticated mathematical models (Wikle & Royle 2005) and programs that simply attempt to determine whether or not a species is present at a given site (Manley et al. 2005). Some primarily rely on mark-recapture data (Freedberg & Bowne 2006), others use data from harvests (Tolimieri & Levin 2005), and still others use remote sensing (Robinson et al. 2001).

The diversity of monitoring programs makes it difficult for researchers, resource managers, or conservation planners to get a good general picture of what real-world monitoring programs entail. Although a number of reviews have made recommendations for monitoring programs (e.g., Gibbs et al. 1998; Yoccoz et al. 2001; Witmer 2005), there is little information available on the extent to which these recommendations are influencing monitoring programs on the ground. This means that it is often challenging for those involved in monitoring to know whether their programs are compatible with programs for other species or at other agencies. Furthermore, the search for optimal designs for monitoring programs has become a fertile area for research. Researchers have compared the statistical power or efficiency of various monitoring strategies (Strayer 1999; Field et al. 2005; Joseph et al. 2006; Pollock 2006), proposed methods for linking monitoring activity directly to management decisions (Yokomizo et al. 2003; Gerber et al. 2005), and developed more sophisticated (and potentially more useful) approaches for collecting and analyzing monitoring data (Wikle & Royle 1999, 2005; MacKenzie et al. 2005; Staples et al. 2005). Nevertheless, without a good general picture of existing monitoring programs, it is difficult to know whether this research is being used or even whether it is relevant to the majority of existing monitoring programs.

We used an on-line survey tool (SurveyMonkey, Portland, Oregon) to survey a large segment of the monitoring community of North America and, to a lesser extent, Europe. We set out to develop a general understanding of what species are being monitored, how they are being monitored, why they are being monitored, and what considerations have shaped the design of monitoring programs. In addition, we used the results of the survey to examine how monitoring programs have changed over the past 2 decades and to examine differences in monitoring programs run by distinct types of entities (e.g., government agencies vs. nongovernmental organizations).

Methods

Survey Questions

We designed the survey to assess how population monitoring programs were being carried out and why they were being carried out in that way. With respect to general background information, we inquired about the type of organism being monitored, the country and habitat in

which monitoring was taking place, the type of organization doing the monitoring, and the number of years the monitoring program has been running. With respect to methodology, we asked about the number of sites surveyed, the frequency of visits to each site, the spatiotemporal sampling scheme, the types of data being collected, and the timeline for monitoring. With respect to conceptual issues, we asked about motivation for monitoring, major goals of the monitoring program, various influences on program design, level of satisfaction with data being collected, perceived limitations on monitoring effort, and degree of interest in redesigning or altering existing monitoring programs (Table 1). The full set of questions can be viewed at the following Web site: http://www.nceas.ucsb.edu/~marsh.

Survey Distribution

We sought input from as many people as possible who were actively involved in monitoring plant or animal populations. To accomplish this we sent emails to people identified from Internet searches of agencies involved in monitoring. We attempted to recruit a diverse mix of people at federal, state, and local agencies, nongovernmental organizations, volunteer monitoring organizations, and environmental consultants and contractors. We sent over 800 email requests: the greatest volume of intended recipients was at state natural heritage agencies (194), the Nature Conservancy (174), the U.S. Forest Service (157), the U.S. Geological Survey (128), and the U.S. National Park Service (67). The message that we sent explained the purposes of the survey and carried a link to the survey Web page. Recipients were invited to forward the survey instructions and Web link to anyone else they believed would be interested in completing the survey. Because many species are monitored as part of multispecies monitoring programs, we asked respondents to choose one species for the purposes of filling out the survey.

We did not believe it was possible to achieve a true random sample of all individuals involved in population monitoring. The universe of population monitoring programs is poorly defined and has no central listing, although several organizations are working on developing registries (e.g., Natural Resources Monitoring Partnership in the United States and EuMon in Europe). Furthermore, because it was often difficult to identify appropriate contact persons, we wanted to allow people to pass the survey on to others, and this could not be done within a randomized framework. Ultimately, we decided to seek a large and diverse sample of individuals engaged in population monitoring rather than a truly random one.

Table 1. Basic characteristics of the population monitoring programs included in our Web survey.

	Respondents (%)
What type of organism is the species that you are monitoring?*	
plant	38
bird	17
terrestrial mammal	11
fish	10
amphibian	8
invertebrate	7
other	12
Is this monitoring program simultaneously tracking other species?	
Yes, with approximately equal focus on multiple species.	40
No, monitoring program is exclusively focused on this one species.	34
Yes, but there is one primary target species.	26
In what kind of habitat is this monitoring program being conducted?	
terrestrial	62
freshwater	25
multiple habitats	10
marine	4

**For organism types, responses totaling <5% (e.g., reptiles, mollusks, marine mammals) are included in the category "other."*

Analysis of Survey Results

We summarized general patterns in the responses, but did not attempt to analyze or present every possible permutation of our results. We then analyzed the responses stratified across two classification variables. First, we compared monitoring programs based on the year in which they were initiated, which allowed us to examine how monitoring programs have changed over time. Second, we compared monitoring programs at federal agencies with monitoring programs at state and local agencies and with monitoring programs at nongovernmental organizations to determine whether different kinds of agencies carried out monitoring in different ways.

Because monitoring programs were not sampled randomly, the use of p values to draw inferences about response frequencies would be somewhat questionable. Nevertheless, presenting all differences in response frequencies also would not be particularly useful. Thus, for each set of stratified analyses, we provide information about differences in response frequencies only for questions for which a chi-square test indicated significant heterogeneity among responses or where Kruskal–Wallis tests indicated significant differences for ordinal variables such as satisfaction scores. When we did find significant heterogeneity among categories, we present the individual response frequencies that had margins of error (95% CI) that did not overlap between categories. These margins of error were typically 3–6%, depending on frequency of the response, and they reflect only potential effects of sampling error and not biases due to who received or responded to the survey (Lohr 1999). Because we focused on the most informative responses,

rather than report all possible responses, the frequencies provided may not total to 100%.

Results

Summary of Responses

We received 311 responses to the survey. Several respondents left some of the questions blank, yielding between 296 and 310 responses for each question. The majority of our responses came from the United States (86%), although we also had 5% from Canada and 9% from various European countries. Responses from outside the United States were quite similar to those from within the United States—we found no significant differences in response frequencies between the United States and other countries for any questions ($p > 0.10$ in all cases). Thus, we pooled responses from all countries in subsequent analyses.

Responses included a solid representation of programs for plants, birds, mammals, fishes, and amphibians (Table 1). Programs were relatively evenly divided between single species and multispecies (Table 1). Both terrestrial and freshwater habitats were well represented, although we received few responses for marine monitoring programs (Table 1). The most commonly selected motivation for population monitoring was that species were of "conservation concern" (62%). A number of other species were being monitored because they were considered indicators or surrogates for other species or for ecosystem health (18%) or because they were invasive (8%). The specific characteristics of the populations (i.e., state variables) being monitored were much more diverse. About 31% of programs were focused on monitoring a continuous population index (usually counts of individuals). But substantial numbers of respondents were using several other state variables, including presence and absence in the study area (15%), demographic parameters such as survival or reproduction (13%), an estimate of true population size (12%), the proportion of an area occupied by the target species (9%), and categorical or ordinal indices of abundance (8%). With respect to the goals of each monitoring program, by far the most common goal was to detect trends in state variables (53%). A moderate number of respondents were using monitoring for other purposes, including evaluation of a particular management strategy or intervention (17%), assessment of a specific environmental impact (8%), or expansion of our general knowledge about an organism (8%). For programs with a specified timeline, most respondents hoped to achieve these goals within 3–5 years (31%), 6–10 years (28%), or 11–20 years (26%).

As for the design of monitoring programs, the most common number of monitoring sites for a species was 11–100 (43%), followed by 2–10 (29%), and 101–1000 (20%). The frequency of visits to each site was variable, with 1 visit per year (30%) and 2–5 visits per year (29%) the most common (Table 2). By far the most frequently used design was fixed sampling of the same set of sites in each sample period (60%). Interestingly, the most common form of variable sampling consisted of surveying different sites in different years based on "logistical considerations (e.g., weather, accessibility, personnel availability)" (14%). More sophisticated sampling designs with rotating sampling locations (7%), random selection of survey sites in each sampling period (6%), or combinations of fixed and random survey sites (5%) were substantially less common. Pilot data were collected by 68% of respondents prior to initiating the monitoring program, with data on survey methods (26%) and time-series data (23%) the most common types (Table 2). The main influence on the chosen design was first-hand knowledge of the target species (66%), followed by advice from species experts (55%), knowledge of other monitoring programs (52%), and published descriptions of monitoring programs (47%). Advice from statisticians (25%) and power analysis or computer simulation (17%) were less often cited as influences.

Respondents reported that their monitoring programs were commonly limited by lack of money or equipment (42%) or by time (27%). Only about 10% of respondents said there were no substantial limitations to monitoring effort. About half (51%) of respondents thought it was "likely" or "almost certain" that the monitoring program would be expanded if more money, time, or personnel were available. Similarly, about 40% of respondents appeared to be open to changing the design of their monitoring program, whereas 40% claimed they would need a "very good reason" to make a change, and 20% thought that the design was "pretty much fixed." Respondents were quite satisfied with their monitoring programs, perhaps surprisingly so. Seventy-six percent reported being generally satisfied or very satisfied, and only 3.4% were generally unsatisfied or very unsatisfied. Responses to several other design and concept-related responses are summarized in Table 2.

Changes in Monitoring Programs Over Time

The original survey classified programs that were <2 years old separately from programs that were 2–5 years old. For the analysis of changes in monitoring programs over time, we combined these 2 classes to yield 4 time categories: programs <6 years old ($n = 123$), programs 6–10 years old ($n = 78$), programs 11–20 years old ($n = 78$), and programs >20 years old ($n = 23$). We kept the over-20 category separate despite the small sample size because we believed that these older programs might differ from newer programs.

Over the past 2 decades, the primary motivation for monitoring shifted away from "conservation concern"

Table 2. Summary responses for conceptual and design-oriented questions about programs for monitoring plants and animals in North America and Europe.*

Question and responses	*Respondents (%)*
What kinds of data are you collecting as part of the monitoring program?	
presence/absence of the target organism at each sampling location	72
counts of organisms	64
categorical data about density or abundance (e.g., classes or ratings)	53
mark-recapture data on individuals or groups	25
other	31
On average how often is each site surveyed as part of the monitoring program?	
once per year	30
2–5 times per year	28
once every 2–3 years	10
<1 time every 3 years	9
other	21
What kinds of changes have been made to the monitoring program since its inception?	
changes to the overall design of the program	37
changes to the data-collection techniques	34
no significant changes made to the monitoring program since its inception	46
other	9
What kinds of pilot data were collected before initiating the monitoring program?	
no pilot data collected	32
data on the error or precision associated with specific survey techniques	26
time-series data (e.g., year-to-year estimates of abundance or density)	23
life-history data (e.g., survival, reproduction, growth of individuals)	19
not sure what pilot data were collected	17
other (please specify)	12
To what extent have statistical methods that will ultimately be used to analyze the monitoring data been considered?	
statistical methods have been determined	58
statistical methods have been considered but not formally decided on	18
statistical methods have not yet been determined	16
not involved with the data analysis, so not sure	7

**For compact presentation, several questions have been abridged from their original form and responses with low frequencies have been grouped into the "other" category. The full survey and results can be viewed at http://www.nceas.ucsb.edu/~marsh.*

(Fig. 1). Seventy-four percent of programs 11–20 years old were in this category, whereas 57% of programs started in the last 5 years were in the conservation-concern category. At the same time, monitoring programs designed to track pest species or to advance general scientific knowledge increased by 4–10%. The primary state variables in the newer programs often differed from those of the oldest programs (Fig. 2): about 14% of surveys begun in the last 5 years were designed to monitor the proportion of area occupied, whereas only a single program (<1%) older than 11 years used this state variable for monitoring. Programs that primarily monitored presence and absence also increased in each succeeding time period. Presence–absence programs represented less than 9% of programs 20 years or older but more than 20% of programs initiated in the last 5 years. At the same time, programs that focused primarily on monitoring demographic parameters (e.g., survival, reproduction, growth) or estimating population size appeared to become less common (Fig. 2).

The specified goals for monitoring also shifted over the period covered by the survey (Fig. 3). For the oldest programs, 85% were aimed at detecting trends, whereas only 45% of the most recent programs listed trend detection as the primary goal. Programs aimed at increasing general scientific knowledge expanded from 3% in the oldest 2 categories to 14% in the newest class of monitoring programs. Programs aimed at understanding the effects of some intervention or management activity increased from 10% in the oldest 2 classes to 26% in the newest class of programs. Some of these results may have reflected variable timelines for different kinds of programs as much as changes in their popularity. For example, programs with the goal of increasing scientific knowledge tended to have relatively short timelines, meaning that there are probably few older programs of this type.

There were differences among categories in the extent to which methods for statistical analysis had been determined. In the oldest programs, 95% of respondents stated that analysis methods had been determined, whereas in the newest programs, 54% made this claim. Nevertheless, these differences were largely due to the programs that were over 20 years old. The percentage of 11- to 20-year-old programs in which analysis methods had been determined (63%) was only a little larger than the percentage for the newest programs.

The major influences on the design of monitoring programs also changed somewhat over time. The newest

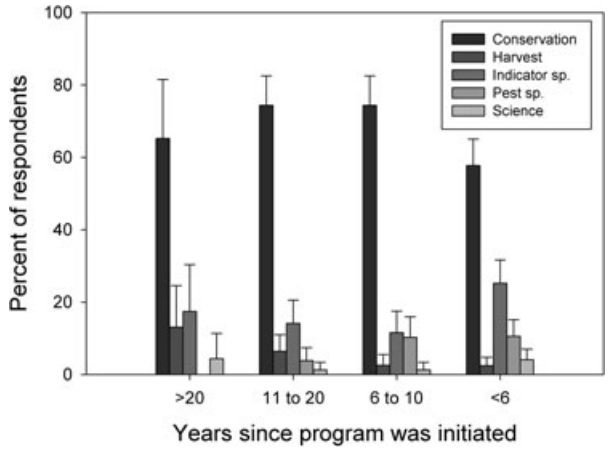

Figure 1. Changes over time in motivations for monitoring populations of plants and animals. Grouped bars show the most common motivations for programs begun more than 20 years ago, programs begun between 11 and 20 years ago, programs begun 6–10 years ago, and programs begun within the past 5 years (<6). Error bars show margins of sampling error.

programs were more likely to have relied on published studies (56% vs. 39% for all older programs). At the same time, newer programs were less likely to have relied on first-hand knowledge of the target species (54% vs. 70% for all older programs). Interestingly, incorporation of statistical advice, power analysis, or computer simulation

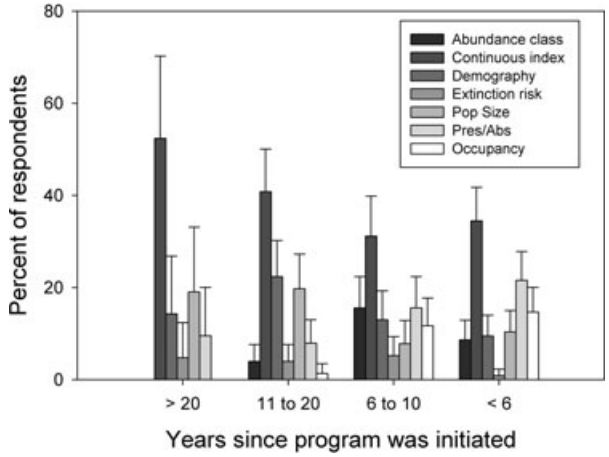

Figure 2. Changes over time in state variables used for monitoring populations of plants and animals. Grouped bars show the most common state variables for programs begun more than 20 years ago, programs begun between 11 and 20 years ago, programs begun 6–10 years ago, and programs begun within the past 5 years (<6). Error bars show margins of sampling error (pop, population; pres/abs, presence/absence).

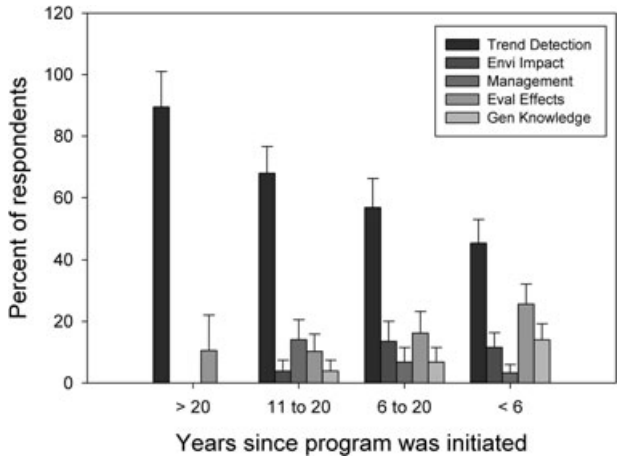

Figure 3. Changes over time in the specified goals of programs monitoring populations of plants and animals. Grouped bars show the most commonly specified goals for programs begun more than 20 years ago, programs begun between 11 and 20 years ago, programs begun 6–10 years ago, and programs begun within the past 5 years (<6) (envi, environmental; eval, evaluate; gen, general). Error bars show margins of sampling error.

was relatively uncommon (16–24%) in all programs and there was little increase over time (Fig. 4).

Differences among Agencies

Of our respondents who indicated their affiliation, 102 were at federal agencies (including Native American tribes), 102 were at state, provincial, or local government agencies, 72 were at nongovernmental organizations or volunteer programs, 17 were at academic organizations, 6 were contractors or consultants, and 4 indicated that monitoring programs were cooperative between different types of organizations. Given the small sample sizes for some of these groups, we considered 3 groups: (1) federal agencies, (2) state, provincial, and local agencies, and (3) nongovernmental organizations (including volunteer-run programs).

The frequency with which various taxa were monitored differed among these 3 classes. Nongovernmental organizations were more likely than federal agencies to monitor plants (49% vs. 31%), federal agencies were more likely than state agencies to monitor birds (25% vs. 14%), and state agencies were more likely than federal agencies to monitor reptiles (8% vs. 1%).

The use of particular sampling designs also differed among organizations. State agencies were less likely than federal agencies or nongovernmental organizations to use designs in which the same set of sites were sampled in every year (52% vs. 70% and 73%). State agencies were more likely to vary the sites sampled from year to year due to "logistical considerations (e.g. weather,

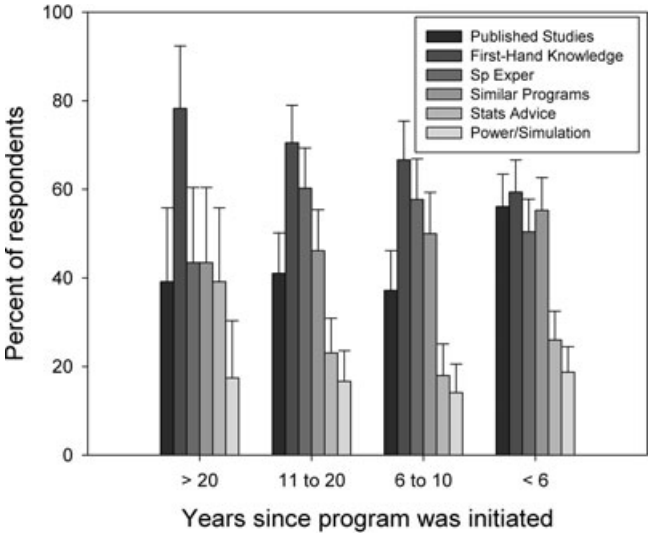

Figure 4. Changes over time in the major influences on programs monitoring populations of plants and animals. Grouped bars show the most common influences on programs begun more than 20 years ago, programs begun between 11 and 20 years ago, programs begun 6–10 years ago, and programs begun within the past 5 years (<6) (sp exper, species expertise; stats, statistical). Error bars show margins of sampling error.

accessibility, personnel availability)" (24% vs. 8% and 11%). Federal agencies were also somewhat more likely than nongovernmental organizations to use designs in which the subset of sites to be surveyed was selected randomly in any given sample period (10% vs. 3%), although margins of error overlapped slightly for this comparison.

Organizations reported contrasting limitations on monitoring activity. Federal agencies were more likely than nongovernmental organizations to report being primarily limited by funding and equipment (53% vs. 29%), with state agencies intermediate between these two (41%). State agencies were more likely than federal agencies to report being primarily time limited (38% vs. 20%); nongovernmental organizations were intermediate (30%) in this category. Finally, nongovernmental organizations were more likely than federal agencies to report being limited by the number of accessible sites at which the species occurs (13% vs. 3%, with 4% reported for states).

Other findings from the survey that were not statistically robust but that may be important include the following: (1) nongovernmental organizations were consistently 25–35% less likely than federal or state agencies to collect pilot data before initiating monitoring programs (depending on the type of pilot data); (2) nongovernmental organizations were about 10% less likely to report that methods for statistical analysis of monitoring data had been determined; (3) nongovernmental organizations were 14% more likely to have consulted experts on the species to be monitored, but were only about half as likely to have consulted statisticians in the course of designing monitoring programs. People who worked for nongovernmental organizations were significantly less satisfied with their monitoring programs compared with people at federal agencies, although the magnitude of the difference in satisfaction scores was not large (mean = 3.72 on a scale of 1–5 for nongovernmental organizations, vs. 3.93 for state agencies and 4.06 for federal agencies).

Discussion

We designed our survey to answer some basic questions about population monitoring programs. Where do these programs come from? How are the designs chosen and how do design considerations depend on monitoring agency, organism, and size of the program? What statistical and research advances are being incorporated into population monitoring programs and how are monitoring programs changing over time? Because there were no strictly right or wrong answers to questions in the survey, we attempt to avoid unnecessary assertions about whether people are monitoring the way we (or other people) believe they should.

That said, we believe there is both good and bad news in our results. On the positive side, many monitoring programs are being conducted with formal protocols that involve large numbers of sites and thorough collection of population data at each site. Although we did find some differences among monitoring programs run by federal agencies, state agencies, and nongovernmental organizations, there were more similarities among these programs than differences. In addition, people who answered the survey reported remarkably high levels of satisfaction with the data being collected—only about 4% of respondents claimed to be unsatisfied or very unsatisfied with their monitoring program. On the negative side, few monitoring programs (even the recently created ones) cited statistical advice or any kind of formal power analysis as an important influence on the program (Fig. 4). Furthermore, only a little more than half (54%) of new monitoring programs appeared to have determined in advance the statistical methods to be used for analysis. Although there is no empirical proof that advance attention to statistical considerations enhances success of monitoring programs, the goals of monitoring (e.g., detection of trends, determination of whether a management strategy is working) are essentially statistical in nature. Given this, it is hard to imagine that considering issues of statistical power or efficiency in advance would not generally be a good thing.

Our results showed that a "typical" population monitoring program is established because of conservation concerns, collects count data at a number of sites, and analyzes these data to test for trends in some index of abundance. Such programs are designed from expert knowledge about the species and knowledge of similar programs for other species, but do not explicitly address statistical considerations. People doing the monitoring typically want initial results about whether or not the population is declining within about 10 years time.

Beyond this typical program, there appeared to be considerable diversity in the design and goals of monitoring programs, and this diversity appeared to have increased in the past decade. Monitoring programs designed to track the proportion of area occupied or to determine presence or absence seem to have gained popularity. In addition, monitoring programs are increasingly being used to test management approaches and to expand our general knowledge of organisms, rather than simply to detect trends.

A number of respondents used the "other" option for several of the design-related questions and described some very sophisticated monitoring programs. These respondents outlined programs in which one set of fixed sites is sampled yearly, whereas another set is subject to random surveys, or they outlined designs in which adaptive sampling, on the basis of the findings of previous surveys, is used. Nevertheless, on balance, these more sophisticated designs were not particularly common. This is perhaps best illustrated by the fact that the most common variable sampling design (by a factor of more than 2:1) consisted of sampling different sites in different years based on logistical, rather than design considerations. Basing a monitoring program on logistical considerations may be an unavoidable reality in many situations, but it is unlikely to be optimal for achieving any specific set of monitoring goals.

Similarly, with the exception of area-occupied approaches (MacKenzie et al. 2005), there was little evidence that recent "advances" in the design of monitoring programs have made substantial inroads into real programs. For example, only a handful of respondents (3%) said they were monitoring extinction risk (sensu Staples et al. 2005) or were using adaptive sampling to minimize parameter uncertainty in space and time (1%; sensu Wikle & Royle 1999, 2005), and only a few more (6%) respondents were using monitoring to determine when to undertake some specific management action (sensu Yokomizo et al. 2003; Gerber et al. 2005). It may simply be that these and other recent advances need more time to permeate into actual monitoring programs. Nevertheless, it is also likely there are some real hurdles associated with monitoring approaches that require more sophisticated approaches for design and analysis.

As we noted previously, survey respondents were not chosen randomly and various components of sample and response bias could not be assessed. Because of this, our summary response frequencies should not be taken to represent the universe of population monitoring programs. We did not sample programs that were not easily found through Internet searches, and we rarely got responses from outside North America. There were almost certainly biases in who received the survey or chose to respond to it. For example, the generally high level of satisfaction reported for monitoring programs could be partly due to a lack of interest in responding from individuals who have negative feelings about their monitoring commitments. On the other hand, there was no particular reason to expect huge differences in response frequencies between people who were, for example, monitoring birds versus amphibians or between people collecting count data versus people collecting occupancy data. Some biases could exist here, but we do not think it would interfere with the goal of gaining a general picture of what monitoring programs entail. Similarly, we believe that the results of our stratified comparisons of monitoring programs over time and across agencies were less likely to have been influenced by nonrandom sampling.

There were some additional limitations to our survey methodology. Although we asked respondents involved in monitoring multiple species to choose one species for the purposes of the survey, there was no way to ensure that some individuals did not submit multiple surveys. In addition, it is possible that different individuals may have responded with information about the same monitoring program. That said, when we sorted our responses according to basic features of the monitoring programs (e.g., type of organism, type of monitoring agency, number of sites, frequency of visits), we found only 3 sets of matching responses (out of 311), and all of these differed in the specific kinds of data that people claimed to be collecting. Thus, we believe any issues with duplicate responses had minimal influence on our results. In addition, respondents were specifically asked to comment on ongoing monitoring programs. As a result the reported "age" of a monitoring program reflects not only when it was initiated but also its time horizon. Thus, short-term monitoring programs begun a decade or more ago would not be represented in the survey, whereas newer short-term programs were more likely to be included. Finally, these kinds of surveys are subject to biases due to subtle issues in the working of questions, the order of possible responses, and the order of questions (Lohr 1999). For all these reasons, our results provide only a broad picture of population monitoring in North America and should not be referenced for precise estimates of the characteristics of population monitoring programs.

People involved in population monitoring may find our results useful on several levels. First, they show what kinds of monitoring programs are most frequently used and what kinds of programs are more rare. It is not necessarily the case that the more common designs are superior. But knowing how others are conducting monitoring allows one to know when aspects of a new program are

particularly unconventional. Second, the survey provides a set of questions that program managers should be able to answer prior to initiating any monitoring activity. Consideration of the goals of monitoring, the timeline for these goals, and the best sources of information for how to achieve these goals is an important step in creating effective monitoring programs, as has been emphasized previously (e.g., Yoccoz et al. 2001; Witmer 2005). Third, our results may help enhance communication between those involved in research on population monitoring and the managers and planners who are putting these programs into action. For example, monitoring programs that use count data from multiple sites to detect population trends appear to be quite common, which provides an argument for developing tools to help design these sorts of programs and to analyze the data they produce (e.g., Gerrodette 1993; Gibbs et al. 1998). In a similar vein, because other promising approaches appear to be making fewer inroads into real monitoring programs, our results highlight the need for researchers to make the tools for designing these programs as accessible as possible for practitioners.

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