2

Setting objectives in field studies

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2.1 Basic concepts for a good start

Considerable financial and human resources may be wasted due to poor research design and implementation. In addition, poor planning can result in taking non-repeatable or unreliable data that are of no or limited use, and leads to the paradox of "data-rich, information-poor." Rigorous study planning and the definition of clear and realistic goals can help avoid wasted effort. Before undertaking field studies, biologists first must define their objectives and then assess the availability of resources necessary to accomplish them. This is a key stage, and any uncertainty or vagueness at this point could prove detrimental to the success and usefulness of the study.

There are two different approaches in scientific investigation: inductive and deductive methods. The inductive or exploratory method relies on gathering data without first identifying hypotheses to be tested; results may then be explained based on the data gathered. However, science involves more than accumulating data and then searching for patterns. A useful study must start with an observation that identifies a problem or question to be resolved. The observation should have biological significance and be based on current evolutionary theory (Wolff and Krebs 2008). For example, amphibian populations are declining: what are the causes? Two related species hybridize on just a narrow contact zone: why? Habitats are fragmented by human activity: what effects does this have on population persistence, and why (e.g. dispersal abilities, food resources, population demography, genetics, susceptibility to predators, and human activities)?

As science is an activity focused on understanding natural processes and, especially in modern times, in devising solutions to problems, the hypothesis-based deductive method was developed (James and McCulloch 1985). An *hypothesis* is a statement related to an observation which may be true, but for which proof has not yet been found. The function of the hypothesis is to direct the search for order among facts. Fieldwork then serves to test one's hypothesis, thereby scientifically demonstrating correlation, causation, or the absence thereof. The hypothesis must of necessity regard some facts as more significant than others, based on the researcher's previous experience, familiarity with the literature, and individual interpretation.

As scientific knowledge is rarely complete, any list of potential alternative hypotheses is also unlikely to be complete. Therefore, alternative hypotheses for the particular problem or question being considered must also be formulated. Thus, it is necessary to conduct research with both the hypothesis and alternative hypothesis in mind, as more than one cause may be contributing to any single effect (Wolff and Krebs 2008). For example, Jaeger (1972) used enclosures to test the mechanism of interspecific competition between two species of plethodontid salamanders, hypothesizing that it resulted from either differential exploitation of food resources or through interference. Both primary and alternative hypotheses are formulated and tested so that researchers can determine which explanations best fit the results obtained. Unsupported hypotheses can be rejected, but even the most parsimonious hypothesis may not be fully accepted because there still may be underlying explanations as yet untested (Senar 2004). Repeated experimentation involving alternative hypotheses eventually allows researchers to gain a measure of confidence in the validity of empirically supported hypotheses (Jaeger and Halliday 1998). Both hypotheses and data are essential for credible science since, as Krebs (1999) concluded, hypotheses without data are not very useful, and data without hypotheses are useful only for an inductive approach.

Ecology is an empirical science that requires data from the "real" world, and a field study is a tool which can ultimately lead to the acceptance or rejection of an hypothesis. After repeated experimentation and validation, data and information from many field studies are synthesized and organized into concepts of how nature functions. These concepts are the result of the integration between what scientists think they know (based on previous research and observation) and newly acquired data (Ford 2000). Asking the right question is important, because the type of question asked and the particular techniques and methods used in hypothesis-driven research strongly influence what is discovered and the direction of future research. During the course of this feedback process, scientists come to a better understanding of the phenomena they study (Figure 2.1).

Scientists present what they want to accomplish during a field study in terms of goals and objectives. A *goal* is a statement that explains what the study is designed to accomplish. It is usually a broad and general statement, inclusive of

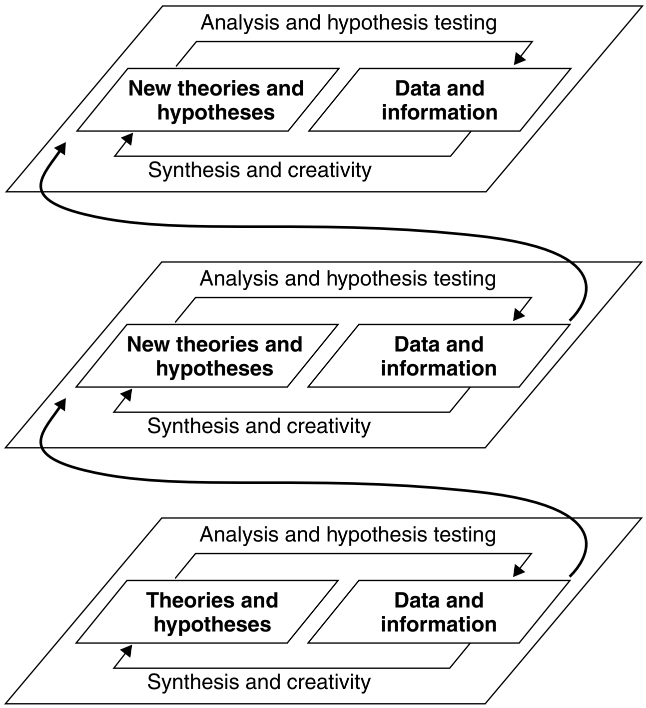

Fig. 2.1 The cycle of scientific investigation and the shift towards the spiral of knowledge.

a long-term direction. The goal is then split into specific, measurable *objectives* that indicate how the goal can be achieved within a specified time frame, and the expected results.

Defining a study's objectives clearly is the first and probably the most important single step in research planning, and is a key element in a successful project. The goals of research can be *non-applied* (i.e. aimed at increasing or changing existing knowledge) or *applied* (i.e. focused on solving practical questions), or both. Rather than addressing an effect, a study should focus on the cause of the phenomenon in question. Separating effects from causes is a major challenge when setting objectives. For example, acid rain has well-known causes, but much research today focuses on the effects or seeks solutions to limit its impact. In another example, many recent studies have reported on amphibian declines (Stuart *et al.* 2004), but many fewer have identified specific causes (e.g. Becker *et al.* 2007). It is important that amphibian biologists do not limit their focus to specific taxa; otherwise, they lose sight of the fact that similar effects may be occurring in other taxa. Amphibian biologists need to establish closer links with researchers studying similar problems in other taxa (Halliday 2005).

Ideally, the cycle of scientific investigation should proceed from data and information gathering and analysis, to quantifying knowledge, and to conceptual understanding. A logical, stepwise approach of scientific inquiry (Lehner 1996) should be followed: (1) perceive that a problem/question exists; (2) formulate a possible explanation (i.e. devise an hypothesis); (3) formulate alternative hypotheses; (4) identify the best approach to test the hypothesis (i.e. theoretical models, experiments, or field observations); (5) collect and analyze data; (6) support or reject the hypothesis; and (7) understand the meaning and implications of the results. The original hypothesis can then be modified, experiments repeated and, with time, conceptual understanding attained.

2.2 Steps required for a successful study

Ecological systems are large and complex and, at times, unpredictable. The more complex the system, the more uncertainties arise. Data are most often obtained within the parameters of a limited number of samples, restricted time, or specific area, and then applied to larger scales. By carefully framing the hypothesis and deciding the most practical, meaningful, and objective method of study, degree of error can be minimized (Hayek 1994). The following section presents some of the most important issues that must be considered when planning a field study.

2.2.1 Temporal and spatial scales

The issue of scale has three components (Schneider 2001): (1) pressing problems in ecology often exist within timescales of decades or centuries, and cover large areas; (2) most data can be gathered directly for only short periods of time and over small areas; (3) patterns measured at small scales do not necessarily hold true at larger scales; nor do processes observed at smaller scales necessarily exist at larger ones. Thus, an inappropriate scale limits the inference of the results.

Spatial and temporal scales can be classified as gradient, interval, discrete, and continuous (Bernstein and Goldfarb 1995). Setting temporal and spatial scales involves defining their boundaries and helps to answer three practical questions: where, for how long, and how often? Selecting the appropriate scale is difficult because of environmental heterogeneity in both time and space. Amphibian populations and communities also vary widely throughout time and space, since they are influenced by a multitude of environmental variables (Meyer *et al.* 1998; Pechmann *et al.* 1991; Pellet *et al.* 2006).

Temporal scales are rarely discussed explicitly, but they are often assumed to span years rather than generations. Many time-dependent phenomena such as extinction, predator–prey interactions, competition, and succession reveal important insights if considered on a generational scale (Frankham and Brook 2004). The current distribution and abundance of animal species inhabiting an area is the result, in part, of the impact of geological processes (e.g. plate tectonics, orogenesis, sea-level changes, major catastrophes), ecological processes (e.g. competition, predation, climate), life-history traits (e.g. dispersal), and recent human impacts (e.g. changes in vegetation and habitat structure, overexploitation, introduction of nonindigenous species). For example, in the Northern Hemisphere the Pleistocene–Holocene post-glacial recolonizations of species and human activities (e.g. habitat destruction and alteration) are the two major factors shaping the current distribution of amphibians. Objectives of a time-scale component of a study plan should include such factors as short-term (less than one generation), intermediate (more than one to a few generations), and long-term (many generations, and inclusive of a large spatial scale and monitoring activities).

Spatial scales and objectives are strongly interconnected. Selection of a study site includes such factors as the complexity of local macro- and microhabitats and, at large spatial scales, biogeographical provinces and landscapes (Morrison 2002). Of great importance to the overall study plan are the criteria for describing vegetation, whether gross (e.g. foliage height, diversity), physiognomy (physical structure), or floristic (plant taxonomic description). The relative usefulness of structural or floristic measures depends on the spatial scale of the analysis. For example, whereas most studies do not require a detailed description of plant taxa, species lists might be essential for characterizing microhabitat and trophic (resource) availability.

The importance of choosing the correct scale can be exemplified by a study assessing population fluctuations within a particular species: the first step would be to understand the distribution of the species in order to thoroughly sample all areas, rather than by biasing results by sampling in only one small portion of the range. In another example, a study of the movement patterns of a species may focus on individual distributional patterns, daily or weekly movements, seasonal migrations related to reproduction or dispersal, or on region-wide range shifts through years or decades.

2.2.2 Choosing the model species

Many amphibian species have restricted distributions and complex habitat requirements. Some amphibian populations, especially among temperate pond-breeding species, are maintained by episodic reproduction that occurs in a sporadic and unpredictable manner (Alford and Richards 1999). If a number of different species is available for study, selecting an experimental species should be based on an understanding of its life history (i.e. feeding, habitat use, dispersal abilities, reproduction, behavior, predators, phylogeography, population genetics) and its suitability in resolving the particular question being asked (Wolff and Krebs 2008). For example, a species with low detectability is not a good choice for a mark–recapture study since it will require a considerable sampling effort and entail potential capture bias (Weir *et al.* 2005). The role of keystone species (e.g. *Eleutherodactylus bransfordii* in Costa Rican forests), umbrella species (e.g. *Rana sylvatica* in the Milwaukee river basin), or flagship species (e.g. *Salamandra lanzai* in the Western Alps) can also be considered. Rare or threatened species are often selected because of conservation applications, but research on them could incur potential risks due to ethical considerations. Researchers should avoid choosing a rare or threatened species if common or less vulnerable surrogate species can be selected.

2.2.3 Pilot/desk study

A preliminary pilot study usually helps to develop and test realistic and achievable objectives, and avoids later shortcomings and failures. Usually a pilot study is carried out on short temporal and small spatial scales, and allows the testing of conceptual models and methods. What might seem simple during office planning might prove completely different or unworkable in the field. Even a simple review of the literature can prove helpful in avoiding mistakes, however.

2.2.4 Elaborate a conceptual model

A conceptual model (e.g. a simple box diagram showing components and linkages) is a simplified model of the system to be studied. There are no ideal methods to employ; instead, a multitude of models are available to choose from with various degrees of complexity. Conceptual models are helpful in that they can be used to select the variables to be measured that might be considered important to the study. Since professionals with diverse backgrounds have different philosophies or approaches to using models, it is recommended that each team member contribute knowledge of and/or expertise with various models, then develop an integrated study model from which to work (Maher *et al.* 1994).

After model development, many of the design questions become more obvious. A model need not embrace all components of the system; it needs only to be adequate for the scope of the investigation. There is always a possible risk that the conceptual model is inappropriate or over-simplified; thus, a slightly more complex model may need to be developed. Adopting a more complex model focuses researchers on collecting additional data that might prove important, despite the extra costs involved with sampling and measurements. In other words, it might be better to collect more data than appears necessary at first, than to discover later that some important parameter was omitted. A pilot study helps to avoid under- or over-collecting data. Although conceptual models help researchers identify what to measure, the timing of studies is determined by the natural history of the species of interest.

2.2.5 The SMART approach

Specific objectives allow for greater chances of conducting a successful research project. SMART stands for specific, measurable, attainable, relevant, and time (Piotrow *et al.* 1997), an approach used in project writing that also helps in formulating specific and measurable objectives within study plans. SMART helps devise objectives that are clear and concise, indicates what is to be achieved, addresses only attainable results, indicates when each stage will be completed, and is not encumbered by idealistic aspirations.

- S: The *specific* part of an objective defines what will be done and where it will occur. When setting objectives, ask simple questions that can be answered, and avoid ambiguities, the use of buzzwords or jargon (e.g. "cutting-edge"), and pompous phrasing.
- M: *Measurable* is an attribute of an activity or its results. The source of and mechanism for collecting measurable data are identified, and collection of these data is determined feasible. If the objective of the study is to document trends (i.e. an increase or decrease of one or more measurable variables), then a baseline is required to act as a reference point (e.g. habitat availability, characteristics and use; amphibian community structure; population size). If a baseline is not yet available then it will be useful to first have it established.
- A: *Attainable* refers to the probability of conducting the proposed activities within the established time frame with the available resources and support. It also includes the external factors critical to success. Doing research today, for example, can become difficult due, in part, to increasing administrative restrictions (Prathapan *et al.* 2008). Other external factors include unforeseen costs, shifts in exchange rates, obtaining collecting and access permits, changes in legislation, and political, security, and health (both human and animal) issues. In coping with external factors, a risk analysis is useful because it allows for planning alternative strategies.
- R: Some useful measures for the *relevance* of the study's objectives are the utility and value of the results for practical purpose (e.g. management of protected areas, better conservation measures, and ecological restoration). It

may be difficult to determine how relevant the objective may be, especially since the true relevance may not be apparent until the study is completed (e.g. if a drought were to affect a long-term study of amphibian breeding). Perhaps an easy way to evaluate the relevance is to answer the "so what" question, thus avoiding undertaking studies of limited or no interest.

- T: Finally, the *time* required to complete the project will depend on the parameters discussed above.

2.2.6 Applying the SMART approach to plan an amphibian inventory

In the following example, the SMART approach is used as the basis for setting up an inventory of amphibian species in a national park or reserve.

- *Specific*: determine whether to inventory all amphibian species, or only those of special interest, such as rare, threatened, or endemic species. Set the spatial limits of the study, such as the administrative boundary of the park or reserve, or specific habitats of interest (e.g. temporary ponds; roads in areas which bisect amphibian dispersal corridors; high elevations containing unique habitats or species richness, such as cloud forests).
- *Measurable*: select parameters to be measured (e.g. presence/not detected, relative abundance, density, sex or life stage, percentage of area occupied), select methods appropriate for each species (especially taking detection probabilities into account), and decide habitat parameters (e.g. temperature, humidity, vegetative cover, characteristics of aquatic habitats).
- *Attainable*: identify resources and available support (e.g. funding, work force) and administrative considerations (e.g. collecting and access permits, training staff for field data collection, animal care and use requirements, security issues).
- *Relevance*: provide concise statements as to the importance of the research, and whether it has practical applications. The relevance of the proposed research is particularly important in field studies, especially if it will aid in the management of protected areas and species conservation. Utility also assists in determining research approaches. For example, incorporating measures of abundance with detection probabilities, in addition to occupancy models, is much more informative in determining status than occupancy models alone.
- *Time*: the research schedule (planning, fieldwork, data analysis, report and publication preparation) should be clearly stated based on the previously outlined parameters and limiting factors.

2.2.7 Experimental versus field studies

Biological communities, apart from their high internal complexity, are subject to random, naturally occurring fluctuations involving both physical and biotic parameters (e.g. heat, cold, drought, effects of disease, and spread of invasive species). Stochastic fluctuations such as these are a major source of statistical variance in nature, resulting in a shift by some researchers towards less complex and more controlled field and laboratory experimental designs (see Chapter 6). Such a reductionist approach can be framed within a simpler conceptual model where the number of variables of interest is reduced in return for minimizing uncontrolled environmental fluctuation.

Still, there is an experimental continuum between laboratory and field studies (Figure 2.2). Perhaps some of the most powerful experimental tools which can provide the statistical rigor required for hypothesis testing are outdoor experiments (Fauth 1998; Rowe and Dunson 1994; Chapter 6). Controlled experiments maximize a researcher's ability to detect a response to variables of interest (e.g. food, density of individuals, hydroperiod). The best approach is to use observations in nature coupled with experimental analysis. For example, Wilbur (1997) used both natural and artificial ponds to investigate complex food webs in temporary ponds, and their effects on the larval amphibian community.

2.2.8 Methods for sampling, data storage, and analysis

Selecting an appropriate research technique is not an easy task, especially since "trendy" methods may not be the best ones to use. Methods selected must be adequate for the proposed objectives, and it is best to test them first to determine

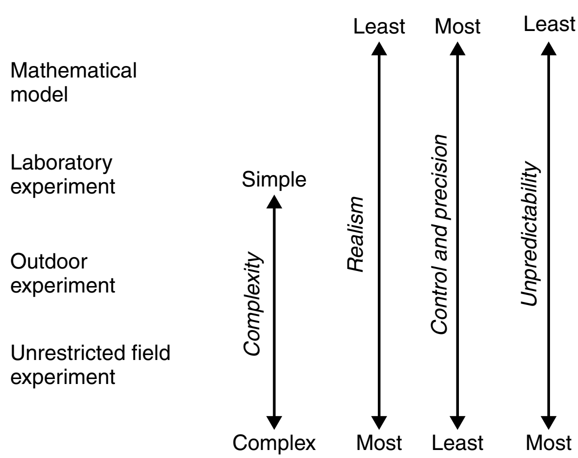

Fig. 2.2 Trade-offs between complex and simple experiments.

efficiency and effectiveness. Researchers should adopt complimentary models, applicable and relevant methods, and an altogether SMART use of study plans, resources, and results. The most important elements in any study plan are accurate and precise methods that meet the objectives of the study. A cost-benefit analysis can prove helpful in the final selection of the methods (Arntzen *et al.* 1995, 2004).

The sampling design should be both *efficient* (a better use of sampling effort in obtaining results) and *simple* (easily comprehended and easily implemented) (Scott and Köhl 1993). Statistical analyses often have biases or limitations in ecological studies (Krebs 1999; Pollock *et al.* 2002). Statistical significance may not be the equivalent of biological significance. Focusing too much on statistical issues may prove deceptive or lead to inaccurate conclusions. One way to minimize the potential of error is to incorporate power analysis into study designs (Yoccoz 1991). Statistical power refers to the ability of a test to correctly reject a null hypothesis, and is frequently evaluated in the context of the sample size required to detect an effect of a given magnitude (Michener 2000).

When using probability statistics, it is possible to make two kinds of error: a researcher may claim there is a difference when one does not exist, or can fail to detect a difference when one does exist (Underwood 1997). The first type of error is estimated by the traditional probability value ($\propto=0.05$) associated with statistical tests. If a researcher rejects the null hypothesis at this level, then there is still a 5% chance that he/she is in error.

The second type of error is more difficult to estimate because it depends on the sample size, the magnitude of effect, and sample variability. Researchers are likely to correctly reject a null hypothesis with larger sample sizes, larger effect sizes, or less variable samples. Alternatively, a higher critical value may be selected (e.g. $\propto=0.1$) as an indication of statistical significance.

Statistical power is a measure of the proportion of time that a researcher would correctly reject the null hypothesis if an experiment could be repeated an infinite number of times; statistical power is usually estimated by computer simulation. The goal of a power analysis is to define a level of confidence in the research results; it can also be used in determining trends and in setting optimal sample size. A discussion of power analysis is available through StatSoft (www.statsoft.com/textbook/stpowan.html).

2.3 Trade-offs and pitfalls

There are several pitfalls that can and should be avoided when establishing objectives in field studies (Bardwell 1991). The most common ones are: (1) addressing the wrong problem; (2) stating the problem in a way that no solution is possible;

(3) prematurely accepting a solution as the only possible answer; and (4) using data and information that are either incorrect (e.g. inaccurate information in the scientific literature) or irrelevant. There are several additional pitfalls that may be avoided by careful planning and a thorough understanding of the questions to be asked (Tucker *et al.* 2005). Four of the most frequent are listed below.

1) The statistical framework might be inadequate, since many techniques developed in the context of controlled experimentation are sometimes incorrectly applied to field data, resulting in an inappropriate use of the null hypothesis (Johnson 1999).
2) Researchers and technicians might differ in their skills, use non-comparable methods, or have different personal goals. Training prior to the start of field collection of data and a comparison of each person's abilities helps to minimize these problems.
3) Methods may be changed during a study. This could lead to an incompatibility of data sets and limit the interpretation of results.
4) The locations of permanent sample sites are not properly recorded so that different areas are subsequently revisited or sampled.

When designing fieldwork, researchers need to be aware of potential options and trade-offs, and try to balance them (Hairston 1989). Examples include: (1) complexity versus simplicity (e.g. choices ranging from theoretical models to field experiments), (2) confidence in results versus general application (e.g. high confidence can be achieved at short temporal and small spatial scales and with relatively simple goals and conceptual models, but the results will be of limited value), and (3) replication versus sophistication of experimental design, recognizing that it is impossible to simultaneously maximize precision, realism, and generality (Levins 1968).

2.4 Ethical issues

While ecological field studies have generated a wealth of useful and important data, the environmental impacts of these studies have rarely been quantified. A basic assumption is that the relative benefits of research outweigh the potential short-term costs to the study animals or habitats (Farnsworth and Rosovsky 1993). Even the simple act of observation, however, may affect the behavior of the study organisms. Repeatedly visiting different sites during fieldwork can have negative impacts, either by spreading or introducing nonindigenous species (Whinam *et al.* 2005) or diseases, such as amphibian chytrid fungus (Garner *et al.* 2005), or by microhabitat alteration (e.g. turning logs). Preventive measures, such as equipment disinfection (Chapter 26) and routine checks for unwanted "passengers" (e.g. seeds) are now widely used (ARG-UK 2008).

Controversies continue regarding the negative effects of some common techniques. For example, toe-clipping, historically one of the most widely used marking techniques, has recently received much criticism (Chapter 8; May 2004; McCarthy and Parris 2004). Critics, however, have not provided much evaluation of the impacts of alternative procedures. Apart from dorsal or ventral pattern mapping by photography or computer imaging, which are non-invasive, all other marking techniques have disadvantages (Phillott *et al.* 2007). The effects of toe-clipping vary among species, and therefore must be assessed accordingly. Other marking methods for amphibians are available, although they are not as economic or as easy to use, but which have fewer risks (Chapter 8; Ferner 2007). Toe-clipping also may be prohibited by regulatory constraints; information on regulations is best obtained and evaluated during the planning stage. Thus, there may be a trade-off between the risks associated with methodology and the knowledge to be gained, even when the species may be benefited (Funk *et al.* 2005).

Field studies often involve years of hard work. In the end, the results may provide few insights compared to the amount of effort to acquire them, unless careful planning precedes the initiation of research activities. Careful planning optimizes researcher effort and helps ensure that the data recorded will be statistically accurate, with beneficial results in advancing knowledge of amphibian ecology and conservation biology.

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