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REVIEW: AMPHIBIAN SURVEYS IN FORESTS AND WOODLANDS

KIRSTEN M. PARRIS

Centre for Resource and Environmental Studies, The Australian National University, Canberra ACT 0200, Australia

ABSTRACT: Amphibian surveys provide information on the distribution, abundance and habitat requirements of species, and the environmental variables that control diversity. Such information is needed for effective conservation planning and management of forests and woodlands, including monitoring of amphibian populations in a period of apparent global decline. Amphibian surveys can be time-consuming and expensive, and many issues must be addressed to maximize the reliability of the resulting data. Sampling techniques that are effective in one region or habitat type may be less so in another, and a preliminary study comparing different techniques before undertaking a survey may be necessary. Data collected in poorly designed surveys can be unsuitable for statistical analysis, and may sometimes present a misleading picture of the distribution, abundance and habitat requirements of amphibian species. This review examines issues of survey design, assesses past amphibian surveys in forest and woodland habitats, and provides recommendations for planning an amphibian survey. Firstly, the study area and survey aims should be identified, and proposed sampling techniques assessed using relevant literature or a pilot study. Ethical issues associated with proposed sampling techniques should also be considered. The number, size and arrangement of the survey units (e.g. plots, sites or transects) should be sufficient to address the survey aims. The survey units should be systematically surveyed several times with appropriate sampling techniques.

Declining amphibian populations have been observed around the world in the last 20 years. For example, 28 Australian frog species have reportedly declined in this period (Osborne, 1989; Czechura and Ingram, 1990; McDonald, 1990; Ingram and McDonald, 1993; Richards et al., 1993; Hollis, 1995; Gillespie and Hollis, 1996; Mahoney, 1996), with a number apparently disappearing altogether (Ingram and McDonald, 1993). The majority of these species are forest-dwelling frogs that breed in streams. The causes of Australian frog declines are uncertain, but possibilities include climate change (Osborne 1989; Ingram, 1990), depletion of the ozone layer and an increase in ultra-violet radiation (Ferraro and Burgin, 1993b), disease (Laurance et al., 1996; Berger et al., 1998), habitat destruction (Tyler and Davies, 1985; Ferraro and Burgin, 1993a), salinity (Ferraro and Burgin, 1993b) and pollution of water and soil with heavy metals and pesticides (Tyler, 1994). There is no evidence that a single factor is responsible for all amphibian declines (Halliday, 1998; cf Laurance et al., 1996), and a synergistic effect may be operating. For example, pollution of waterways or increased ultra-violet radiation may lead to physiological stress and increased susceptibility to disease.

In many cases, lack of baseline information on population sizes and natural fluctuations has hindered assessment of amphibian declines in Australia and elsewhere (Pechmann and Wilbur, 1994; Gillespie and Hollis, 1996). Without long-term data on species distributions and population sizes, it is difficult to distinguish declines from natural population fluctuations (Pechmann et al., 1991; Blaustein et al., 1994; Pechmann and Wilbur, 1994). Surveys provide data for assessing the distribution and habitat requirements of species and assemblages. These data are needed to assist conservation of biological diversity in forests and woodlands, including planning and management of effective, representative nature reserves (Burbidge, 1991; Ferrier, 1991; Stohlgren et al., 1995).

Faunal surveys can be difficult, time-consuming and expensive (Margules and Austin, 1991), and there are many issues to consider when planning a survey to maximize the value and reliability of the resulting data. These include choice of appropriate sampling techniques, sufficient survey effort to fulfill the aims of the study, and a systematic design. Data collected during a systematic survey or monitoring program, undertaken at replicated, independent sites, are suitable for statistical analysis (Heyer et al., 1994). This review examines four components of survey design, and reviews previous amphibian surveys in forest and woodland habitats. It also provides recommendations for planning amphibian surveys and identifies areas for further research.

SURVEY DESIGN

1. Sampling Techniques

There is a variety of techniques for sampling amphibians (Heyer et al., 1994). Each is suitable for detecting species with particular life history traits and behavior. The most commonly used techniques for sampling amphibians include opportunistic and systematic searches, pitfall traps, listening for and recording the advertisement calls of male anurans (frogs and toads), larval sampling, and

Table 1. Target species, advantages and disadvantages of a variety of techniques for sampling amphibians.

Technique	Target species	Advantages	Disadvantages
Pitfall trapping - dry traps	Ground-dwelling species, poor jumpers and climbers	Does not harm animals, can detect active animals that are not calling	Poor capture rates, labor intensive, expensive to establish
Pitfall trapping - wet traps	Ground-dwelling species	Potentially higher capture rates than dry traps, less labor intensive	Destructive technique - can kill large numbers of animals
Funnel traps	Ground-dwelling species	Easier to install than pitfall traps	Captured animals can quickly dehydrate and die
Observational searches	Active or obvious species	Does not disturb habitat, cheap	Does not detect concealed animals
Investigative searches	Active and sedentary species	May find more animals than observational searches, cheap	Disturbs habitat
Destructive searches	Active and sedentary species	May find more animals than less intensive searches, cheap	Destroys habitat, may scare animals before they are found
Night driving	Large, active species	Can detect a large number of species with relatively little effort	Limited inference can be drawn regarding habitat use, requires a vehicle (and roads)
Coverboards	Salamanders, some anurans	Non-destructive technique, suitable for long-term studies	Materials can be expensive, not suitable for short-term studies or remote, steep terrain
Larval/tadpole sampling	Species with aquatic larvae	Can detect species at a site when adults are absent	Larvae can be difficult to identify
Counting and/or recording calls	Anuran species that are calling during the survey, prolonged breeders	Detects calling animals that cannot be seen, quick, non-destructive	Does not detect animals that are present but not calling
Automatic recording of calls	Anuran species that are calling during the survey, loud callers	Does not require researchers to be present, non-destructive	Equipment can be expensive, technical difficulties possible

the use of artificial coverboards. A summary of the target species, advantages and disadvantages of 11 sampling techniques appears in Table 1.

An amphibian fauna may be comprised of large and small, burrowing, ground-dwelling and arboreal species, explosive and prolonged breeders, and species that may or may not require free water to breed (e.g., Czechura, 1991). Because each technique for sampling amphibians best detects a certain subset of the fauna, use of complementary sampling techniques is often necessary to detect all the species in a survey area (Bury and Raphael, 1983; Friend, 1984; Osborne, 1985; Heyer et al., 1994). However, few studies have systematically compared different sampling techniques and determined the most appropriate ones for a given habitat or region and its corresponding amphibian fauna (e.g., Greenburg et al., 1994; Pearman et al., 1995; Parris et al., in press). Other, less systematic studies have used different sampling techniques at different times or in different places, confounding comparisons (e.g., Bury and Raphael, 1983; Mitchell et al., 1993). A summary of studies comparing techniques for sampling amphibians in forests and woodlands appears in Table 2.

Searches for amphibians take many forms (Heyer et al., 1994). Searches can be conducted during the day or at night, at streams, ponds and dams or in forest areas away from water, in pre-determined plots or transects or in an opportunistic fashion. The intensity of searches varies from observation of active amphibians (Crump and Scott, 1994) to investigation of likely refuges such as leaf litter, logs and rocks (Jaeger, 1994; Jaeger and Inger, 1994; Gillespie and Hollis, 1996), to destruction of microhabitats with hoes, machetes or metal claws (e.g., Heyer and Berven, 1973).

All seven studies comparing nocturnal searches with other techniques for sampling amphibians in forests and woodlands found nocturnal searches to be the most effective (Braithwaite, 1985; Berrill et al., 1992; Denton and Beebee, 1992; Pearman et al. 1995; Holloway, 1997; Shirose et al., 1997; Parris et al., in press). Nocturnal searches detected more species and/or more individuals than diurnal searches, pitfall traps, tadpole netting, counts of calling males, automatic tape recorders, artificial coverboards and artificial aquatic habitats (Table 2). Searches of daytime refuges can detect certain species if suitable microhabitats are investigated (Heyer and Berven, 1973; Gillespie and Hollis, 1996). However, only one of six studies comparing diurnal searches with other sampling techniques found it to be the most effective for detecting amphibians (Bury and Raphael, 1983; Table 2).

Night driving is a search technique that uses a road as a transect. It involves driving slowly along a section of road at night, counting the amphibians seen per unit time with spotlights or the vehicle's headlights (Shaffer and Juterbock, 1994). Night driving is suitable for detecting large, active species that move through the landscape away from breeding sites, and works best on wet nights when these amphibians are moving. Campbell and Christman (1982) detected more amphibian species with night driving than with pitfall traps or two types of diurnal searches during a comparative study in Florida. The majority of the species not detected with night driving were small amphibians that may have been difficult to see from a moving vehicle. Data derived from night driving may be of limited use in discerning the habitat requirements of the species found. The road and its surroundings may be hostile habitats that the amphibians are moving through on their way to somewhere more favorable, such as a breeding site.

Pitfall traps consist of holes in the ground lined with buckets, tins or pipes, that animals fall into (Corn, 1994). They are often set with drift fences, which are arranged to guide animals moving along the ground into the traps (Corn, 1994). Dry pitfall traps are empty except for a wet sponge or some leaf litter placed in the bottom to provide refuge and moisture for captured animals (Greenburg et al., 1994). Wet pitfall traps contain preservatives such as alcohol and formalin, and are designed to preserve the captured animals as specimens. Because wet pitfall traps kill all animals they catch including invertebrates, reptiles, mammals and amphibians, they can cause large-scale mortality, especially when left open for long periods of time (e.g., Webb, 1991; Mitchell et al., 1993, 1997).

Pitfall traps are suitable for sampling active, ground-dwelling species that are not strong jumpers or climbers (Osborne, 1985; Dodd, 1991; Corn, 1994). Arboreal or inactive species that are unlikely to encounter a trap, and species that can climb or jump out of a trap are not well sampled with this technique. Pitfall trapping was the most effective sampling technique in two of six comparative studies, detecting more amphibian species than funnel traps in the Ocala National Forest, Florida (Greenburg et al., 1994) and artificial coverboards in forest wetlands in Virginia and South Carolina (Mitchell et al., 1993). Research on the efficiency of various pitfall trap systems indicates that traps > 30 cm deep set on both sides of drift fences > 15 m long catch the most animals (Vogt and Hine 1982; Braithwaite, 1983; Friend, 1984; Osborne, 1985; Bury and Corn, 1987; Table 2). Osborne (1985) tested the ability of eleven species of frogs to escape from pitfall traps of different depths. He found that tree frogs could climb out of traps of any depth, but that terrestrial myobatrachid frogs generally could not jump out of traps > 30 cm deep.

The advertisement calls of male frogs are a distinguishing character that can be used to identify species (Blair, 1958; Littlejohn, 1968). Amphibians calling along a transect or in a quadrat can be counted and their calls recorded. Calls can also be periodically recorded at study sites using tape recorders with automatic timing devices, which turn on and off at specified times (Peterson and Dorcas, 1994). This technique only detects species that are calling at the time of survey. Calling activity varies seasonally and diurnally, and in response to recent and prevailing weather conditions (Heyer et al., 1994). It can be difficult to count frogs accurately when they are calling in chorus. In these cases, an index of calling activity can be used to estimate numbers. The number of Fowler's toads and bullfrogs detected with call count surveys was proportional to but consistently lower than the number found with intensive nocturnal searches when the two techniques were compared in Ontario (Shirose et al., 1997). Automatic tape recorders detected fewer species of amphibians than nocturnal searches during a comparative study in Queensland, Australia (Parris et al., in press). The four species not detected with tape recorders either did not call during the survey or had quiet calls that were difficult to record.

Sampling amphibians with artificial coverboards involves arranging wooden boards, roof tiles or metal sheeting in standard arrays in the study area, then looking underneath them at regular intervals for sheltering amphibians (DeGraaf and Yamasaki, 1992; Denton and Beebee, 1992; Mitchell et al., 1993; Fellers and Drost, 1994; Davis, 1997). The coverboards act as artificial

Table 2. Studies comparing techniques for sampling amphibians in forests and woodlands. *Denotes an unsystematic study.

Reference	Location	Sampling techniques	Best technique
Braithwaite, 1985	Northern Territory, Australia	Nocturnal searches, diurnal searches, pitfall traps	Nocturnal searches
Holloway, 1997*	East Victoria, Australia	Nocturnal searches, diurnal searches, tadpole netting, automatic tape recorders	Nocturnal searches
Parris et al., in press	South-east Queensland, Australia	Nocturnal searches, pitfall traps, automatic tape recorders	Nocturnal searches
Denton and Beebee, 1992	South and north-west England	Nocturnal searches, diurnal searches, artificial cover	Nocturnal searches
Berrill et al., 1992	Southern Ontario, Canada	Nocturnal searches, call surveys, automatic tape recorders	Nocturnal searches
Shirose et al., 1997	Ontario, Canada	Call surveys, nocturnal searches	Nocturnal searches
Pearman et al., 1995	Tena, Ecuador	Nocturnal searches, diurnal searches, artificial cover, artificial aquatic habitats	Nocturnal searches
Campbell and Christman, 1982	Florida, USA	Night driving, diurnal quadrat searches, diurnal time-constrained searches, pitfall traps	Night driving
Greenburg et al., 1994	Florida, USA	Pitfall traps, single-ended funnel traps, double-ended funnel traps	Pitfall traps
Bury and Raphael, 1983*	California, USA	Pitfall traps, diurnal time-constrained searches	Time-constrained searches
Mitchell et al., 1993*	Virginia and South Carolina, USA	Large wet pitfall traps, small dry pitfall traps, artificial cover	Large wet pitfall traps
Braithwaite, 1983	Northern Territory, Australia	Pitfall traps with drift fences, pitfall traps covered with metal sheeting	Pitfall traps with drift fences
Friend, 1984	Northern Territory, Australia	One- and two-directional pitfall traps	Two-directional pitfall traps
Osborne, 1985	Canberra, Australia	Pitfall traps of different depths 5 - 40 cm	Traps > 30 cm deep
Vogt and Hine, 1982	Wisconsin, USA	Pitfall traps with drift fences < 15 m and > 15 m	Pitfall traps with drift fences > 15 m long
Bury and Corn, 1987	Oregon and Washington, USA	Pitfall traps with 5 m, 2.5 m and no drift fences	Pitfall traps with 5 m drift fences

shelter for amphibians. Coverboards work especially well for salamanders, which generally shelter below surface objects such as logs during wetter periods of the year (Fellers and Drost, 1994). Denton and Beebee (1992) found artificial cover in the form of roof tiles to be of limited value for detecting natterjack toads Bufo calamita in England. Both B. calamita and B. bufo used the artificial cover during spring and autumn, but left in summer to take refuge further underground and avoid hot, dry conditions (Denton and Beebee, 1992).

Sampling amphibian larvae can be an effective way to detect species breeding at a site, and is particularly useful when adult animals are no longer present. Larvae can be sampled with seines, dipnets, rigid enclosures or underwater traps (Shaffer et al., 1994), and counted to give information on the species present and their abundance. The adults of explosive breeding species such as Litoria brevipalmata, the green-thighed frog from eastern Australia, may only be present at a body of water for one or two nights per breeding season, while their larvae will usually spend weeks or months developing to metamorphosis (Natrass and Ingram, 1993; Tyler, 1994). Larval sampling can therefore detect species that other techniques miss (e.g. Pearman et al., 1995). However, in some regions there is no comprehensive guide to amphibian larvae and problems with identification, particularly in areas of high species richness, may mean that larvae must be raised to metamorphosis (e.g. Osborne, 1985). This may be impractical for studies with a large number of survey sites, as larvae from each site would need separate aquaria.

Results of the comparative studies summarized in Table 2 indicate that nocturnal searching is a consistently effective technique for detecting amphibians in a range of forest and woodland habitats. Conversely, diurnal searches and pitfall traps appear to be less effective. However, it may be inappropriate to extrapolate the results of previous studies to different habitats or regions, as techniques that are effective in one place may be less so in another. For example, Braithwaite (1985) surveyed the frog fauna of Kakadu National Park in the Northern Territory, Australia using diurnal searches, nocturnal searches and dry pitfall traps with drift fences. Dry pitfall traps detected 15 out of 23 frog species found, with a capture rate of 25.1/100 trap nights in the wet season (Braithwaite, 1985). In contrast, dry pitfall traps detected only seven frog species out of 34 at a capture rate of 2.1/100 trap nights during recent fauna surveys in the forests of northeast New South Wales, Australia (New South Wales National Parks and Wildlife Service, 1994). Most of the amphibians caught in pitfall traps during both studies were burrowing and ground-dwelling frogs, but they comprised a larger proportion of the frog fauna at Kakadu. A preliminary or pilot study determining the most effective combination of techniques for sampling the amphibian fauna in a study area may be a useful first step in planning a survey (e.g., Pearman et al., 1995). Pilot studies are particularly helpful, if not essential, when an amphibian fauna is poorly known.

2. Survey Effort

Amphibian activity, and thus detectability, varies spatially, seasonally and with current or recent weather conditions (Duellman and Trueb, 1986; Heyer et al., 1994). As a consequence, several visits to a survey site are generally required to detect all the amphibian species present (e.g., Hecnar, 1997; Pearman, 1997). Hasty surveys may fail to find some species, especially those that are rare, cryptic or active for short periods of time such as explosive breeders. The survey effort required to fulfill the aims of a survey will vary with season, habitat conditions, the diversity, composition and activity patterns of the amphibian fauna in the study area, and the sampling techniques used. Again, a pilot field study can provide information on the survey effort needed when using different sampling techniques in a given study area.

There is little information on the survey effort required to detect a specified proportion of the species at a site with a given technique (Osborne, 1985), or to be confident that a species is absent when not detected. However, previous studies indicate that more repeat sampling is required with trapping than nocturnal searching. Months of continuous pitfall or funnel trapping may be required to detect all the species at a site (Bury and Corn, 1987; Greenburg et al., 1994), although arboreal species are unlikely to be detected with pitfall traps, regardless of survey effort. Parris et al. (in press) estimated the survey effort required to be confident that a frog species is absent when not detected with different sampling techniques. Up to 140 nights of pitfall trapping but only six nights of nocturnal searching or tape recording are needed to be 95% sure of the absence of Pseudophryne raveni, a common, ground-dwelling frog, from forest streams in Queensland, Australia.

In general, more survey effort will be required to detect rare or cryptic species than common species. This can be important in studies investigating possible effects of human activities in forests, such as logging, on the resident amphibian fauna. Rarer species may be most vulnerable to habitat disturbance, but least likely to be detected in pre-logging surveys or environmental impact assessments. The survey effort required to detect all species of an amphibian fauna is likely to increase with its diversity. Amphibian surveys conducted outside the main breeding season in cold or temperate habitats are unlikely to find most species present, regardless of survey effort, resulting in unreliable data (Heyer et al., 1994).

3. Statistical Considerations

Data collected during a systematic survey or monitoring program, undertaken at replicated, independent survey sites, are suitable for statistical analysis of relationships between the amphibians at a site and habitat variables, amphibian activity and weather conditions, or population trends over time (e.g. Pechmann et al., 1991; Denton and Beebee, 1992; Petranka et al., 1994; Welsh and Lind, 1995). Ideally, survey sites should represent the range of environmental variation in the study area, such as variation in climate, forest type, land systems or aquatic habitats (Austin and Heyligers, 1991; Petranka et al., 1994; Pearman, 1997). Sites should be far enough apart that the presence of a species at one site is not influenced by its presence or absence at another (Sokal and Rohlf, 1981).

An unsystematic experimental design, insufficient replication or dependence between sites reduce the value of survey data. Differences in sampling techniques or survey effort between sites may invalidate comparisons of their amphibian fauna. Insufficient replication of sites will limit the power of consequent statistical analyses to detect significant effects. For example, in a study of habitat variables influencing amphibian assemblages in the Appalachian forests of Virginia, Mitchell et al. (1997) surveyed five sites, one in each of five forest types. They found no significant relationships between the number or diversity of amphibians and habitat variables, and did not fulfill the aims of their study. Dependence between survey sites will compromise analyses of between-site

Table 3. A selection of previous amphibian surveys in forests and woodlands, arranged alphabetically by continent. Sites were considered independent if > 1 km apart. A survey was considered systematic if sites were selected systematically, and surveyed with the same sampling techniques the same number of times. ? = insufficient information provided.

Reference	Location	Target species	Sampling techniques	Repeat sampling	Number of sites	Sites independent	Systematic survey
Raxworthy and Nussbaum, 1994	Northern Madagascar	Frogs	Pitfall traps, opportunistic searches	Yes	16	?	No
Inger and Colwell, 1977	Northern Thailand	Amphibians	Diurnal and nocturnal transect and stream searches, diurnal plot searches	Yes (searches at streams only)	?	?	?
Inger and Voris, 1993	Borneo	Stream-breeding frogs	Nocturnal searches at streams, tadpole sampling	Yes	18	Yes	No
Inger et al., 1987	South India	Amphibians	Diurnal and nocturnal transect searches, diurnal plot searches	?	?	?	?
Andrews et al., 1994	Northern New South Wales, Australia	Frogs	Diurnal plot searches, pitfall traps, nocturnal searches at water bodies	Yes (pitfall traps only)	36	?	No
Driscoll, 1998	Southwestern Western Australia	*Geocrinia alba, G. vitellina*	Nocturnal call surveys, removal sampling	Yes	12	?	No
Friend and Cellier, 1990	Kakadu N.P, Northern Territory, Australia	Frogs	Diurnal and nocturnal searches, pitfall traps	Yes	70	?	Yes
Gillespie and Hollis, 1996	Southeast Australia	*Litoria spenceri*	Diurnal stream searches	No	135	?	Yes
Goldingay et al., 1996	Southern New South Wales, Australia	Frogs	Diurnal plot searches, nocturnal searches at waterbodies	Yes	77	?	No
Hollis, 1995	Baw Baw Plateau, Victoria, Australia	*Philoria frosti*	Diurnal call surveys and searches for egg masses	Yes	44	?	Yes
Lemckert, 1995	Northern New South Wales, Australia	Frogs	Night driving, nocturnal searches at water bodies	?	?	No	No
Mahoney, 1993	Central New South Wales, Australia	Frogs	Nocturnal searches at water bodies	Yes	6	Yes	Yes
McDonald, 1990	Eungella, Central Queensland, Australia	*Rheobatrachus vitellinus, Taudactylus spp.*	Nocturnal and diurnal searches at streams	Yes	?	?	?

Table 3. continued

Reference	Location	Target species	Sampling techniques	Repeat sampling	Number of sites	Sites independent	Systematic survey
NSW NPWS, 1994	Northern New South Wales, Australia	Frogs	Nocturnal searches at streams, pitfall traps	Yes	191	Yes	Yes
Osborne, 1989	Mountains of southern New South Wales, Australia	*Pseudophryne corroboree*	Diurnal call surveys, tadpole sampling	Yes	411	?	?
Parris and McCarthy, in press	Southeast Queensland, Australia	Stream-breeding frogs	Nocturnal searches, automatic tape recorders and pitfall traps at streams	Yes	19	Yes	Yes
Richards et al., 1993	North Queensland, Australia	Stream-breeding frogs	Nocturnal and diurnal searches and tadpole netting at streams	Yes	47	?	Yes
Smith et al, 1994	Northern New South Wales, Australia	Frogs	Diurnal plot searches, pitfall traps, nocturnal searches at water bodies	Yes (pitfall traps only)	77	?	No
Torr, 1993	Daintree N.P., North Queensland, Australia	Frogs	Diurnal and nocturnal searches, pitfall traps	Yes (pitfall traps only)	?	No	No
Woinarski and Gambold, 1992	Kakadu N.P, Northern Territory, Australia	Frogs	Diurnal and nocturnal searches, pitfall traps	Yes	370	No	Yes
Brana et al., 1996	Northern Spain	Lake-breeding amphibians	Diurnal searches, tadpole sampling	?	16	?	Yes
Sjogren, 1994	Sweden	*Rana lessonae*	Diurnal and nocturnal searches at ponds	Yes	200	No	No
Stumpel and van der Hoet, 1998	The Netherlands	Pond-breeding amphibians	Diurnal pond searches, larval sampling	Yes	133	?	Yes
Aubry et al., 1988	Washington, USA	Amphibians	Diurnal searches in forest stands	No	45	?	Yes
Beauregard and Leclair, 1988	Quebec, Canada	Frogs	Funnel traps	Yes	30	?	Yes
Bury and Corn, 1988	Oregon and Washington, USA	Amphibians	Diurnal searches and pitfall traps in forest stands	Yes	30	Yes	No
Bury et al., 1991	Oregon and Washington, USA	Aquatic amphibians	Diurnal stream searches	No	59	Yes	Yes

Table 3. continued

Reference	Location	Target species	Sampling techniques	Repeat sampling	Number of sites	Sites independent	Systematic survey
Collins et al., 1988	Arizona, USA	*Ambystoma tigrinum stebbinsi*	Diurnal searches at waterbodies, dip netting	*?*	*30*	*Yes*	*?*
Corn and Bury, 1991	Oregon, USA	Amphibians	Pitfall traps, diurnal searches of down wood	Yes (Pitfall traps only)	50	?	No
Dalrymple, 1988	Florida, USA	Amphibians	Funnel traps, day and night driving, nocturnal and diurnal searches	Yes	13	No	?
Hecnar and M'Closkey, 1997	Ontario, Canada	Pond-breeding amphibians	Diurnal searches, larval sampling Yes	118	?	?	
Jones, 1988	Arizona, USA	Amphibians	Pitfall traps, night driving, nocturnal Yes searches at waterbodies	183	?	No	
Mitchell et al., 1997	Virginia, USA	Terrestrial amphibians	Pitfall traps	Yes	5	Yes	Yes
Petranka et al., 1994	North Carolina, USA	Salamanders	Diurnal plot searches	No	52	No	Yes
Ramotnik and Scott, 1988	New Mexico, USA	*Plethodon neomexicanus, Aneides hardii*	Diurnal plot searches	*No*	*123*	*?*	*Yes*
Saugey et al., 1988	Arkansas, USA	Salamanders in caves	Searches of caves and mines and mines	Yes	31	?	No
Welsh and Lind, 1995	Northwestern California, USA	*Plethodon elongatus*	Diurnal plot searches	?	57	No	Yes
Aichinger, 1987	Panguana, Peru	Stream- and pond-breeding frogs	Diurnal and nocturnal searches	Yes	7	No	Yes
Crump et al., 1992	Northern Costa Rica	*Bufo periglenes*	Diurnal? searches	Yes	?	?	?
Gascon, 1991 No	Amazonian Brazil	Aquatic-breeding frogs		Tadpole netting	Yes	53	Yes
Lips, 1998	Puntarenas Province, Costa Rica	Amphibians	Nocturnal and diurnal stream searches, diurnal plot searches	Yes (stream searches only)	6	No	No

Table 3. continued

Reference	Location	Target species	Sampling techniques	Repeat sampling	Number of sites	Sites independent	Systematic survey
Lips, 1999	Western Panama	Amphibians	Nocturnal and diurnal searches, tadpole netting	Yes	14	No	No
Marsh and Pearman, 1997	Northern Ecuador	Amphibians	Nocturnal transect searches	Yes	16	No	Yes
Pearman, 1997	Amazonian Ecuador	Amphibians	Nocturnal searches	Yes	23	?	Yes

variation, resulting in inflated estimates of statistical significance (Sokal and Rohlf, 1981).

4. Ethics

Field surveys involve active observation of animals and may result in accidental or deliberate disturbance of amphibians in their natural habitat. Non-destructive sampling techniques are important for maintaining the integrity of a study population, and protecting rare and endangered species (Gibbons, 1988). Use of sampling techniques that kill animals or severely disturb their habitat raises ethical issues (Farnsworth and Rosovsky, 1993). Researchers need to consider possible negative impacts on their study animals before using destructive sampling techniques.

Investigative searching that destroys the refuges of amphibians and reptiles in and under trees, logs, leaf litter and soil can have a considerable adverse effect on the resident herpetofauna and its habitat (Davis, 1997). Wet pitfall traps containing alcohol or other preservatives kill all animals that fall into them, including rare and endangered species, and can cause large-scale mortality (Webb, 1991; Mitchell et al., 1993, 1997). For example, researchers caught 40 hip-pocket frogs (Assa darlingtoni) and 21 sphagnum frogs (Philoria sphagnicolus) in wet pitfall traps established to catch invertebrates during a survey in forests in northeast New South Wales, Australia (New South Wales National Parks and Wildlife Service, 1994). Both are listed as vulnerable and rare (Schedule 12) species in New South Wales.

Dry pitfall traps can also kill large numbers of animals if they not checked regularly enough, as captured animals can desiccate, starve or be eaten by predators (Buhlmann et al., 1988; Halliday, 1996). During a survey of forest vertebrates in Oregon and Washington, Bury and Corn (1987) initially checked their pitfall traps every three days, then only every seven days. Almost all 3904 mammals they caught died in the traps. Most of the 2180 amphibians and reptiles caught were still alive when the traps were checked, although the researchers subsequently collected them as specimens (Bury and Corn, 1987). This is an extreme example, but researchers need to justify a decision to include destructive techniques in their study, particularly in situations where more benign techniques could be used. Ethical concerns surrounding the use of destructive sampling techniques are compounded if surveys are not designed to ensure the research questions can be answered.

PREVIOUS AMPHIBIAN SURVEYS IN FORESTS AND WETLANDS

The design, sampling techniques, and survey effort used in 44 previous amphibian surveys in forests and woodlands around the world are summarized in Table 3. This is not an exhaustive list, but represents the range of approaches used to survey amphibians in forest and woodland habitats, excluding experimental and population studies. Over half the papers in Table 3 did not include sufficient information on the method of their survey for a reader to determine the number or independence of survey sites, or whether the survey was systematic or included repeat sampling. This information is needed for a survey to be scientifically evaluated.

The target species of the surveys in Table 3 varied from a single species to all the amphibians present in a large study area. Thirty of the 44 studies used a combination of sampling techniques, and 33 included repeat sampling with at least one technique. Twenty studies were classed as systematic, with systematically selected sites surveyed the same number of times with the same techniques. Thirteen systematic studies included repeat sampling at survey sites (Table 3). Only two studies included systematic repeat sampling with a combination of techniques at systematically selected, independent survey sites (NSW NPWS, 1994; Parris and McCarthy, in press).

Survey sites should be far enough apart that the presence of a species at one site is not influenced by its presence or absence at another (Sokal and Rohlf, 1981). For the purposes of Table 3, I defined sites as independent if they were 1 km apart, although the actual distance needed to ensure independence will vary between species and habitats. Information on the proximity of survey sites was provided in only 20 of the papers listed in Table 3. Of these, nine studies had independent survey sites. This indicates that independence of sites has not been widely considered during survey planning, despite dependence between sites violating a key assumption of most statistical analyses. Six of the 11 studies in Table 3 with dependent sites (< 1 km apart) included statistical analysis of data between sites (Dalrymple, 1988; Petranka et al., 1994; Sjogren, 1994; Lemckert, 1995; Welsh and Lind, 1995; Woinarski and Gambold, 1992).

Many amphibian surveys in Australian forests and woodlands have been combined with surveys for other vertebrate groups, resulting in inadequate survey effort for amphibians, particularly rare and cryptic species (Milledge, 1993). Such surveys have frequently used inappropriate techniques for sampling amphibians, such as diurnal searches and pitfall traps in forest plots away from water bodies (e.g., Webb, 1991; Andrews et al., 1994; Smith et al., 1994, 1995; Fanning, 1995; Goldingay et al., 1996). A survey to investigate forestry impacts on the fauna of the Urbenville Forest Management Area in northern New South Wales detected only two frogs during diurnal searches at 180 forest plots, while wet pitfall traps caught just seven of the 42 frog species known from the study area (Andrews et al., 1994). Consequently, Andrews et al. (1994) found no effect of forest type or logging on the richness of amphibian species at their survey sites.

Pitfall trapping and diurnal searches away from water are unlikely to detect most amphibians in the temperate and sub-tropical forests of eastern Australia because they are rarely found in terrestrial areas. However, terrestrial sampling of amphibians can be effective in wetter forests such as those of northwestern North America, where much of the amphibian fauna breeds and/or shelters in terrestrial areas (Leonard et al., 1993). A series of amphibian surveys in Douglas-Fir forests in Washington, Oregon and California successfully used diurnal searches and pitfall trapping at terrestrial sites (Bury and Raphael, 1983; Corn and Bury, 1991; Gilbert and Allwine, 1991; Aubrey and Hall, 1991; Bury et al., 1991). Pitfall traps and time-constrained searches detected both salamanders and frogs, while searches of down wood detected salamanders sheltering in and under logs on the forest floor. This demonstrates the effectiveness of sampling techniques varying with the composition of the amphibian fauna in a study area, and the need to consider the biology of the target species when planning a survey.

CONCLUSION AND RECOMMENDATIONS

Planning an amphibian survey to maximize its effectiveness and the value of the resulting data involves consideration of a wide range of issues. Suggested steps when planning an amphibian survey are:

1. Identify your study area and the question(s) you wish to answer (survey aims).
2. Review the literature on the amphibians in your study area. If they have been poorly studied, undertake a pilot study to compare the effectiveness of a number of sampling techniques, and assess the sampling effort that might be required to fulfill your survey aims. All sampling techniques should be used concurrently at the same sites to ensure a valid comparison.
3. Consider possible negative effects of destructive sampling techniques before deciding to use them. In some countries, ethics approval for a project will not be granted if use of destructive techniques is proposed.
4. Determine the size of sites, plots or transects (sampling units) appropriate for the study area and the survey questions.
5. Determine the number and arrangement of sites needed to address the survey questions. For example, if you are interested in the effects of forest fragmentation on amphibians, locate sites in a number of different patches and a number of contiguous forest areas.
6. Choose sites to represent the range of variation of one or more relevant parameters in the study area. In the example above, these could be the range of patch sizes and their proximity to contiguous forest. If planning to analyze variation between sites, ensure that sites are located far enough apart to be independent.
7. Systematically survey the selected sites with one or more sampling techniques suitable for your target species. Repeat, as indicated by the pilot study and the survey aims.

More information is needed on the effectiveness of different techniques for sampling amphibians in different forest and woodland habitats. In addition, the survey effort required to fulfill the aims of a study, such as detecting a particular species if it is present, is largely unknown in many areas of the world. These issues of amphibian survey design require further research.

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