Journal of Applied Ecology

British Ecological Society

Journal of Applied Ecology 2010, **47**, 227–234 doi: 10.1111/j.1365-2664.2009.01755.x

Assessing ethical trade-offs in ecological field studies

Kirsten M. Parris[1]*, Sarah C. McCall[1], Michael A. McCarthy[1], Ben A. Minteer[2], Katie Steele[3], Sarah Bekessy[4] and Fabien Medvecky[5]

[1]*School of Botany, University of Melbourne, Vic. 3010, Australia;* [2]*School of Life Sciences, Arizona State University, Tempe, AZ 85287-4501, USA;* [3]*Department of Philosophy, Logic and Scientific Method, London School of Economics, Houghton Street, London WC2A 2AE, UK;* [4]*School of Global Studies, Social Science & Planning, RMIT University, GPO Box 2476V Melbourne, Vic. 3001, Australia; and* [5]*Department of Philosophy, University of Sydney, NSW 2006, Australia*

Summary

1. Ecologists and conservation biologists consider many issues when designing a field study, such as the expected value of the data, the interests of the study species, the welfare of individual organisms and the cost of the project. These different issues or values often conflict; however, neither animal ethics nor environmental ethics provides practical guidance on how to assess trade-offs between them.

2. We developed a decision framework for considering trade-offs between values in ecological research, drawing on the field of ecological ethics. We used a case study of the population genetics of three frog species, in which a researcher must choose between four methods of sampling DNA from the study animals. We measured species welfare as the reduction in population growth rate following sampling, and assessed individual welfare using two different definitions: (i) the level of suffering experienced by an animal, and (ii) the level of suffering combined with loss of future life.

3. Tipping the tails of tadpoles ranked as the best sampling method for species welfare, while collecting whole tadpoles and buccal swabbing of adult frogs ranked best for the first and second definitions of individual welfare, respectively. Toe clipping of adult frogs ranked as the worst sampling method for species welfare and the first definition of individual welfare, and equal worst for the second definition of individual welfare.

4. When considering species and individual welfare simultaneously, toe clipping was clearly inferior to the other sampling methods, but no single sampling method was clearly superior to the other three. Buccal swabbing, collecting tadpoles and tail tipping were all preferred options, depending on the definition of individual welfare and the level of precision with which we assessed species welfare.

5. *Synthesis and applications*. The decision framework we present can be used by ecologists to assess ethical and other trade-offs when planning field studies. A formal decision analysis makes transparent how a researcher might negotiate competing ethical, financial and practical objectives. Defining the components of the decision in this way can help avoid errors associated with human judgement and linguistic uncertainty.

Key-words: amphibians, animal welfare, conservation, decision theory, ecological ethics, frogs, toe clipping

Introduction

Ecologists and conservation biologists encounter many practical and ethical issues when designing field surveys (Minteer & Collins 2005a, b). The scientific value of a study, its cost, the welfare of individual study organisms and the interests of the population or species as a whole may conflict. Although such conflicts of values are commonplace, they are rarely addressed systematically by researchers. Here, we present a framework for explicitly considering trade-offs among values in ecological research, focussing particularly on what some researchers are now calling 'ecological ethics' (Minteer & Collins 2005a, b, 2008).

Ecologists looking for scholarly clarity on ethical issues generated by their work are likely to be struck by the unsettled discussion in practical ethics surrounding the moral status and

*Correspondence author. E-mail: k.parris@unimelb.edu.au

significance of non-human individuals, populations and ecosystems. Environmental philosophers – those in the academic community who have written most extensively on these questions – have not established a meaningful consensus on the moral standing of animals, plants and ecological systems. For example, what is the value of a rare species of plant compared with a herd of mountain goats threatening the plant's survival? The field is beset by debates over these very issues, pitting those who champion the interests of individual sentient animals (or individual organisms more generally) against defenders of the 'intrinsic value' of biological wholes, such as species and ecosystems (e.g. Callicott 1989; Hargrove 1992; Varner 1998). Most environmental philosophers appear to be largely occupied with the philosophical and/or ethical justification for the recovery, conservation, and protection of wild species and ecosystems, rather than the pain and suffering of research animals. As a result, philosophical defences of the interests of animals (counted singly) are considered as the purview of 'animal ethics', which encompasses both utilitarian/welfare and rights-based approaches (Singer 1990; Regan 2004).

The rift between environmental and animal ethics poses intellectual and practical difficulties for researchers wishing to assess the trade-offs between the welfare of individual organisms and the welfare of wild species and ecosystems in ecological field studies. Indeed, the divide between environmental and animal ethics is in many respects recreated in the ecological and conservation sciences (e.g. Perry & Perry 2008). There, animal welfare concerns often become separated from the population/ecological considerations that motivate most ecologists and conservation biologists, even though study design can have significant impacts on the welfare of individual animals.

Since there is no single tradition or framework in ethical theory that provides clear and practical guidance for researchers working with a complex assortment of plants, animals, populations and ecological systems, such analysis must be informed by multiple ethical foundations and principles from a range of domains in normative and practical ethics. Towards this end, ecological ethics has emerged recently as a more concrete style of environmental ethical analysis that incorporates a broad range of normative considerations in assessing the ethical implications of ecological research and biodiversity management (Minteer & Collins 2005a, b, 2008).

While many field ecologists must gain approval for their work through their institution's animal ethics committee, they maintain personal responsibility for the wellbeing of their study organisms, and must decide whether the potential benefits of a study outweigh any ethical concerns about its implementation (e.g. Australian Government 2004). Indeed, being an ethical scientific researcher requires a commitment to continual moral reflection and self-criticism, a process of deliberation and individual judgment that goes beyond simple adherence to research regulations and codes of conduct, as essential as these are to the evaluation of research practices. Furthermore, regulations regarding ethical conduct in ecological research are largely concerned with vertebrates and certain invertebrates such as octopus and squid; other invertebrates, plants, habitats or ecosystems are not usually considered.

A small number of important papers in ethics have attempted to address animal welfare issues in ecological field research (e.g. Bekoff & Jamieson 1996; Monamy & Gott 2001; Marsh & Kenchington 2004; Swart 2004; Vucetich & Nelson 2007; Minteer & Collins 2008; Perry & Perry 2008), but to our knowledge, none has developed an ethically oriented decision framework to guide researchers in the design of their studies. We believe that animal welfare and environmental/conservation impacts can and should be evaluated in ecological research. Both individual and population-level welfare can be considered in a common multi-criteria decision framework, which we describe here. This article presents the framework, and then uses a case study of the population genetics of three endangered frog species to illustrate the approach.

The framework

Many issues might be considered when a researcher designs a study, including the scientific value of the study; its monetary cost; the welfare of biological units such as species or ecosystems; and the welfare of individual organisms. Scientific value includes worth assigned to the inferential power of the data and the practical utility of the new information. In general, inferential power will increase with an increase in data, for example, the number of samples, number of details examined, number of taxa and the length of time and space that a study spans, measureable as a reduction in uncertainty (Dakins 1999; McCarthy & Parris 2008). In turn, we can expect that as these factors increase in size, the sum cost of equipment and personnel will also increase. Practical utility might also be expected to increase when inferences can be made with greater confidence, but this will partly depend on the effort that a researcher puts into communicating their work to interest groups and the public. The communication method and time dedicated to dissemination are two factors that influence whether, and how rapidly, information is applied (Haines & Jones 1994; Robertson & Hull 2001; Pullin *et al.* 2004).

Species welfare and individual welfare are two important components of the ethics of ecological research, but their relative importance has not been resolved in ethical discourse. This is partly because of the current conceptual limitations and compartmentalization of ethical analysis in the mainstream literature, and partly because of the challenge of evaluating qualitatively distinct notions of 'harm' in such cases (Norton 1995). Still, it is often possible to identify the primary ethical concerns of a study. Furthermore, we believe that we can begin to compare the welfare impacts of the research on individuals and species with a degree of logical rigour, despite a number of caveats and qualifications. The framework allows for explicit consideration of different ethical positions, as well as uncertainty and subjective judgements regarding the impacts of a study on the species or system in question.

The ethical evaluation of ecological field research is challenging on both philosophical and methodological counts. This is because an expanded analysis of negative research impacts, understood in the language of 'harm' (applied here to both individuals and species), is complicated by the difficulty of measuring harm to individual organisms and species in a consistent and non-arbitrary manner. There are certainly significant descriptive and normative differences between harming sentient individual animals and harming collectives such as populations and species (Norton 1995). In the latter case, harm becomes less a question of the infliction of pain and suffering and more about negative impacts on population dynamics, species viability and ecosystem function. To complicate matters further is the vexed issue of different understandings of harm associated with pain (i.e. stress and suffering of sentient animals) on the one hand, and the death of an organism on the other. Although a persuasive argument could be made that death imposes the worse harm in all cases (Regan 2004), it is possible to argue that the experience of a high degree of pain over a significant period of time is worse than a relatively painless death (Rollin 2006). Furthermore, different moral frameworks, such as utilitarianism and rights theory, may evaluate these harms in different ways.

We present a case study of a researcher who must decide how to design an ecological field study, initially considering the four criteria of species welfare, individual welfare, scientific value and monetary cost. However, by holding one or more of these values constant, we can examine trade-offs among the remaining values. Here, we adjust sample sizes such that the scientific value of each option is the same, and assume that our researcher is not concerned by the variation in cost between options. This leaves us with a trade-off between the welfare of the study species and the welfare of individual organisms, in which we consider one definition of species welfare and two definitions of individual welfare.

Case study: population genetics of three frog species

Studies of the population genetics of a species can provide useful information for conservation management of wildlife, such as the effective size of a population, or the impact of habitat fragmentation on dispersal between populations (Beebee 2005; Arens *et al*. 2007). Such studies require samples of DNA from a number of individuals from each population included in the study. Consider the case of a researcher who plans to study the population genetics of three frog species (*Bufo boreas*, *Rana aurora* and *Rana temporaria*) using microsatellite genotyping to assess how frequently individual frogs disperse between isolated populations. The researcher must decide how to collect DNA samples from the study animals, which leads to an interesting scientific and ethical dilemma.

SAMPLING METHODS

In the past, whole animals were collected for genetic studies (e.g. Larson 1983; Moritz 1992). Refinement of genetic techniques has since allowed smaller samples of DNA to be used for analysis. Our researcher can choose between four methods of DNA collection. These are: (i) clipping a single toe from an adult frog (McGuigan *et al*. 1998); (ii) taking a buccal swab from an adult frog (Broquet *et al*. 2007); (iii) collecting a whole tadpole (Hitchings & Beebee 1996); and (iv) clipping the tail of a tadpole (Snell & Evans 2006). The scientific value of the information gained using each method (in this case, how reliably they provide sufficient DNA for analysis) is likely to vary. In addition, each method harms the individuals involved in different ways, and each could have an impact on the future growth rate of the study populations.

Toe clipping

Use of a single, clipped toe as a DNA sample is a common practice when studying the population genetics of amphibians (e.g. McGuigan *et al*. 1998; Funk *et al*. 2005). Clipping more than one toe from a frog or salamander reduces the probability that the marked animal will be caught again (Davis & Ovaska 2001; Parris & McCarthy 2001; McCarthy & Parris 2004; McCarthy, Weller & Parris 2009), and the impact of clipping a toe increases with the number of toes already removed (McCarthy & Parris 2004). This reduction in return rate could be because of a reduction in survival, a change in behaviour such that the marked animal is less likely to be recaptured, or a combination of the two. Waddle *et al*. (2008) used a mark–recapture model that considered recapture probabilities to investigate the effect of toe clipping on two species, the green treefrog *Hyla cinerea* and the squirrel treefrog *H. squirella*. The return rate of both species declined with increasing numbers of toes clipped. In *H. cinerea*, this was clearly because of reduced survival; in *H. squirella*, the reason (reduced survival, reduced probability of recapture, or both) was less clear. No study provides data on the effect of clipping the first toe from an amphibian in the wild. However, anecdotally, we are aware that amphibians occasionally die from the stress of being handled. Death because of handling will influence the survival rate of marked frogs regardless of the number of toes removed. While there is uncertainty about the extent of the impacts, clipping a single toe raises some ethical concerns about the welfare of individual frogs and the population as a whole (May 2004; McCarthy & Parris 2004; Minteer & Collins 2005b).

Buccal swabbing

The use of buccal swabs for DNA collection is relatively new in ecology and conservation biology, although the method is well established in other fields such as medicine and veterinary science (Broquet *et al*. 2007). Recent studies show that buccal swabs can provide sufficient DNA for microsatellite genotyping for a range of amphibian species (Pidancier, Miquel & Miaud 2003; Broquet *et al*. 2007). Synthetic cotton swabs are used to collect mucosal cells from the buccal cavity (mouth), so researchers must open the frog's mouth to take the sample. Pidancier *et al*. (2003) reported that a small amount of bleeding from the mouth sometimes occurred during sampling. As for toe clipping, we expect that handling stress could lead to the death of a small proportion of buccal-swabbed animals. The effects of buccal swabbing on individual frogs and the population as a whole are likely to be smaller than for toe clipping, but there are still some ethical concerns regarding the impact of this method on individual and species welfare.

Sampling tadpoles (collecting tadpoles and tail tipping)

Collecting DNA samples from tadpoles is an alternative to collecting samples from adult frogs. A whole tadpole can be collected (Hitchings & Beebee 1996; Beebee & Rowe 2001), or one can obtain a DNA sample by clipping the tip of a tadpole's tail (Snell & Evans 2006). However, some species of frogs are very difficult to distinguish as tadpoles, so a researcher may need to collect extra tadpoles or tail tips to account for possible misidentifications. We know that collection of whole tadpoles will result in the death of all individuals sampled, and expect that tail tipping will result in the death of a proportion of sampled animals; for example, as a result of stress during sampling, or later in the animal's life because of infection or reduced mobility. Generally, tadpoles have a low probability of surviving to adulthood (e.g. *c.* 2 in 1000 for red-legged frogs *Rana aurora*; Biek *et al.* 2002). Thus, a reduction in the survival rate of tadpoles may have a negligible effect on a population, particularly in the presence of density dependence. The decision whether to collect whole tadpoles or clip their tails requires an ethical judgement: researchers must decide whether it is better to kill an animal swiftly or to cause it discomfort/pain. We represent contrasting perspectives on this question with two definitions of individual welfare. The following section provides an outline of how species welfare and individual welfare were evaluated for the case study.

DECISION CRITERIA

Species welfare

We used the reduction in population growth rate following sampling to measure species welfare. The sampling method with the smallest reduction in population growth rate was considered to have the least impact on the species. As the population growth rate is a function of vital rates such as births and deaths, it can be used to explore the sensitivity of a given population to changes in these rates (Caswell 2000), thereby providing information on population viability. In this instance, we evaluated the change in population growth rate following the death of either frogs or tadpoles as a result of DNA sampling. Other measures that could alternatively or consecutively be used to represent species welfare include population viability, the predicted change in the rate of reproduction or dispersal, and changes in vital rates over a given length of time.

We examined how the population growth rate was influenced by collecting DNA from individuals using the four methods. We constructed a three-stage population growth matrix for our three study species – *B. boreas*, *R. aurora*, *R. temporaria* – using the models of Biek *et al.* (2002). The three stages were pre-metamorphs, juveniles and adults, with the population censused just after breeding (i.e. when tadpoles were present). In all cases, we assumed that the local population size was 200 adults, with the number of tadpoles given by the stable age distribution (Caswell 2001). In these models, the number of tadpoles is predicted to be much larger than the number of adults. For each species, we calculated the population growth rate with an additional 2% mortality of 100 toe-clipped adults (i.e. the survival rate of clipped animals was 98% of the survival rate in the absence of toe clipping), and compared this with 1% mortality of buccal-swabbed adults, and 100% and 10% mortality of 200 collected and tail-tipped tadpoles, respectively. To account for the effect of uncertain tadpole identifications in the field, we also determined the mortality rate of adults that would have the same effect on the population growth rate as collecting 200 tadpoles. In this case, our researcher collected 200 tadpoles to be sure of having 100 samples of the target species.

Mortality of 2% of adults with one toe clipped is feasible; the effect is possibly larger (McCarthy & Parris 2004). Mortality of 1% of adults following buccal swabbing is also feasible, but the effect could be negligible or larger. The value of 10% mortality for tail-tipped tadpoles is based on data showing effects of tail injury on growth, development and survival rates of tadpoles (Wilbur & Semlitsch 1990; Parichy & Kaplan 1992). Slower growth and development following tail tipping may increase tadpole mortality by delaying metamorphosis. In ephemeral aquatic habitats, many tadpoles die from desiccation when a pond or stream dries out before they have metamorphosed into frogs.

Individual welfare

Despite recent advances in pain research, the extent of pain and suffering experienced by non-human animals such as amphibians can be difficult to measure. Current knowledge of animal pain suggests that procedures painful to humans are also painful to non-human animals, and that pain perception in amphibians is analogous to that in mammals (Machin 1999; Livingston 2002). A recent study of the eastern red-spotted newt *Notophthalmus viridescens* from North America found that analgesia reduced adverse behavioural reactions following the amputation of both forelimbs, indicating that the newts experienced pain following the surgical procedure (Koeller 2009). But to our knowledge, there is no specific information available on the type and extent of pain and suffering caused by toe clipping or buccal swabbing frogs, or tail tipping or collecting tadpoles.

We included two definitions of individual welfare in our analysis: (i) level of suffering, and (ii) level of suffering and loss of future life. For both definitions, we considered that organisms with a higher sentience (the level of suffering and pleasure that they could potentially experience; Jamieson 2008) have a greater capacity to suffer relative to organisms with a lower sentience, and assumed that frogs have greater sentience than tadpoles. We ranked sampling methods on an ordinal scale from 1 to 4, where 1 is the method considered to have the lowest negative impact on individuals (i.e. cause the least pain and suffering), and 4 the method with the greatest negative impact. We analysed the decision with each definition of individual welfare separately.

Results

SPECIES WELFARE

Based on Biek *et al.*'s (2002) population growth matrix, we predicted the decrease in population growth rate of the three frog species following sampling with each of the four methods (Table 1). This decrease was used to ordinally rank sampling methods from that having the least impact (smallest decrease in population growth rate, 1) to that having the greatest impact (4). The ordinal rankings were identical across the three species; in each case, toe clipping had the greatest negative impact on the population growth rate, and tail tipping had the least impact. As the decrease in population growth rate for buccal swabbing, collecting tadpoles and tail tipping were very similar, these options could be viewed as approximately equivalent in ranking. Uncertainty surrounding our estimates of the population growth rate following sampling (e.g. because of model uncertainty and uncertainty regarding the mortality caused by each sampling method) provides additional justification for ranking these three options equally.

The effect of collecting 200 tadpoles from populations of this size was very small – equivalent to additional adult mortality of 0·1–0·65% across the three species. For all three species, the relative influence of adult mortality and tadpole mortality would not depend on the assumed population size. Thus, the population-level impact of killing tadpoles would be much smaller than that of killing adults. Unless mortality caused by sampling DNA from adult frogs were very low, sampling tadpoles (by either tail tipping or collecting tadpoles) would be preferable from the perspective of population growth rate. We assumed density-independent population growth, although density dependence in tadpole survival is likely (Vonesh & De la Cruz 2002). Including density dependence in the model would further reduce the effect on the population of killing tadpoles.

INDIVIDUAL WELFARE

An ordinal ranking of individual welfare was made for each definition of this criterion [i.e. (i) welfare decreased with increasing levels of suffering, and (ii) welfare decreased with increasing levels of suffering and loss of future life; Table 2]. Taking the first definition of individual welfare, collecting tadpoles was ranked as the sampling method with least impact, but when considering the second definition, buccal swabbing was ranked as the method with least impact. For both definitions, toe clipping was ranked as the worst or equal-worst sampling method. While we ranked collecting tadpoles as the best sampling method when the definition of individual welfare included only the level of suffering, we ranked this method as equal worst when we included both suffering and loss of future life.

We reached these rankings as follows. Under the first definition of individual welfare, we viewed toe clipping as bearing the greatest harm as we expected it to be more painful than buccal swabbing, tail tipping or collecting tadpoles. We considered the level of handling stress to be similar for toe clipping and buccal swabbing, and higher than that experienced by tadpoles during tail tipping or collection (as tadpoles are less sentient than frogs). There is some evidence that toe clipping of salamanders does not increase blood levels of stress hormones (adrenaline/noradrenaline) more than handling alone (Kinkead, Lanham & Montanucci 2006). Even though we considered frogs to be more sentient than tadpoles, we judged that the collective suffering of 200 tail-tipped tadpoles would be greater than that of 100 buccal-swabbed frogs. We expected

Table 2. The ranking of four methods for sampling DNA from frogs, from that expected to cause the least harm (1), to the greatest harm (4)

Sampling method	Species welfare: Precise	Species welfare: Approximate	Individual welfare: Suffering	Individual welfare: Suffering and loss of life
Tail tipping	1	2	3	2
Collecting tadpoles	2	2	1	3·5
Buccal swabbing	3	2	2	1
Toe clipping	4	4	4	3·5

Rankings are the same for each of the three study species, *Bufo boreas*, *Rana aurora* and *Rana temporaria*. The two criteria considered are species welfare and individual welfare, with two levels of precision for species welfare and two definitions of individual welfare. Precise rankings are based on the predicted reduction in population growth rate following sampling; approximate rankings consider the first three methods to have a similar impact on population growth rate.

Table 1. Decrease in the population growth rate of the three study species following mortality expected from each of the four sampling methods

Sampling method	Deaths expected	*Bufo boreas* Decrease (%)	*Bufo boreas* Ranking	*Rana aurora* Decrease (%)	*Rana aurora* Ranking	*Rana temporaria* Decrease (%)	*Rana temporaria* Ranking
Tail tipping (200 tadpoles sampled)	10%: 20 animals	< 0·001	1	0·028	1	< 0·001	1
Collecting tadpoles (200 tadpoles sampled)	100%: 200 animals	0·028	2	0·071	2	0·057	2
Buccal swabbing (100 frogs sampled)	1%: 1 animal	0·18	3	0·16	3	0·085	3
Toe clipping (100 frogs sampled)	2%: 2 animals	0·35	4	0·33	4	0·17	4

The methods are ranked ordinally from that causing the least harm to species welfare (1), to that causing the greatest harm (4).

the death of tadpoles following collection to be rapid, and therefore the duration of pain and stress to be shorter than that caused by the other three sampling methods. As such, we ranked the collection of tadpoles as causing less suffering than tail tipping.

When considering both suffering and the loss of future life in our definition of individual welfare, we ranked toe clipping and collecting tadpoles as the equal-worst sampling methods. We were unable to distinguish which of these would cause greater harm to individuals. Collecting tadpoles would result in the death of 200 tadpoles, as opposed to a much smaller number of tadpole and frog deaths from the other sampling methods. However, in the absence of firm data on the extent of suffering caused by any of the sampling methods, we judged that the suffering of toe-clipped frogs would be likely to last longer and be of greater intensity than the suffering of the tadpoles killed for collection. A proportion of the toe-clipped frogs could potentially die as a consequence of the procedure, for example, from future infection (Liner, Smith & Castleberry 2007) or a reduction in the ability to forage and avoid predators (Davis & Ovaska 2001; McCarthy & Parris 2004). We also predicted the reduction in the expected length of future life (summed across the sample population) with toe clipping to be greater than with buccal swabbing, tail tipping and collecting tadpoles. We did not attempt to precisely determine the effect of DNA sampling on the expected length of future life. The above statements are based on the reasoning that many tadpoles die before adulthood (e.g. as cited above, *c.* 998 in 1000 for red-legged frogs *Rana aurora*; Biek *et al.* 2002), and our expectation of fewer deaths with buccal swabbing than toe clipping. We predicted tail tipping to have a greater effect on expected future life relative to buccal swabbing, and determined that this loss of life would outweigh the higher suffering caused by buccal swabbing. This left buccal swabbing as the best sampling method, and tail tipping as the second best method.

DECISION TABLE

As the four DNA sampling methods were ranked identically for species welfare across the three study species (Table 1), and we did not consider the species separately for individual welfare (Table 2), we provide a generic decision table that identifies the sampling methods that are non-dominated (Table 3). In decision theory, a sampling method is dominated by another when it is ranked worse in at least one criterion and not better in all others considered (Resnik 1987). Thus, a dominated option is clearly inferior to at least one alternative. The set of non-dominated options is composed of those options that are not dominated by any of the others. We do not discriminate further between the options in the non-dominated set, but regard all of these as preferred options (Moffett & Sarkar 2006).

When considering the precise measure of species welfare (based on the predicted impacts of DNA sampling on the population growth rate), and assessing individual welfare as the level of suffering, we were unable to distinguish a preference between collecting tadpoles and tail tipping (Table 3). However, when both suffering and loss of future life were considered as part of individual welfare, we identified buccal swabbing and tail tipping as the superior options. While we did not identify a single preferred sampling method, we were able to identify the inferior options under our criteria. Under the first definition of individual welfare, we determined that toe clipping and buccal swabbing were inferior sampling options. Under the second definition, we ranked toe clipping and collecting tadpoles as worse than buccal swabbing and tail tipping.

Table 3. The list of non-dominated sampling options when two criteria, species welfare and individual welfare, are considered in a decision on the method for sampling DNA from frogs

Criteria	Individual welfare 1: suffering	Individual welfare 2: suffering and loss of life
Species welfare		
Precise	Collecting tadpoles	Buccal swabbing
	Tail tipping	Tail tipping
Approximate	Collecting tadpoles	Buccal swabbing

A sampling method is dominated by another when it is ranked worse in at least one criterion and not better in all others considered.

In contrast, if we assume that buccal swabbing, collecting tadpoles and tail tipping all have approximately the same impact on the population growth rate, then tadpole tail tipping is dominated by buccal swabbing and collecting tadpoles (Table 3). As such, when buccal swabbing, collecting tadpoles and tail tipping are ranked equally for species welfare, individual welfare determines which option will be ranked highest. This makes sense, as we identified toe clipping as the worst or equal-worst option for species welfare and both definitions of individual welfare (Table 2); it can effectively be eliminated from the decision. If all remaining options are ranked equally for species welfare, the ranking for individual welfare will hold sway.

Discussion

Many ethical questions arise in the design of ecological studies (Farnsworth & Rosovsky 1993; Minteer & Collins 2005a). These questions can influence our decision to do a study, and if so, how it will be conducted. However, these decisions can be complex. The objectives and ethical stances of different people or groups might conflict (Keeney 1982; O'Neill, Holland & Light 2008), and both forecasting and accurately representing people's values are beset by uncertainty (Tversky & Kahneman 1974; Keeney 1982; Tversky & Simonson 1993). In an attempt to deal with this complexity, we advocate the use of formal decision-making techniques, which we illustrate with the example of genetic sampling of frogs. While there are many value-based issues that could be explored for this scenario, we have focused on one trade-off within the framework of ecological ethics – how to consider both the welfare of individual animals and the welfare of a study species. Despite their significance, ethical considerations such as these are rarely incorporated systematically in scientific decision making, typically because they are viewed as either too conceptual (and thus impractical) or too subjective to include in formal, analytical reasoning about research design.

Some researchers may argue that the ethics of ecological field studies is the responsibility of an institution's animal use or ethics committee, rather than the responsibility of ecologists themselves. However, the role of such committees is to ensure that the use of animals during a given study complies with the relevant legislation and/or code of practice (e.g. Australian Government 2004). Ecologists maintain personal responsibility for the wellbeing of their study organisms, and for ethical reflection on the likely impacts and benefits of a proposed study (Australian Government 2004). Ethical decision making is not the same thing as following a regulation or law; in fact, regulations and laws themselves can be unethical, or unclear on key ethical issues. Furthermore, the decisions of different animal use committees have been shown to be remarkably inconsistent, even when operating under the same legislation (Plous & Herzog 2001).

We used a decision table to help us choose a sampling method for our case study. The table does not provide a definitive 'best' method, nor is it intended to be the only correct way of comparing the four sampling methods. In fact, one of the strengths of the framework is that it allows for differences in ethical standards or viewpoints among researchers. In addition, there are a variety of alternative multi-criteria decision methods which differ in their mathematical properties, as well as the type of information they use (see Moffett & Sarkar 2006 for a recent survey). We have not made explicit reference to democratic considerations, but any part of our model could be subject to a democratic procedure. For example, instead of including a single person's ranking of the options, we could combine the opinions of a number of stakeholders.

We think the formal approach to decision making taken in this case study has some useful characteristics. At a fundamental level, formally framing the decision encourages exploration of the issues, even when data and time are scarce. Our decision table also makes explicit the different values and results in our decision, clearly describes which views have been considered, and makes transparent how a researcher might negotiate competing ethical objectives. Defining the components of the decision can help avoid some of the errors associated with human judgement and linguistic uncertainty (Regan, Colyvan & Burgman 2002). Although some uncertainty is likely to persist, we describe the information sources and subjectivity underpinning our predictions. These advantages have parallels with other formal methods of decision analysis and prediction (Burgman 2000). In addition to these heuristic benefits, we have identified sampling methods that our hypothetical decision maker can relegate as clearly inferior. In all our decision analyses (i.e. for each combination of the precise and approximate rankings for species welfare, and the two definitions of individual welfare), toe clipping was ranked as the worst or equal-worst method. For the researcher in our case study, this option can be eliminated from the decision. Finally, formal decision-making processes such as this one could provide a useful teaching exercise for students learning about research ethics.

While the researcher in our case study was only concerned with two criteria when making her decision, a suite of other factors could potentially be considered. The monetary cost of each sampling method, the required on-ground work, dependability of a sampling method, the conservation status of the species, and the logistic feasibility of each sampling method might also influence a researcher's choice. The breeding pattern of a species may influence how easily one can find tadpoles or frogs at different times of the year. A further issue might be the value of additional information that can be derived from a procedure. While our example was only concerned with obtaining DNA, other researchers might consider additional information that can be derived from samples. For example, bone from clipped toes can be used to age frogs (Acker, Kruse & Krehbiel 1986). Whole tadpoles can be preserved as voucher specimens that could provide biological and taxonomic data for future projects (Huber 1998). These specimens could also provide additional animal tissue if extraction of the original DNA sample were unsuccessful.

One clause within our decision was the assumption that the study was necessary – there is no option to forfeit all sampling. However, this could be a preference if even a low level of harm to either individual animals or a species is of concern. In addition, the value of the research itself may be another reason to include the option of no sampling within the decision (Parris & McCarthy 2008). The value of ecological research is not only determined by its potential to provide relevant information for management. The likelihood that the information will be useful is also critical, which in turn depends on the communication skills of researchers and their willingness to engage with decision makers (Pullin et al. 2004). The potential of the project to make a valuable contribution to conservation will also depend on the timeliness of information and the social, economic and political acceptability of research recommendations.

Acknowledgements

This study is a product of the AEDA CERF workshop on the value and impact of ecological field research, held in Romsey, Australia in March 2008. We thank Fiona Fidler, Hugh Possingham and Brendan Wintle for their important contributions to planning and discussions. The Applied Environmental Decision Analysis research hub (AEDA) is funded by the Commonwealth Environment Research Facilities (CERF) programme, an Australian Government initiative that promotes world class, public-good research.

References

Acker, P.M., Kruse, K.C. & Krehbiel, E.B. (1986) Aging *Bufo americanus* by skeletochronology. *Journal of Herpetology*, **20**, 570–574.

Arens, P., van der Sluis, T., van't Westende, W.P.C., Vosman, B., Vos, C.C. & Smulders, M.J.M. (2007) Genetic population differentiation and connectivity among fragmented moor frog (*Rana arvalis*) populations in The Netherlands. *Landscape Ecology*, **22**, 1489–1500.

Australian Government (2004) *Australian Code of Practice for the Care and Use of Animals for Scientific Purposes*, 7th edn. Australian Government, Canberra.

Beebee, T.J.C. (2005) Conservation genetics of amphibians. *Heredity*, **95**, 423–427.

Beebee, T.J.C. & Rowe, G. (2001) Application of genetic bottleneck testing to the investigation of amphibian declines: a case study with natterjack toads. *Conservation Biology*, **15**, 266–270.

Bekoff, M. & Jamieson, D. (1996) Ethics and the study of carnivores: doing science while respecting animals. *Carnivore Behavior, Ecology, and Evolution* (ed. J.L. Gittleman), pp. 15–45. Cornell University Press, Ithaca.

Biek, R., Funk, W.C., Maxell, B.A. & Mills, L.S. (2002) What is missing in amphibian decline research: insights from ecological sensitivity analysis. *Conservation Biology*, **16**, 728–734.

Broquet, T., Berset-Braendli, L., Emaresi, G. & Fumagalli, L. (2007) Buccal swabs allow efficient and reliable microsatellite genotyping in amphibians. *Conservation Genetics*, **8**, 509–511.

Burgman, M.A. (2000) Population viability analysis for bird conservation: prediction, heuristics, monitoring and psychology. *Emu*, **100**, 347–353.

Callicott, J.B. (1989) *In Defense of the Land Ethic*. SUNY Press, Albany.

Caswell, H. (2000) Prospective and retrospective perturbation analyses: their roles in conservation biology. *Ecology*, **81**, 619–627.

Caswell, H. (2001) *Matrix Population Models: Construction, Analysis, and Interpretation*, 2nd edn. Sinauer Associates, Sunderland.

Dakins, M.E. (1999) The value of the value of information. *Human and Ecological Risk Assessment*, **5**, 281–289.

Davis, T.M. & Ovaska, K. (2001) Individual recognition of amphibians: effects of toe clipping and fluorescent tagging on the salamander *Plethodon vehiculum*. *Journal of Herpetology*, **35**, 217–225.

Farnsworth, E.J. & Rosovsky, J. (1993) The ethics of ecological field experimentation. *Conservation Biology*, **7**, 463–472.

Funk, W.C., Blouin, M.S., Corn, P.S., Maxell, B.A., Pilliod, D.S., Amish, S. & Allendorf, F.W. (2005) Population structure of Columbia spotted frogs (*Rana luteiventris*) is strongly affected by the landscape. *Molecular Ecology*, **14**, 483–496.

Haines, A. & Jones, R. (1994) Implementing findings of research. *British Medical Journal*, **308**, 1488–1492.

Hargrove, E. (ed.) (1992) *The Animal Rights/Environmental Ethics Debate: The Environmental Perspective*. SUNY Press, Albany.

Hitchings, S.P. & Beebee, T.J.C. (1996) Persistence of British natterjack toad *Bufo calamita* Laurenti (Anura: Bufonidae) populations despite low genetic diversity. *Biological Journal of the Linnean Society*, **57**, 69–80.

Huber, J.T. (1998) The importance of voucher specimens, with practical guidelines for preserving specimens of the major invertebrate phyla for identification. *Journal of Natural History*, **32**, 367–385.

Jamieson, D. (2008) *Ethics and the Environment: An Introduction*. Cambridge University Press, Cambridge.

Keeney, R.L. (1982) Decision analysis: an overview. *Operations Research*, **30**, 803–838.

Kinkead, K.E., Lanham, J.D. & Montanucci, R.R. (2006) Comparison of anesthesia and marking techniques on stress and behavioural responses in two *Desmognathus* salamanders. *Journal of Herpetology*, **40**, 323–328.

Koeller, C.A. (2009) Comparison of Buprenorphine and Butorphanol analgesia in the eastern red-spotted newt (*Notophthalmus viridescens*). *Journal of the American Association for Laboratory Animal Science*, **48**, 171–175.

Larson, A. (1983) A molecular phylogenetic perspective on the origins of a lowland tropical salamander fauna 1. Phylogenetic inferences from protein comparisons. *Herpetologica*, **39**, 85–99.

Liner, A.E., Smith, L.L. & Castleberry, S.B. (2007) Effects of toe-clipping on the survival and growth of *Hyla squirella*. *Herpetological Review*, **38**, 143–145.

Livingston, A. (2002) Ethical issues regarding pain in animals. *Journal of the American Veterinary Medical Association*, **221**, 229–233.

Machin, K. (1999) Amphibian pain and analgesia. *Journal of Zoo and Wildlife Medicine*, **30**, 2–10.

Marsh, H. & Kenchington, R. (2004) The role of ethics in experimental marine biology and ecology. *Journal of Experimental Marine Biology and Ecology*, **300**, 5–14.

May, R.M. (2004) Ecology: ethics and amphibians. *Nature*, **431**, 403.

McCarthy, M.A. & Parris, K.M. (2004) Clarifying the effect of toe clipping on frogs with Bayesian statistics. *Journal of Applied Ecology*, **41**, 780–786.

McCarthy, M.A. & Parris, K.M. (2008) Optimal marking of threatened species to balance benefits of information with impacts of marking. *Conservation Biology*, **22**, 1506–1512.

McCarthy, M.A., Weller, W.F. & Parris, K.M. (2009) Effects of toe clipping on survival, recapture and return rates of Jefferson Salamanders (*Ambystoma jeffersonianum*) in Ontario, Canada. *Journal of Herpetology*, **43**, 394–401.

McGuigan, K., McDonald, K., Parris, K. & Moritz, C. (1998) Mitochondrial DNA diversity and historical biogeography of a wet forest-restricted frog (*Litoria pearsoniana*) from mid-east Australia. *Molecular Ecology*, **7**, 175–186.

Minteer, B.A. & Collins, J.P. (2005a) Ecological ethics: building a new tool kit for ecologists and biodiversity managers. *Conservation Biology*, **19**, 1803–1812.

Minteer, B.A. & Collins, J.P. (2005b) Why we need an ecological ethics. *Frontiers in Ecology and the Environment*, **3**, 332–337.

Minteer, B.A. & Collins, J.P. (2008) From environmental to ecological ethics: toward a practical ethics for ecologists and conservationists. *Science and Engineering Ethics*, **14**, 483–501.

Moffett, A. & Sarkar, S. (2006) Incorporating multiple criteria into the design of conservation area networks: a minireview with recommendations. *Diversity and Distributions*, **12**, 125–137.

Monamy, V. & Gott, M. (2001) Practical and ethical considerations for students conducting ecological research involving wildlife. *Austral Ecology*, **26**, 293–300.

Moritz, C. (1992) The population biology of *Gehyra* (Gekkonidae). III. Patterns of microgeographic variation. *Journal of Evolutionary Biology*, **5**, 661–676.

Norton, B. (1995) Caring for nature: a broader look at animal stewardship. *Ethics on the Ark: Zoos, Animal Welfare, and Wildlife Conservation* (eds B.G. Norton, M. Hutchins, E.F. Stevens & T.L. Maple), pp. 102–121. Smithsonian Institution Press, Washington, DC, USA.

O'Neill, J., Holland, A. & Light, A. (2008) *Environmental Values*. Routledge, London, UK.

Parichy, D.M. & Kaplan, R.H. (1992) Developmental consequences of tail injury on larvae of the Oriental Fire-Bellied Toad, *Bombina orientalis*. *Copeia*, **1992**, 129–137.

Parris, K.M. & McCarthy, M.A. (2001) Identifying effects of toe clipping on anuran return rates: the importance of statistical power. *Amphibia-Reptilia*, **22**, 275–289.

Parris, K.M. & McCarthy, M.A. (2008) Toe clipping of anurans for mark-recapture studies: acceptable if justified. *Herpetological Review*, **39**, 148–149.

Perry, D. & Perry, G. (2008) Improving interactions between animal rights groups and conservation biologists. *Conservation Biology*, **22**, 27–35.

Pidancier, N., Miquel, C. & Miaud, C. (2003) Buccal swabs as a nondestructive tissue sampling method for DNA analysis in amphibians. *Herpetological Journal*, **13**, 175–178.

Plous, S. & Herzog, H. (2001) Reliability of protocol reviews for animal research. *Science*, **293**, 608–609.

Pullin, A.S., Knight, T.M., Stone, D.A. & Charman, K. (2004) Do conservation managers use scientific evidence to support their decision-making? *Biological Conservation*, **119**, 245–252.

Regan, T. (2004) *The Case for Animal Rights*, 2nd edn. University of California Press, Berkeley.

Regan, H.M., Colyvan, M. & Burgman, M.A. (2002) A taxonomy and treatment of uncertainty for ecology and conservation biology. *Ecological Applications*, **12**, 618–628.

Resnik, M. (1987) *Choices: An Introduction to Decision Theory*. University of Minnesota Press, Minneapolis, MN, USA.

Robertson, D.P. & Hull, B.R. (2001) Beyond biology: toward a more public ecology for conservation. *Conservation Biology*, **15**, 970–979.

Rollin, B.E. (2006) Euthanasia and the quality of life. *Journal of the American Veterinary Medical Association*, **228**, 1014–1016.

Singer, P. (1990) *Animal Liberation*, 2nd edn. Avon Books, New York, NY, USA.

Snell, C. & Evans, I.H. (2006) Discrimination of moor frog (*Rana arvalis*) and common frog (*Rana temporaria*) individuals using a RAPD technique. *Herpetological Journal*, **16**, 363–369.

Swart, J.A. (2004) The wild animal as a research animal. *Journal of Agricultural & Environmental Ethics*, **17**, 181–197.

Tversky, A. & Kahneman, D. (1974) Judgement under uncertainty: heuristics and biases. *Science*, **185**, 1124–1131.

Tversky, A. & Simonson, I. (1993) Context-dependent preferences. *Management Science*, **39**, 1179–1189.

Varner, G.E. (1998) *In Nature's Interests?: Interests, Animal Rights, and Environmental Ethics*. Oxford University Press, Oxford.

Vonesh, J.I. & De la Cruz, O. (2002) Complex life cycles and density dependence: assessing the contribution of egg mortality to amphibian declines. *Oecologia*, **133**, 325–333.

Vucetich, J.A. & Nelson, M.P. (2007) What are 60 warblers worth?: killing in the name of conservation. *Oikos*, **116**, 1267–1278.

Waddle, H.J., Rice, K.G., Mazzotti, F.J. & Percival, H.F. (2008) Modeling the effect of toe clipping on treefrog survival: beyond the return rate. *Journal of Herpetology*, **42**, 467–473.

Wilbur, H.M. & Semlitsch, R.D. (1990) Ecological consequences of tail injury in *Rana* tadpoles. *Copeia*, **1990**, 18–24.

Received 24 September 2009; accepted 23 November 2009
Handling Editor: E.J. Milner-Gulland