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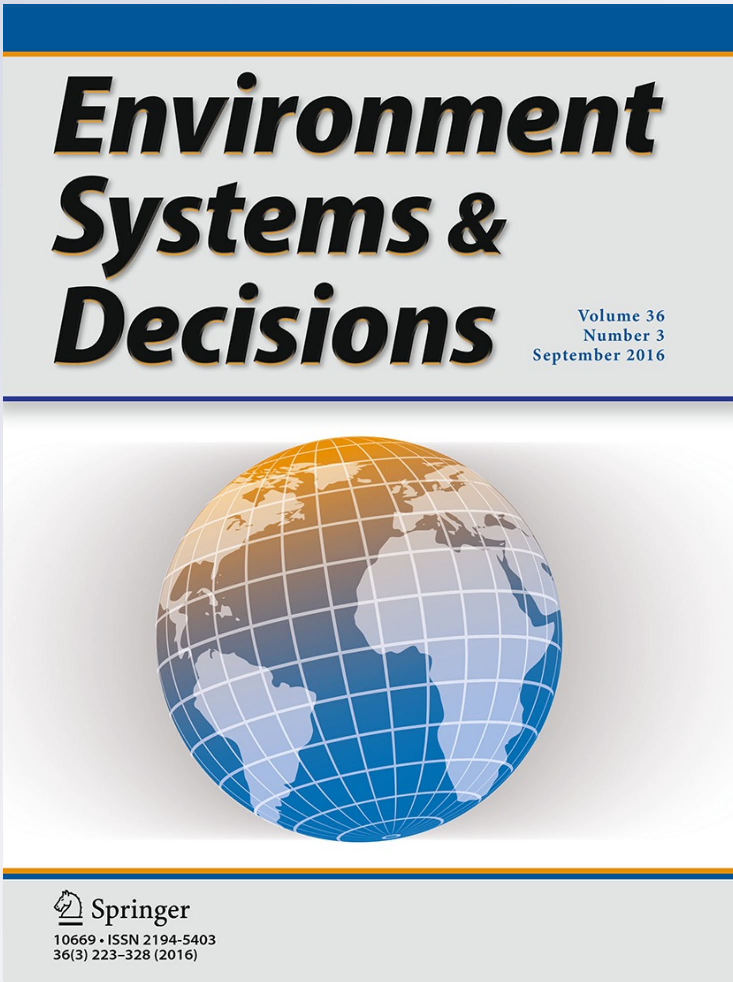
Environment Systems and Decisions
Formerly The Environmentalist

ISSN 2194-5403
Volume 36
Number 3

Environ Syst Decis (2016) 36:302-309
DOI 10.1007/s10669-016-9603-8



Springer

Environ Syst Decis (2016) 36:302–309
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Published online: 18 July 2016

Abstract In this paper we consider uses of value of information studies in conservation biology. It is a common assumption that more and better quality data will lead to better conservation management decisions. Indeed, this assumption lies behind, and motivates, a great deal of current work in conservation biology. Of course, more data can lead to better decisions in some cases but decision-theoretic models of the value of information show that this need not always be the case: sometimes the cost of data collection is too high. While such value of information studies are well known in economics and decision theory circles, their applications in conservation biology are relatively new. These studies are a valuable tool for conservation management, and we outline some of the potential applications. We also offer some advice about, and problems with, implementing value of information studies in conservation settings.

Keywords Decision theory · Value of information · Game theory · Conservation decisions · Monitoring

1 Information and decisions

It is natural to think that more information will lead to better decision making and thus better outcomes. Indeed, this line of thought seems to motivate a great deal of current data collection in conservation biology. While it is true that more information can improve decision making, it is important to recognise that this is not always the case. A simple example will illustrate this. Consider the following bet on the outcome of a coin toss: you receive \$20, if it lands heads; you pay \$10 otherwise. Suppose that all you know about the bias of the coin is that the probability of heads is somewhere between 0.6 and 0.4. Seeking further information may narrow down the probability in question. But a simple sensitivity analysis of the decision model here shows that the expected utility of accepting the bet is greater than rejecting it.[1] No further information is required in deciding whether to accept this bet or not.

Of course, we might be interested in a different question. We might be interested in the value of our expected earnings on accepting the bet. In order to tackle this question we will require further information but for the basic question of whether to accept the bet, we do not require anything more. But note how different the situation would be if the probability of heads were specified to be somewhere in the range of 0.2–0.4. Because the interval [0.2, 0.4] straddles the critical value of 1/3, all we can say is that if the probability of heads is between 1/3 and 0.4, we should accept the bet but not otherwise.[2] This time our

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[1] Let p be the probability of heads and $(1 - p)$ the probability of tails. The expected monetary value of accepting the bet is: $20p - 10(1 - p) = 30p - 10$. This is greater than zero (the expected monetary value of not accepting the bet) whenever p is greater than 1/3. So if the probability of heads is greater than 1/3, it is rational to accept the bet. In particular, in the case in question, the lowest p can be is 0.4 so it is rational to accept the bet—irrespective of the exact value of p.

[2] It might be tempting to argue that we should not accept the bet because there is more of the interval with unfavourable values of p. That is, the length of the interval [0.2, 1/3] is longer than the length of [1/3, 0.4]. But this is to make the further unwarranted assumption that there is a uniform distribution over the interval [0.2, 0.4]. This was not part of the set-up. We know nothing about the distribution in question and should not confuse such ignorance with knowing that p is distributed uniformly across the interval in question.

sensitivity analysis does not help in deciding whether to accept the bet.

It is worth noting that these examples are simple but not without real-world instances. There are many practical situations where it is worth subjecting decisions to a simple sensitivity analysis. We have in mind examples where further information is sought, yet the decision would be the same no matter how the results of the search for further information turn out. For example, some medical diagnostic tests have this character. Radiographing a suspected broken toe costs time and money (not to mention the radiation exposure to the patient), and yet the treatment for a bruised toe or a broken toe is the same: strap it and avoid any activities that hurt the toe. The value of information delivered by the radiographic examination in this decision about treatment is zero. Of course the same information might be valuable for other purposes. For instance, typically a broken toe will take longer to mend than a bruised toe, so the radiographic examination will have some value in determining, for example, when the patient can expect to be able to kick a football again.

So far we have seen how sensitivity analysis can sometimes tell us that we do not need any further information, as in the first betting example and the radiography example. But it also helps in the more problematic second betting example. In such cases the sensitivity analysis tells us that there is no clear course of action until we reduce the uncertainty. We consider such cases in more detail in the next section.

2 Value of information analysis

Consider the following example. How much should you pay to know the result of a fair coin toss when faced with accepting or rejecting the following bet? You receive $20, if it lands heads; you pay $10 otherwise. This is a good bet, with expected monetary value of $5. But if you knew the result of the coin toss in advance, you could accept the bet, in case the coin landed heads reject the bet otherwise. This would give you an expected monetary value of $10, $5 more than simply accepting the bet with the uncertainty in place. You should thus pay up to $5 for the information in question and we say that *the value of this (perfect) information* is $5. This information is called *perfect information* because it is definitive with respect to the coin toss: you are told that either the coin landed heads or it landed tails. You can think of perfect information as arising from a perfectly reliable information channel (e.g. a perfectly reliable witness to the coin toss).

We can generalise this to cases of imperfect information: the value of semi-reliable information channels. We will not go into the details here (see Raiffa 1968; Gould 1974; Resnik 1987). For present purposes it is sufficient to note that we can calculate the value of imperfect information and the value of imperfect information is always less than that of perfect information. We can also do cost-benefit analysis on whether to seek more-reliable information versus less-reliable information. Again we will not go into the details here. The bottom line is that it does not always pay to get the best information available—sometimes the price is too high.

We can just as easily apply value of information studies to the utility side of decision making. For example, suppose we only know the bounds on the value of an outcome (rather than the exact value of that outcome), we can calculate how much information about the precise value of the outcome is worth. Consider the following bet on the outcome of a fair coin toss: you receive either $5 or $15 (with each prize equally likely), if it lands heads; you pay $10 otherwise. The expected monetary value of accepting the bet is the same as not accepting it; it's $0 and decision theory recommends indifference between accepting and not accepting the bet. But suppose you could find out the exact value of the prize for heads. Suppose the prize is $5. You would then not accept the bet, for, in that case, the expected monetary value of accepting the bet is −$2.50. But if the value of the prize for heads is $15, you would accept the bet, for it now has an expected monetary value of $2.50. The information about the exact value of the prize is thus worth $2.50 to you and you should be prepared to pay up to this amount for the information in question. Although such value of information studies applied to utilities are of considerable interest, for the rest of this paper we will focus on the more common epistemic applications (i.e. applications to probabilities).

It is important to note that the phrase "value of information" is rather misleading. This phrase suggests that the information itself has some value or other. But as our examples thus far have shown, this is not the case. Rather, the information has some value *relative to a particular well-defined decision*. The value of the information gained from the radiograph of the suspected broken toe is zero, *for the decision of the immediate medical treatment of the toe*. But the information from the radiograph might have value for other decisions such as whether to enlist a replacement player for the football team. The value of information is always relative to a particular decision context. This context sensitivity can easily be overlooked and is especially important when we turn our attention to conservation applications, as we do in the next section.

3 Conservation applications

These straightforward applications of sensitivity analysis and, more generally, value of information studies have many important applications. Such studies are widely used in mining exploration, medical tests, business, and finance. Until recently, applications in conservation biology have been relatively new but their use would seem to be growing.[3]

We start with a relatively straightforward conservation application, albeit, one with a somewhat surprising recommendation. Rhodes et al. (2011) considered the cost of monitoring studies aimed at resolving the uncertainty about birth and death rates of Koalas, and the effect of forest cover on these rates. It was shown that there is little value in additional monitoring; the money spent on monitoring would be better spent directly on conservation efforts: "[I]f resolving uncertainty costs more than 1.7 % of the koala management budget, it would be more cost-effective to allocate that money to direct management action now." (Rhodes et al. 2011). Alternatively we could focus monitoring efforts, not on charismatic species, nor on those on which there is little known, but, rather, on those where further information is most valuable. Reducing ignorance is not the name of the game, it's improving management decisions.

Another conservation example that is less obviously about value of information. There has been a great deal of debate around the practice of toe clipping of frogs for mark and recapture studies (see e.g. McCarthy and Parris 2004; Phillott et al. 2007; May 2004). Toe clipping is a quick and effective way of marking and later identifying frogs. It is not without its critics though. The criticisms are usually expressed in terms of ethical concerns about the practice. Setting aside what Robert May calls "the casual barbarity of [...] toe clipping" (May 2004), the debate has revolved around whether toe clipping harms the population (because of increased mortality rates as a result of inflammation and infection) and whether toe clipping results in decreased recapture rates, thus effecting the validity of any study employing this methodology. In short, the ethical argument is simply that the harm inflicted is not worth it.

This debate can be usefully recast as a debate about the value of the information received from the relevant mark and release studies (McCarthy and Parris 2008). The previous ethical concerns about harm to the population are recast as questions about whether the harm inflicted on the frog population in question is worth the benefits of having the relevant information from a particular mark and release study. The concern about decreased recapture rates is recast as a question about the reliability of the information gained and this, in turn, can be the subject of a value of partial information study. Notice that on this way of looking at the issues we do not get any blanket pronouncements such as "toe clipping is never justified" or "toe clipping is always justified". As always in value of information studies, it depends on what you're going to do with the information. Value of information studies thus recommend looking at the studies on a case-by-case basis and to evaluate their worth in terms of improvement in management decisions. This is clearly a useful way to proceed and an improvement over existing debates couched in ethical terms.[4]

The benefits of value of information studies are clear. In the examples just considered we stand to put our koala conservation budget to more effective use and be able to make fine discriminations about whether specific frog mark and release studies are justified. But as with many formal decision tools, value of information studies need to be used with a certain amount of caution. Their limitations need to be understood and various potential problems of implementation in conservation settings need to be appreciated.[5]

3.1 Proper framing of the problem

One can easily be led astray by incorrectly framing the relevant decision problem and, as a result, not properly appreciating the value of the information. For example, sometimes data can be valuable for purposes of bargaining. Possessing data that drive home just how rare some charismatic species is might be used in motivating the release of funds directed at conservation strategies for the species in question. While these same data might not be useful in determining the ultimate recovery strategy, focussing solely on recovery management decisions undersells the value of the information in question. In circumstances such as these, the data can be used to increase the budget rather than using up a part of the existing fixed budget (as might be assumed in an alternative framing of the problem). In short, the problem needs to be framed as one where information is used to increase the budget, rather than one where information is used to choose a better recovery strategy. This serves to highlight how the purpose to which the information will be put needs to be explicitly stated and the problem framed accordingly.

There is nothing new here. Care should always be taken in applying decision models. Poor results arising from inappropriate framing of the decision problem in question is not a failing of the decision-theoretic methodology. But

[3] See, for example, Colyvan et al. (2011), Keisler et al. (2014), Moore and McCarthy (2010), Rhodes et al. (2011), Runge et al. (2011) and Runting et al. (2013) and articles in the 2014 special issue of *Environmental Systems and Decisions* devoted to value of information.)

[4] It also helps with related debates about long-term effects of flipper tags on penguins (McCarthy and Parris 2008; Gauthier-Clerc et al. 2004).

[5] What follows should be thought of as a few useful tips and words of caution about applications of value of information studies in conservation biology. It is not intended as a serious challenge to actual or potential uses of the value of information framework.

neither are such framing issues easy to dispense with. Finding the appropriate formulation of a value of information decision can be difficult and requires careful reflection on what the aim of the exercise is and to what purposes we might put the data in question.

3.2 Challenges in application

Applying formal decision tools also gives rise to various challenges in application. These involve massaging the real-world scenario into the format required for the application of the decision tool.

One issue that arises in the conservation setting is that value of information studies generally need to trade in a common currency—typically monetary value—but, as we are well aware, we need to deal with other kinds of value attached to conservation outcomes. Many conservation management problems involve making trade-offs between monetary value and various environmental values. Of course these are the kinds of currency exchanges we need to make in conservation biology anyway, but it is worth noting explicitly that value of information studies typically do require a single currency for the relevant values, be it monetary value, a biodiversity measure, or whatever.[6]

Another issue concerns the kind of uncertainties involved. Value of information inherits from decision theory the assumption that all uncertainty can be quantified and, in particular, that it is quantified via probabilities. In conservation biology we are often uncertain about how much uncertainty there is (i.e. we are uncertainty about the probability distribution in question) and arguable there are other sources of uncertainty, such as linguistic uncertainty, that do not submit to a probabilistic treatment (Regan et al. 2002).[7] In short, we need to be clear about whether the uncertainties in question can be appropriately quantified. To be sure, there are ways of dealing with these recalcitrant kinds of uncertainty other than standard probability theory but accommodating such uncertainty and non-classical methods into the standard value of information framework requires further work.

3.3 Value of information for other contexts

We need to be careful not to overlook potential long-term value. A particular piece of information might have low short-term value for a particular decision but the long-term value (for future decisions) might be significant. For example, bird watching in many countries is largely conducted purely for its own sake, as a hobby by amateurs. The data collected over the years by these amateurs had little value beyond the satisfaction it brought to the participants in its collection. But these data are now valuable components of long-term data sets, painting a clear picture of changes in bird numbers and species over long time periods (Møller and Fiedler 2010). It is all too easy to overlook such value in a narrowly-construed value of information study conducted at the time of data collection.

Strictly speaking, value of information models do no more than provide an assessment of the value of some piece of information for some specified purposes. But in the conservation setting the cost of data collection is usually seen as a component of an overall conservation budget. That is, money spent on data collection is money not available to be spent on conservation measures. But funds not spent on data collection are not always available (in their entirety) for conservation efforts. For example, resources cannot always be (costlessly) reallocated. Sometimes funds are tied to particular data collection projects and cannot be reallocated to conservation interventions at all. Other times there are significant costs associated with the change of focus: for example, with "retooling" from data collection to conservation management. This is not a criticism of value of information studies, for there is nothing in such studies that requires (costless) reallocation of resources. Rather, this is a warning about using value of information studies in inappropriate contexts (or using too simple a model of resource reallocation).

More generally, one might raise concerns about overlooking the value of conservation biology as an independent and worthwhile exercise in its own right. Conservation biology is not merely the hand maiden to conservation management and it should not be treated as such. The value of knowing more about an ecosystem, say, should not be left out of the picture, even if the knowledge gained has no direct effect on any particular conservation management decision. After all such "pure" research is pursued in other areas of science and there seems no reason to banish such research from conservation biology.[8] There has to be a place for research for its own sake—for reasons of intellectual curiosity, if you like.[9]

[6] A means of affecting a currency conversion will do just as well.

[7] For example, vagueness in language (i.e. categories, such as "acceptable risk" that permit border-line cases and are not black and white) gives rise to such linguistic and arguably non-probabilistic uncertainty (Regan et al. 2002).

[8] To take an example from another science: the value of pretty much any cosmological research is zero—the knowledge gained of the structure of the big bang, for example, simply makes no difference to any of the decisions we make in our everyday lives. Yet there is no denying that such cosmological research is worthwhile. It's just that standard value of information studies are not well equipped to demonstrate the value of such research.

[9] It is possible to include such less-tangible values into the set-up but the decision problem typically becomes less tractable, in part because of the disagreement over, and difficulty in, quantifying the values in question.

The practical question of how to trade off possible long-term benefits against identifiable short-term benefits is not easy. There are three quite distinct cases to consider: (1) information gathered for pure science, for intellectual curiosity and with no intended benefits for practical decisions (2) information gathered for the purposes of improving a specific well-defined decision and (3) information gathered because it might be useful for some ill-defined or unknown decision down the track. Surely there should be a place for (1), pure scientific research, and it might be argued that such research is not an appropriate target for value of information studies.[10] The question is how to guard against cases of (3) which might slip though under the guise of (1) or gesturing towards (2) with potential long-term goals. In other words, it may be difficult to rule out any information as valueless because the information can always be recast as (1) pure science or (2) potentially valuable information for some future and unspecified important decisions.[11]

There are no easy answers here. On the one hand, we do not want our data collection exercises to be too short-sighted but on the other hand we do not want to provide trivial justification for any arbitrary data collection. Perhaps all we can do is to insist that claims that information is valuable be subjected to scrutiny to ascertain which of (1)–(3) we're dealing with and, where appropriate, to identify and clearly articulate the relevant decision context(s).

4 Conservation and game theory

With these remarks about the uses of value of information studies in conservation biology in place, let's now turn to a novel conservation application of value of information studies. This example helps to illustrate the variety of applications that exist for these studies and the generality of the methodology.

Consider a multi-national plan for protection of an endangered species. Various migratory birds and African elephants are clear examples where more than one country needs to be involved in any systematic conservation management strategy. There are a number of different situations to consider:

1. The species in question is protected if and only if at least one party cooperates.
2. The species in question is protected if and only if most parties cooperate.
3. The species in question is protected if and only if all parties cooperate.

Situations such as this are modelled as cooperation games.[12] There are many such cooperation games, with the specific game in each case determined by the details of the case. Some of the well-known games relevant to such situations are *the stag hunt*, *the prisoner's dilemma*, and *chicken*.

Recall that two-player versions of these three games can be represented as below, where the players are "column" and "row" and the combined decisions of the two agents (to cooperate or to defect) determine a unique outcome (the lower right four cells in each matrix) with the ranking of these outcomes given by the ordered pairs (first for row and the second for column) and where the larger number represents the better outcome for the respective agent (Tables 1, 2, 3).

In the stag hunt game we find that the best outcome is achieved if both parties cooperate (In the jargon of game theory, the (3,3) outcome is *Pareto optimal*—no player can improve their outcome without making the other player worse off). But this solution is unstable because the threat of the other party defecting while the first party continues to cooperate, delivers the worst outcome for the first party. This motivates the first party to defect, as a kind of safety measure, and vice versa. We thus find that the (2,2) solution is more stable (In the jargon of game theory, it is a *Nash equilibrium*—no player can do better than this outcome by unilaterally changing their strategy). The problem here is that the stable outcome (the Nash equilibrium) does not coincide with the jointly preferable outcomes (the Pareto optimal outcome).

There is a similar problem in the game of chicken. Here there are two Nash equilibria and they coincide with two Pareto optimal outcomes—the (2,1) and the (1,2) outcomes—but they are not symmetric. This gives rise to a different kind of instability: if each player tries for their preferred outcome, they risk bringing about the worst solution—the (0,0) solution.[13]

[10] Although we still need to identify, and give priority to, more interesting pure science over run-of-the-mill and mundane research.

[11] Thanks to an anonymous referee for this way of putting the issue. See also the related and very interesting literature on targeted versus surveillance monitoring (e.g. Nichols and Williams 2006).

[12] A game, in the intended technical sense, is a kind of decision situation where more than one agent is involved, and the agents do not necessarily share common goals. Each agent is thus making decisions to further their own agenda. Classic examples of such games are chess and the cold-war arms race (Hanley and Folmer 1999; Osborne 2003; Poundstone 1992).

[13] This game is named after a car game where two drivers drive at high speed down a road towards one another. If one driver swerves to avoid the impending collision ("cooperates") that driver loses (represented by a payoff of 1 in the matrix) while the driver who does not swerve ("defects") is the winner (represented by the payoff of 2 in the matrix). If they both swerve (i.e. both "cooperate"), they both lose (represented by the (1,1) outcome), and if neither swerves (i.e. they both "defect"), they collide and both are much worse off than in any other scenario (represented by the (0,0) cell in the matrix).

Table 1 The stag hunt game

	Cooperate	Defect
Cooperate	3,3	1,2
Defect	2,1	2,2

Table 2 The game of chicken

	Cooperate	Defect
Cooperate	1,1	1,2
Defect	2,1	0,0

Table 3 The prisoner's dilemma

	Cooperate	Defect
Cooperate	2,2	0,3
Defect	3,0	1,1

In the Prisoner's Dilemma, there are three Pareto optimal solutions ((2,2), (0,3), and (3,0)) and there is one Nash equilibrium (the (1,1) outcome) but the Nash equilibrium does not coincide with any of the Pareto optimal solutions. Here we find that defection by both parties is the stable strategy—the Nash equilibrium (1,1)—but this outcome is clearly suboptimal. Indeed, this outcome is dominated by the cooperative Pareto optimal solution of (2,2).

It can be shown that multi-player versions of these two games arise in the context of cooperative conservation management (Colyvan et al. 2011). For example, if all parties need to cooperate to achieve the desired conservation outcome, this can be represented as a stag hunt. If only some parties need to cooperate in order to achieve the desired conservation outcomes, this can be represented as a game of chicken. The way to resolve the instabilities in question and to get the desired level of cooperation is to impose a system of penalties for defecting or a system of rewards for cooperating (or both) so that the structure of the situation is transformed into one represented in the following game (Table 4).

Here we have one Nash equilibrium and one Pareto optimal solution and they coincide (the (3,3) cell in the matrix) so cooperation of both parties is assured—no party has any motivation to defect.

This is all well and good but the system of penalties and rewards required to transform the stag hunt game into this game is different from those required to transform the game of chicken into this stable game. What do we do if we are uncertain about the starting point, about which game we're playing? That is, what do we do if we are uncertain whether the desired conservation outcome depends on all parties cooperating or merely requires some parties to cooperate? Such uncertainty means that we do not know which game we are playing.

Table 4 The transformed game with stable cooperation

	Cooperate	Defect
Cooperate	3,3	2,1
Defect	1,2	1,1

Clearly there is reason to gain more information about the structure of the situation in order to resolve the uncertainty in question. But how much should we be willing to pay for this information? Not surprisingly the answer comes from a value of information study. Each game is taken to be a state in a meta-decision problem, with the value of the game treated as the input in an expected utility calculation for specified actions (in this case the actions will be the implementation of a system of rewards and penalties) We can then conduct a routine value of information analysis to determine how much to invest in determining the structure of the game.

We start by replacing the simply rank orderings of outcomes we've used in the previous games with full utility functions, as we had in the earlier examples of value of information studies. Next we define the concept of *the expected value of a game*. This is the expected value, for a given player, of the outcome of the game. Now consider two players engaged in a conservation game such as those described above. Let's supposed that the players do not know whether they are engaged in a game of chicken or a prisoner's dilemma. Consider one of the players in this game. This player can calculate the expected value of the game for her. She then sets up a standard decision matrix, where the actions at her disposal are "defect" or "cooperate" and the relevant state are "the game is chicken" and "the game is prisoner's dilemma". This player will have some subjective probabilities about which game is being played. Once these are provided, we have the following standard decision matrix, where u_1 is the expected utility of cooperation in the game of chicken, v_1 is the expected utility of cooperation in the prisoner's dilemma, u_2 is the expected utility of defecting in the game of chicken, v_2 is the expected utility of defecting in the prisoner's dilemma, and p is the probability that the game is chicken (Table 5).

The utilities of the two actions can be calculated and the value of further information about the nature of the game can be calculated in the usual way.

That's from the vantage point of a given player in the game but we're interested in an external vantage point—the vantage point of a regulator who wishes to ensure cooperation in order to achieve specific conservation goals. This complicates matters a little. We need to introduce the regulator into the initial games as a further player.[14] These

[14] This might seem like an odd way to proceed, since the regulator has the power to transform the structure of the game from chicken or prisoner's dilemma into something else. But this is just to say that the

Table 5 The decision matrix when the game is uncertain

	Chicken	Prisoner's dilemma
Cooperate	u_1, p	v_1, $(1-p)$
Defect	u_2,p	v_2, $(1-p)$

Table 6 The regulator's decision matrix when the game is uncertain

	Chicken	Prisoner's dilemma
Introduce penalties	u_1, p	v_1, $(1-p)$
Introduce different penalties	u_2, p	v_2, $(1-p)$
Do not intevene	u_3, p	v_3, $(1-p)$

more complicated n-person games are then set up and we consider the decision problem from the vantage point of the regulator (as we did above for one of the other players). The regulator then must decide between: (1) introducing a system of penalties and rewards that would transform the game of chicken to the cooperative game, (2) introducing a different system of penalties and rewards that would transform prisoner's dilemma to the cooperative game, or (3) do nothing. Using the obvious extension of the notation from our previous example, the regulator's decision matrix will look like this (Table 6).

As before, we then calculate the relevant expected utilities and the value of information about the nature of the game is calculated.

This application of value of information studies is interesting for a couple of reasons. First, it demonstrates that the application of these studies goes beyond simple decision problems and can fruitfully be applied to meta-decisions involving game theory. Second, complex game-theoretic scenarios are widespread and uncertainty about the details of the structure of the game is a real issue. Game theory assumes that the structure of the game is given and offers no advice as to what to do in the face of such structural uncertainty. Value of information studies are a useful tool to have available and can offer a way forward.[15]

5 Summary

We've seen a variety of ways in which value of information analyses can be fruitfully used in conservation management. Value of information studies allow us to assess the value of monitoring versus direct conservation management, where at least sometimes there is reason to forego further monitoring in favour of direct conservation management interventions. Value of information studies can also shed light on the relative value of monitoring different species/populations. For example, it will help us find those species better served by further monitoring. This, in turn, allows for better allocations of resources for monitoring across species and helps in identifying critical areas where monitoring will be particularly valuable. Value of information studies provide a useful way of understanding and adjudicating some (allegedly) ethical debates such as those involving toe clipping of frogs in mark and release studies. Finally, value of information studies can be helpful in pursuing game-theoretic methods to model cooperative conservation management problems.

Clearly there are great benefits in conducting routine value of information studies but such studies are not a panacea. We need to be aware of the limitations of value of information studies. In particular, we should: not neglect long-run value; recognise that not all decisions are optimisation problems under constraint; be aware that resources cannot always be (costlessly) reallocated. Perhaps most important of all, we should be open to the idea that sometimes scientific investigation is a worthwhile exercise in its own right, irrespective of any immediate uses the data may have or fail to have. Conservation biology deserves the dignity of an independent existence.[16]

With these cautions in place, there remains a great deal of scope for more widespread use of value of information studies in conservation biology. After all, it is widely agreed that conservation biology and conservation management are underfunded. Properly used, value of information studies can help ensure that our precious conservation budgets give us the biggest bang for our buck.

Acknowledgments I am indebted to Jack Justus, Mick McCarthy, Maureen O'Malley, Kirsten Parris, Hugh Possingham, Helen Regan, and Luke Russell for valuable discussions on the topic of this paper and to two anonymous referees for this journal for several very constructive suggestions. I am also indebted to audiences at the University of Tromsø, Tromsø, Norway, the 2013 Munich-Sydney-Tilburg Models and Decisions conference at the Ludwig-Maximilians University in Munich, Germany and the 2013 Society for Risk Analysis (Australia and New Zealand) conference at the Australian National University, Canberra, Australia. Work on this paper was supported by an Australian Research Council Future Fellowship Grant (Grant number: FT110100909).

Footnote 14 continued
regulator has moves at their disposal that change the payoffs of the other players in the game. This is just what it is to be a player in a game. Once the regulator is added to the games in question, the games are no longer simple games of chicken, prisoner's dilemma and the like. But that is neither here nor there. We can still model the resulting scenario with game theory.

[15] This novel application of value of information studies was first suggested by Colyvan et al. (2011) but without presenting the details.

[16] In some cases we also need to factor in the cost of the value of information study itself. Sometimes these studies require considerable resources (additional scenario modelling and the like) and this cost should not be ignored.

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