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The costs of increasing precision for ecosystem services valuation studies

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ABSTRACT

Ecosystem services valuation (ESV) is increasingly used to provide the impetus to sustainably manage and restore ecosystems. When undertaking an ESV study, the available resources, desired scope, and necessary precision must be considered before determining the most appropriate approach. A broad range of techniques exist to support valuation studies, requiring a range of financial, time, and personnel resources. We surveyed authors that completed 56 responses around valuation studies regarding their total costs (including personnel costs) and the perceived precision of their results. Results show that the perceived precision of their results is statistically significant and increases with the cost of a study (adjusted $R^2 = 0.29$, $p = 0.018$) and the number of person years required to complete it ($R^2 = 0.31$, $p = 0.22$). Understanding the trade-offs between the costs of the study and the precision of the results allows policymakers and practitioners to make more informed decisions about which ESV methods are most cost effective for their needs. For example, basic value transfer techniques require minimal resources to implement but lack precision in the final estimates, while integrated modelling techniques provide dynamic, spatially explicit, and more precise estimates but are significantly more expensive and time consuming to implement. However, these techniques are not mutually exclusive. A quick, inexpensive initial analysis may support and motivate more elaborate and detailed studies.

1. Introduction

Ecosystems, and the services they produce, are the foundation on which our society and economy depend. The ability of ecosystems to generate different services to support livelihoods and natural regeneration is dependent on their healthy condition and the ability of communities to access them (Muthee et al., 2018). However, over the past few decades, these services have been significantly diminished globally (Costanza et al., 2014; Sutton et al., 2016), with 60% being either degraded or unsustainably managed (Millennium Ecosystem Assessment (MEA), 2005). Much of this reduction is due to the decisions practitioners and policymakers make around land-use and development. Policymakers use ecosystem services (ES) research for a range of purposes, including to raise awareness, build support for plans, investments, policies, and to directly inform decisions (Costanza et al., 2017; McKenzie et al., 2014).

Ecosystem service valuation (ESV) is one tool that allows for holistic decisions-making around development trade-offs, land-use planning, and the provision of public goods and services (Millennium Ecosystem Assessment (MEA), 2005; Tisdell and Xue, 2013). ESV estimates a value in monetary units of ecosystem services[1] (Costanza, 2020; Costanza et al., 2011). This contributes to better decision-making around the trade-offs related to natural capital and ecosystem services by putting everything in the same units.

Thousands of ESV studies have been conducted all over the world (de Groot et al., 2012). Those studies that have been successfully used in policy and decision-making have five common characteristics: 1) identifying a clear policy need; 2) strong stakeholder engagement; 3) robust communication; 4) good governance; and 5) clearly understood valuation process (Avishek et al., 2012; Nursey-Bray et al., 2014; Waite et al.,

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[1] This is not to be confused with using market or exchange values to estimate this value. Instead, it converts all market and non-market values into monetary units based on trade-offs with at least one good or services that is denominated in monetary units.

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2015).

Overall, additional knowledge about ES and their value to society improves government policy and investment (Fisher et al., 2008). Marre et al. (2016) found that policymakers consider the concept of ES and ESV useful and necessary for decision-making. However, they also found that policymakers are more likely to trust values that relate to commercial activities.

Other studies have shown that policymakers use and trust ES knowledge more readily if they believe that the information is credible, legitimate, and relevant (Cash et al., 2003; Cook et al., 2013; Posner et al., 2016). However, these three characteristics have trade-offs that need to be recognized. For example, a valuation study done quickly may be required to meet urgent policy needs (relevance) but sacrifice in-depth quality (credibility) and limit stakeholder engagement (legitimacy) (Sarkki et al., 2014). A trade-off around communicating results may also occur when the message is simplified for clarity and brevity, but sacrifices pertinent information around risk and uncertainty.

Ultimately, we want to have studies with high credibility that can support policy decisions. But what contributes to credibility? The credibility of science, which underlies its effective use in policy decisions, depends on both its correspondence with observed reality (the precision and accuracy of results) and the degree of participation and buy-in by the affected stakeholder communities. Science relies on the peer review process to combine these two elements and produce "credible" or believable results. But the peer-reviewed scientific literature is not generally accessible to policymakers and they must rely on second-hand judgements of credibility. They must also make judgements about the cost of achieving a level of credibility necessary to support policy decisions.

Here we assume that a peer review process has determined that the studies we include in our database are credible from the perspective of the scientific community. The second contributor to credibility – the relative precision and accuracy of the results – is thus the key variable. What does it cost to get the level of precision necessary to support a given policy decision? As Table 1 shows, that depends on the type of decision being supported, but also on the spatial scale and other details of the decision context.

Understanding the costs and benefits in choosing various methods and levels of precision is critical in making informed decisions. The costs may include personnel with varied expertise, time commitment, and potentially specialized data. Benefits include trade-offs in choosing methodologies, as they provide different levels of quality and precision in the results.

Table 1
The range of uses for ecosystem service values. From Costanza et al. (2014).

Use of Valuation	Appropriate values	Appropriate spatial scales	Precision Needed
Rising awareness and interest	Total values, macro aggregates	Regional to global	Low
National income and well-being accounts	Total values by sector and macro aggregate	National	Medium
Specific policy analysis	Changes by policy	Multiple depending on policy	Medium to high
Urban and regional land use planning	Changes by land use scenario	Regional	Low to medium
Payment for ecosystem services	Changes by actions due payment	Multiple depending on system	Medium to high
Full cost accounting	Total values by business, product, or activity and changes by business, product, or activity	Regional to global, given the scale of international corporations	Medium to high
Common asset trusts	Totals to assess capital and changes to assess income and loss	Regional to global	Medium

Determining which method to use to value an ecosystem and its service depends on which service is being valued, the spatial and temporal extent of the ecosystem, what resources are available, and the required precision of the study. The required precision in a study is typically determined by the purpose of the study and the corresponding preciseness of its results (Table 1).

In this paper, we investigate the trade-offs between the costs of the study and the precision of the results to allow policymakers and practitioners to make more informed decisions about which ESV methods are most cost effective to employ for their needs.

2. Methods

Determining which ecosystem services valuation (ESV) method to use in a study requires an understanding of the costs and benefits associated with each method. Often, the costs and benefits of doing a study are not stated in the literature which describes the process and the results of the valuation. To determine some of the costs and benefits of these studies, we surveyed study authors about ESV methods to determine the trade-offs between them.

We performed a *meta*-analysis of the academic literature undertaking different ESV studies. The survey of study authors included questions about the perceived precision of the results, challenges encountered, data requirements, and uptake of study results in policy planning and decision-making. Survey results are reported only in aggregated form to ensure confidentiality.

We used Brander et al. (2018c) as a guide for which valuation methods and studies to assess. This list was also used by the Ecosystem Services Valuation Database (de Groot et al., 2020). The list was modified based on the valuation methods provided in the survey responses. The valuation methods assessed in this paper include:

Avoided Costs estimates the costs that would have been incurred in the absence of a service. For example, this method can be used to estimate the avoided flood and wind damages to properties during a cyclone due to coastal wetlands and the protection they provide (Costanza et al., 2008).

Choice modelling asks individuals their stated preferences (choices) for scenarios with different combinations of attributes, including ecosystem services and a monetized attribute, to estimate the value of an ecosystem (Morrison and Bennett, 2000).

Contingent valuation (willingness-to-pay) estimates an ES value by posing hypothetical scenarios that involve some valuation of alternatives (Tussupova et al., 2015). For example, how much are people willing to pay for increased preservation of beaches and shorelines.

Energy Analysis estimates the value of an ecosystem using biological productivity, assuming that the energy captured by an ecosystem can be converted into an economic value using a money-to-energy conversion factor (Costanza et al., 1989).

Group Valuation brings stakeholders together in a discourse-based process to discuss the value they attach to the ecosystem services. This methodology assumes that public decision–making should result, not from aggregation of separately measured individual preferences, but from open public debate to provide a societal willingness-to-pay for the ecosystem good or service (Farber et al., 2006).

Hedonic Pricing estimates the price an individual will pay for associated goods (Sander and Haight, 2012). For example, housing prices along the coastline tend to exceed the prices of inland homes. Some of this difference can be attributed to the proximity and view of the ocean or other ecosystem amenity.

Input-Output Modelling analyses the interdependencies between environmental and economic flows in a given context (Cordier et al., 2017). Environmentally extended input–output (EEIO) models, for example, analyse the flow of consumption inputs such as energy and resources and output residuals such as pollution and net effect on the whole system. This technique can produce "shadow prices" for ecosystem services.

Life Satisfaction uses decreases in self-reported life satisfaction (LS) points (on a 1 to 10 scale) to estimate the tangible and intangible changes due to changes attributable to the value of ecosystem services. For example, flooding due to a lack of wetlands causes a decrease in LS, caused by both tangible damages, and intangible stress (Fernandez et al., 2019).

Marginal Product Estimation is the price that ecosystem goods or services users are willing to pay, or accept or avoid, an extra unit of ES (De Pellegrin Llorente et al., 2018). Marginal value of ecosystem goods and services becomes higher when the products are scarce and lower when the products are abundantly supplied.

Market Value/Price (Gross Revenue) directly obtains the prices for goods or services from the market (Kubiszewski et al., 2013b). This is mostly used for provisioning services like timber or food, which are the easiest of the ES to value with market values. However, the market value must be divided into the amount attributable to ES due to other inputs (like labour and capital).

Production Function estimates the production relationship between ES and final economic activity (National Research Council, 2005). For example, how do wetlands contribute to the production of fish, which are ultimately marketed?

Replacement Cost estimates how much it would cost to replace a specific ES with a human-made constructed alternative (Costanza et al., 2011). For example, nutrient cycling and waste treatment, which upstream forests do for free, can be replaced with engineered treatment systems. The cost of these treatment plants is an estimate of the value of the treatment service provided by the forest.

Simulation modelling uses systems dynamics models to simulate the complex relationships between ecosystem functions, services, and their contributions to wellbeing in comparison with other contributors to wellbeing (Boumans et al., 2002).

Travel Costs uses the expenses of travel to a recreation site to reflect the implied value of the recreation service. This method is often used to value the recreation areas that attract visitors by assuming that the value placed on that area must be at least what they were willing to pay to travel to it (Pendleton et al., 2011).

Value (Benefit) Transfer uses previously completed primary ESV studies to estimate the value of ecosystem services on another area (Johnston et al., 2015). The value being transferred can also be improved based on expert modification of the original value (Kubiszewski et al., 2013a) or by building statistical models of the relationship of ESV with a range of other variables.

3. Results

Combining the survey results with the study attributes table, we created a summary table which aggregates the studies using each of the methodologies listed above (Table 2).[2] We were able to utilize 56 valuation survey responses from study authors (questions in Appendix 1). The survey responses are summarized in Table 2, the 56 responses can be seen in full Appendix 2. Although 56 responses is a relatively small sample, it is sufficient to provide us with the ability to begin to assess the critical issues, costs, and advantages faced by researchers. Future research will expand the survey and provide more statistical power.

We asked study authors to rank the 'precision' of their results on a scale of 1 (very low) to 10 (very high). This admittedly subjective approach to ranking precision gave us at least a useful first approximation. We assume that the study authors are in the best position to understand the precision of their study's results. We recognize that these results are only the "perceived" precision as seen by the study authors, not an objective measure of precision. The subjectively assessed precision can depend on the resources used to perform the study, difficulty in doing the study, expertise in the valuation method, feedback following the release of the study, and other variables.

Table 3 shows regression results for costs and FTEs versus the perceived precision, respectively. The correlation between total costs and perceived precision was stronger (adjusted $R^2 = 0.31$) than the correlation between FTEs and precision (adjusted $R^2 = 0.29$). We also found that different methodologies potentially had a large range in the costs and FTEs required to perform a valuation study (Figs. 1 and 2). In short, as more time and money were spent on a valuation study, the authors perceived the precision as being greater.

We also ran a regression looking at costs versus FTEs to see how closely corelated these two independent variables were. We found that the adjusted R^2 was 0.49 (Table 3). Although the regressions we ran had a low sample size, all three regressions were statistically significant (Table 3). We intend to expand this sample in future research.

Another important characteristic of a valuation study is which, and how many, biomes and ecosystem services can be included when undertaking a specific valuation methodology. Fig. 3 shows the average number of biomes and ecosystem services included in each type of methodology.

For some of the valuation studies, the costs were extensive (Table 2 and Appendix 2). One of the questions asked in our survey was "Did you have a grant to do this valuation study? If so, from whom…?" The majority of studies received funding directly from a national government, most often the environmental, ecology, or natural resources division. However, some studies were also funded by the federal education division or state governments. A few were funded by independent entities including foundations or international NGOs.

Respondents were asked the questions: "Which specific expertise or training were used by people on the study?" and "List the kinds of data you needed to do this valuation study." Full responses to both questions can be found in Appendix 2. The expertise needed was primarily statistics, survey creation, modelling, and GIS. This data included both primary and secondary data, depending on the methodology used.

Another question asked: "Did the data cost you anything to acquire?" The majority of respondents indicated that there were no data costs associated. Those that responded that there were data costs indicated that they came in the form of survey design and implementation. Model development and other costs related to time and wages were also sometimes considered.

When the survey respondents were asked what "challenges you encountered in the process of doing the study?", the majority stated that they had difficulties around data collection. This included time constraints, lack of data, and environmental conditions like drought. Other challenges included coordination of, and communication with, participants in deliberation sessions or surveys. Adequate communication of results was also brought up in the responses. Full responses can be seen in Appendix 2.

For the survey question: "Were there any positive outcomes that resulted from this valuation study?", responses included informing policymakers of study outcomes, adjustments to economic decisions, influencing future academic studies, and no known positive outcomes. In terms of policy impacts, some studies had direct influence on local council policies and had direct on-the-ground policy implications, while other researchers briefed national ministers on study results. Other studies were used to adjust tourism and park entry fees and help motivate new park facilities. However, in most studies, the greatest impact was through increased awareness of ESV and on other academic research. Full responses can be seen in Appendix 2.

4. Discussion

Each of the valuation methods have trade-offs associated with them, with Croci et al. (2021) closely linking the choice of methodology to ESs

[2] Disaggregated results are not being published due to a request of various survey respondents.

Table 2
The aggregated results of the costs and benefits of various valuation methods.

Valuation Method	Total # of studies	Average Spatial extent of studies in `000 ha	Average # of Biomes	Average # of Ecosystem Services	Average Cost in 2015 $US (SD)	Average Full Time Equivalents (SD)	Average Perceived Precision (SD)	Studies Used
Avoided Costs	4	245,954	1	5	124,405 (88,810)	1.93 (2.72)	7.8 (1.26)	(Brander et al., 2018b), (Costanza et al., 2008), (Sandhu et al., 2008), (Waite et al., 2014)
Choice modelling	8	2422	2	7	80,256 (96,324)	1.12 (0.91)	7.8 (0.89)	(Brander et al., 2018a), (Czajkowski et al., 2016), (Failler et al., 2015), (Glenk and Martin-Ortega, 2018), (Schuhmann et al., 2017), (Lliso et al., 2020; Owuor et al., 2019; Vermaat et al., 2016)
Contingent valuation	6	17,481	1	2	83,156 (68,991)	1.30 (0.73)	7.7 (1.86)	(Chen et al., 2013), (Farr et al., 2014), (Farr et al., 2016), (Jala and Nandagiri, 2015), (Loomis et al., 2000), (Stoeckl et al., 2010)
Energy Analysis	1	5666	1	4	4635	0.05	3.0	(Costanza et al., 1989)
Group Valuation	3	314	1	4	166,679 (151,570)	1.34 (1.25)	7.7 (0.58)	(Kenter et al., 2016), (Mavrommati et al., 2017), (Chen et al., In Review)
Hedonic Pricing	4	61	2	2	63,152 (40,695)	1.28 (0.49)	6.0 (0.82)	(Belcher and Chisholm, 2018), (Belcher et al., 2019), (Czembrowski and Kronenberg, 2016)
Input-Output Modelling	2	51,007,200	5	5	23,906 (5,524)	0.18 (0.11)	6.0 (2.83)	(Patterson, 2002), (Costanza and Neill, 1981)
Life Satisfaction	3	17,460	3	3	63,796 (3,872)	1.35 (0.21)	7.0 (1.41)	(Jarvis et al., 2017), (Fernandez et al., 2019)
Marginal Product Estimation	2	17,445	1	9	87,506 (29,659)	1.50 (0)	8.0 (0)	(Mustika et al., 2016), (Stoeckl et al., 2010)
Market Value/ Price (Gross Revenue)	6	43,112	1	4	43,537 (57,086)	0.84 (0.74)	7.2 (1.33)	(Melaku Canu et al., 2015), (Grabowski et al., 2012), (Stanley et al., 2013), (Sutton and Anderson, 2016), (Quoc Vo et al., 2015), (Porter et al., 2009)
Production Function	1	151	1	1	57,666	1.50	6.0	(Thi Tran et al., 2016)
Replacement Cost	5	400	1	3	51,553 (57,273)	1.00 (0.91)	7.2 (0.45)	(Wang et al., 2018), (Trégarot et al., 2017), (Huxham et al., 2015), (Hema and Indira, 2014), (Rumble et al., 2015)
Simulation modelling	2	3	1	4	65,966 (73,784)	0.43 (0.39)	7.0 (1.41)	(Higgins et al., 1997), (Taylor et al., 2018)
Travel cost	4	466	1	1	38,415 (46,195)	0.75 (0.42)	7.8 (1.89)	(Zella and Ngunyali, 2016), (Farr and Stoeckl, 2018), (Matthew et al., 2013), (Stoeckl and Mules, 2006)
Value (Benefit) Transfer	5	68,959	9	17	68,170 (76,047)	1.00 (1.26)	5.8 (2.59)	(Kubiszewski et al., 2013a), (Liu et al., 2010), (Seidl and Moraes, 2000), (Sutton and Peniche, 2019)
Total/Average	**56**	**3,428,473**	**2**	**5**	**68,187**	**1**	**7**	

Table 3
This table show the results of regression between costs and FTEs versus the perceived precision, as well as the results of costs versus FTEs.

Regression	Adjusted R^2	Prob > |t|
Costs vs Precision	0.31	0.0177
FTEs vs Precision	0.29	0.0221
Costs vs FTEs	0.49	0.0021

to be valued. For example, group valuation is expensive to do because it requires the organization of stakeholder workshops, and, on occasion, payments to the stakeholder for their participation. However, it also has a relatively high perceived precision. Group valuation is a good choice if time and money are available and community input, buy-in, and engagement are desirable. On the other hand, value (benefit) transfer has one of the lowest perceived precisions. It is, however, a relatively quick and inexpensive methodology to run, with the benefit that it can incorporate a large number of ecosystem services in multiple biomes. This allows for policymakers to get a good overview of the value of ecosystem services at low cost.

It is critical to remember that these valuation studies are not mutually exclusive. Value transfer can be done quickly and inexpensively to determine an order of magnitude for the ESV. This can be followed up by a more time-consuming and expensive methodology that provides a more precise value based on which services are deemed most important.

We also recognize that this paper has a relatively small sample size, but the results we found are statistically significant (Table 3) and important in the decision-making process. We believe that as further research will confirm our general conclusions.

In this paper, we survey perceived precision. This is a very subjective assessment by the study author on how precise their results are. Incidentally there are two occurrences in our survey where two co-authors responded independently regarding the same study. One of these was for a hedonic pricing study, and the other for a life satisfaction study. For the hedonic pricing study, both authors estimated similar FTEs, but provided significantly different total cost estimates, one saying $74,804 and the other $31,746. For precision, they provided similar estimates or 6 and 7. In the case of the life satisfaction study, both co-authors provided similar (not exact) FTEs and total cost estimates, as well as similar precision estimates of 6 and 7.

When doing a ESV study, trade-offs are unavoidable. As Martín-

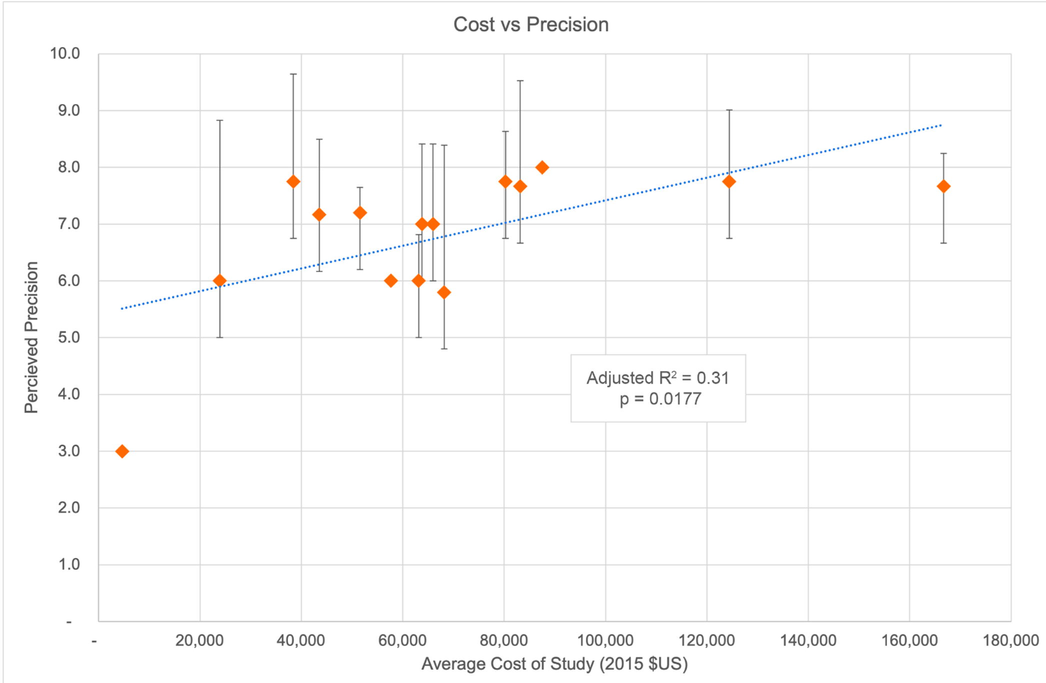

Fig. 1. Shows the average cost of the study in dollars versus the perceived precision.

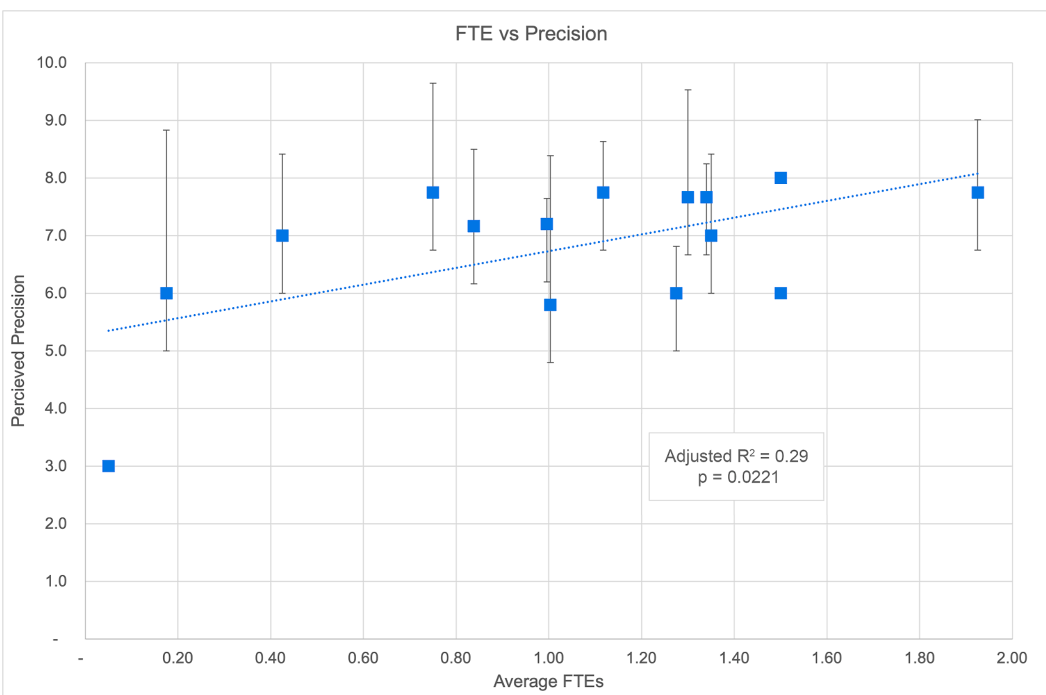

Fig. 2. Shows the average FTEs used to perform a study versus the perceived precision.

López et al. (2014) suggest, developing a comprehensive and integrated methodological framework for ecosystem services valuation remains a challenge, since different methods elicited different values based on the services being assessed. Understanding the needs and context of the study, and its potential uses, is critical in determining how to choose between these trade-offs. In certain circumstances, for swift policy decisions, one might need to sacrifice quality in favour of speed. If a deadline is not met, the study results may become irrelevant. However, this may reduce the credibility and legitimacy of the study. One solution is to plan on a dynamic process in advance, versus striving to achieve short deadlines.

Survey respondents were overall positive about the impacts of their studies. They believed that most had a positive impact either on policy, academia, or the public. This impact was mostly seen through increased awareness. This awareness led to either further academic studies on similar topics or indirect policy intervention through communication with policymakers. Very few respondents believed that their studies had *direct* impact on policies.

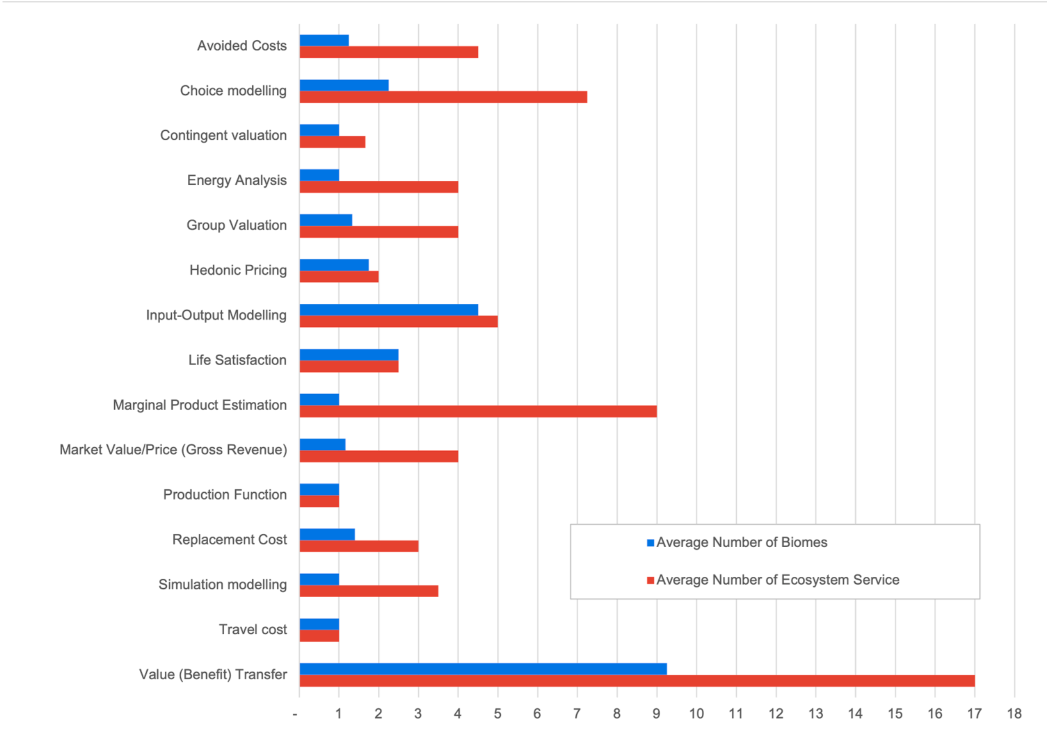

Fig. 3. Show the average number of biomes and ecosystem services that each type of study included.

However, Rogers et al. (2015) found that valuation studies had less impact than researchers believed. Publication of an academic paper is insufficient in creating impact, especially in policy, as information flows differently in the two spheres (Gibbons et al., 2008). Verbal communication and non-academic publications are critical for dissemination.

Whether an expensive or inexpensive valuation method is selected, ESV studies do require funding. The survey respondents indicated that funds most often came from government entities interested in the results of the studies. This increases the probability that results will be used by that government entity to inform their decisions. However, several of the studies did not receive any specific funding, but were done out of interest and to further academic knowledge.

5. Conclusion

There is an urgent need to bridge the gap between science and policy (Brundtland, 1997; Turnhout et al., 2008). However, this gap is more complex than a linear one-way process. It requires the establishment of a two-way relationship between the different actors in the policy process (van Kerkhoff and Lebel, 2006; Lövbrand, 2011). This argues for the joint construction of knowledge which will increase the time and funds required, but will also increase perceived precision, as well as relevance and legitimacy (van den Hove, 2007).

However, these kinds of relationships are often made more difficult by entrenched professional cultures, dysfunctional institutional incentive structures, and perverse reward systems (Myers, 2001). Often, in academia, synthesis and on-the-ground application of knowledge may be seen as not very important for advancing academic careers (Jacobson et al., 2004). This culture has hindered communication and implementation of research.

Overcoming these barriers will require moving beyond the constraints of academia and establishing relationships with decisionmakers and the public as critical collaborators. Creating an understanding around the valuation processes might be an initial step in reducing some of the uncertainties around ecosystem service valuation. Clearly outlining the trade-offs of these valuation techniques can provide a roadmap to guide their co-production and implementation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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