Exploring Dual Discount Rates for Ecosystem Services: Evidence from a Marine Protected Area Network

Abstract:

This paper presents a joint estimation of the willingness to pay for conservation activities aimed at preserving the flow of ecosystem services provided by a marine protected area network and respondents' personal discount rate using a contingent valuation survey. This work contributes to the literature on identifying people's discount rates by moving beyond the use of the exponential schemes to include a hyperbolic discount rate through variations in the timing and duration of the provision of public goods. We present evidence that different discounting processes are associated with different programs, which depend on the type of ecosystem services under protection, including seed banks and biodiversity conservation for tourism activities. The results show the importance of using decreasing discounting (hyperbolic discounting) for projects aimed at preserving biodiversity for tourism activities. Using exponential discounting undervalues the net benefits associated with tourism by 23%, thus affecting projects' cost-benefit analyses. These results are crucial for informing the design of marine conservation programs by clarifying the relationships among conservation project goals, the discounting used, and the relevant lifetime project assessment.

Key words: intertemporal preferences, discount rate, exponential discounting, hyperbolic discounting, contingent valuation, marine protected areas.

JEL codes: Q, Q22, Q51

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Introduction

In the last few decades, initiatives such as the Millennium Ecosystem Assessment (MEA, 2005) have promoted the inclusion of the concept and valuation of ecosystem services (ESs). This is because it provides a way to highlight the role of the environment for human welfare, aid decision-making processes, and avoid an underestimation of the economic relevance of the different benefits nature provides through conservation initiatives (Dasgupta, 2001; De Groot et al., 2010; Haines-Young and Potschin, 2013; Landers and Nahlik, 2013).

Informed decision making in conservation necessarily involves the important aspect of linking ESs with human welfare over a relevant time span. Despite the large body of literature assessing the economic value of ESs, there is limited evidence regarding the future value of these services (Barbier et al., 2011; Bateman et al., 2013; De Groot et al., 2010; MEA, 2005) and how people value benefits (or costs) that will accrue in the medium or long term. Most of the evidence regarding the future value of ESs is based on consumption models, focusing on the substitutability analysis between manufactured goods and ESs (Baumgärtner et al., 2015; Drupp, 2018). Nevertheless, there is a lack of knowledge regarding the relationship between individuals' valuation over time and the type of ES.

When considering human wellbeing, assumptions are implicitly made about the way in which individuals place value on future net benefits, or the *discount rate* applied by individuals to the present benefits that will occur in the future. Thus, determining the appropriate discount rate for different projects or conservation programs associated with the maintenance or restoration of different ESs is a vital issue when assessing the future flows of costs and benefits. Ultimately, the discount rate used to assess a conservation initiative can determine whether a project is beneficial to society or not.

In this article, we use the contingent valuation (CV) method to jointly estimate the willingness to pay (WTP) and the discount rate for different ESs provided by a Marine Protected Area (MPA) network. Individuals were asked about their willingness to pay an annual amount for a specific number of years to develop a conservation program aimed at ensuring the protection of the ecosystem in the protected area. Each interviewee was required to evaluate the MPA network, which was composed of five areas. The areas, which are officially classified according to legal status as either "genetic marine reserves" or "biodiversity marine reserves," have specific characteristics and seek to meet different objectives. We also specify an intertemporal decision model using both hyperbolic and exponential discounting, thereby providing evidence regarding which type of discounting individuals use to value the future benefits associated with different types of conservation programs.

The regular practice of project assessment, through cost-benefit analysis, suggests that constant discount rates be used and associated with exponential discounting (OMB, 2003; Zhang et al., 2007). However, there has been a debate about the rationality of this assumption in the context of nature conservation and/or environmental program assessments whose effects extend over a long period (several decades or more). The use of a constant discount rate implies that the perceived net benefits in the distant future are marginally considered in the evaluation of a present policy (Dasgupta, 2008; Gollier and Weitzman, 2010; Goulder and Williams, 2012; Karp, 2005; Karp and Tsur, 2011;

Schneider et al., 2012). This raises concerns about using constant discount rates to assess policies aimed at sustaining future ESs, such as those intended to reduce the effects of anthropogenic stressors, including climate change, to promote biodiversity conservation, and to prevent overfishing or ocean pollution. Furthermore, there are ethical implications in using exponential discounting factors for long-term environmental and conservation policies and projects, as this type of discounting reduces long-term values to the extent that they become insignificant in the present (Dasgupta, 2008; Gowdy et al., 2013; Karp, 2005).

An alternative to exponential discounting is to use a decreasing discount rate in which the time preference rate tends to decrease over time; this approach is associated with hyperbolic discounting. In hyperbolic discounting, distant costs and benefits are discounted by lower rates than those that are less distant (Chapman, 1996; Frederick et al., 2002; Thaler, 1991). This distinction allows long-term benefits to be relevant to decisions on enduring projects (Karp, 2005). Karp (2005) and Karp and Tsur (2011) show that hyperbolic discounting may adequately represent environmental problems with perceived catastrophic consequences in the distant future.

Furthermore, it is also possible that individuals use different discount rates depending on the type of good they are valuing, which is known as dual discount rates (Hasselmann et al., 1997; Tol, 2004). Most studies analyzing dual discounting have been conducted from a conceptual or theoretical perspective (Weikard and Zhu, 2005; Gollier, 2010; Gueant, 2012; Echazu et al., 2012). The general conclusion is that environmental goods should be discounted with lower discount rates than manufactured goods. From an empirical perspective, and using a Ramsey growth model at the global level, Baumgärtner et al. (2015) found that ESs should be discounted at lower rates than manufactured goods. On global average, they estimate that ESs discount rates should be approximately 0.9%

points lower that manufactured goods. They not only suggest using different discount rates depending on the type of good under analysis, but also that these rates are country specific, with larger differences between ESs and manufactured good rates in less developed countries. Using a model based on a constant elasticity of substitution utility specification and based on global metadata on WTP for different ESs, Drupp (2018) found that manufactured goods and ESs should be discounted using a different rate, with ESs using a lower rate. In addition, Richards and Green (2015) experimental analysis finds that the discount rate for environmental goods is hyperbolic and generally lower than that used for financial goods.

A large body of literature has inferred discount rates using experimental elicitation, but most studies address issues such as health (Attema and Versteegh, 2013; Dolan and Gudex, 1995; Redelmeier and Heller, 1993), future rewards (Harrison et al., 2002; Kirby, 1997; Kirby et al., 1999) and risk behavior (McDonald et al., 2017; Tanaka et al., 2010; Viscusi and Moore, 1989) with only a few applications which relate to environmental goods[1]. The results from the experimental elicitation are wide, and show discount rates ranging from 0% (Redelmeier and Heller, 1993) to 5,747% (Kirby, 1997).

Contingent valuation (CV) surveys are another approach that has been used to infer discount rates by asking individuals about their WTP for environmental goods using different time periods. There is some controversial evidence suggesting that the WTP might not vary or scarcely varies when individuals face a single payment or annual payments of a similar magnitude, also known as the *temporal embedding effect* (Johnson et al., 2006; Bateman and Langford, 1997; Carson and Mitchell, 1993; Carson et al., 1997; Faccioli et al., 2016; Kahneman and Knetsch, 1992; and Stevens et al., 1997). However, this effect is

[1] See appendix I for detailed references.

context dependent and requires further analysis in the literature (Johnston et al., 2017, Cook et al., 2018). Nevertheless, stated preferences (including CV and choice experiments) are the only methodologies that allow researchers to learn about people's preferences for situations that are not yet available and to build prospective scenarios that are essential to designing and evaluating environmental policies, cost benefit analysis, and damage assessment (Carson, 2012; Kling et al., 2012).

In this article, we contribute to the economic literature on ES discounting by: (i) assessing ESs discounting within a stated preferences framework, unlike previous applications which address it using consumption models; ii) assessing ES discounting using both a hyperbolic discount scheme and an exponential discount scheme, at an individual level; and iii) providing more evidence for dual discounting on ESs for developing countries.

Materials and Methods

CV uses questionnaires to elicit people's WTP for a good or service, thus creating a hypothetical market in which people can declare their preferences. There have been thousands of CV applications in diverse areas of economics, and the main results have been summarized in numerous publications on theoretical and empirical issues (Bateman et al., 2001; Carson et al., 2003; Hoyos and Mariel, 2010; Mitchell and Carson, 1989). The CV method has some limitations, mainly related to the hypothetical scenario definition, embedding effect, anchoring effect, and interview bias, among others (Bateman and Willis, 2001; Carson et al., 2003). Some of these issues could be exacerbated depending on the socioeconomic level of the country in which the study is conducted (Whittington, 1998, 2004). Despite the latter, these limitations can be managed following good practices for economic valuation summarized by Arrow et al. (1993), Whittington (2002), Whittington (2010), and Johnston et al. (2017).

In this paper, we use and modify the model proposed by Bond et al. (2009). Our application is novel since we allow for both a hyperbolic discount scheme and an exponential discount scheme. Specifically, we a) evaluate whether individuals discount their decisions in a decreasing manner, b) endogenously obtain both the preference rates and the WTP for the alternative payment schemes, and c) obtain the present value WTP (PVWTP) by considering both the preference rates and the WTP for the relevant discounting schemes over different decision periods.

Exponential versus hyperbolic discount rates

The classic economic perspective uses the exponential discounting factor to obtain the present value of future net benefits. Assuming a constant return rate (*r*) and a finite stream of constant benefits, such as for the WTP for conservation programs, the expression for the present value (PV) is:

$$PV = \sum_{t=0}^{n} \frac{WTP_t}{(1+r)^t} \quad [1]$$

As shown in [1], for a constant discount rate, the discounted amount depends only on the period in which the flows are updated.

Sometimes, individuals make their decisions as if the amounts offered in the future have a higher value when these discounts are conducted earlier in time. For example, many individuals would prefer to receive $100 today over $110 tomorrow, but few individuals would prefer to receive $100 in 30 days over $110 in 31 days. This situation can be modeled using hyperbolic discounting. By using hyperbolic discounting, the present value of flows depends on when the updating occurs and the length of time for which the flows are updated. Equation [2] shows the PV computed using the hyperbolic discounting function proposed by Herrnstein (1981) and Mazur (1987)[2]

$$PV = \sum_{t=0}^{n} \frac{WTP_t}{(1+rt)} \qquad [2]$$

From [1] and [2], neither the exponential nor hyperbolic discounting depends on the amount to be discounted in each period (WTP_t), since it only depends on the way in which the discount rate is included in the discounting factor.

Model of the present value willingness to pay (PVWTP)

Within the CV framework, it is possible to infer the individual discount rate by analyzing the sensitivity of the WTP to different payment periods. Following Bond et al. (2009), individuals were asked whether they are willing to pay an amount of money, B_i, in each period for *t* periods to finance conservations programs that ensure the flow of benefits associated with the ESs. Bond et al. (2009) used the exponential discount rate; thus, we modify their model to include hyperbolic discounting. While equation [1] converges when the number of periods goes to infinity, equation [2] diverges. Nevertheless, to make the calculation comparable between the exponential and the hyperbolic discounting, we can use an arbitrarily large finite number (in this case, we used 100 years, which is larger than the average human lifespan), for which it is possible to simplify the mathematical expression in

[2] Other possible expressions for a hyperbolic discount are the generalized hyperbolic discount function $\delta = 1/(1+\alpha t)^{\gamma/\alpha}$ or the quasi-hyperbolic function (Chabris, Laibson and Schuldt, 2006; Benhabib et al, 2010; Richards and Green, 2015). We tried with both alternatives, but the maximum likelihood techniques did not converge.

a similar way to Bond et al. (2009). If we consider a horizon of n years*,* the present value of the benefits for individual i (WTP_i) given a discount rate, r*,* is given by the following:

$$V_0^n(WTP_i) = WTP_i \cdot \left(\sum_{t=0}^{t=n} \frac{1}{(1 + r \cdot t)} \right) = WTP_i \cdot \left(\frac{\psi\left(n + \frac{1}{r} + 1\right) - \psi\left(\frac{1}{r}\right)}{r} \right) \qquad [3]$$

In equation [3], n is a very long time horizon and $\psi(\cdot)$ is the digamma function (Wu et al., 2000). The algebraic details are shown in the Appendix II.

On the other hand, if the individuals pay B_i from year 0 for t_i years, then the present value can be represented as follows:

$$\begin{aligned} V_t(B_i) &= B_i \cdot \left(\sum_{t=0}^{t=t} \frac{1}{(1 + r \cdot t)} \right) \\ &= B_i \cdot \left(\frac{\psi\left(t_i + \frac{1}{r} + 1\right) - \psi\left(\frac{1}{r}\right)}{r} \right) \end{aligned} \qquad [4]$$

Given that both the WTP_i and the discount rate are not directly observable, we can express the individual decision in terms of a latent variable, y_i. Given a positive response (yes), this indicator will have the value $y_i = 1$, and in the other cases (no, no response, he/she does not know, etc.), the indicator will be $y_i = 0$. Therefore, the decision can be represented as follows:

$$y_i = \begin{cases} 1 & \text{if} \quad V_0^n(WTP_i) \geq V_t(B_i) \\ 0 & \text{in any other case} \end{cases} \qquad [5]$$

Following Bond et al. (2009), the generation of individual i's benefits is $WTP_i = X_i\beta + \sigma\varepsilon_i$, where $\varepsilon_i \sim N(0, 1)$. The probability of observing a negative response to an offered amount B_i^t can be written as follows:

$$
\begin{aligned}
Pr\{y_i = 0\} &= Pr\{\, V_0^{\infty}(WTP_i) < \; V_t(B_i^t)\} \\
&= Pr\left\{(X_i\beta + \sigma\varepsilon_i)\cdot\left(\frac{\psi\left(n+\frac{1}{r}+1\right)-\psi\left(\frac{1}{r}\right)}{r}\right) < B_i\cdot\left(\frac{\psi\left(t_i+\frac{1}{r}+1\right)-\psi\left(\frac{1}{r}\right)}{r}\right)\right\} \\
&= Pr\left\{\varepsilon_i < -\frac{X_i\beta}{\sigma} + \frac{B_i^t}{\sigma}\cdot\delta(r,t_i)\right\}
\end{aligned}
\qquad [6]
$$

where

$$
\delta(r,t_i) = \left(\frac{\psi\left(t_i+\frac{1}{r}+1\right)-\psi\left(\frac{1}{r}\right)}{r}\right)\Bigg/\left(\frac{\psi\left(n+\frac{1}{r}+1\right)-\psi\left(\frac{1}{r}\right)}{r}\right)
$$

in the hyperbolic formulation, and $\delta(r,t_i) = 1-(1+r)^{-t_i}$ in the exponential formulation. In this case, t_i is known, and corresponds to the period in which each payment schedule is offered to the interviewees, but r is unknown. Bond et al. (2009) propose two ways to estimate WTP$_i$: 1) they consider the discount rate exogenous and estimate the WTP$_i$ for t_i payment schedules, and 2) they consider r endogenous by econometrically identifying δ. We selected the second approach and considered r as an unknown parameter to estimate.

The following likelihood function can be derived from [6]:

$$
lnL = \sum_{i=1}^{N_i}\left\{y_i ln\left[1-\Phi\left(-\frac{X_i\beta}{\sigma}+\frac{B_i}{\sigma}\cdot\delta(r,t_i)\right)\right] + (1-y_i) ln\left[\Phi\left(-\frac{X_i\beta}{\sigma}+\frac{B_i}{\sigma}\cdot\delta(r,t_i)\right)\right]\right\}
$$

[7]

where $\mathbf{X}_i$ is a vector of the individuals' characteristics; B_i is the cost to interviewees if they accept the program; and β, σ, and r are the parameters to be estimated. Therefore, with equation [7], we can jointly estimate the WTP_i and r.

Case Study

Since 1962, establishing MPAs has been suggested as an efficient way to conserve biodiversity provided by ocean and coastal areas (Agardy, 1994; NPS, 1962; Saunders et al., 2015). Accordingly, today there are approximately 15,000 MPAs around the world, covering a surface equivalent to 3% of the world's oceans (UNEP-WCMC and IUCN, 2016). This study is focused on a coastal Chilean MPA network, which covers an area equivalent to 8,579 ha, and includes the following areas: La Rinconada (331.6 ha), in the Antofagasta region; Chañaral Island (2,894 ha), in the Atacama Region; Choros—Damas Islands (3,863 ha), in the Coquimbo Region; and Pullinque (740 ha) and Putemun (751 ha), on Chiloé Island. While there are other MPAs in Chile, this study concentrates on those under the exclusive administration of the national fisheries service. Figure 1 shows the MPAs under analysis, including the main ESs provided.

[Figure 1 around here]

Each MPA was created to meet specific objectives and they have characteristics that enable them to be classified according to the flow of ESs generated. The first category includes La Rinconada, Pullinque and Putemun, which were created to ensure the flow of ESs associated with strategic commercial shellfish species. These areas can be exploited through authorized extractive activities or as seed banks. Their objectives include recovering natural populations, strengthening the availability of seeds, and promoting the participation of artisanal fishers and groups of growers in the management of species such as the northern scallop, the Chilean scallop, and the Chilean mussel (*Choro Zapato)*.

On the other hand, the MPAs of Chañaral Island and Choros—Damas Islands are devoted to biodiversity conservation activities, focusing on emblematic species of marine mammals such as the bottlenose dolphin, Humboldt penguin, sea lion, and birds, which are not subject to exploitation. In this case, their flow of benefits is associated with tourism activities based on marine biodiversity. Even though both MPAs, Chañaral Island and Choros—Damas Islands, provide nearly the same tourism activities based around flagship species, the activities developed in Choros—Damas Islands are well known and consolidated.

Survey Design and Implementation

We developed a face-to-face survey that was conducted from September to November 2009 in six cities, four of which are located near the MPAs (Antofagasta, La Serena, Ancud, and Castro), and the other two, Concepcion and Santiago, were selected due to their relatively large populations.

The design of the final survey followed three steps. First, in each area, we developed five workshops with local communities, including fishers, authorities, and NGOs, to identify the ESs provided by the MPA. Second, we conducted four focus groups (two in Concepción and two in Santiago) to explore how people reacted to specific aspects of the hypothetical scenario and to identify wording problems or misleading sections in the survey. Third, we applied 100 pilot surveys to field-test the design of the instrument (50 surveys in Concepcion and 50 in Santiago).

We relied on a random sampling process based on the National Socioeconomic Household Survey (CASEN), using a probabilistic multistage sampling, and randomly selecting the neighborhood and blocks. Next, we systematically selected the households to be interviewed. This means that we selected one household in each block starting in the northern corner, and if we did not obtain an answer from that house, we skipped the next four houses and knocked on the door of the next house. More than 90% of households agreed to participate in the study, with the lowest response rate in the highest income households. The sampling process provided a usable sample of 1,389 observations. Table 1 shows the summary of the sample statistics.

[Table 1 around here]

Based on the pilot study answers, using an open-ended format, we defined the first bid candidates to be offered in each MPA. Then, following Cooper's optimal design methodology (Cooper, 1993) we determined the initial payoff vector to be offered for each area. Using these values, we conducted an iterative process of bid construction during the survey implementation, in which after a defined number of surveys (generally 100) were implemented, we redefined the optimal payoff vector using a sequential optimal design methodology (Nyquist, 1992). We followed this procedure until the payoffs vector stabilized[3]. The presentation of these bids was randomly assigned among interviewees until we met the optimal portion of the sample for the bid vector design.

The survey included three sections. Section A was a warm-up section in which we asked respondents questions of general interest, including their views about the country's main environmental problems, the relevance of environmental issues to their daily lives, and their knowledge about the MPA network. Section B presented the study area and explained the MPAs' legal status, along with the differences across MPAs within the network regarding the ESs that are provided. This was done using visual aids including maps and pictures. This section included both the hypothetical market description and the WTP question. Finally, section C aimed to collect the socioeconomic characteristics of those interviewed as well as those of his/her household.

In section B, interviewees were given the following valuation context:

[3] Appendix III shows the detailed BID vector offered to the interviewees.

"The national fisheries service is responsible for preserving and improving the flow of ecosystem services provided by the MPA network through a series of conservation programs. Due to its legal status, the use of the MPAs cannot be changed. The service faces a budget constraint in which it can afford only 10% of the total financial resources needed to reach its objective. Thus, in order to obtain the necessary funds to develop these programs, the Chilean government is planning to call for a referendum in which they will ask every household in the country whether or not they are willing to pay a certain amount of money, with the purpose of supporting each of the conservation programs. The evaluation will be done for each MPA individually. If the majority votes in favor, then each Chilean household must pay, and the program for that MPA will be developed. If majority consensus is not reached, the program cannot be developed, and it is likely that the area will decrease its flow of ecosystem services."

Once the valuation context was explained, we provided the interviewees with specific information about each area. For instance, for the Choros—Damas Islands, the information provided was their location, extension, conservation program objective (in this case biodiversity-based tourism), and the description of the ESs provided as follows:

"The Choros—Damas Islands' biodiversity is characterized by a resident population of bottle-nose dolphins (40 individuals), sea otters (28 individuals), sea lions (1,123 individuals), and Humboldt penguins (1,479 individuals). The conservation actions will take place in the next 8[4] *years, helping to keep the current biodiversity levels for future generations."*

Then, the valuation question was worded as follows:

"Are you willing to pay \$$B_t$ annually for the next_T_year(s) to develop conservation actions that ensure the flow of the ecosystem services of this area in the future?"

To avoid both order and anchoring effects in the valuation responses, we used advance disclosure (Bateman et al., 2004; Day et al., 2012). That is, people knew from the

[4] Each MPA requires different actions to assure the provision of the ESs.

beginning that they would have to respond to 5 valuation questions and we provided all the information and the description of each MPA in advance (before any valuation question). Additionally, the order of the valuation question for the MPA presented in the survey was randomized. Each interviewee received one of the following payment schedules (T years), which was also randomly assigned: 1) a single payment, 2) payments for the next 5 years, and 3) payments for the next 10 years.

Results and Discussion

The survey results show that respondents' "*yes*" ratio increases as the payment period increases (Table 2). For instance, conservation programs in Chanaral show a "*yes*" answer ratio of 35% for one year, but as the payment period becomes longer, the ratio increases to 47% for 10 years.

[Table 2 around here]

To evaluate whether individuals discount their decisions in a decreasing manner, we divided the sample according to the time-period offered in the survey, and computed the discount rate for each group assuming an exponential discount factor.[5] The assumption considered here is that if the interviewees discount their preferences exponentially, the rates for both periods (5 and 10 years) must be constant over time, while decreasing rates suggest hyperbolic discounting. Thus, if the discount rate for both periods remains constant, exponential discounting is the proper way to update the conservation program flow of benefits. On the other hand, if the discount rate decreases over time, then the appropriate form of discounting is hyperbolic. We used a one-sided mean comparison test to assess the

[5] We tested using differences in the explanatory variables across different samples, and we could not reject the hypothesis of homogeneity across the samples.

null hypothesis of equal discount rates between both samples against the alternative hypothesis of decreasing discount rates.

[Table 3 around here]

Table 3 summarizes the estimated discount rates for each conservation program and time length. The last column shows the p-value of the mean-comparison test for decreasing rates. For some conservation programs the null hypothesis is rejected, meaning that discount rates decrease over time, and in this case, the rate is higher for the shorter term (5 years). For instance, in the conservation program for the Chañaral MPA, the discount rate decreases from 257.9% for the 5-year time horizon to 84.9% for the 10-year period, while for the Choros—Damas MPA, it decreases by almost one-third from 164.7% to 68.9% for the payment periods of 5 and 10 years, respectively. On the other hand, in conservation programs for both La Rinconada and Pullinque MPAs, we do not have evidence to reject the null hypothesis. For these programs aimed at preserving the flow of shellfish seed provision, the discount rate changes, but it is within larger confidence intervals, thus making the difference statistically insignificant.

If we analyze the discount rate for conservation program types, our results suggest that individuals' time preferences are different depending on the objective of the program. For instance, MPA conservation programs at preserving biodiversity for tourism activities, in which long-term benefits—such as natural heritage—are relevant, show a decreasing discount rate. These results apply for both the Chañaral and Choros—Damas MPAs, meaning that hyperbolic discounting should be used to calculate future benefits associated with conservation programs in these MPAs. On the other hand, for those MPAs in which conservation programs are aimed at preserving the flow of seed supply, we do not have sufficient evidence to reject the null hypothesis. Thus, for these MPAs, the use of hyperbolic discounting is not recommended. This is the case for programs developed in both the La Rinconada and Pullinque MPAs. Our results show that for programs in the Putemun MPA, hyperbolic discounting appears to be appropriate for the conservation program assessment, despite the fact that it is a provider of mussel seeds.

The estimation of the individual discount rate—as an endogenous parameter of the WTP model—was computed assuming both exponential and hyperbolic discounting, depending on the conservation program. For those programs in which the null hypothesis is rejected, we use hyperbolic discounting, and use exponential discounting otherwise. The annual WTP was computed for all the payment schedules—single payment, payments for the next 5 years, and payments for the next 10 years—using a 100-year time horizon[6].

The results show that the individual discount rate varies considerably depending on the conservation program's goal [Table 4]. For instance, the discount rate for the conservation program in the Chañaral MPA—assuming hyperbolic discounting—decreases from 256.1% in year 0 to 71.9% in year 1. For the Choros—Damas MPA, it decreases from 187% to 65.1%. Meanwhile, for the Putemun MPA, it decreases from 230.7% in year 0 to 69.7% in year 1. On the other hand, in the conservation program for the La Rinconada MPA, the discount rate remains constant at 69.5%, while for the Pullinque MPA, it remains at 372.2%.

The results show that the sign of the constant is positive and statistically significant for all the conservation programs, while that of the interviewees' environmental preferences is positive but statistically significant only for the conservation programs developed in the La Rinconada MPA. As expected, the sign of the income parameter is positive and

[6] We tried different time lengths, and the results are similar (see appendix IV for both the mathematics and the results).

statistically significant for all the conservation programs, which is consistent with economic theory. The age parameter is negative and statistically significant for all the conservation programs, thus implying that older people give lower values to the conservation programs. The gender parameter is negative but not statistically significant for all the conservation programs and, as expected, if the interviewee is familiar with the area his/her WTP increases.

The discount rates—both exponential and hyperbolic—reported in this study are high [69–372%]; however, the figures are within the same order of magnitude as those in previous studies using CV. For instance, Stevens et al. (1997) reported a discount rate within the range [50 – 270%] for the restoration of Atlantic salmon, Kim and Haab (2009) reported a rate within the range [20 – 100%] for oyster reef restoration programs, Bond et al. (2009) reported a rate within the range [23 – 80%], and Egan et al. (2015) reported a rate within the range [62 – 104%]. On the other hand, our results are conservative in comparison with other studies that do not use CV in which the discounting rates range from negative values to infinity and commonly have values above 3 and 4 digits (Chapman et al., 1999; Chapman and Winquist, 1998; Kirby, 1997). For instance, Loewenstein (1987) used experiments to analyze delays in consumption and reported a discount rate of -6%, while Kirby and Maraković (1996) reported a discount rate within the range [500 – 1500%] for the same topic (appendix I shows a list of papers and their corresponding methodologies). Finally, we compare our results with the market rates as a benchmark. The maximum (and sometimes the minimum) market interest rate is approximately 49% annually in the Chilean formal markets (see appendix V for details), but it is much higher in informal markets (anecdotal evidence suggests values near 40% per month[7]). Therefore, our results do not appear to be outside of a reasonable range according to the literature and market values.

The annual benefits are estimated using the formula $E[WTP_i] = X_i'\hat{\beta}$, where $\mathbf{X}_i$ is a column vector containing the means of the characteristics of the sample and $\hat{\beta}$ is the estimated coefficients for both the hyperbolic and exponential discounting (Table 4). The WTP across conservation programs shows mixed results, with the highest WTP related to conservation programs developed in Chañaral (associated with preserving biodiversity for tourism activities); followed by programs in La Rinconada and Putemun, both associated with preserving the flow of shellfish seed provision[8].

[Table 4 around here]

Figure 2 shows the evolution of the individual discount rate for those conservation programs in which a hyperbolic discount seems to be most appropriate: Putemun, Choros—Damas, and Chañaral.

[Figure 2 around here]

As shown in Figure 2, the discount rate varies across conservation programs, meaning that individuals have different temporal preferences. For instance, for any time horizon—but especially in short term periods—the programs developed in the Choros—Damas MPA show a discount rate lower than that for the other MPAs, meaning that the short-term benefits provided by that program are less penalized than the benefits provided by the others. The Choros—Damas MPA is a well-known hotspot of conservation-based

[7]http://www.elmostrador.cl/noticias/mundo/2016/10/21/que-son-los-prestamos-gota-a-gota-que-grupos-criminales-de-colombia-exportan-a-chile/

[8] Following a referee's suggestion, we estimated the model with *r* as a linear function of socioeconomic variables. The results are similar to those presented here. See the details in appendix VI.

tourism activities which could explain this result. Figure 2 also shows a large decrease in the discount rate within the 5-year period for all the conservation programs.

Present value of the Willingness to Pay (PVWTP)

Table 6 shows the present value of the benefits flow within the network for different lengths of time, using the associated discounting type for conservation programs in each MPA.

[Table 5 around here]

As shown in Table 5, the PVWTP converges, meaning that the present value does not change by adding an additional period to the summation at different speeds based on the discounting used. For those programs using exponential discounting, the PVWTP converges faster, reaching a constant value within 25 years for La Rinconada with USD 11.7, and within 5 years for Pullinque with USD 2.8. On the other hand, since hyperbolic discounting places more weight on the very long-term benefits, its convergence speed is slower. According to our results, the convergence will occur over a period longer than a human lifetime: greater than 300 years for the conservation programs developed in the Chañaral, Choros—Damas, and Putemun MPAs.

Among conservation programs for which hyperbolic discounting is recommended (Chañaral, Choros—Damas, and Putemun MPAs) the analysis of the PVWTP evolution shows that the PVWTP changes at almost the same pace with a dramatic reduction in its change (*%Difference of PVWTP* in Figure 3) in the very short-term (less than 5 years). Although under hyperbolic discounting some weight is placed on the benefits in the very long term, Figure 3 suggests that most of the value is composed by short-term benefits.

[Figure 3 around here]

MPAs that target marine biodiversity show decreasing discounting rates (hyperbolic discounting), while for the MPAs devoted to seed supply—associated with short-term benefits—the evidence is not sufficient to reject the null hypothesis (constant discount rates). These results are consistent with previous research that suggests the existence of dual discount rates (Almansa and Martínez-Paz, 2011; Baumgärtner et al., 2015; Drupp, 2018; Gollier, 2010; Weikard and Zhu, 2005; Weitzman, 1994), as the direct benefits associated with seed supply are perceived as imperfect substitutes for biodiversity conservation in the context of uncertainty. Moreover, the values of the discount rates implicitly derived through the CV survey are high but are in line with previous studies. The latter point holds despite the large interest rates used in formal/informal markets in Chile. Thus, it is reasonable to think that respondents are not influenced by the high markets rates in place, and that the values derived using CV are indeed evidence of dual discounting.

Regarding the discount rate type, the program proposed for the Putemun MPA is an interesting case, as it shows a decreasing discount rate even though it is devoted to seed supply. This result seems to contradict the general conclusions found for the other reserves. Putemun MPA is aimed at providing *Choro Zapato* (Chilean mussel) seeds, which is an activity deeply rooted within the Chiloe island communities' cultural heritage (Rivera et al., 2017). Thus, it appears that the respondents are valuing both the cultural heritage and the short-term benefits associated with seed supply. Even though our analysis cannot validate this hypothesis, previous studies have already highlighted the economic value of traditional productive activities within Chiloe Island (Barrena et al., 2014; Nahuelhual et al., 2014).

Conclusion

Our results suggest that people use different discounting factors depending on the MPA conservation objective, and that they use a decreasing discount rate—hyperbolic discount—for those programs aimed at preserving biodiversity for tourism activities. We found larger statistical uncertainty in the testing of constant discount rates in the case of La Rinconada and Pullinque, which are both MPAs aimed at promoting the flow of shellfish seed supply. In these cases, we could not reject the hypothesis of equality in the discount rate across periods, and therefore, the use of hyperbolic discounting is not recommended. This evidence suggests that respondents answered the CV questions differently, depending on the MPA conservation goal.

We shed light on the potential tradeoff between discounting the present value of the benefits of environmental programs and the consistency of the discounting factor used. The use of constant discount rates makes the long-term benefits negligible in terms of their present value; thus, environmental projects with short-term costs and long-term benefits might not pass a cost-benefit analysis when using constant return rates. For instance, a conservation project aimed at increasing biodiversity in the Choros—Damas MPA will converge to its PVWTP of USD 10.93 in year 25 under exponential discounting. Using hyperbolic discounting, the relevant timeframe of analysis is more than 300 years, with a PVWTP converging to USD 13.31. This result means that under exponential discounting, the program's PVWTP is undervalued by approximately 23%, thus affecting any cost-benefit analysis carried out.

Despite the contributions of our study, more research could validate our empirical findings in other settings and considering other ESs. For instance, a cross-country study aimed at assessing the influence of market rates on the implicit time preference rate would allow us to fine-tune our results. The temporal value of ESs in other contexts than marine reserves is worth further exploration. There is limited evidence about how people value conservation programs for which the net benefits will be generated in the medium or long term. Thus, more research is necessary to understand the role played by 1) the lack of knowledge about the discount rates, 2) future generations' preferences, and 3) future biophysical conditions on the future value of ESs.

This study emphasizes both the relevance of the discounting factor used for the assessment of MPA conservation programs and the relevant project lifetime. According to our results, for those MPAs aiming to promote the flow of shellfish seed provision, it appears that the proper way of accounting for the conservation programs' benefits is using a short-term basis, which will highlight the weight of net benefits in the near future. On the other hand, for those MPAs aimed at preserving the flow of biodiversity for recreational activities, a long-term basis is required to emphasize the relevance of the conservation programs' development for future generations. Considering these dual discount rates could provide decision makers with better tools to perform cost-benefit analyses regarding the design of MPAs and to inform environmental impact assessments for other types of coastal investments.

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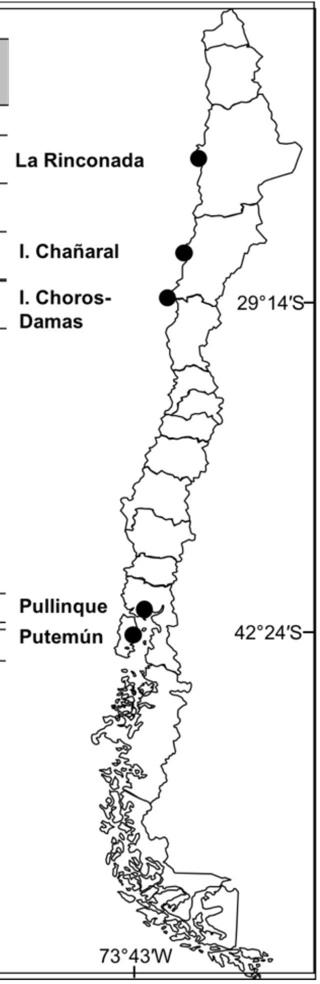
Figure 1: Network of the studied Marine Protected Areas

Main Ecosystem service	Conservation objective	Area (Ha.)
Seed supply	Scallop (*Argopecten Purpuratus*)	331.61
Tourism activities	Marine Biodiversity	2894
Tourism activities	Marine Biodiversity	3863
Seed supply	Oyster (*Tiostrea Chilensis*)	740
Seed supply	Mussel (*Choromytilus chorus)*	751



Source: Vásquez *et al.* (2010).

Figure 2: Discount rate evolution for conservation programs in each MPA

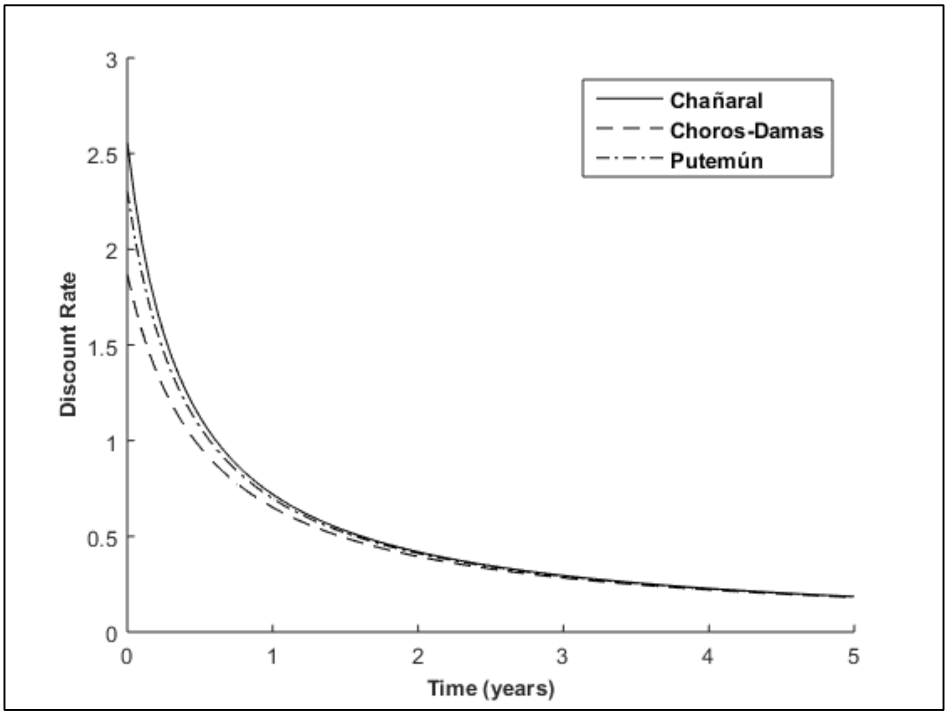


Figure 3: Differences in the PVWTP evolutions for programs using hyperbolic discounting

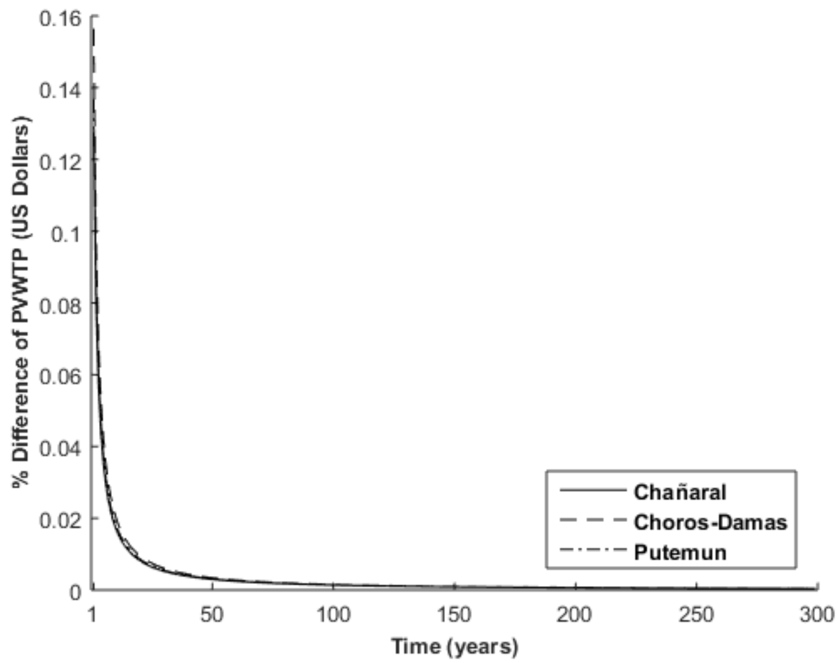


Table 1: Descriptive Statistics

Statistic	Mean	St. Dev.	Min	Max
Environmentalist (1=Yes)	0.017	0.128	0	1
Income (US dollars)	984.645	976.832	143.678	5,747
Age	42.351	15.268	18	88
Gender (1 = Female)	0.503	0.500	0	1
Familiarity- Chañaral (1=Yes)	0.308	0.462	0	1
Familiarity- Choros-Damas (1=Yes)	0.344	0.475	0	1
Familiarity- La Rinconada (1=Yes)	0.298	0.458	0	1
Familiarity- Pullinque (1=Yes)	0.173	0.378	0	1
Familiarity- Putemun (1=Yes)	0.204	0.403	0	1
Population Means, from the National Socio-Economic Survey (CASEN)				
Population Income		1314.131		
Population Age		35.042		
Female Rate		51.04%		

Table 2: Positive response rate

	Chañaral		Choros-Damas		Rinconada		Pullinque		Putemún	
	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
1 year	333	175	321	171	208	127	296	152	303	147
%	65.55%	34.45%	65.24%	34.76%	62.09%	37.91%	66.07%	33.93%	67.33%	32.67%
5 years	206	174	249	198	294	257	259	197	263	237
%	54.21%	45.79%	55.71%	44.29%	53.36%	46.64%	56.80%	43.20%	52.60%	47.40%
10 years	264	237	229	221	263	240	255	230	233	206
%	52.70%	47.30%	50.89%	49.11%	52.29%	47.71%	52.58%	47.42%	53.08%	46.93%

Table 3: Discount rate (*r*)

MPA	Main Conservation Program Goal	*r* 5 years	*r* 10 years	**Comparison Test P-value**
Chañaral	Biodiversity-based tourism	2.579*	0.894***	**0.062**
		(1.080)	(0.183)	
Choros—Damas	Biodiversity-based tourism	1.647**	0.689***	**0.070**
		(0.626)	(0.166)	
La Rinconada	Seed supply	0.573*	0.779**	**0.736**
		(0.195)	(0.261)	
Pullinque	Seed supply	4.313	3.555	**0.440**
		(3.760)	(3.305)	
Putemun	Seed supply	1.977**	0.809***	**0.032**
		(0.610)	(0.164)	

Note: Standard errors in parenthesis. *** p<0.001, ** p<0.01, and * p<0.05.

Table 4: Exponential and Hyperbolic Estimations for the WTP

	Chañaral	**Choros-Damas**	**La Rinconada**	**Pullinque**	**Putemún**
	Hyperbolic	**Hyperbolic**	**Exponential**	**Exponential**	**Hyperbolic**
Constant	0.905***	0.895***	1.160***	2.092***	0.445***
	(0.140)	(0.164)	(0.199)	(0.439)	(0.075)
Environmentalist	0.330	0.484	0.867*	0.824	0.191
	(0.300)	(0.332)	(0.392)	(0.873)	(0.148)
Income	0.195**	0.294***	0.399***	0.824***	0.134***
	(0.068)	(0.085)	(0.101)	(0.239)	(0.036)
Age	-0.182***	-0.216***	-0.281***	-0.579***	-0.080***
	(0.029)	(0.036)	(0.044)	(0.103)	(0.015)
Gender	-0.110	-0.129	-0.127	-0.285	-0.043
	(0.069)	(0.081)	(0.098)	(0.225)	(0.037)
Familiarity	0.360***	0.292***	0.429***	1.077***	0.187***
	(0.087)	(0.087)	(0.116)	(0.288)	(0.047)
Sigma	0.910***	1.101***	1.320***	3.022***	0.493***
	(0.104)	(0.126)	(0.158)	(0.362)	(0.049)
r	2.561***	1.870***	0.695***	3.722+	2.307***
	(0.610)	(0.461)	(0.172)	(2.236)	(0.519)
		Discount Rate = $-r/(1+rt)$			
Year 0	2.561	1.870	0.695	3.7229	2.307
Year 1	0.719	0.651	0.695	3.7229	0.697
		Willingness to Pay (WTP)			
WTP (US dollars)	**5.637**	**3.316**	**4.814**	**2.2697**	**3.694**
WTP P-Value	**0.000**	**0.000**	**0.000**	**0.1137**	**0.000**
N	1,389	1,389	1,389	1,389	1389
Log-likelihood	780.794	815.436	836.414	839.5175	801.820

Standard errors in parenthesis. ***p < 0.001, **p < 0.01, *p < 0.05, and +p<0.1

Table 5: PVWTP for different time periods in US dollars

		5 years	10 years	25 years	50 years	100 years	150 years	300 years
Chañaral	Hyperbolic	9.700	11.051	12.956	14.443	15.950	16.836	18.355
Choros-Damas	Hyperbolic	6.385	7.454	8.976	10.169	11.380	12.093	13.317
La Rinconada	Exponential	11.245	11.705	11.740	11.740	11.740	11.740	11.740
Pullinque	Exponential	2.879	2.879	2.879	2.879	2.879	2.879	2.879
Putemun	Hyperbolic	6.593	7.570	8.953	10.034	11.129	11.774	12.879

Appendix I: Discount rates from several studies.

Study	Type	Goods	Time range	Discount Rates	
				From	To
Maital and Maital (1976)	Experimental	Money and coupons	1 year	70%	
Hausman (1979)	Field	Money	Undefined	5%	89%
Gately (1980)	Field	Money	Undefined	45%	300%
Thaler and Shefrin (1981)	Experimental	Money	3 months to 10 years	7%	345%
Ainslie and Haendel (1983)	Experimental	Money	Undefined	96000%	
Houston (1983)	Experimental	Money	1 to 20 years	23%	
Loewenstein (1987)	Experimental	Money and injury	0 to 10 years	-6%	212%
Moore and Viscusi (1988)	Field	Life years	Undefined	10%	12%
Benzion et al. (1989)	Experimental	Money	6 months to 4 years	9%	60%
Viscusi and Moore (1989)	Field	Life years	Undefined	11%	
Moore and Viscusi (1990a)	Field	Life years	Undefined	2%	
Moore and Viscusi (1990b)	Field	Life years	Undefined	1%	14%
Shelley (1993)	Experimental	Money	6 months to 4	8%	27%
Redelmeier and Heller (1993)	Experimental	Health	1 day to 10 years	0%	
Cairns (1994)	Experimental	Money	5 to 20 years	14%	25%
Shelley (1994)	Experimental	Money	6 months to 2 years	4%	22%
Chapman and Elstein (1995)	Experimental	Money and health	6 months to 12	11%	263%
Dolan and Gudex (1995)	Experimental	Health	1 month to 10 years	0%	
Dreyfus and Viscusi (1995)	Field	Life years	Undefined	11%	17%
Kirby and Maraković (1995)	Experimental	Money	3 to 29 days	3678%	
Chapman (1996)	Experimental	Money and health	1 to 12 years	Negative	300%
Kirby and Maraković (1996)	Experimental	Money	6 hrs to 70 days	500%	1500%
Pender (1996)	Experimental	Food	7 months to 2 years	26%	69%
Wahlund and Gunnarsson (1996)	Experimental	Money	1 month to 1 year	18%	158%
Cairns and Van der Pol (1997)	Experimental	Money	2 to 19 years	13%	31%

Green et al. (1998)	Experimental	Money	3 months to 20 years	6%	111%
Johannesson and Johansson (1997)	Experimental	Life years	6 to 57 years	0%	3%
Kirby (1997)	Experimental	Money	1 day to 1 month	159%	5747%
Madden et al. (1997)	Experimental	Money and drugs	1 week to 25 years	8%	
Chapman and Winquist (1998)	Experimental	Money	3 months	426%	2189%
Holden et al. (1998)	Experimental	Money and food	1 year	28%	147%
Cairns and Van Der Pol (1999)	Experimental	Health	4 to 16 years	6%	
Chapman et al. (1999)	Experimental	Money and health	1 to 6 months	13%	19000%
Coller and Williams (1999)	Experimental	Money	1 to 3 months	15%	25%
Kirby et al. (1999)	Experimental	Money	7 to 186 days	50%	55700%
Van Der Pol and Cairns (1999)	Experimental	Health	5 to 13 years	7%	
Chesson and Viscusi (2000)	Experimental	Money	1 to 25 years	11%	
Ganiats et al. (2000)	Experimental	Health	6 months to 20 years	Negative	116%
Hesketh (2000)	Experimental	Money	6 months to 4 years	4%	36%
Van der Pol and Cairns (2001)	Experimental	Health	2 to 15 years	6%	9%
Warner and Pleeter (2001)	Field	Money	0 to 22 years	0%	71%
Harrison et al. (2002)	Experimental	Money	1 to 37 months	28%	
Kirby and Petry (2004)	Experimental	Money	1 week to 6 months	1%	8%
Viscusi et al. (2008)	Experimental	Water Quality	2 to 6 years	8%	14%
Epper et al. (2011)	Experimental	Money	1 to 4 months	21%	47%
Attema and Versteegh (2013)	Experimental	Health	0 to 10 years	2%	5%
Grijalva et al. (2014)	Experimental	Government bonds	100 years	<1%	>20%
McDonald et al. (2017)	Experimental	Mortality risk	23 years	11%	

Source: Malhotra et al. (2002) and revised literature.

Appendix II: Digamma function.

The hyperbolic discount factor suggested by Herrnstein (1981) and Mazur (1987) in equation (4) in the text can be derived from the difference of two digamma functions (Wu et al. 2000 and Gilula, 2015). Following Gronwall (1916) page 138, the digamma function is given by the following:

$$\psi(s) = \frac{\partial ln(\Gamma(s))}{\partial s} = \frac{\Gamma'(s)}{\Gamma(s)} = -\frac{1}{s} + \sum_{1}^{\infty}\left[\ln\left(1+\frac{1}{s}\right) - \frac{1}{s+t}\right]$$

Using the series $C = \sum_1^\infty \left[\frac{1}{t} - \ln\left(1+\frac{1}{t}\right)\right]$ and $-\frac{1}{s} = \sum_0^\infty \left[\frac{1}{s+t+1} - \frac{1}{s+v}\right]$, Gronwall showed that the digamma function can be expressed as follows:

$$\psi(s) = -C - \frac{1}{s} + \sum_{1}^{\infty}\left[\frac{1}{t} - \frac{1}{s+t}\right] == -C + \sum_{0}^{\infty}\left[\frac{1}{t+1} - \frac{1}{s+t}\right]$$

Furthermore, the difference in the two digamma functions is the following:

$$\psi(s+n) - \psi(s) = \left(\frac{1}{s} + \frac{1}{s+1} + \frac{1}{s+2} + \cdots + \frac{1}{s+n-1}\right) = \sum_{t=0}^{n-1}\left(\frac{1}{s+t}\right)$$

This is for an integer s and n periods. By using $s = \frac{1}{r}$ and adding one more period (n+1), we have the following:

$$\psi\left(\frac{1}{r} + (n+1)\right) - \psi\left(\frac{1}{r}\right) = \frac{1}{\left(\frac{1}{r}\right)} + \frac{1}{\left(\frac{1}{r}+1\right)} + \frac{1}{\left(\frac{1}{r}+2\right)} + \cdots + \left(\frac{1}{\frac{1}{r} + (n+1) - 1}\right)$$

Dividing by r, this expression reduces to the following:

$$\frac{\psi\left(\frac{1}{r}+n+1\right) - \psi\left(\frac{1}{r}\right)}{r} = \left(1 + \frac{1}{1+r} + \frac{1}{1+2r} + \cdots + \frac{1}{1+rn}\right) = \sum_{t=0}^{n}\left(\frac{1}{1+rt}\right)$$

This is the expression used in equation (4) in the text.

Additional References

Gilula, M., 2015. The digamma function and explicit permutations of the alternating harmonic series.
Gronwall, T., 1916. An elementary exposition of the theory of the gamma function. The Annals of Mathematics 17, 124-166.

Wu, T.-C., Tu, S.-T., Srivastava, H., 2000. Some combinatorial series identities associated with the digamma function and harmonic numbers. Applied Mathematics Letters 13, 101-106.

Appendix III: Bids for conservation programs in each MPA (US dollars)

	Chañaral			Choros-Damas			La Rinconada			Pullinque			Putemun		
	1 year	**5 years**	**10 years**	**1 year**	**5 years**	**10 years**	**1 year**	**5 years**	**10 years**	**1 year**	**5 years**	**10 years**	**1 year**	**5 years**	**10 years**
1%	0.96	0.21	0.11	0.96	0.21	0.11	0.96	0.21	0.12	0.96	0.21	0.11	0.96	0.21	0.12
5%	1.92	0.42	0.23	1.53	0.34	0.20	1.92	0.73	0.24	1.72	0.38	0.21	0.96	0.31	0.23
10%	6.70	0.97	0.36	6.48	0.99	0.80	2.49	0.80	0.62	2.87	0.99	0.37	0.96	0.37	0.25
25%	15.13	3.02	1.84	11.49	2.76	2.39	12.07	2.34	1.17	9.58	2.95	1.36	9.96	1.73	1.20
50%	35.44	11.42	8.82	28.74	7.65	7.48	17.82	5.68	4.39	23.75	7.65	4.77	22.61	6.72	5.62
75%	55.75	17.96	16.57	47.13	15.18	13.16	44.25	10.55	8.15	48.85	16.78	9.44	42.15	14.25	11.01
90%	81.99	36.52	23.83	64.18	35.11	27.12	65.90	16.86	17.78	109.00	35.11	17.78	52.11	21.23	16.40
95%	121.26	54.49	42.09	109.00	53.44	41.28	121.26	23.84	30.17	165.90	54.25	40.47	65.90	22.02	19.63
99%	217.05	84.18	62.81	222.80	110.88	82.72	190.23	60.35	54.01	222.80	110.88	63.38	65.90	37.81	24.47
Total	**508**	**380**	**501**	**492**	**447**	**450**	**335**	**551**	**503**	**448**	**456**	**485**	**450**	**500**	**439**

Appendix IV: Mathematic formulation and WTP for different time lengths for the exponential discount rate scheme

Following Bond et al. (2009), on the benefits side, the present value of constant annual benefits is computed as follows:

$$\begin{aligned} PV_0^{\infty} &= WTP_i \cdot \sum_{t=0}^{\infty} \frac{1}{(1+r)^t} \\ &= WTP_i \cdot \left(1 + \sum_{t=1}^{\infty} \frac{1}{(1+r)^t}\right) \\ &= WTP_i \cdot \left(1 + \frac{1}{r}\right) \\ &= WTP_i \cdot \left(\frac{1+r}{r}\right) \end{aligned}$$

On the costs side, we can represent a finite flow of payments as the difference between two infinite series, the first one starting at $t = 1$ and the other one starting at $t = n$:

$$\begin{aligned} PV_n(B_i) &= PV_0^{\infty}(B_i) - PV_n^{\infty}(B_i) \\ &= B_i \cdot \left(\sum_{t=0}^{\infty} \frac{1}{(1+r)^t} - \sum_{t=n}^{\infty} \frac{1}{(1+r)^t}\right) \\ &= B_i \cdot \left(\frac{1+r}{r} - \left(\frac{1}{(1+r)^n} + \frac{1}{(1+r)^{n+1}} + \frac{1}{(1+r)^{n+2}} + \cdots + \frac{1}{(1+r)^{\infty}}\right)\right) \\ &= B_i \cdot \left(\frac{1+r}{r} - \frac{1}{(1+r)^n}\left(1 + \frac{1}{(1+r)^1} + \frac{1}{(1+r)^1} + \cdots + \frac{1}{(1+r)^{\infty}}\right)\right) \\ &= B_i \cdot \left(\frac{1+r}{r} - \frac{1}{(1+r)^n} \cdot \frac{1+r}{r}\right) \\ &= B_i \cdot \frac{1+r}{r} \cdot \left(1 - \frac{1}{(1+r)^n}\right) \end{aligned}$$

This is the same as Bond et al. (2009). By redefining the benefits as a finite flow, the expression changes to the following:

$$\begin{aligned} PV_n(WTP_i) &= PV_0^{\infty}(WTP_i) - PV_n^{\infty}(WTP_i) \\ &= WTP_i \cdot \frac{1+r}{r} \cdot \left(1 - \frac{1}{(1+r)^n}\right) \end{aligned}$$

The true WTP is not observed. We define y_i as an indicator variable that takes the value of 1 if respondents answer 'yes' to the WTP question, and 0 otherwise. By assuming a linear specification for WTP, we get the following:

$$WTP_i = X_i{}'\beta + \sigma\varepsilon_i$$

In this, $\varepsilon \sim N(0,1)$, the probability of a negative response from individual i facing an annual payment of B_i for n years, and finite annual benefit flows of m years can be defined as follows:

$$\begin{aligned}
\Pr(y_i = 0) &= \Pr\left(WTP_i \cdot \frac{1+r}{r} \cdot \left(1 - \frac{1}{(1+r)^{m_i}}\right) < B_i \cdot \frac{1+r}{r} \cdot \left(1 - \frac{1}{(1+r)^{n_i}}\right)\right) \\
&= \Pr\left((X_i{}'\beta + \sigma\varepsilon_i) \cdot \left(1 - \frac{1}{(1+r)^{m_i}}\right) < B_i \cdot \left(1 - \frac{1}{(1+r)^{n_i}}\right)\right) \\
&= \Pr\left(X_i{}'\beta + \sigma\varepsilon_i < B_i \cdot \frac{\left(1 - \frac{1}{(1+r)^{n_i}}\right)}{\left(1 - \frac{1}{(1+r)^{m_i}}\right)}\right) \\
&= \Pr\left(\varepsilon_i < -\frac{X_i{}'\beta}{\sigma} + \frac{B_i}{\sigma} \cdot \frac{\delta_C(r, n_i)}{\delta_B(r, m_i)}\right)
\end{aligned}$$

where $\delta_C(r, n_i) = 1 - (1+r)^{-n_i}$ and $\delta_B(r, m_i) = 1 - (1+r)^{-m_i}$. Taking again the normality assumption, the Log-likelihood function can be written as follows:

$$\begin{aligned}
\ln(L) = \sum_{i=1}^{N} \Bigg[y_i \cdot \ln\left(1 - \Phi\left(-\frac{X_i{}'\beta}{\sigma} + \frac{B_i}{\sigma} \cdot \frac{\delta_C(r, n_i)}{\delta_B(r, m_i)}\right)\right) + (1 - y_i) \\
\cdot \ln\left(\Phi\left(-\frac{X_i{}'\beta}{\sigma} + \frac{B_i}{\sigma} \cdot \frac{\delta_C(r, n_i)}{\delta_B(r, m_i)}\right)\right) \Bigg]
\end{aligned}$$

Indeed, if $m = \infty$, $\delta_B(r, m_i) = 1$ and the Log-likelihood changes to the following:

$$\begin{aligned}
\ln(L) = \sum_{i=1}^{N} \Bigg[y_i \cdot \ln\left(1 - \Phi\left(-\frac{X_i{}'\beta}{\sigma} + \frac{B_i}{\sigma} \cdot \delta_C(r, n_i)\right)\right) + (1 - y_i) \\
\cdot \ln\left(\Phi\left(-\frac{X_i{}'\beta}{\sigma} + \frac{B_i}{\sigma} \cdot \delta_C(r, n_i)\right)\right) \Bigg]
\end{aligned}$$

This is the same as Bond (2009).

Appendix IV, part B: Estimation results for La Rinconada, assuming a finite benefit stream and exponential discount rate.

	100 years	**30 years**	**10 years**	**5 years**
Constant	1.160***	1.160***	1.166***	1.250***
	(0.200)	(0.200)	(0.198)	(0.195)
Environmentalist	0.867*	0.867*	0.872*	0.934*
	(0.393)	(0.393)	(0.394)	(0.417)
Income	0.400***	0.400***	0.402***	0.430***
	(0.101)	(0.101)	(0.101)	(0.106)
Age	-0.282***	-0.282***	-0.283***	-0.303***
	(0.044)	(0.044)	(0.043)	(0.041)
Gender	-0.127	-0.127	-0.128	-0.137
	(0.098)	(0.098)	(0.098)	(0.105)
Familiarity	0.430***	0.430***	0.432***	0.463***
	(0.116)	(0.116)	(0.116)	(0.119)
Sigma	1.321***	1.321***	1.328***	1.423***
	(0.159)	(0.159)	(0.154)	(0.134)
r	0.695***	0.695***	0.695***	0.695***
	(0.173)	(0.173)	(0.173)	(0.173)
N	1389	1389	1389	1389
Log-likelihood	836.414	836.414	836.414	836.414
WTP (US dollars)	4.815	4.815	4.839	5.185
WTP P-Value	0.000	0.000	0.000	0.000

Standard errors in parenthesis. ***$p < 0.001$, **$p < 0.01$, *$p < 0.05$

Appendix IV, part C: Estimation results for Chanaral, assuming different time lengths and hyperbolic discount rate

	100 years	300 years	500 years	1000 years
Constant	0.905***	0.786***	0.740***	0.687***
	(0.140)	(0.128)	(0.122)	(0.116)
Environmentalist	0.330	0.287	0.270	0.250
	(0.300)	(0.261)	(0.246)	(0.228)
Income	0.196**	0.170**	0.160**	0.148**
	(0.069)	(0.060)	(0.057)	(0.053)
Age	-0.182***	-0.158***	-0.149***	-0.138***
	(0.030)	(0.027)	(0.026)	(0.024)
Gender	-0.111	-0.096	-0.091	-0.084
	(0.069)	(0.060)	(0.057)	(0.053)
Familiarity	0.361***	0.313***	0.295***	0.274***
	(0.088)	(0.078)	(0.075)	(0.070)
Sigma	0.910***	0.790***	0.745***	0.690***
	(0.104)	(0.100)	(0.097)	(0.094)
r	2.561***	2.561***	2.561***	2.561***
	(0.611)	(0.611)	(0.611)	(0.611)
N	1389	1389	1389	1389
Log-likelihood	780.795	780.795	780.795	780.795
WTP (US dollars)	5.637	4.894	4.611	4.276
WTP P-Value	0.000	0.000	0.000	0.000
PV-WTP	15.950	15.934	15.932	15.929

Standard errors in parenthesis. ***$p < 0.001$, **$p < 0.01$, *$p < 0.05$, and +$p < 0.1$

Appendix IV, part D: Estimation results for Chanaral, assuming different time lengths and hyperbolic discount rate

	100 years	30 years	10 years	5 years
Constant	0.905***	1.086***	1.330***	1.551***
	(0.140)	(0.158)	(0.182)	(0.205)
Environmentalist	0.330	0.396	0.485	0.566
	(0.300)	(0.359)	(0.439)	(0.511)
Income	0.196**	0.235**	0.288**	0.335**
	(0.069)	(0.081)	(0.098)	(0.113)
Age	-0.182***	-0.219***	-0.268***	-0.313***
	(0.030)	(0.033)	(0.038)	(0.043)
Gender	-0.111	-0.133	-0.163	-0.190
	(0.069)	(0.082)	(0.100)	(0.117)
Familiarity	0.361***	0.432***	0.530***	0.618***
	(0.088)	(0.101)	(0.118)	(0.133)
Sigma	0.910***	1.092***	1.338***	1.560***
	(0.104)	(0.107)	(0.105)	(0.101)
r	2.561***	2.560***	2.561***	2.559***
	(0.611)	(0.610)	(0.611)	(0.610)
N	1389	1389	1389	1389
Log-likelihood	780.795	780.795	780.795	780.795
WTP (US dollars)	5.637	6.765	8.284	9.664
WTP P-Value	0.000	0.000	0.000	0.000
PV-WTP	15.950	16.018	16.239	16.632

Standard errors in parenthesis. $^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$, and $^{+}p < 0.1$

Appendix V: Interest rates for credits of Chilean banks and other financial institutions

Entity	Min. rate (%)	Max. Rate (%)
Banco Falabella	8.4	40.8
Banco del Estado	9.12	35.88
Banco Santander	11.4	47.76
Corpbanca	11.4	45.72
Banco de Chile	11.4	44.28
Scotiabank	11.76	44.16
ABC	12.0	47.88
DIN	12.0	47.88
Banco Credichile	12.0	47.88
Johnson's	16.08	48.36
Banco del Desarrollo	17.76	45.6
Banco París	21.6	46.68
Coopeuch	23.13	37.8
Atlas	23.88	47.88
Hites	27.12	48.99
Banco Condell	28.04	47.88
Banefe	28.44	47.88
Más Jumbo	30.96	47.88
París/Más París	30.96	47.88
CMR	30.96	45
Presto	46.8	46.8
Ripley	47.88	48
La Polar	47.88	47.88
Corona	48	48
Salcobrand	48.24	48.24
Tricard	48.96	48.96
Xtra	48.96	48.96

Appendix VI: Estimation results: *r* as a linear function of the socioeconomic variables

	Chañaral	**Choros-Damas**	**La Rinconada**	**Pullinque**	**Putemún**
	Hyperbolic	**Hyperbolic**	**Exponential**	**Exponential**	**Hyperbolic**
Constant	0.937^{***}	0.785^{***}	1.180^{***}	2.086^{***}	0.519^{***}
	(0.157)	(0.148)	(0.190)	(0.409)	(0.087)
Environmentalist	0.326	0.371	0.850^{*}	0.826	0.200
	(0.303)	(0.262)	(0.369)	(0.845)	(0.157)
Income	0.203^{**}	0.244^{***}	0.379^{***}	0.819^{***}	0.146^{***}
	(0.072)	(0.072)	(0.095)	(0.227)	(0.040)
Age	-0.187^{***}	-0.172^{***}	-0.269^{***}	-0.571^{***}	-0.087^{***}
	(0.031)	(0.033)	(0.041)	(0.096)	(0.017)
Gender	-0.034	-0.071	-0.174^{+}	-0.287	-0.085^{+}
	(0.086)	(0.072)	(0.102)	(0.219)	(0.049)
Familiarity	0.249^{**}	0.005	0.300^{*}	0.978^{**}	0.064
	(0.094)	(0.079)	(0.123)	(0.318)	(0.064)
Sigma	0.930^{***}	0.862^{***}	1.262^{***}	2.996^{***}	0.520^{***}
	(0.110)	(0.128)	(0.143)	(0.341)	(0.058)
			Discount parameters		
Constant	3.079^{**}	2.141^{***}	1.108^{**}	4.849^{**}	3.775^{***}
	(1.082)	(0.631)	(0.343)	(1.602)	(1.005)
Gender	1.352^{+}	0.196	-0.309		-0.776
	(0.802)	(0.180)	(0.243)		(0.624)
Familiarity	-1.791^{+}	-1.898^{***}	-0.572^{+}	-3.021	-2.203^{*}
	(0.951)	(0.558)	(0.313)	(1.869)	(0.959)
			Discount Rate		
Year 0	3.079	1.488	1.108	4.849	3.325
Year 1	0.755	0.598	1.108	4.849	0.769
			Willingness to Pay (WTP)		
WTP (US dollars)	6.062	2.964	4.836	2.394	3.824
WTP P-Value	0.000	0.002	0.000	0.105	0.000
N	1389	1389	1389	1389	1389
Log-likelihood	777.145	808.410	833.621	839.204	795.623

Standard errors in parenthesis. $^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$, and $^{+}p < 0.1$