Estimating the Value of Threatened Species Abundance Dynamics

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Date of Draft: 11/10/2020

Abstract: A large amount of conservation spending is aimed at improving the abundance of species that are threatened with extinction. A key barrier to using economics to inform conservation allocation is the lack of information on the marginal benefits of increases in the abundance of threatened species that occur at different points in time. This paper develops a choice experiment method aimed at estimating two key parameters in a dynamic willingness-to-pay function: the current marginal benefit of increases in threatened species abundance and the rate implicitly used to discount future marginal benefits. An application to threatened Coho salmon along the Oregon coast illustrates the method. We find that the public values a marginal change in Coho population from $8 to $19 per household with a discount rate for future increments in salmon abundance of 2.1%. We apply these results to an instantaneous and permanent marginal increase in salmon abundance of 0.79% resulting from a policy change in a single watershed and show this marginal change can generate over $63 million in present value of social marginal benefits to the greater Pacific Northwest region. Results also provide direct evidence that conservation activities that achieve immediate abundance gains for a threatened species (or prevent immediate losses) produce significantly higher benefits than activities that gradually achieve the same abundance gains.

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1. Introduction

Decisions about conservation investments are classic economic choices that occur at the margin: protecting a parcel of natural land from conversion to other uses through an easement; restoring a tidal wetland by removing dikes that hold back sea water; extending a regulatory no-harvest zone in riparian forests. Optimal conservation theory suggests that such investments should occur when the marginal benefits of a conservation action exceed the marginal costs (Wu and Boggess 1999; Watzold and Drechsler 2005; Polasky et al. 2014; de Vries and Hanley 2015). Applying economic conservation theory to an investment decision that incrementally increases the abundance of a threatened or endangered species is challenging because quantifying the benefits of the investment requires measurement of non-use values (Boyle and Bishop 1987; Loomis and White 1996; Richardson and Loomis 2009). While stated preference (SP) methods provide a way to measure non-use values, the existing literature is not well-suited to estimating non-use values arising from a marginal change in the abundance of a threatened species for two reasons. First, most studies focus on estimating the value of a change in the official conservation status of a species, such as an improvement from endangered or threatened to recovered (i.e., de-listing) under the U.S. Endangered Species Act (ESA) (Lew 2015). Recovered status is usually reached through a non-marginal increase in abundance. It is generally not possible to consistently derive a per-unit marginal value of *abundance* from a non-market value estimate of an improvement in recovery status. Second, the public's time preferences matter since conservation actions today may generate species abundance changes that occur at different points in time. For example, preserving an area of forest may prevent the population of a resident species from declining in the short run, while restoring adjacent forest may gradually increase abundance of the same species over a longer time period as the trees grow.

This paper introduces a method for estimating the present value of public nonconsumptive benefits generated by efforts to increase threatened or endangered species abundance over time. The method links an innovation in choice experiment (CE) design with a two-stage econometric procedure. The CE survey experimental design presents respondents with graphical and numerical information describing alternative abundance time paths for a threatened species. The econometric analysis uses conventional estimates of household willingness-to-pay (WTP) for time paths of increased abundance (first stage) in calculations that recover the structural parameters of a household-level nonconsumptive dynamic WTP function (second stage). The resulting nonconsumptive dynamic WTP function can then be applied to value abundance time paths that are not included in the experimental design, including marginal changes that do not result in official species recovery.

We illustrate the method using a recent choice experiment on conservation activities aimed at increasing the abundance of a threatened Pacific Coho salmon species (*Oncorhynchus kisutch*) within the federally defined Oregon Coast (OC) Coho salmon evolutionary significant unit in the United States (Lewis et al. 2019). Applying our method to this choice experiment produces estimates that the public discounts future abundance changes for Coho salmon at a rate of 2.1%. Further, we find heterogeneity in respondent WTP, as respondents with a 4-year college degree are WTP approximately $0.19/household for a current-period <u>one-year</u> increase in salmon abundance of 1,000 fish, which represents a marginal 0.67% increase from the current baseline abundance; respondents without a 4-year degree are WTP just under $0.08/household for the same increase. By estimating parameters in a dynamic WTP function, our method proves particularly useful in monetizing empirically-estimated biophysical impacts of marginal conservation investments on threatened species abundance. To illustrate the potential

applicability of our estimates, we consider a recent policy change that eliminated a salmon hatchery in one watershed in our study area and which has been estimated by fisheries biologists to generate an immediate marginal increase in OC Coho salmon abundance of 1,190 fish per year (~0.79% of baseline abundance) (Jones et al. 2018). Applying our estimated dynamic WTP function to this 1,190 fish increase in salmon abundance and scaling to the full population of just under 10 million households in our study region, we find estimated benefits of approximately $63 million in present value. We further analyze how alternative time paths of salmon abundance affect our estimates of population nonconsumptive benefits, highlighting the substantial public benefits that arise from conservation investments that achieve quicker increases in species abundance.

Our main contribution is a practical method that translates a conventional SP survey (extended to include explicit abundance time paths) to an empirical structural equation for the household-level present value of threatened species abundance changes. The results we obtain would not be feasible to generate using nearly all prior SP studies. This is because it is routine in SP survey design to emphasize official recovery status while either not clearly specifying or experimentally varying the magnitude and timing of abundance changes (Loomis and Richardson 2009; Lew 2015). Without this information in the experimental design, the per-unit value of species abundance cannot be disentangled from household time preferences. We provide a numerical illustration to make this point explicit.

Our method bridges what is ultimately an unnecessary gap between the nonmarket valuation literature and applied research that needs nonmarket value estimates to compare with market-valued benefits and costs. The natural science literature is increasingly estimating empirical production functions that could be used as the basis for implementing optimal

conservation theory. For example, the fisheries science literature has conducted numerous empirical assessments of the impacts of marginal conservation activities on salmon abundance, such as land use (Bradford et al. 2000), beaver dams (Leidholt et al. 1992), wood placement in streams (Roni and Quinn 2001), and boulder weir placement (Roni et al. 2006).

Our method also contributes to the natural capital valuation toolkit (Guerry et al. 2015). Recent work on natural capital valuation utilizes techniques from capital theory to empirically price natural stocks, which do not in general follow socially optimal time paths (Fenichel and Abbott 2014). These exercises risk substantially underestimating the shadow price of stocks that produce economically-significant nonmarket benefits for the public (Yun et al. 2017). Fenichel and Abbott (2014) stress "…the vital importance of nonmarket valuation techniques […] for quantifying…" net benefits – which they label dividends – of natural capital (2014, p. 8), and call for the methodology to be extended to incorporate empirical estimates of nonmarket benefits (p. 19). The technique we propose makes this integration possible, and is the first, to the best of our knowledge, that offers precisely the empirical structural representation of household-level nonmarket values that is necessary in order to comprehensively value time paths of species abundance in a natural capital framework.

2. A Model of Willingness-to-Pay for Time Paths of Species Abundance

2.a Nonconsumptive dynamic WTP function

In this section, we develop a simple dynamic model of a household's WTP for a time path of monotonic increases in the abundance of a threatened species. Suppose conservation actions are expected to increase the abundance of a species (X_t) from an initial baseline $\bar{X}$ to a final level X_T

by terminal time T, and hold abundance at that level permanently. We assume the time path of the abundance *increase* in time t relative to $\bar{X}$ is described by the "beta growth function" (Yin et al. 2003):

$$\Delta abund(t, \bar{X}, X_T, T, \omega) = (X_T - \bar{X}) \left(1 + \left[\frac{T-t}{T-\omega}\right]\right) \left(\frac{t}{T}\right)^{\frac{T}{T-\omega}} \qquad (1)$$

Here ω is a parameter that influences the timing of the maximum rate of change in abundance. For any given baseline and final abundance levels, lower values of ω imply a quicker path to the final abundance level X_T (Figure 1). Therefore, a lower value of ω could be used to reflect greater conservation investments in the early years of a program. We use the beta function to represent growth because i) it allows us to fix terminal abundance (X_T) and baseline abundance ($\bar{X}$) while varying the rate of abundance change in our choice experiment design, and ii) provides a typical "s-shaped" growth function that is commonly used with many renewable resources like fish stocks and tree growth.[2]

We take a simple approach that defines b as the current money-metric benefit per unit of abundance increase, and r as the individual's constant discount rate. Therefore, a household's present value of willingness-to-pay (PVWTP) for a conservation program that generates a time path leading to a permanent gain in abundance is:

$$PVWTP(\bar{X}, X_T, r, T, \omega) = \int_{t=0}^{T} b \cdot \Delta abund(t, \bar{X}, X_T, T, \omega) \cdot e^{-rt} \cdot dt + \frac{b \cdot (X_T - \bar{X}) \cdot e^{-rT}}{r} \qquad (2)$$

We label Eq. (2) the "nonconsumptive dynamic WTP function". Consider two time paths defined by Eq. (2) that differ only in terms of the value of ω: e.g., ω_1 and ω_2, where $\omega_1 < \omega_2$. A

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[2] Another key feature of the beta function is that it assumes monotonic growth, which may not be applicable in all cases.

convenient result is that the ratio of the PVWTP corresponding to the two time paths does not depend on b, X_T or $\bar{X}$:

$$\frac{PVWTP(\bar{X}, X_T, r, T, \omega_1)}{PVWTP(\bar{X}, X_T, r, T, \omega_2)} = \frac{\left\{\left[\int_{t=0}^{T} e^{-rt} \cdot \left(1 + \left[\frac{T-t}{T-\omega_1}\right]\right)\left(\frac{t}{T}\right)^{\frac{T}{T-\omega_1}}\right] + e^{-rT}\frac{1}{r}\right\}}{\left\{\left[\int_{t=0}^{T} e^{-rt} \cdot \left(1 + \left[\frac{T-t}{T-\omega_2}\right]\right)\left(\frac{t}{T}\right)^{\frac{T}{T-\omega_2}}\right] + e^{-rT}\frac{1}{r}\right\}} \equiv G(\omega_1, \omega_2, r, T) \tag{3}$$

The practical use of this result is the following. If estimates of PVWTP corresponding to known values of ω_1, ω_2, and T are available, then we can numerically solve Eq. (3) for r. A key feature of a CE survey used for this method is that values of ω and T are determined by an experimental design. Next, since Eq. (2) is linear in b, we can substitute in the estimate $\hat{r}$ to obtain an estimate of $\hat{b}$, again using an estimate of PVWTP for the associated path. While there are other growth functions besides the beta function from Eq. (1) that could potentially be used, our current implementation requires that growth functions must have the property from Eq. (3) to uniquely identify the discount rate. The most straightforward implication of the nonconsumptive dynamic WTP function in Eq. (2) is that individuals are WTP more for a time path that achieves earlier than latter gains in abundance, ceteris paribus. The implication of the ratio in Eq. (3) is that the percentage that individuals are WTP for a quicker time path (ω_1) compared to a slower time path (ω_2) – where $\omega_1 < \omega_2$ – is defined by the discount rate and not the baseline or ending abundance level.

2.b Why the nonconsumptive dynamic WTP function can't be estimated from past literature

Past stated preference literature on threatened species typically estimates WTP for either a status change in the threatened status of the species (e.g. Lew and Walmo 2011; Boxall et al. 2012), or

for large non-marginal changes in species abundance that does not specify or vary the time path of abundance change in the experimental design (e.g. Loomis 1996; Lew et al. 2010).[3] While it is straightforward why an estimate of the marginal current benefit of a unit of abundance (*b*) can't be estimated from WTP for status changes that don't explicitly link to abundance, it is perhaps less clear why *b* cannot be estimated from WTP for large non-marginal changes in species abundance. To illustrate how difficult it is to obtain estimates of marginal benefits (*b*) given the information found in the existing literature, we focus on an example from Loomis (1996), who estimated the WTP for increases in salmon abundance that were expected to follow a dam removal project on the Elwha River in Washington, USA. Loomis found an average household WTP of $68/year (1996 $) – or $112.88/year in 2020 dollars – for the dam removal program that was eventually expected to generate 300,000 more returning salmon to the Elwha River watershed. While the time taken to reach 300,000 more salmon was not made explicit in Loomis (1996), a later government fish restoration plan of the dam removal projected it would take 25 years for the salmon recovery to be achieved (Ward et al. 2008). If we use the beta function from Eq. (1) to describe the increase to 300,000 salmon over a period of *T*=25 years, and we use Loomis' result that average WTP is $112.88/year (2020 $) for the time horizon of 10 years used in his study, then we can only obtain an estimate of *b* from Eq. (2) if we assume both a discount rate *r* and a rate of change in salmon abundance (set with parameter *ω*). If we assume that *r*=0.01 and *ω*=0, then solving Eq. (2) for *b* using the present value of Loomis' estimated WTP over 10 years as the left-hand side of Eq. (2) would give us *b*=$3.92 per 100,000 fish. If we instead assume a higher discount rate and slower rate of change in abundance (*r*=0.1 and *ω*=20), solving

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[3] An exception is Bell et al. (2003), who estimates WTP for smaller scale abundance changes in Pacific Coho salmon in select watersheds in Oregon and Washington. However, the focus is on use values from an enhanced salmon catch to five very small coastal communities as opposed to broader nonconsumptive values.

Eq. (2) for *b* using the present value of Loomis' estimated WTP over 10 years would give us

b=$128.21 per 100,000 fish. So, a higher but still reasonable discount rate combined with a

slower but still reasonable rate of abundance change generates an estimate of *b* that is almost 33

times larger.[4] Clearly, using WTP information for a large-scale conservation program to infer

marginal benefits (*b*) will be greatly assisted by known or estimated values of *r* and ω, and we

are aware of no prior stated preference studies of threatened species with such information.

3. Choice Experiment and Econometric Framework

3.a. The Oregon Coast Coho Salmon Choice Experiment

We use a choice experiment originally described in Lewis et al. (2019) to elicit preferences from

the general public for conservation scenarios where the abundance of a threatened Pacific Coho

salmon species is defined by a fixed baseline $\bar{X}$ and varies by a final steady-state abundance X_T

achieved in *T*=50 years, and the speed with which abundance increases occur (i.e., the level of

ω). In fall of 2017, 5,000 mail surveys were sent to a random sample of households in the greater

Pacific Northwest of the U.S. – Washington, Idaho, Oregon, and northern California (Bay Area

and north). The choice experiment survey was designed with a set of realistic conservation

investment scenarios consistent with salmon life histories and management policies to estimate

the nonmarket values for Oregon Coast Coho salmon (*Oncorhynchus kisutch*). The survey design

used two government recovery plans to guide scenario development for the surveys: the Oregon

Coast Coho Conservation Plan for the State of Oregon (State of Oregon 2007) and the Federal

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[4] The paths with the fast rate (ω=0) and the slow rate (ω=20) of abundance changes in this example both lead to 300,000 more salmon in *T*=25 years. However, by year 15, the path with the fast rate achieves 84% of the final abundance change while the path with the slow rate has 23% of the final change.

Government's 2016 Recovery Plan for Oregon Coast Coho Salmon Evolutionary Significant Unit (NOAA 2016). Moreover, input on the information provided in the survey was supplied by an advisory panel composed of fisheries biologists, fishery and resource managers, and economists. The survey was also pre-tested through several focus groups and a formal pilot survey (Lewis et al. 2019).

Survey respondents were asked their preferences across recovery scenarios that varied with the following attributes (Table 1): i) whether OC Coho were "Recovered" or remained "Threatened" under the ESA, ii) the average abundance (number) of adult fish returning to freshwater streams in a defined terminal time of 50 years, iii) the speed at which the returning adult fish population is increased over 50 years, and iv) recreational fishing regulations including fishing season and harvest limits. Each choice scenario presents respondents with a graph of the dynamic path of salmon abundance (Table 1), and an important feature of our experimental design was our use of the beta function from Eq. (1). The design randomly varies the speed of increase in salmon abundance as either "Quick" ($\omega = 13.7$) or "Slow" ($\omega = 38.7$) as in Figure 1. So, survey respondents are explicitly asked to express their preference for a "quick" increase in salmon abundance. We use a D_0-optimal experimental design (Huber and Zwerina 1996) to determine attribute levels accounting for multiple correlations and restrictions among the attributes, and each survey includes three choice experiment questions – the same status quo alternative is included in every choice question with a $0 cost, along with two conservation scenarios with non-zero costs selected from Table 1. For each of the three choice experiment *questions*, respondents selected one preferred choice, giving us three choice responses per survey respondent. There were a total of 20 unique survey versions randomly distributed among survey respondents. Fig. 2 presents an example choice card.

The response rate from the mail survey was 21%, accounting for deceased respondents and undeliverable surveys. An initial analysis of the choice experiment data was conducted by Lewis et al. (2019) and results indicate population-level non-market benefits of up to $518 million for $\Delta abund$=100,000 returning salmon in T=50, and benefits of up to $277 million for achieving conservation goals quickly ($\omega = 13.7$) rather than slowly ($\omega = 38.7$) for conservation scenarios ranging from $\Delta abund$=100,000 returning salmon to $\Delta abund$=375,000 returning salmon. Since the baseline salmon abundance is $\bar{X}$=150,000 fish, the benefit estimates from Lewis et al. can be interpreted as estimates from a set of non-marginal conservation scenarios, as they do not exploit the features of the beta function of abundance growth to estimate either the discount rate r nor the current marginal benefit b of abundance. Therefore, their model estimates are not conducive to recovering the benefits from marginal conservation investments, nor for time-paths of abundance changes that deviate from what was used in the experimental design. In the next section, we develop a two-stage econometric model to overcome these shortcomings. Interested readers are referred to significant additional details about survey development, experimental design testing, other pretesting activities, survey implementation, and sample selection analysis provided in an extensive supplemental document from Lewis et al. (2019).[5]

3.b First-Stage Random Utility Model

We specify a random utility model that accommodates heterogeneous preferences through random parameters. This is the first-stage model that yields the estimates of WTP needed in the

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[5] Available at https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0220260.

second stage to recover estimates of the dynamic parameters. Respondent n's random utility U_{nik} from choosing restoration alternative i from choice question k is:

$$U_{nik} = -\exp(\beta_{n1})Price_{nik} + \beta_{n2}Rec_{nik} + \beta_4^{Quick_{nik}}\beta_5^{Rec_{nik}}[\beta_{n3} + \gamma_n College_n]\Delta Abund_{50nik} + \cdots$$

$$\beta_{n6}Fishing1_{nik} + \beta_{n7}Fishing2_{nik} + \varepsilon_{nik} \tag{4}$$

Here $Price_{nik}$ is the annual price of the restoration program (in \$100s); Rec_{nik} is a binary indicator of whether Coho salmon are officially de-listed, or recovered, under the ESA (=1) or not (=0); $\Delta Abund_{50nik}$ represents the change in abundance (relative to the baseline) of returning OC Coho salmon that occurs in T=50 years (in 100,000s);[6] $Quick_{nik}$ is a binary indicator of whether returning salmon abundance rises quickly (=1) or slowly (=0); $Fishing1_{nik}$ is a binary indicator of whether the Coho salmon fishing season is annual with a 5 fish/year limit (=1) or not (=0); and $Fishing2_{nik}$ is a binary indicator of whether the Coho salmon fishing season is annual with a 10 fish/year limit (=1) or not (=0). The status quo is modeled with an alternative-specific constant, β_{n0} representing the utility of the current state. The probability that respondent n makes choice i on choice card k is:

$$P_{nik} = Prob[U_{nik} > U_{njk} \ \forall \ j \neq i] \tag{5}$$

Previous analysis of these data by Lewis et al. (2019) found that respondents with a 4-year college degree ($College_n$=1) had a higher marginal utility for $\Delta Abund_{50nik}$, and so we include a dummy-variable indicating whether respondent n has a 4-year degree ($College_n$) as an interaction with $\Delta Abund_{50nik}$. Lewis et al. (2019) also found that the sample income was

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[6] The connection between first stage variables $\Delta abund_{50nik}$ and $Quick_{nik}$ in Eq. (4) and the beta growth function $\Delta abund(t, \bar{X}, X_T, T, \omega)$ (Eq. (1)) is as follows. The experimental design uses the same value of baseline abundance ($\bar{X}$) and terminal time ($T = 50$) in all choice occasions. Only ω and X_T vary. The value of $Quick_{nik}$ sets ω to one of two values (quick or slow). Conditional on this ω_{nik} and the final absolute abundance $X_{T,nik}$, $\Delta abund_{50nik} = \Delta abund(T, \bar{X}, X_{T,nik}, T, \omega_{nik}) = X_{T,nik} - \bar{X}$.

representative of the population, and they found no evidence of observable preference

heterogeneity based on race, gender, or age of the respondent, and no evidence of sample

selection based on unobservables. Therefore, we only include $College_n$ to indicate observable

heterogeneity. Unobservable preference heterogeneity is captured through random parameters in

Eq. (4), except for the multiplicative parameters β_4 and β_5 which enters as fixed.[7]

The random utility specification can be used to estimate the present value WTP for a

conservation program leading to abundance increases that are defined by the terminal time

abundance change ($\Delta Abund_{50}$) and the dummy variable indicating speed of abundance change

($Quick$) as:

$$WTP(\Delta abund_{50}, Rec, Quick, College) = \frac{\beta_2 Rec + \beta_4^{Quick} \beta_5^{Rec}[(\beta_3 + \gamma College)\Delta abund_{50}]}{\exp(\beta_1)} \quad (6)$$

For the case where "recovery" is not achieved ($Rec = 0$), the ratio of WTP of interest for

determining the nonconsumptive benefit function discount rate in the second stage reduces to:[8]

$$\frac{WTP(\Delta abund_{50}, Rec=0, Quick=1, College)}{WTP(\Delta abund_{50}, Rec=0, Quick=0, College)} = \beta_4 \quad (7)$$

For our purposes, the fact that the WTP ratio in Eq. (7) reduces to a single estimated parameter is

a key advantage of the multiplicative RUM specification in Eq. (4) since it allows us to identify

the respondent discount rate *r* with a single RUM parameter by application of the theory in Eq.

(3).

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[7] We were unable to obtain convergence when β_4 and β_5 were specified as random, likely due to the multiplicative nature of these parameters.

[8] The experimental design defines the payment vehicle as "[a]dded cost to your household each year for 10 years". We rely on this definition to write the ratio in Eq. (6) as involving WTP rather than PVWTP as shown in Eq. (3), since the sum of constant discrete discount factor weights applied to the numerator and denominator to evaluate the present value computation would cancel, leaving the (constant) annual WTP terms,

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3.c Second-Stage Calculation of Nonconsumptive Benefit Function Parameters

Given first-stage estimates of random utility model parameters from Eq. (4), calculating

nonconsumptive benefit function parameters b and r in the second stage is fairly straightforward.

First, an important consideration is that, since WTP for a scenario depends on college attainment

(Eq. (6)), second stage computation of b will also depend on college attainment. This means we

must calculate two estimates of b: $\hat{b}_{\text{No College}}$ for non-college households, and $\hat{b}_{\text{College}}$ for

households with college attainment.

To generate point estimate (median) values of $\hat{r}$, $\hat{b}_{\text{No College}}$, and $\hat{b}_{\text{College}}$ along with

confidence intervals, we adapt standard Krinsky and Robb (1986) simulation methods to the

second-stage calculations. We first draw J sets of RUM model parameters ($\widetilde{\boldsymbol{\beta}}_j$) using the point

estimates and fitted covariance matrix from the first stage. For each jth parameter vector draw,

we simulate a distribution corresponding to each random parameter using H Halton draws. Since

each simulated $\tilde{\beta}_{4j}$ is a fixed rather than heterogenous parameter, we find a single value of $\tilde{r}_j$

by setting Eq. (3) equal to $\tilde{\beta}_{4j}$ and solving numerically. Our preferred point estimate, $\hat{r}$ is the

median value of $\tilde{r}_j$, and we produce a confidence interval by calculating quantiles of the

simulated discount rates.

To obtain $\hat{b}_{\text{No College}}$, and $\hat{b}_{\text{College}}$, we simulate distributions for these parameters

utilizing values of $\tilde{r}_j$ and $\widetilde{\boldsymbol{\beta}}_j$. We first use $\tilde{r}_j$ along with the jth parameter vector draw to produce

draws of the present value of WTP for different time paths of abundance in the experimental

design that do not lead to recovery ($P\widehat{VWT}P_j(College)$).[9] Next, we use Eq. (2) to calculate values of $\tilde{b}_{\text{No College},j}$ and $\tilde{b}_{\text{College},j}$ corresponding to $\tilde{r}_j$. Similar to how we handle $\tilde{r}_j$, we calculate median values and confidence intervals from the simulated distributions of $\tilde{b}_{\text{No College},j}$ and $\tilde{b}_{\text{College},j}$.

4. Estimation Results

Parameters from the random parameters logit (RPL) model in Eq. (4) are estimated with maximum simulated likelihood using 2,000 Halton draws and results are presented in Table 2. Parameter estimates indicate strongly significant and positive coefficients for the main utility parameters ($p<0.05$) except for the two dummy variables regarding recreational fishing regulations (fishing1, fishing2), which are jointly insignificant from zero using a likelihood ratio test ($p<0.05$). The other parameters indicate that respondents gain utility from official recovery (de-listing), from higher terminal period abundance of salmon, and from achieving terminal period abundance levels quickly. We also find evidence of strong respondent heterogeneity in preferences, plus our results confirm Lewis et al.'s (2019) finding that college graduates gain more utility than non-college graduates for steady-state salmon abundance.[10]

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[9] Specifically, if $\widehat{WTP}_j$ is the jth Krinsky-Robb (KR) simulation of median household annual WTP, then we form $P\widehat{VWT}P_j = \widehat{WTP}_j \sum_{t=0}^{10} \left(\frac{1}{1+\tilde{r}_j}\right)^t$. Since first-stage WTP results used in this calculation involve functions of random parameters, we take the median over the H draws from the random parameters corresponding to the jth KR simulation iteration.

[10] The prior analysis of Lewis et al. (2019) uses the same variables that we do in Eq. (4), but with a different specification where all variables were linear and additive, e.g. the $Quick$ variable was included as a linear term and as an interaction with $\Delta Abund$. While our specification in Eq. (4) has a slightly worse fit (log-likelihood of -2020.59) than the linear and additive specification from the Lewis et al. (2019) paper (log-likelihood of -2016.16), our specification has the advantage of imposing the restrictions required to estimate the dynamic WTP parameters by imposing the $G(\omega_1, \omega_2, r, T)$ ratio from Eq. (3). We refer interested readers to additional supplemental analyses

Parameter estimates for the second-stage dynamic parameters are presented in Table 3. The estimated $G(\omega_1, \omega_2, r, T)$ ratio from Eq. (3) is found from $\widehat{\beta_4} =1.36$, indicating that the average WTP for a quick increase in salmon abundance ($\omega=13.7$) is 36% larger than the average WTP for a slow increase ($\omega=38.7$) that generates the same final abundance target. Given $G(\omega_1, \omega_2, r, T)=1.36$, the implied average rate at which respondents discount future abundance increases is solved numerically as $\hat{r}=0.021$. Finally, the current period benefits that respondents derive for an extra 100,000 returning salmon in a given year is determined by solving for b from Eq. (2), using the estimated discount rate of $\hat{r}=0.021$. We find that $\hat{b}_{No\ College}=\$7.83$ per 100,000 fish per household and $\hat{b}_{College} = \$19.09$ per 100,000 fish per household for college graduates. As expected, college graduates are willing to pay more for an increment of abundance than those without a college degree.

5. Application – Valuing the Observed Partial Recovery of Coho Salmon in Salmon River, OR

5.a Valuing effects from a hatchery removal

We now illustrate an application of our estimated parameters from the nonconsumptive dynamic WTP function to recent conservation actions aimed at increasing the abundance of Oregon Coast Coho salmon in one small watershed, the Salmon River along the central Oregon coast. The Salmon River is a small watershed with approximately 81 km of Coho spawning habitat that has received multiple conservation interventions. A system of dikes in the Salmon River estuary was removed between 1978 and 1996, re-establishing historical tidal marsh acreage that can be used

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in Lewis et al. (2019), who found that results were unaffected by sample selection bias based on unobservables, and that results were robust to potential protest respondents, attribute non-attendance, and stratified sampling.

by Coho. To assist the recovery of Oregon Coast Coho salmon, the Oregon Department of Fish and Wildlife ceased stocking hatchery Coho into the Salmon River in 2007. A "before-after-impact-control" (BAIC) analysis of returning adult Coho to the Salmon River finds that the average annual abundance of fish has increased by approximately 1,190 individual fish during the years 2013-2016, an effect attributed to the hatchery program discontinuation (Jones et al. 2018). Importantly, the hatchery discontinuation led to "an immediate wild population increase during the post-hatchery period" (Jones et al. 2018 p.51). An extra 1,190 fish per year is a marginal change (0.79%) in the ESU-wide abundance. Valuing the benefits of 1,190 additional returning adult salmon provides an example of the usefulness of our nonconsumptive dynamic WTP estimates. An immediate increase of 1,190 additional fish is worth approximately $0.141 / household / y using our structural parameter estimates.[11] Multiplying across the 9,408,059 households in the greater Pacific Northwest, the benefits are $1,327,917 / y. The study by Jones et al. (2018) was an ex-post evaluation that did not assess whether the additional abundance of fish would be expected to increase more. If we interpret the increased fish to the Salmon River as an immediate change following Jones et al.'s (2018) interpretation, then the present value of an infinite stream of 1,190 additional fish / y is $63.2 million when evaluated at our estimated 2.1% discount rate.

5.b Valuing Dynamic Paths – Alternative paths to achieve a 1,190-fish steady-state increase

We highlight the role of dynamics in threatened species abundance by exploring the magnitude of benefit differences that arise from alternative dynamic paths to the terminal period increase in

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[11] This is a population weighted measure reflecting that 35.8% of the population has a 4-year college degree.

returning salmon abundance of 1,190 fish from the previous section. Consider three paths of dynamic increases in fish abundance, where all three result in a permanent increase of 1,190 returning fish after the end of 50 years (Fig. 3, Panel A). The slow and quick paths are defined using parameters from our experimental design, including the terminal time T and rate of change parameter ω. We compare the benefits of these paths to the benefits from an instantaneous increase described in section 5.a, which is outside of our experimental design and which we can only value because of our estimation of the nonconsumptive dynamic WTP function.

While all three time paths that we consider ultimately produce the same gain in abundance, the nonconsumptive value they deliver differs significantly. The root of this difference is evident when one compares the present value of abundance gains realized through each year (Fig. 3, Panel B). The instantaneous increase produces the most nonconsumptive benefit early on when the penalty imposed by discounting is smallest. This same feature explains the separation in the present value of gains realized by the quick vs. the slow path through year 50.

Our model of household-level nonconsumptive benefits assumes that households value future abundance levels after year 50, when the population is stable regardless of the time path. Inspecting the contribution of overall PVWTP from gains prior to year 50 and after year 50 reveals that nonconsumptive benefits from the future after year 50 can comprise the majority of the value unless the time path increases to near the final value rapidly (Fig. 3, Panel D). This result is driven partly by the low estimated range of the discount rate, r (95% CI: (0.0132, 0.0274)). Since we find that households with college attainment have a higher current nonconsumptive value per unit of abundance, they accrue greater benefit from early gains in abundance (Fig. 3, Panel C). However, they also receive a larger benefit from permanent gains

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farther in the future relative to non-college households, all else being equal, and so the relative value of time paths pre- and post-year 50 are qualitatively similar (Panel D). A further implication is that efforts aimed at either restoring or saving an immediate change in salmon abundance by amount $\Delta Abund$ provide significantly more benefits than restoration efforts that would gradually increase salmon abundance to eventually reach $\Delta Abund$. In particular, the present value population benefits of a permanent instantaneous increase in 1,190 returning salmon is approximately \$63 million, while the corresponding present value benefits of a slow (quick) increase that eventually reaches 1,190 returning salmon after 50 years is just over \$32 million (\$43 million).

This comparison of the present value of benefits over a range of time paths that reach the same final species abundance highlights the need for valuing abundance time paths outside of the experimental design used in our survey. Eliminating the hatchery led to an estimated immediate increase in returning salmon, and imposing one of the paths from our experimental design – slow ($\omega=38.7$) or quick ($\omega=13.7$) with a terminal time of $T=50$ – would have led to a significant underestimate of the nonconsumptive benefits. Therefore, the advantage of estimating parameters in the nonconsumptive dynamic WTP function is the ability to value a wide range of scenarios involving abundance changes over time.

6. Discussion

Many individual conservation investments are motivated by the plight of threatened and endangered species, and the accumulation of numerous marginal investments comprises many official species recovery plans. Valuing marginal investments in natural capital to improve threatened species habitat faces at least two key challenges. First, the benefits from improving

the abundance of threatened and endangered species include non-use values (Krutilla 1967), and measurement of such values typically requires stated preference methods (Freeman 2003). Second, conservation investments generate time-paths of marginal changes in species abundance, and valuing the dynamics of species abundance changes requires knowledge of parameters in a nonconsumptive dynamic WTP function: the current period benefit of an increment in abundance and the rate with which people discount future abundance change values. While there is a significant stated preference literature on threatened and endangered species (e.g. see the reviews by Loomis and Richardson 2007; Lew 2015), this literature has focused on valuing official recovery status changes (e.g., ESA listing status) and has not generated key dynamic parameters in a WTP function that could be used to value marginal changes in threatened species abundance. Therefore, the existing non-market valuation literature generally is unable to value individual natural capital investments (Fenichel and Abbott 2014) that marginally increase species abundance but do not lead to species recovery, and is unable to put monetary values on ecological evidence of the impacts of marginal conservation investments on threatened species abundance (e.g. Roni and Quinn 2001; Jones et al. 2018).

This paper shows how to recover key dynamic WTP parameters for changes in the abundance of a threatened species, and we apply the method to the problem of estimating the benefits of incremental conservation efforts aimed at increasing the abundance of a Coho salmon species (*Oncorhynchus kisutch*) within the federally defined Oregon Coast (OC) Coho salmon evolutionary significant unit, which is listed as threatened under the ESA. The choice experiment method requires an experimental design where i) respondents are presented with final period species abundance levels which are varied in the design, and ii) respondents are presented with some depiction of the time-path of abundance gains (e.g., a graph) which result from application

of the biological beta function with <u>known</u> parameters which are varied in the design (e.g., quick vs. slow). Given these basic experimental design elements embedded in a choice experiment, we develop a two-stage estimation process to generate dynamic WTP parameters, with i) a first-stage random utility model with multiplicative parameters that can be estimated with conventional random parameters approaches, and ii) a second-stage where a WTP ratio is used to implicitly solve for average respondent discount rates which then identify the current period per-unit benefit of an increment in species abundance. The nonconsumptive dynamic WTP parameters can be used to value any time path of changes in species abundance and can be used to estimate benefits for a population of individual consumers. Using empirical estimates that eliminating a salmon hatchery in a single watershed in our study region immediately increased wild Coho salmon abundance by 1,190 fish, we apply our method to show that this conservation investment generated population benefits of $1.3 million / y, and a steady-state stream of such benefits is worth a present value of $63 million when evaluated at our estimated 2.1% discount rate for salmon abundance. We show that an alternative conservation strategy, which slowly increases salmon abundance to the same 1,190 fish change, generates roughly half the level of benefits. Thus, our results provide direct empirical evidence that conservation activities that achieve immediate abundance gains for a threatened species (or prevent immediate losses) produce significantly higher benefits than activities that gradually achieve the same abundance gains.

Empirical estimates of conservation impacts on physical abundance of threatened species are voluminous in the natural science literature, and our approach contributes an important new application of stated preference non-market valuation estimates to put monetary values on the estimated impacts of small conservation efforts on threatened species abundance. Our approach

integrates all current best practices in stated preference design (Johnston et al. 2017) with a simple methodological approach that will greatly increase the flexibility with which non-market valuation estimates can be used. Thus, developing a strong future linkage between stated preference research, optimal conservation theory, and empirical natural science production function estimation could be used to inform conservation decision-making and better integrate areas within environmental economics and between environmental economics and ecology.

We view this research as advancing the state-of-the-art of integrating ecological-economic policy analysis models and nonmarket valuation models. Simply put, our view is that these literatures should "talk to each other" more effectively: nonmarket valuation studies should produce estimates that models can use, and models should generate credible scenarios that can be valued. This level of integration is rare in applied work, and we see two extensions to this research that would help to further bridge the divide. First, while the expected abundance time paths we include in the SP survey are credible in that they are within the envelope of recovery plan assumptions, we did not produce the quick and slow time paths using an empirical population-dynamic model. Building on proof-of-concept provided by this research, the next step for SP studies of species conservation should be to investigate the feasibility of incorporating output from such a model into the experimental design. The potential benefits of doing so include enhanced credibility of WTP function estimates and stronger internal consistency of policy analysis involving nonmarket benefits.

A second related area for further work on this methodology is understanding the impact of uncertainty on values for marginal abundance changes and time preferences revealed by SP surveys. In our application, salmon abundance numbers exhibit substantial year-to-year variability, and while the survey instrument informs respondents of sources of variability like

ocean conditions, the expected abundance paths shown in the experimental design do not include

stochasticity. A key question that has not been investigated, to our knowledge, is whether the

choice experiment method can support a design that includes both dynamic paths of abundance

change and intuitive measures of year-to-year variability. Understanding whether nonmarket

valuation surveys can isolate public values for both properties of species abundance changes

over time is critical in order to determine the extent to which nonmarket values can be

incorporated into policy analysis.

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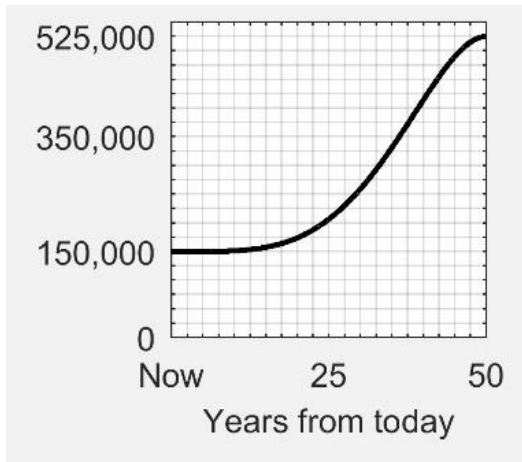
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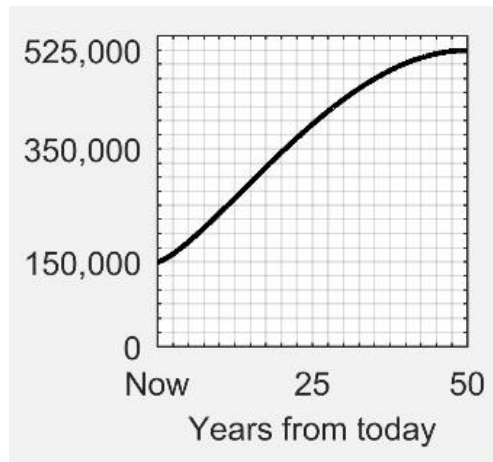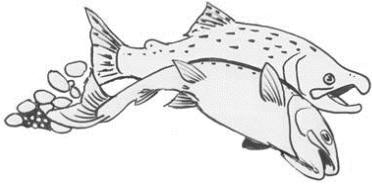Slow Path ($\omega = 38.7$)   Quick Path ($\omega = 13.7$)

Figure 1. Graphical depiction of the beta function with alternative ω parameters. The y-axis is the abundance of the species, while the x-axis is time. In this figure, $abund_b$=150,000, $abund(T)$=525,000, $\Delta abund(T)$=375,000 and the terminal time T=50 years.

	Results in 50 years		
	Status Quo	**Alternative A**	**Alternative B**
Population Status	Threatened	Recovered	Recovered
Population Size	150,000 fish	525,000 fish	375,000 fish
Population over Time	No Change	Slow Change	Quick Change
Recreational Fishing (# of fish that can be kept)	Periodically Closed 5 fish/year	Open Every Year 10 fish/year	Open Every Year 5 fish/year
Added cost to your household each year for 10 years	$0	$100/year	$350/year
Which alternative do you prefer? (Choose One)	◯₁ Status Quo	◯₂ Alternative A	◯₃ Alternative B

Figure 2. Example choice card question. Attributes are selected from the experimental design in Table 1, and there are 60 unique choice cards.
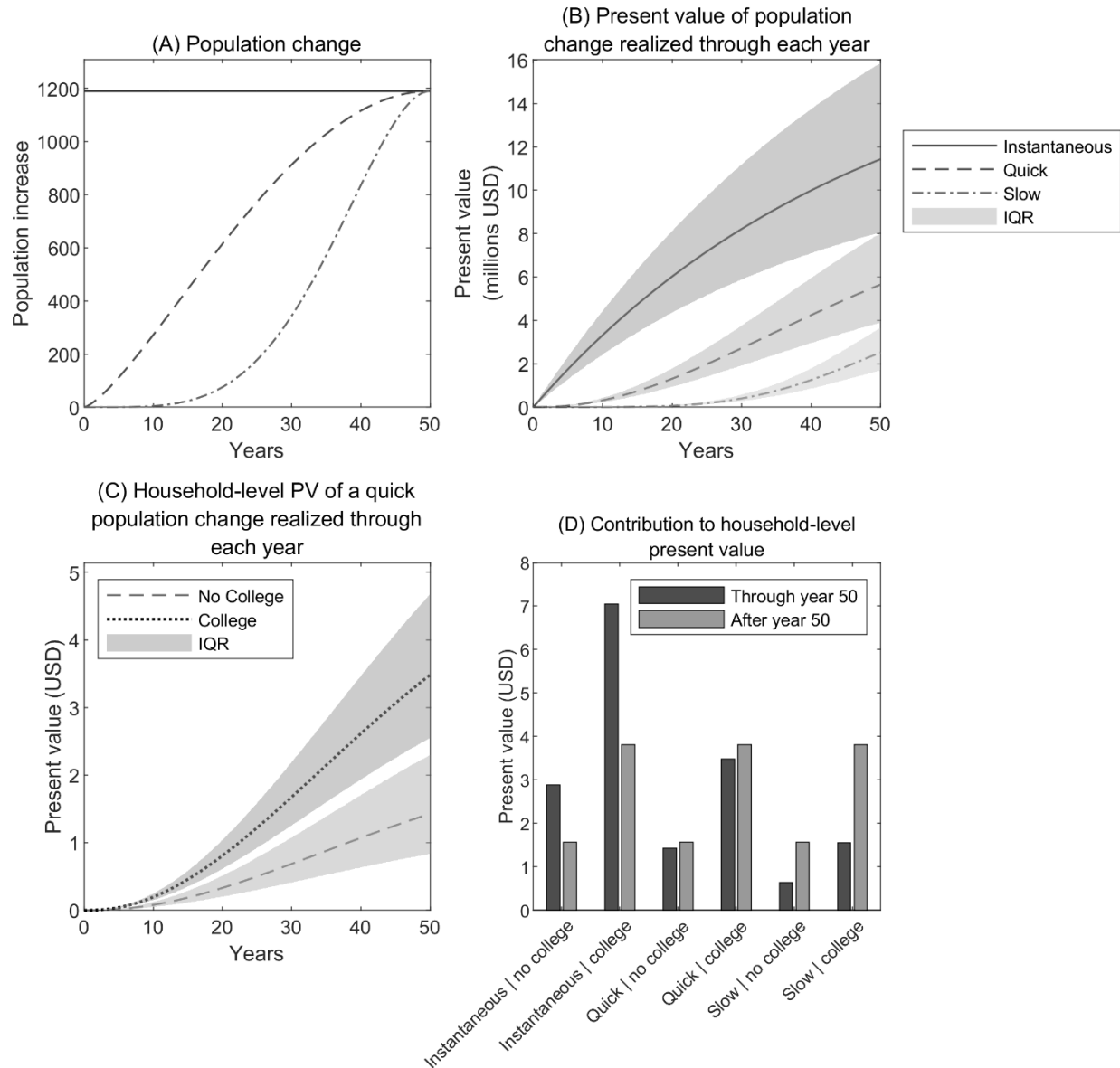
Figure 3. Comparing the value of time paths of abundance gains for a threatened species. (A) Time paths of population increase. (B) Population-level present value of WTP for time paths shown in Panel A, shown in terms of PVWTP for population gain realized through each year. (C) Household-level PVWTP for the quick time path (Panel A). (D) Contribution to overall household PVWTP from each time path pre- and post-year 50.

Table 1. Experimental design attributes and levels of attributes used in the stated preference survey for recovery of Oregon Coast Coho salmon given to US Pacific Northwest residents

Attribute	Levels of attribute
Endangered Species Act Status	(1) Threatened (2) Endangered
Number of returning fish in 50 years	(1) 150,000 (status quo only) (2) 250,000 (3) 325,000 (4) 375,000 (5) 525,000
Speed of increase in number of returning fish	(1) No change (status quo only) (2) Slow (accompanied with a graph like this) (3) Quick (accompanied with a graph like this)
Fishing regulations (season & harvest limits)	(1) Open occasionally with 5 fish/year bag limit (2) Open annually with 5 fish/year bag limit (3) Open annually with 10 fish/year bag limit
Annual cost of program	(1) $0 (status quo only) (2) $10 (3) $20 (4) $50 (5) $75 (6) $100 (7) $150 (8) $250 (9) $350

Table 2. Random Parameters Logit Estimates of Choice Model

		Main Model	
		Parameter	Std. Error
Status Quo	ASC	-11.81*	1.70
Parameter Means	log(Price)	0.66*	0.12
	Recovered	1.26*	0.37
	$\Delta Abund_{50}$	0.58*	0.19
	Quick interaction	1.36*	0.07
	Recovered interaction	0.63*	0.11
	Fishing1	-0.08	0.12
	Fishing2	0.07	0.20
Parameter standard Deviations	SD(Price)	1.74*	0.10
	SD(Recovered)	2.00*	0.39
	SD($\Delta Abund_{50}$)	0.41	0.50
	SD(Fishing1)	0.48	0.41
	SD(Fishing2)	0.25	0.87
	SD(ASC)	10.00*	1.43
College interaction	College interaction	0.65*	0.21
	SD(College interaction)	0.06	0.51
	Log-likelihood	-2020.59	

Note: * indicates $p < 0.05$.

Table 3. Estimates of Dynamic WTP Parameters

	$\hat{r}$ (discount rate)	$\hat{b}_{\text{No College}}$ (per 100,000 fish gained)	$\hat{b}_{\text{No College}}$ (per 100,000 fish gained)
Estimate (median)	0.021	$7.83	$19.09
(95% CI)	(.0132, 0.0274)	($1.47, $20.20)	($8.71, $34.29)