Calculations Regarding Wild-Animal Suffering

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Abstract

Utilitarian animal welfarists generally assume that animal lives in the wild are worth living and that we ought to preserve the environment in order to make such lives possible. In this paper, I argue that the lives of most animals in the wild are not worth living and that habitat reduction may sometimes increase net wild-animal utility.

I first develop a model for the change in wild-animal expected aggregated utility that results from a given environmental impact. I then apply it to three scenarios and demonstrate that in most cases, environmental destruction has net benefits—even when the animals are mildly happy during most of their lives. (Specifically, in several of the examples, ecological demolition is good as long as the positive aggregated utility of living for a week is less than, roughly, $\frac{1}{3}$ to $\frac{1}{10}$ the magnitude of the pain of experiencing death.)

1 About this piece

I wrote this paper in summer 2006 at age 19, during the evenings and weekends while I was interning with my Congressman's office in Washington, DC. While I had been thinking about the problem of wild-animal suffering since learning that animals were sentient in summer 2005, this paper represented my first main attempt at calculating how anthropogenic environmental changes affect wild-animal suffering. Because this paper's formulas are hopelessly over-complicated and unrealistic, I later trimmed the excessive math and converted the piece into something more readable: [67].

Even when I wrote this piece, I knew that my mathematical modeling was probably more a fun exercise than a practical endpoint. I do appreciate the way in which my model highlights relevant variables to look out for. But its ecological assumptions are so simplified that my conclusions are unlikely to be terribly realistic. Often practical data invalidates what you thought would be the case using your model. Of course, data can be noisy too, so some balance between theory and data is best.

But if you're going to develop a model, you should make it simple. Probably the signal of what my formulas in this piece express could be mostly captured with a vastly more compact expression. Simplicity improves transparency and computational efficiency. Several simplified models making different assumptions would be much more informative than an ugly expression that no one can interpret, and using many models would help in analyzing sensitivity to specific assumptions.

I hope ecologists attempt more serious calculations of wild-animal suffering using standard ecological models. Consider this piece a baby shower for the field of welfare biology [53]. I feel that I've since developed more refined views on some of the issues discussed in this piece, as explained elsewhere on `http://utilitarian-essays.com/` .

The remainder of this article is my original text from 2006 with some modifications made on 3 Aug. 2014. I don't now agree with all the assumptions in this essay, but I've left most of them alone so that this piece can serve as a time capsule into history.

—Brian Tomasik, 3 Aug. 2014

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2 Preface

I write this paper in the spirit of exploration. I do not pretend to be an expert on any of the topics that I discuss, nor do I claim that my analysis is definitive. Rather, I hope to provoke discussion on what seem to me some highly important but largely overlooked issues.

> If you would be a real seeker after truth, it is necessary that at least once in your life you doubt, as far as possible, all things.
>
> —Rene Descartes [60]

3 Introduction

Most animal welfarists consider themselves environmentalists [50]. Many writers have pointed out the natural alliance that should exist between environmentalists and animal welfarists [38, 23]. Environmentalists should welcome the substantial ecological benefits of vegetarianism [49, 70, 21, 42], while animal welfarists should (it is assumed) support preservation of habitat for wild animals. And larger animal-welfare groups—despite some recurrent conflicts with environmentalists [48]—have helped to support environmental policies, including the California Desert Protection Act, the Endangered Species Act [50], and preservation of the Arctic National Wildlife Refuge [62].

Yet, many authors have noted a fundamental divide between the two camps. In a 1980 essay, J. Baird Callicott asserted that "the value commitments of the humane movement seem at bottom to betray a world-denying or rather a life-loathing philosophy" [12, p. 31]. If animal welfarists regret the violence and brutality of the natural world—so the argument goes—then they reject nature itself. Indeed, Ned Hettinger argues that "Respecting nature means respecting the ways in which nature trades values, and such respect includes painful killings for the purpose of life support" [28, pp. 13-14].

Usually, animal welfarists have responded that intervention in nature does not follow from moral concern for animals.[1] The *Animal Ethics Encyclopedia* has this to say:

> The only way predation could stop is if humans killed off all predators. It may seem silly to want to kill off all predators, or even try. But up to the 1970's people were doing just this. Many populations of predators were trapped, poisoned or shot all over the world. Wolves, for instance were destroyed in the hundreds of thousands from almost all the US. [. . .]
>
> So what happens when people kill off all predators. The numbers of prey animals increase dramatically in their absence. Huge numbers of prey animals eat all their food and then starve to death in the resulting famine. A few animals survive, however, and their population and vegetation recover. But then the cycle keeps repeating itself. So killing off predators increases suffering. [. . .]
>
> [P]redation is actually necessary for life because nature can only work when one thing eats another. Nature is a cycle of life and death and we have no alternative but to accept that. [56]

Of course, we do have an alternative: reduce nature itself. None of these authors mentioned that possibility because they maintained the implicit assumption

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[1] There are some notable exceptions to this, such as [61, 52, 24, 14].

that, on balance, it's good for animals to live in the wild. In this paper, I question that assumption.

4 A Utilitarian Framework for Analysis

Definition: An *organism* $\omega(t)$ is any unified collection of matter that exists at time t. The set of all disjoint organisms at t is $\Omega(t)$.

Examples of organisms: Rocks, trees, camels, stars, computers, people, and bacteria.

Definition: $\Pi_{\omega(t)}$ is the probability that a given $\omega(t) \in \Omega(t)$ is sentient.

Examples:

- $\Pi_{\omega(t)} \approx 1$ for the following types of $\omega(t)$s: people, monkeys, cows, chickens, blue jays, and (potentially) computers of the future [39].
- $\Pi_{\omega(t)} \approx 0$ for the following types of $\omega(t)$s: amoebas, bacteria, trees, flowers, rocks, water molecules, air molecules, and computers of the present.

Definition: *Aggregated utility*, U, is the expected-value sum total of the utility in the universe over all time, where utility is counted equally regardless of which organism happens to experience it or when it happens to be experienced. The unit is the *util*.

$$U := \int_{-\infty}^{\infty} \left(\sum_{\omega(t) \in \Omega(t)} \Pi_{\omega(t)} u\big(\omega(t)\big) \right) dt, \tag{1}$$

where $u\big(\omega(t)\big)$ is the utility that $\omega(t)$ would experience if it were sentient.

Assumption: U is finite. This assumption requires the following conditions, C:

- C_1: $\Pi_{\omega(t)} u\big(\omega(t)\big)$ is never infinite,
- C_2: $\Pi_{\omega(t)} u\big(\omega(t)\big)$ is never nonzero for an infinite number of $\omega(t)$s, and
- C_3: $\sum_{\omega(t) \in \Omega(t)} \Pi_{\omega(t)} u\big(\omega(t)\big)$ is never nonzero for an infinite time.

C_1 is true so long as there's no such thing as an infinitely strong preference. C_2 and C_3 present more serious difficulties that will not be addressed here [8].

Definition: *Utilitarianism* is an ethical doctrine whose goal is to maximize U.

Definition: $_I$ refers to the state of the universe given a certain environmental impact I. $_{\neg I}$ refers to the counterfactual universe in which I didn't occur.

Examples: I might be, for instance,

- an asteroid impact
- slashing and burning of the rainforest
- farming on grassland.

Definition: The change in U that is due to I is simply

$$\Delta U(I) := U_I - U_{\neg I}. \tag{2}$$

Definition: (1) treated time as a continuous variable. Henceforth, however, I divide up time into discrete periods of equal length. I call these intervals "weeks," but really any intervals would do, and I'll change the units according to specific circumstances.

Definition: $t = 0$, also denoted by $_0$, represents the time when I begins. Thus, $t = 1$ or $_1$ represents something that happens one week after I.

Definition: $t = T$ represents the time at which I ceases to impact U. By Assumption 3.1, T must be finite (for if it weren't, U_I and/or $U_{\neg I}$ would be infinite).

Definition: Let N be the component of U that is not affected by whether I or $\neg I$ is the case. N includes all utility that existed before I took place, as well as all utility that will exist after T. In fact, N includes at least all utility outside of I's future light cone up to T.

Definition: Let E be the component of U on which I *does* have an effect.

$$\begin{aligned} U_I &\equiv N_I + E_I; \\ U_{\neg I} &\equiv N_{\neg I} + E_{\neg I}. \end{aligned} \tag{3}$$

Identity: Since $N_I \equiv N_{\neg I}$, (2) becomes

$$\Delta U(I) \equiv E_I - E_{\neg I}. \tag{4}$$

Definition: A *species* σ is any arbitrary set of organisms.[2] Σ is the set of all species that have ever and will ever exist. Σ includes all species that would exist under I *and* under $\neg I$, so it's possible that not all of the members of Σ will actually have existed.

Example: Perhaps $\sigma_1 = \{\text{field mice}\}$, $\sigma_2 = \{\text{humans}\}$, and $\sigma_3 = \{\text{Tyrannosaurus rex}\}$. $\Sigma = \{\sigma_1, \sigma_2, \sigma_3, \ldots\}$.

Definition: Only a subset of Σ will be affected by a given I.[3] Moreover, I will not necessarily affect all of the members of every σ that is impacted. For each $\sigma \in \Sigma$, let $a \subseteq \sigma$ represent the set of only those members of σ that are affected by I. Similarly, let $A \subseteq \Sigma$ represent the set of only those species that are affected by I.

Definition: E_a is the component of E due to organisms in a. Thus,

$$E \equiv \sum_{a \in A} E_a. \tag{5}$$

Definition: $E_a(t)$ is the component of E_a that the members of a experience at t.

$$E_a \equiv \sum_{t=0}^{T} E_a(t). \tag{6}$$

Definition: Divide $E_a(t)$ into three exhaustive components:

$$E_a(t) \equiv L_a(t) + D_a(t) + K_a(t). \tag{7}$$

- $L_a(t)$ represents the aggregated utility that the members of a experience due to regular living at t.

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[2] For convenience, we might say that, *e.g.*, elephants constitute one species while giraffes constitute another, but this classification is actually immaterial. Indeed, for some organisms (such as, potentially, sentient computers of the future), the standard biological definitions will no longer apply.

[3] The dinosaurs, for instance, will not be affected by drilling in the Arctic National Wildlife Refuge.

- $D_a(t)$ is the (presumably negative) aggregated utility experienced by those members of a that die at t for any reason other than the direct impact of I.
- $K_a(t)$ is the (presumably negative) aggregated utility experienced by those members of a that are killed directly by I at t. $(K_a(t))_{\neg I} := 0$.

Example: Suppose that $a = \{\text{squirrels}\}$. I is a falling boulder that lands on top of several squirrels at $t = 0$, causing -500 utils. Another group of squirrels simultaneously dies of natural causes with pain of -700 utils. Here, $(K_a(0))_I = -500$ and $(D_a(0))_I = -700$.

If the boulder had not fallen, all of the squirrels that it crushed would have been eaten by a gnome at $t = 0$, with the same painfulness of death. Now,

$$\begin{aligned}(D_a(0))_{\neg I} =& -500 \text{ [from the gnome]} + \\ & -700 \text{ [from the other squirrels that died]} \\ =& -1,200.\end{aligned}$$

$(K_a(0))_{\neg I} = 0$ because $(K_a(t))_{\neg I} := 0\ \forall t$.

Definition: $p_a(t)$ represents the population of a at t.

Definition: $b_a(t)$ is the number of births of members of a at t. $d_a(t)$ is the number of deaths of members of a at t from any cause other than the direct impact of I. $k_a(t)$ is the number of members of a killed by the direct impact of I.

Definition:

$$\begin{aligned}\overline{L_a}(t) &:= \begin{cases}\frac{L_a(t)}{p_a(t)} & \text{if } p_a(t) \neq 0,\\ 0 & \text{if } p_a(t) = 0.\end{cases}\\ \overline{D_a}(t) &:= \begin{cases}\frac{D_a(t)}{d_a(t)} & \text{if } d_a(t) \neq 0,\\ 0 & \text{if } d_a(t) = 0.\end{cases}\\ \overline{K_a}(t) &:= \begin{cases}\frac{K_a(t)}{k_a(t)} & \text{if } k_a(t) \neq 0,\\ 0 & \text{if } k_a(t) = 0.\end{cases}\end{aligned} \tag{8}$$

By definition of $(K_a(t))_{\neg I}, (\overline{K_a}(t))_{\neg I} \equiv 0$.

Assumption 3.2: $\overline{L_a}(t), \overline{D_a}(t)$, and $\overline{K_a}(t)$ are constant functions of t. That is, $\forall t, \overline{L_a}(t) = \overline{L_a}, \overline{D_a}(t) = \overline{D_a}$, and $\overline{K_a}(t) = \overline{K_a}$.

Identity: Combining (6), (7), and (8),

$$E_a \equiv \sum_{t=0}^{T} \Big(\overline{L_a} p_a(t) + \overline{D_a} d_a(t) + \overline{K_a} k_a(t) \Big). \tag{9}$$

Identity: Combining (4), (5), and (9),

$$\begin{aligned}\Delta U(I) \equiv & \left(\sum_{a \in A} \left(\sum_{t=0}^{T} \Big(\overline{L_a} p_a(t) + \overline{D_a} d_a(t) + \overline{K_a} k_a(t) \Big) \right) \right)_I - \\ & \left(\sum_{a \in A} \left(\sum_{t=0}^{T} \Big(\overline{L_a} p_a(t) + \overline{D_a} d_a(t) \Big) \right) \right)_{\neg I} . \end{aligned} \tag{10}$$

5 A Discrete Model for the Impact of Environmental Changes on Animal Utilities

(10) is true merely by definition. It is general enough that it can describe the change in U that results from *any* event affecting *any* population whatsoever. In this section, I introduce assumptions to make the model more specific for wild animals.

Identity: By the definitions of $b_a(t)$, $d_a(t)$, and $k_a(t)$,

$$p_a(t+1) \equiv p_a(t) + b_a(t) - d_a(t) - k_a(t). \tag{11}$$

Assumption 4.1: The rate of births is proportional to population size, excluding those members of the population that are being killed at t:

$$b_a(t) = f_a\big(p_a(t) - k_a(t)\big) \tag{12}$$

for some constant f_a.

Assumption 4.2: The rate of natural deaths is partially proportional to population size, excluding those members of the population that are already being killed by I. It is also partially proportional to the difference between the current population size and the carrying capacity $c(t)$ of the habitat at t. Thus,

$$d_a(t) = g_a\big(p_a(t) - k_a(t)\big) + h_a\big(p_a(t) - c_a(t)\big) \tag{13}$$

for some constants g_a and h_a. When the population is below its carrying capacity, resources are more plentiful and fewer young animals die from scarcity.

Presumably $0 < g_a < 1$ and $0 < h_a < 1$.

Assumption 4.3: When a is at its carrying capacity, and when no members of a are being directly killed by I, the population is in equilibrium. That is, when $p_a(t) = c_a(t) \neq 0$ and $k_a(t) = 0$, $p_a(t+1) = p_a(t)$.

Equation: By (11), (12), and (13), $f_a = g_a$ under the conditions of the Assumption 4.3. But since f_a and g_a are constants, f_a always equals g_a, and (11) reduces to

$$p_a(t+1) = p_a(t) + h_a\big(c_a(t) - p_a(t)\big) - k_a(t). \tag{14}$$

Definition: The average lifespan of the members of a is denoted ℓ_a.

Rule: If a population is in equilibrium at t and the rate of deaths at t is constant, then the rate of deaths at t equals $\frac{p_a(t)}{\ell_a}$. To see this, imagine that every member of the population had the exact lifespan ℓ_a. Suppose that a new member of a is born at t, when the population is $p_a(t)$. That member will die in ℓ_a years, at which time exactly all of the $p_a(t)$ members of a that existed before will have died. So $p_a(t)$ members of a die in ℓ_a time units, and since the death rate is constant, it equals $\frac{p_a(t)}{\ell_a}$.

When the conditions of Assumption 4.3 hold, the population is in equilibrium and, by (13), the rate of deaths is constant. Thus,

$$\begin{aligned} d_a(t) &= g_a p_a(t) \quad \text{[by (13) under the conditions of Assumption 4.3]} \\ &= \frac{p_a(t)}{\ell_a} \quad \text{[by the Rule]}, \\ &\text{so that } g_a = \frac{1}{\ell_a}. \blacksquare \end{aligned}$$

Equation: Returning to (9), we can substitute in (13):

$$\begin{aligned} E_a &= \sum_{t=0}^{T}\Big(\overline{L_a}p_a(t) + \overline{D_a}\Big(\frac{1}{\ell_a}\big(p_a(t) - k_a(t)\big) + h_a\big(p_a(t) - c_a(t)\big)\Big) + \overline{K_a}k_a(t)\Big) \\ &\equiv \sum_{t=0}^{T}\Big(p_a(t)\Big(\overline{L_a} + (\frac{1}{\ell_a} + h_a)\overline{D_a}\Big) - c_a(t)h_a\overline{D_a} + k_a(t)\Big(\overline{K_a} - \frac{1}{\ell_a}\overline{D_a}\Big)\Big) \\ &\equiv \Big(\overline{L_a} + (\frac{1}{\ell_a} + h_a)\overline{D_a}\Big)\sum_{t=0}^{T}p_a(t) - h_a\overline{D_a}\sum_{t=0}^{T}c_a(t) + (\overline{K_a} - \frac{1}{\ell_a}\overline{D_a})\sum_{t=0}^{T}k_a(t). \end{aligned} \tag{15}$$

Formula:

$$\begin{aligned} &\forall t \in \mathbb{N},\ p_a(t) = (1-h_a)^t p_a(0) + h_a \mathcal{C}_a(t) - \mathcal{K}_a(t), \\ &\text{where } \mathcal{C}_a(t) := \begin{cases} \sum_{i=0}^{t-1} \Big(c_a(i)(1-h_a)^{(t-1)-i} \Big) & \text{when } t > 0, \\ 0 & \text{when } t = 0, \end{cases} \\ &\text{and } \mathcal{K}_a(t) := \begin{cases} \sum_{j=0}^{t-1} \Big(k_a(j)(1-h_a)^{(t-1)-j} \Big) & \text{when } t > 0, \\ 0 & \text{when } t = 0. \end{cases} \end{aligned} \tag{16}$$

Proof: Proceed by induction.

- Basis steps. When $t = 0$, the left and right sides of (16) both reduce to $p_a(0)$. Similarly, when $t = 1$, (16) gives the same result as does (14) for $p(t+1) = p(1)$.
- Induction hypothesis. Suppose (16) is true for all $t \geq 1$ up to some fixed n.
- Induction step.

$$
\begin{aligned}
p_a(n+1) &= p_a(n) + h_a\big(c_a(n) - p_a(n)\big) - k_a(n) \quad \text{[by (14)]}\\
&\equiv \big(1-h_a\big)p_a(n) + h_a c_a(n) - k_a(n)\\
&= \big(1-h_a\big)\big((1-h_a)^n p_a(0) + h_a\mathcal{C}_a(n) - \mathcal{K}_a(n)\big) + h_a c_a(n) - k_a(n)\\
&\quad \text{[by the induction hypothesis]}\\
&\equiv (1-h_a)^{n+1}p_a(0) + h_a\big(1-h_a\big)\mathcal{C}_a(n) - \big(1-h_a\big)\mathcal{K}_a(n) + h_a c_a(n) - k_a(n)\\
&\equiv (1-h_a)^{n+1}p_a(0) + h_a\big(1-h_a\big)\sum_{i=0}^{n-1}\Big(c_a(i)(1-h_a)^{(n-1)-i}\Big)\\
&\quad - \big(1-h_a\big)\sum_{j=0}^{n-1}\Big(k_a(j)(1-h_a)^{(n-1)-j}\Big) + h_a c_a(n) - k_a(n)\\
&\quad \text{[these substitutions for } \mathcal{C}_a(n) \text{ and } \mathcal{K}_a(n) \text{ are legitimate because } n \geq 1]\\
&\equiv (1-h_a)^{n+1}p_a(0) + h_a\sum_{i=0}^{n-1}\Big(c_a(i)(1-h_a)^{n-i}\Big)\\
&\quad - \sum_{j=0}^{n-1}\Big(k_a(j)(1-h_a)^{n-j}\Big) + h_a c_a(n) - k_a(n)\\
&\equiv (1-h_a)^{n+1}p_a(0) + h_a\sum_{i=0}^{n-1}\Big(c_a(i)(1-h_a)^{n-i}\Big)\\
&\quad - \sum_{j=0}^{n-1}\Big(k_a(j)(1-h_a)^{n-j}\Big) + h_a c_a(n)(1-h_a)^{n-n} - k_a(n)(1-h_a)^{n-n}\\
&\quad [(1-h_a)^{n-n} = 1; \text{ since } h_a \neq 1 \text{ by Assumption 4.2, this will not yield } 0^0,\\
&\quad \text{which is undefined}]\\
&\equiv (1-h_a)^{n+1}p_a(0) + h_a\sum_{i=0}^{n}\Big(c_a(i)(1-h_a)^{n-i}\Big) - \sum_{j=0}^{n}\Big(k_a(j)(1-h_a)^{n-j}\Big)\\
&\equiv (1-h_a)^{n+1}p_a(0) + h_a\mathcal{C}_a(n+1) - \mathcal{K}_a(n+1). \ \blacksquare
\end{aligned}
$$

Formula: For any geometric series $S := \sum_{u=x}^{y} r^u$ with $x, y, r \in \mathbb{R}$ and $y = k + x$ for some $k \in \mathbb{N}$,

$$
S = \begin{cases}
\frac{r^x - r^{y+1}}{1-r} & \text{when } r \neq 1 \text{ and also } r \neq 0 \text{ with } x \leq 0,\\
y - x + 1 & \text{when } r = 1,\\
\text{complex} & \text{when } r < 0, \text{ and } x \text{ and/or } y \notin \mathbb{Z},\\
\text{undefined} & \text{when } r = 0, \text{ and } x \leq 0.
\end{cases} \tag{17}
$$

Proof: I prove only the first case.

$$\begin{aligned}
S &:= r^x + r^{x+1} + r^{x+2} + \ldots + r^y. \\
rS &\equiv r^{x+1} + r^{x+2} + \ldots + r^y + r^{y+1}. \\
S - rS &\equiv r^x - r^{y+1}. \\
S &\equiv \frac{r^x - r^{y+1}}{1-r}. \blacksquare
\end{aligned}$$

Equation:

$$\begin{aligned}
\sum_{t=0}^{T} p_a(t) &= p_a(0)\sum_{t=0}^{T}(1-h_a)^t + h_a\sum_{t=0}^{T}\mathcal{C}_a(t) - \sum_{t=0}^{T}\mathcal{K}_a(t) \quad \text{[by (16)]} \\
&\equiv p_a(0)\frac{1-(1-h_a)^{T+1}}{h_a} + h_a\sum_{t=0}^{T}\mathcal{C}_a(t) - \sum_{t=0}^{T}\mathcal{K}_a(t) \\
&\quad \text{[using (17) with } r = 1-h_a,\ x = 0, \text{ and } y = T; \\
&\quad \text{Assumption 4.2 assures that } r \text{ is well behaved (}i.e.\text{, not 0 or 1)]} \\
&\equiv p_a(0)\frac{1-(1-h_a)^{T+1}}{h_a} + h_a\sum_{t=1}^{T}\mathcal{C}_a(t) - \sum_{t=1}^{T}\mathcal{K}_a(t) \\
&\quad \text{[since } \mathcal{C}_a(0) := 0 \text{ and } \mathcal{K}_a(0) := 0] \\
&\equiv p_a(0)\frac{1-(1-h_a)^{T+1}}{h_a} + h_a\sum_{t=1}^{T}\sum_{i=0}^{t-1}\Big(c_a(i)(1-h_a)^{(t-1)-i}\Big) \\
&\quad - \sum_{t=1}^{T}\sum_{j=0}^{t-1}\Big(k_a(j)(1-h_a)^{(t-1)-j}\Big) \\
&\quad \text{[by definition of } \mathcal{C}_a(t) \text{ and } \mathcal{K}_a(t) \text{ for } t > 0].
\end{aligned} \tag{18}$$

Definition: $c_a(t)$ changes v times between $t = 1$ and $t = T$. (Thus, there are $v + 1$ different values of $c_a(t)$ in that period.) The value of t at which the θth change of $c_a(t)$ occurs is denoted τ_θ. τ_0 is the time when $t = 1$. $\tau_{v+1} := T$.

Example: $a = \{$tortoises that live on a single island$\}$. I represents the arrival of a vast number of tourists who set up tents all over the island, thereby covering up valuable food and space. The island's carrying capacity is reduced to 200. After 6 weeks, the tourists all leave, taking their tents with them. Now the island can hold 600 tortises. The tortoises take 78 weeks days to recover, after which they're back to business as usual. In this example, $v = 1, \tau_0 = 1, \tau_1 = 6, \tau_2 := T = 78, c_a(\tau_0) = 200$, and $c_a(\tau_1) = 600$.

Definition: $k_a(t)$ changes w times between $t = 1$ and $t = T$. The value of t at which the ϕth change of $k_a(t)$ occurs is denoted τ_ϕ. τ_0 is the time when $t = 1$. $\tau_{w+1} := T$.

Identities:

$$
\begin{aligned}
& h_a \sum_{t=1}^{T} \sum_{i=0}^{t-1} \Big(c_a(i)(1-h_a)^{(t-1)-i} \Big) \\
& \equiv h_a \sum_{\theta=0}^{v} \sum_{t=\tau_\theta}^{\tau_{\theta+1}-1} \sum_{i=0}^{t-1} \Big(c_a(i)(1-h_a)^{(t-1)-i} \Big) \\
& \equiv h_a \sum_{\theta=0}^{v} \left(c_a(\tau_\theta) \sum_{t=\tau_\theta}^{\tau_{\theta+1}-1} \sum_{i=0}^{t-1} (1-h_a)^{(t-1)-i} \right) \\
& \quad [c_a(t) \text{ is constant from } t = \tau_\theta \text{ to } t = \tau_{\theta+1} - 1] \\
& \equiv h_a \sum_{\theta=0}^{v} \left(c_a(\tau_\theta) \sum_{t=\tau_\theta}^{\tau_{\theta+1}-1} \left((1-h_a)^{t-1} \sum_{i=0}^{t-1} \left(\frac{1}{1-h_a} \right)^{i} \right) \right) \\
& \equiv h_a \sum_{\theta=0}^{v} \left(c_a(\tau_\theta) \sum_{t=\tau_\theta}^{\tau_{\theta+1}-1} \left((1-h_a)^{t-1} \left(\frac{1 - \left(\frac{1}{1-h_a}\right)^{t}}{1 - \left(\frac{1}{1-h_a}\right)} \right) \right) \right) \\
& \quad [\text{using } (17) \text{ with } r = \frac{1}{1-h_a},\ x = 0, \text{ and } y = t-1; \\
& \quad \text{Assumption 4.2 assures that } r \text{ is not 0 or 1}] \\
& \equiv h_a \sum_{\theta=0}^{v} \left(c_a(\tau_\theta) \sum_{t=\tau_\theta}^{\tau_{\theta+1}-1} \left((1-h_a)^{t-1} \left(\frac{\left(\frac{1}{1-h_a}\right)^{t-1} + h_a - 1}{h_a} \right) \right) \right) \\
& \equiv h_a \sum_{\theta=0}^{v} \left(c_a(\tau_\theta) \sum_{t=\tau_\theta}^{\tau_{\theta+1}-1} \left(\frac{1}{h_a} \big(1 - (1-h_a)^{t}\big) \right) \right) \\
& \equiv \frac{h_a}{h_a} \sum_{\theta=0}^{v} \left(c_a(\tau_\theta) \sum_{t=\tau_\theta}^{\tau_{\theta+1}-1} \big(1 - (1-h_a)^{t}\big) \right) \\
& \equiv \sum_{\theta=0}^{v} \left(c_a(\tau_\theta) \left(\sum_{t=\tau_\theta}^{\tau_{\theta+1}-1} 1 - \sum_{t=\tau_\theta}^{\tau_{\theta+1}-1} (1-h_a)^{t} \right) \right) \\
& \equiv \sum_{\theta=0}^{v} \left(c_a(\tau_\theta) \left((\tau_{\theta+1} - \tau_\theta) - \left(\frac{(1-h_a)^{\tau_\theta} - (1-h_a)^{\tau_{\theta+1}}}{h_a} \right) \right) \right) \\
& \quad [\text{using } (17) \text{ with } r = 1 - h_a,\ x = \tau_\theta, \text{ and } y = \tau_{\theta+1} - 1; \\
& \quad \text{Assumption 4.2 assures that } r \text{ is not 0 or 1}].
\end{aligned}
\tag{19}
$$

By analogous reasoning,

$$
\begin{aligned}
&-\sum_{t=1}^{T}\sum_{j=0}^{t-1}\Big(k_a(j)(1-h_a)^{(t-1)-j}\Big)\\
&\equiv -\frac{1}{h_a}\sum_{\phi=0}^{w}\left(k_a(\tau_\phi)\left((\tau_{\phi+1}-\tau_\phi)-\Big(\frac{(1-h_a)^{\tau_\phi}-(1-h_a)^{\tau_{\phi+1}}}{h_a}\Big)\right)\right).
\end{aligned}
\tag{20}
$$

Equations: Combining (18), (19), and (20),

$$
\begin{aligned}
\sum_{t=0}^{T} p_a(t) = {}& \frac{1}{h_a}p_a(0) - \frac{1}{h_a}p_a(0)(1-h_a)^{T+1}\\
&+\sum_{\theta=0}^{v}\left(c_a(\tau_\theta)\left((\tau_{\theta+1}-\tau_\theta)-\Big(\frac{(1-h_a)^{\tau_\theta}-(1-h_a)^{\tau_{\theta+1}}}{h_a}\Big)\right)\right)\\
&-\frac{1}{h_a}\sum_{\phi=0}^{w}\left(k_a(\tau_\phi)\left((\tau_{\phi+1}-\tau_\phi)-\Big(\frac{(1-h_a)^{\tau_\phi}-(1-h_a)^{\tau_{\phi+1}}}{h_a}\Big)\right)\right).
\end{aligned}
\tag{21}
$$

I enter (21) into (15):

$$
\begin{aligned}
E_a = &\Big(\overline{L_a} + (\frac{1}{\ell_a} + h_a)\overline{D_a}\Big)\Bigg[\frac{1}{h_a}p_a(0) - \frac{1}{h_a}p_a(0)(1-h_a)^{T+1} \\
&+ \sum_{\theta=0}^{v}\Bigg(c_a(\tau_\theta)\Bigg((\tau_{\theta+1} - \tau_\theta) - \Big(\frac{(1-h_a)^{\tau_\theta} - (1-h_a)^{\tau_{\theta+1}}}{h_a}\Big)\Bigg)\Bigg) \\
&- \frac{1}{h_a}\sum_{\phi=0}^{w}\Bigg(k_a(\tau_\phi)\Bigg((\tau_{\phi+1} - \tau_\phi) - \Big(\frac{(1-h_a)^{\tau_\phi} - (1-h_a)^{\tau_{\phi+1}}}{h_a}\Big)\Bigg)\Bigg)\Bigg] \\
&- h_a\overline{D_a}\sum_{t=0}^{T}c_a(t) + (\overline{K_a} - \frac{1}{\ell_a}\overline{D_a})\sum_{t=0}^{T}k_a(t) \\
\equiv &\Big(\overline{L_a} + (\frac{1}{\ell_a} + h_a)\overline{D_a}\Big)\Bigg[\frac{1}{h_a}p_a(0) - \frac{1}{h_a}p_a(0)(1-h_a)^{T+1} \\
&+ \sum_{\theta=0}^{v}\Bigg(c_a(\tau_\theta)\Bigg((\tau_{\theta+1} - \tau_\theta) - \Big(\frac{(1-h_a)^{\tau_\theta} - (1-h_a)^{\tau_{\theta+1}}}{h_a}\Big)\Bigg)\Bigg) \\
&- \frac{1}{h_a}\sum_{\phi=0}^{w}\Bigg(k_a(\tau_\phi)\Bigg((\tau_{\phi+1} - \tau_\phi) - \Big(\frac{(1-h_a)^{\tau_\phi} - (1-h_a)^{\tau_{\phi+1}}}{h_a}\Big)\Bigg)\Bigg)\Bigg] \\
&- h_a\overline{D_a}\Bigg[c_a(0) + \sum_{\theta=0}^{v}\Bigg(c_a(\tau_\theta)\sum_{t=\tau_\theta}^{\tau_{\theta+1}-1}1\Bigg)\Bigg] + (\overline{K_a} - \frac{1}{\ell_a}\overline{D_a})\Bigg[k_a(0) + \sum_{\phi=0}^{w}\Bigg(k_a(\tau_\phi)\sum_{t=\tau_\phi}^{\tau_{\phi+1}-1}1\Bigg)\Bigg] \\
&\quad \text{[the extra } c_a(0) \text{ and } k_a(0) \text{ terms come from the fact that } \tau_0 := 1\text{, not } 0] \\
\equiv &\Big(\overline{L_a} + (\frac{1}{\ell_a} + h_a)\overline{D_a}\Big)\Bigg[\frac{1}{h_a}p_a(0) - \frac{1}{h_a}p_a(0)(1-h_a)^{T+1} \\
&+ \sum_{\theta=0}^{v}\Bigg(c_a(\tau_\theta)\Bigg((\tau_{\theta+1} - \tau_\theta) - \Big(\frac{(1-h_a)^{\tau_\theta} - (1-h_a)^{\tau_{\theta+1}}}{h_a}\Big)\Bigg)\Bigg) \\
&- \frac{1}{h_a}\sum_{\phi=0}^{w}\Bigg(k_a(\tau_\phi)\Bigg((\tau_{\phi+1} - \tau_\phi) - \Big(\frac{(1-h_a)^{\tau_\phi} - (1-h_a)^{\tau_{\phi+1}}}{h_a}\Big)\Bigg)\Bigg)\Bigg] \\
&- h_a\overline{D_a}c_a(0) - h_a\overline{D_a}\sum_{\theta=0}^{v}\Big(c_a(\tau_\theta)\big(\tau_{\theta+1} - \tau_\theta\big)\Big) \\
&+ (\overline{K_a} - \frac{1}{\ell_a}\overline{D_a})k_a(0) + (\overline{K_a} - \frac{1}{\ell_a}\overline{D_a})\sum_{\phi=0}^{w}\Big(k_a(\tau_\phi)\big(\tau_{\phi+1} - \tau_\phi\big)\Big)
\end{aligned}
\tag{22}
$$

$$
\begin{aligned}
&\equiv \Bigl(\frac{\overline{L_a} + (\frac{1}{\ell_a} + h_a)\overline{D_a}}{h_a}\Bigr)\Biggl[p_a(0) - p_a(0)(1-h_a)^{T+1} - \sum_{\theta=0}^{v}\Biggl(c_a(\tau_\theta)\Bigl((1-h_a)^{\tau_\theta} - (1-h_a)^{\tau_{\theta+1}}\Bigr)\Biggr) \\
&+ \frac{1}{h_a}\sum_{\phi=0}^{w}\Biggl(k_a(\tau_\phi)\Bigl((1-h_a)^{\tau_\phi} - (1-h_a)^{\tau_{\phi+1}}\Bigr)\Biggr)\Biggr] \\
&- h_a\overline{D_a}c_a(0) + (\overline{L_a} + \frac{1}{\ell_a}\overline{D_a})\sum_{\theta=0}^{v}\Bigl(c_a(\tau_\theta)\bigl(\tau_{\theta+1} - \tau_\theta\bigr)\Bigr) \\
&+ (\overline{K_a} - \frac{1}{\ell_a}\overline{D_a})k_a(0) + \Bigl(\overline{K_a} - \frac{1}{\ell_a}\overline{D_a} - \frac{\overline{L_a}}{h_a} - \frac{\frac{1}{\ell_a}\overline{D_a}}{h_a} - \overline{D_a}\Bigr)\sum_{\phi=0}^{w}\Bigl(k_a(\tau_\phi)\bigl(\tau_{\phi+1} - \tau_\phi\bigr)\Bigr)
\end{aligned}
$$

Substituting (22) into (5),

$$
\begin{aligned}
E = \sum_{a\in A}\Biggl[&\Bigl(\frac{\overline{L_a} + (\frac{1}{\ell_a} + h_a)\overline{D_a}}{h_a}\Bigr)\Biggl[p_a(0) - p_a(0)(1-h_a)^{T+1} \\
&- \sum_{\theta=0}^{v}\Biggl(c_a(\tau_\theta)\Bigl((1-h_a)^{\tau_\theta} - (1-h_a)^{\tau_{\theta+1}}\Bigr)\Biggr) + \frac{1}{h_a}\sum_{\phi=0}^{w}\Biggl(k_a(\tau_\phi)\Bigl((1-h_a)^{\tau_\phi} - (1-h_a)^{\tau_{\phi+1}}\Bigr)\Biggr)\Biggr] \\
&- h_a\overline{D_a}c_a(0) + (\overline{L_a} + \frac{1}{\ell_a}\overline{D_a})\sum_{\theta=0}^{v}\Bigl(c_a(\tau_\theta)\bigl(\tau_{\theta+1} - \tau_\theta\bigr)\Bigr) \\
&+ (\overline{K_a} - \frac{1}{\ell_a}\overline{D_a})k_a(0) + \Bigl(\overline{K_a} - \frac{1}{\ell_a}\overline{D_a} - \frac{\overline{L_a}}{h_a} - \frac{\frac{1}{\ell_a}\overline{D_a}}{h_a} - \overline{D_a}\Bigr)\sum_{\phi=0}^{w}\Bigl(k_a(\tau_\phi)\bigl(\tau_{\phi+1} - \tau_\phi\bigr)\Bigr)\Biggr].
\end{aligned}
\tag{23}
$$

Finally, I add (23) to (4), noting that under $\neg I, k_a(t) := 0 \ \forall t \in \mathbb{N}$:

$$
\begin{aligned}
\Delta U(I) = \Bigg[\sum_{a \in A} \Bigg[\Big(\frac{\overline{L_a} + (\frac{1}{\ell_a} + h_a)\overline{D_a}}{h_a} \Big) \Bigg[& p_a(0) - p_a(0)(1-h_a)^{T+1} \\
& - \sum_{\theta=0}^{v} \Bigg(c_a(\tau_\theta) \Big((1-h_a)^{\tau_\theta} - (1-h_a)^{\tau_{\theta+1}} \Big) \Bigg) + \frac{1}{h_a} \sum_{\phi=0}^{w} \Bigg(k_a(\tau_\phi) \Big((1-h_a)^{\tau_\phi} - (1-h_a)^{\tau_{\phi+1}} \Big) \Bigg) \Bigg] \\
& - h_a \overline{D_a} c_a(0) + (\overline{L_a} + \frac{1}{\ell_a}\overline{D_a}) \sum_{\theta=0}^{v} \Big(c_a(\tau_\theta) \big(\tau_{\theta+1} - \tau_\theta \big) \Big) \\
& + (\overline{K_a} - \frac{1}{\ell_a}\overline{D_a}) k_a(0) + \Big(\overline{K_a} - \frac{1}{\ell_a}\overline{D_a} - \frac{\overline{L_a}}{h_a} - \frac{\frac{1}{\ell_a}\overline{D_a}}{h_a} - \overline{D_a} \Big) \sum_{\phi=0}^{w} \Big(k_a(\tau_\phi) \big(\tau_{\phi+1} - \tau_\phi \big) \Big) \Bigg] \Bigg]_I \\
& - \Bigg[\sum_{a \in A} \Bigg[\Big(\frac{\overline{L_a} + (\frac{1}{\ell_a} + h_a)\overline{D_a}}{h_a} \Big) \Bigg[p_a(0) - p_a(0)(1-h_a)^{T+1} \\
& - \sum_{\theta=0}^{v} \Bigg(c_a(\tau_\theta) \Big((1-h_a)^{\tau_\theta} - (1-h_a)^{\tau_{\theta+1}} \Big) \Bigg) \Bigg] \\
& - h_a \overline{D_a} c_a(0) + (\overline{L_a} + \frac{1}{\ell_a}\overline{D_a}) \sum_{\theta=0}^{v} \Big(c_a(\tau_\theta) \big(\tau_{\theta+1} - \tau_\theta \big) \Big) \Bigg] \Bigg]_{\neg I} .
\end{aligned}
\tag{24}
$$

Regardless of what happens *after* I, it's clear that the initial ($t = 0$) populations of the members of A have to be the same. Since h_a and T are also identical under I or $\neg I$, the two appearances of the term $\Bigg[\Big(\frac{\overline{L_a}+(\frac{1}{\ell_a}+h_a)\overline{D_a}}{h_a} \Big) \Bigg[p_a(0) - p_a(0)(1 -$

$h_a)^{T+1}\Big]\Big]$ drop out of (24), leaving:

$$
\begin{aligned}
\Delta U(I) = \Bigg[\sum_{a\in A}\Bigg[&\Big(\frac{\overline{L_a} + (\frac{1}{\ell_a} + h_a)\overline{D_a}}{h_a}\Big)\Bigg[-\sum_{\theta=0}^{v}\Big(c_a(\tau_\theta)\big((1-h_a)^{\tau_\theta} - (1-h_a)^{\tau_{\theta+1}}\big)\Big)\\
&+ \frac{1}{h_a}\sum_{\phi=0}^{w}\Big(k_a(\tau_\phi)\big((1-h_a)^{\tau_\phi} - (1-h_a)^{\tau_{\phi+1}}\big)\Big)\Bigg]\\
&- h_a\overline{D_a}c_a(0) + (\overline{L_a} + \frac{1}{\ell_a}\overline{D_a})\sum_{\theta=0}^{v}\Big(c_a(\tau_\theta)\big(\tau_{\theta+1} - \tau_\theta\big)\Big)\\
&+ (\overline{K_a} - \frac{1}{\ell_a}\overline{D_a})k_a(0) + \Big(\overline{K_a} - \frac{1}{\ell_a}\overline{D_a} - \frac{\overline{L_a}}{h_a} - \frac{\frac{1}{\ell_a}\overline{D_a}}{h_a} - \overline{D_a}\Big)\sum_{\phi=0}^{w}\Big(k_a(\tau_\phi)\big(\tau_{\phi+1} - \tau_\phi\big)\Big)\Bigg]\Bigg]_I\\
&+ \Bigg[\sum_{a\in A}\Bigg[\Big(\frac{\overline{L_a} + (\frac{1}{\ell_a} + h_a)\overline{D_a}}{h_a}\Big)\sum_{\theta=0}^{v}\Big(c_a(\tau_\theta)\big((1-h_a)^{\tau_\theta} - (1-h_a)^{\tau_{\theta+1}}\big)\Big)\\
&+ h_a\overline{D_a}c_a(0) - (\overline{L_a} + \frac{1}{\ell_a}\overline{D_a})\sum_{\theta=0}^{v}\Big(c_a(\tau_\theta)\big(\tau_{\theta+1} - \tau_\theta\big)\Big)\Bigg]\Bigg]_{\neg I}.
\end{aligned}
\tag{25}
$$

6 Applications: A Preface

In the following 3 sections, I apply (25) to situations that reflect different types of environmental damage. First, however, I discuss some assumptions and definitions.

Assumption 4.4: $\big(\overline{L_a}\big)_I = \big(\overline{L_a}\big)_{\neg I}$, $\big(\overline{D_a}\big)_I = \big(\overline{D_a}\big)_{\neg I}$, and $\big(\overline{K_a}\big)_I = \big(\overline{K_a}\big)_{\neg I}$. This assumption is not necessary in order to use (25), but I maintain it in all of the applications that follow.

Assumption 4.5: $\overline{D_a} < 0$ and $\overline{K_a} < 0$ for any a. Again, (25) does not depend on assuming this; it is merely more convenient (and no less accurate) to do so.

Definition: The following is what I refer to as the "harmonization procedure." Suppose we enter into (25) all parameters except $\overline{L_a}$, $\overline{D_a}$, and $\overline{K_a}$, and we end up with this equation:

$$\Delta U(I) = -9\overline{L_1} - 30\overline{L_2} - 6\overline{D_1} - 3\overline{D_2} + 5\overline{K_2}. \tag{26}$$

To simplify further, it's easiest just to reexpress some of the parameters in terms of the others. For instance, perhaps we can say that, in general, living for a unit time as species 2 is only half as intense as living for a unit time as species 1: $\overline{L_2} = \frac{1}{2}\overline{L_1}$. Maybe we could also say that the pain of dying is the same for 1 and 2 [$\overline{D_1} = \overline{D_2}$], while the pain of being killed directly by I is only $\frac{3}{5}$ as bad as dying naturally [$\overline{K_2} = \frac{3}{5}\overline{D_2} = \frac{3}{5}\overline{D_1}$]. Now,

$$\begin{aligned}\Delta U(I) &= -9\overline{L_1} - 15\overline{L_1} - 6\overline{D_1} - 3\overline{D_1} + 3\overline{D_1} \\ &= -24\overline{L_1} - 6\overline{D_1}.\end{aligned} \tag{27}$$

Definition:

$$\gamma_a := \frac{\overline{L_a}}{\mid \overline{D_a} \mid} = -\frac{\overline{L_a}}{\overline{D_a}} \quad \text{[since } \overline{D_a} < 0 \text{ by Assumption 4.5],} \tag{28}$$

or, if only $\overline{L_a}$ and $\overline{K_a}$ remain in the equation,

$$\gamma_a := \frac{\overline{L_a}}{\mid \overline{K_a} \mid} = -\frac{\overline{L_a}}{\overline{K_a}} \quad \text{[since } \overline{K_a} < 0 \text{ by Assumption 4.5].} \tag{29}$$

Now (27) becomes

$$\Delta U(I) = (24\gamma_1 - 6)\overline{D_1}. \tag{30}$$

Suppose we want to answer the question, When does I make a net positive impact? That is, when is $\Delta U(I) > 0$? Since $\overline{D_1} < 0$, $\Delta U(I) > 0 \Leftrightarrow 24\gamma_1 - 6 < 0 \Leftrightarrow \gamma_1 < \frac{1}{4}$.

Note: In what follows, I have not adhered to the rules of significant figures. Inasmuch as many of my numbers are made up entirely (so that not even the *first* digit is necessarily accurate), I did not find it necessary to do so.

7 Application 1: Asteroid Impact

7.1 Introduction

Suppose the planet Ybux is inhabited solely by the Wibbles—creatures that are "three foot tall, [and have] long brown shaggy fur, three eyes (one in back of head, two in front), three dear little legs, a beak, and a ten-foot long retractable green tentacle coming out the top ot the head" [29]. [$a = \{\text{Wibbles on Ybux}\}$; $A = \{\{\text{Wibbles on Ybux}\}\}$.] The scarce resources of Ybux allow for a carrying capacity of only 500 [$\big(c_a(t)\big)_{\neg I} = 500 \ \forall t \in \{1, 2, \ldots, T\}$]. Wibbles have an average lifespan between 2 and 12 years [assume it's 5, so that $\frac{1}{\ell_a} = 0.2$].

At $t = 0$, an asteroid [event I] smashes into Ybux, landing on top of 50 Wibbles [$k_a(0) = 50$]. The asteroid impact sends up a cloud of debris so massive that all star light to Ybux is blocked, and the planet's carrying capacity immediately drops to 0 [$\big(c_a(0)\big)_I = 0$]. The debris is so thick that the carrying capacity of Ybux will remain 0 indefinitely [$\big(c_a(t)\big)_I = 0 \ \forall t \in \{1, 2, \ldots, T\}$]. This loss of carrying capacity causes $\frac{1}{2}$ of the remaining Wibbles to die each year, in addition to those that would have died naturally [$h_a = 0.5$].

What would have happened to the Wibbles had the asteroid not struck? They would have continued living for another 10,000 years [$T = 10,000$], after which Ybux would have been blown up by the brutal Fnords [29]. The carrying capacity of the planet would have remained at 500 until that time [$\big(c_a(t)\big)_{\neg I} = 500 \ \forall t \in \{1, 2, \ldots, T\}$].

7.2 Plug and Chug

$$
\begin{aligned}
\Delta U(I) = {} & \Bigg[\Big(\frac{\overline{L_a} + (0.2 + 0.5)\overline{D_a}}{0.5}\Big)\Bigg[-\sum_{\theta=0}^{0}\Bigg((0)\Big((1-0.5)^1 - (1-0.5)^{10{,}000}\Big)\Bigg) \\
& + \frac{1}{0.5}\sum_{\phi=0}^{0}\Bigg((0)\Big((1-0.5)^1 - (1-0.5)^{10{,}000}\Big)\Bigg)\Bigg] \\
& - 0.5\overline{D_a}(0) + (\overline{L_a} + 0.2\overline{D_a})\sum_{\theta=0}^{0}\Big((0)\big(10{,}000 - 1\big)\Big) \\
& + (\overline{K_a} - 0.2\overline{D_a})(50) + \Big(\overline{K_a} - 0.2\overline{D_a} - \frac{\overline{L_a}}{0.5} - \frac{0.2\overline{D_a}}{0.5} - \overline{D_a}\Big)\sum_{\phi=0}^{0}\Big((0)\big(10{,}000 - 1\big)\Big)\Bigg]_I \\
& + \Bigg[\Big(\frac{\overline{L_a} + (0.2 + 0.5)\overline{D_a}}{0.5}\Big)\sum_{\theta=0}^{0}\Bigg(500\Big((1-0.5)^1 - (1-0.5)^{10{,}000}\Big)\Bigg) \\
& + 0.5\overline{D_a}(500) - (\overline{L_a} + 0.2\overline{D_a})\sum_{\theta=0}^{0}\Big(500\big(10{,}000 - 1\big)\Big)\Bigg]_{\neg I} \\
& \equiv (\overline{K_a} - 0.2\overline{D_a})(50) + \Big(\frac{\overline{L_a} + (0.2 + 0.5)\overline{D_a}}{0.5}\Big)\sum_{\theta=0}^{0}\Bigg(500\Big((1-0.5)^1 - (1-0.5)^{10{,}000}\Big)\Bigg) \\
& + 0.5\overline{D_a}(500) - (\overline{L_a} + 0.2\overline{D_a})\sum_{\theta=0}^{0}\Big(500\big(10{,}000 - 1\big)\Big) \\
& = -4{,}999{,}000\overline{L_a} - 999{,}310\overline{D_a} + 50\overline{K_a}.
\end{aligned}
\tag{31}
$$

7.3 Results

Assume that the 50 Wibbles killed by the asteroid were crushed instantaneously, so that $\overline{K_a} = 0$. Then, $\Delta U(I) = -4,999,000\overline{L_a} - 999,310\overline{D_a}$, and I made a positive impact iff $\gamma_a < 0.1999$. That is, if the average utility of life per year for the Wibbles was anything less than $\frac{1}{5}$th as good as the pain of death was bad, then the asteroid made a positive impact on Ybux. Clearly, if life itself was not worth living, then the asteroid was only beneficial.

8 Application 2: Road Kill

8.1 Overview

Let I denote the collective slaughter of animals for one year by direct road kill only.[4] Divide time into weeks. Assuming road kill has no significant long-term impact, $T = 52$. I focus just on mammals, birds, reptiles, and amphibians hit by cars, the collection of which I denote by underscore 1: $_1$. I exclude consideration of insects despite their massive numbers of roadkill deaths.

8.2 Constant Carrying Capacity

Unlike the previous situations, I in this case does not seem to lower carrying capacity. The environment around roads can support pretty much the same number of animals whether cars drive by or not; thus, I assume that $\big(c_1(\tau_\theta)\big)_I = \big(c_1(\tau_\theta)\big)_{\neg I}$ $\forall \theta \in \{0, 1, \ldots, v\}$. This, in fact, causes most of the terms of (25) to drop out, leaving:

$$\begin{aligned}\Delta U_1(I) = \Bigg[&\Big(\frac{\overline{L_1} + (\frac{1}{\ell_1} + h_1)\overline{D_1}}{h_1}\Big) \Bigg[\frac{1}{h_1} \sum_{\phi=0}^{w} \Bigg(k_1(\tau_\phi) \Big((1-h_1)^{\tau_\phi} - (1-h_1)^{\tau_{\phi+1}} \Big) \Bigg) \Bigg] \\ &+ (\overline{K_1} - \frac{1}{\ell_1}\overline{D_1}) k_1(0) + \Big(\overline{K_1} - \frac{1}{\ell_1}\overline{D_1} - \frac{\overline{L_1}}{h_1} - \frac{\frac{1}{\ell_1}\overline{D_1}}{h_1} - \overline{D_1} \Big) \sum_{\phi=0}^{w} \Big(k_1(\tau_\phi) \big(\tau_{\phi+1} - \tau_\phi \big) \Big) \Bigg]_I . \end{aligned} \tag{32}$$

8.3 Estimating k_1:

> The roadkill data for 1993 reported 82% mammals, 15% birds, and 3% reptiles and amphibians.

---

[4] Thus, I does not include, for instance, deaths of bats due to scarcity of insects, nor does it count air pollution or global-climate change.

> Merritt Clifton, Editor [of] *Animal People Newspaper*, used the 1993 roadkill statistics and estimated that the following animals are being killed by motor vehicles:
>
> 41 million squirrels
>
> 26 million cats
>
> 22 million rats
>
> 19 million opossums
>
> 15 million raccoons
>
> 6 million dogs
>
> 350,000 deer. [4]

Adding up the death counts from [4] gives $129.35(10^6)$ mammals. Assume that these are all of the animals counted in the "82% mammals" category. Then, there were also $\frac{.15}{.82}\left(129.35(10^6)\right) = 23.66(10^6)$ birds and $4.73(10^6)$ reptiles and amphibians killed.

The total number killed in a year is $157.74(10^6)$, which translates into $3.02(10^6)$ per week $= k_1(0) = k_1(\tau_0)$.

8.4 Estimating h_1:

I have no specific data, but it seems as though animals larger than insects would take considerably longer to fill in empty carrying capacity. Each week, these animals might fill in—just as a wild guess—$\frac{1}{20}$ of their remaining capacity, making $h_1 = 0.05$.

8.5 Estimating ℓ_1:

Type of Animal	Fraction of the Total Number Killed	Lifespan (weeks)
Squirrels	0.26 [4]	313 [9]
Cats	0.16 [4]	209 [13]
Rats	0.14 [4]	52 [37]
Opossums	0.12 [4]	78 [54]
Raccoons	0.10 [4]	183 [46]
Dogs	0.04 [4]	78 [51]
Deer	0.0022 [4]	522 [16]
Birds	0.15 [4]	72 [30]
Reptiles and amphibians	0.03 [4]	$\sim$ 150 [10, 25]
Total	1.00	$\ell_1 \approx 169$

8.6 Plug and Chug

$$\begin{aligned}\Delta U_1(I) = \Bigg[& \Big(\frac{\overline{L_1} + (\frac{1}{\ell_1} + h_1)\overline{D_1}}{h_1}\Big)\Bigg[\frac{1}{h_1}\sum_{\phi=0}^{w}\Bigg(k_1(\tau_\phi)\Big((1-h_1)^{\tau_\phi} - (1-h_1)^{\tau_{\phi+1}}\Big)\Bigg)\Bigg] \\ & + (\overline{K_1} - \frac{1}{\ell_1}\overline{D_1})k_1(0) + \Big(\overline{K_1} - \frac{1}{\ell_1}\overline{D_1} - \frac{\overline{L_1}}{h_1} - \frac{\frac{1}{\ell_1}\overline{D_1}}{h_1} - \overline{D_1}\Big)\sum_{\phi=0}^{w}\Big(k_1(\tau_\phi)\big(\tau_{\phi+1} - \tau_\phi\big)\Big)\Bigg]_I \\ & = \Big(\frac{\overline{L_1} + (\frac{1}{169} + 0.05)\overline{D_1}}{0.05}\Big)\Bigg[\frac{1}{0.05}\sum_{\phi=0}^{0}\Bigg(3.02(10^6)\Big((1-0.05)^1 - (1-0.05)^{52}\Big)\Bigg)\Bigg] \\ & + (\overline{K_1} - \frac{1}{169}\overline{D_1})\big(3.02(10^6)\big) \\ & + \Big(\overline{K_1} - \frac{1}{169}\overline{D_1} - \frac{\overline{L_1}}{0.05} - \frac{\frac{1}{169}\overline{D_1}}{0.05} - \overline{D_1}\Big)\sum_{\phi=0}^{0}\Big(3.02(10^6)\big(52-1\big)\Big) \\ & = \Big(20\overline{L_1} + (\frac{20}{169} + 1)\overline{D_1}\Big)\Big(57.4(10^6)\Big) \\ & + (\overline{K_1} - \frac{1}{169}\overline{D_1})\big(3.02(10^6)\big) + \Big(\overline{K_1} - \frac{1}{169}\overline{D_1} - 20\overline{L_1} - \frac{20}{169}\overline{D_1} - \overline{D_1}\Big)\Big(154.0(10^6)\Big) \\ & = -1,932(10^6)\overline{L_1} - 109(10^6)\overline{D_1} + 157(10^6)\overline{K_1}.\end{aligned} \tag{33}$$

Dying under the wheels of a car is probably slightly less painful than dying in the jaws of a predator or by starvation. I'll assume $\overline{K_1} = \frac{3}{4}\overline{D_1}$, so that (33) becomes:

$$\Delta U_1(I) = -1,932(10^6)\overline{L_1} + 9(10^6)\overline{D_1}. \tag{34}$$

8.7 Results

$\Delta U_1(I) > 0 \Leftrightarrow \gamma_1 < -0.005$. Thus, I can be said to have had an overall adverse impact even if $\overline{L_1}$ is (slightly) negative—specifically, if living for a week is at most $\frac{5}{1000}$ as bad as dying.

9 Application 3: Eating Meat

I represents a single person's decision to eat a standard meat-containing American diet instead of a vegan diet. Let $_1$, $_2$, and $_3$ respectively denote the effects of I on animals in factory farms, mammals and birds in the wild, and insects in the wild.

9.1 Factory-Farmed Animals: $\Delta U_1(I)$

Instead of applying (25), it's easier to calculate $\Delta U_1(I)$ directly. The average American consumes 32 animals per year, each of which had a weighted-average lifespan of 49 days [31, pp. 6-7]. Divide time into units of weeks. Then we have $\Delta U_1(I) = \frac{49}{7}(32)\overline{L_1} + 32\overline{K_1} = 224\overline{L_1} + 32\overline{K_1}$.

In addition, however, Americans eat 304 eggs per year, each of which took 1.04 days to produce [31, p. 7], which translates into 316 days = 45 weeks of laying time.

> It is usually arranged—by manipulating body weight and day length—for laying hens to start laying eggs at approximately 20 weeks of age. They lay eggs for about 1 year, at which point decreasing egg numbers and eggshell quality mean that it is no longer profitable to continue. When the hens are about 74 weeks old, they either are sent for slaughter as spent laying hens or force-molted and kept for a 2nd laying year. The majority of hens are disposed of after this 2nd laying year; a small number of flocks may be force-molted again and kept for a 3rd laying year. No matter how many years they have been in lay, all laying hens are eventually slaughtered as spent laying hens. [19]

From [19], I'll estimate the length for which a hen lays as 2 years = 104 weeks. Then, the 45 weeks of laying to which I contributes imply creation of $\frac{45}{104}$th of a hen. In total, hens live for 104 weeks of laying + 20 weeks before laying = 124 weeks, so I contributes to $\frac{45}{104}(124) = 53$ weeks of life and $\frac{45}{104}$th of a death. Adding this in to $\Delta U_1(I)$:

$$\begin{aligned}\Delta U_1(I) &= (224\overline{L_1} + 32\overline{K_1}) + (53\overline{L_1} + \frac{45}{104}\overline{K_1}) \\ &= 277\overline{L_1} + 32.4\overline{K_1},\end{aligned} \tag{35}$$

where I'm assuming (perhaps inaccurately) that $\overline{L_1}$ and $\overline{K_1}$ are the same for laying hens as for a weighted average of all other farm animals.

$\Delta U_1(I) > 0 \Leftrightarrow \gamma_1 > 0.12$. Presumably, γ_1 is actually highly negative, so there's practically no chance that $\Delta U_1(I) > 0$. This confirms the vegan stance with respect to farm animals.

9.2 Wild Mammals and Birds: $\Delta U_2(I)$

Again, I use a shortcut to (25). [42, p. 586] and sources therein give the data for the following table. For want of space, I write the titles of the columns below.

Animal product	Column 2	Column 3	Column 4
Chicken	4	0.65	6.4
Eggs	12	1.9	1.5
Pork	80	12.5	4.4
Beef	235	36.8	5.9
Milk	14	2.1	7.7

- Column 2 is the additional number of square meters of crop land that would be required to produce a kilogram of protein from the type of animal product in the corresponding row of Column 1 instead of a kilogram of protein from soybeans.
- Column 3 is the additional number of mammal and bird life-weeks that would be prevented by producing a kilogram of protein from the type of animal product in the corresponding row of Column 1 instead of a kilogram of soybeans.
- Column 4 is the annual number of kilograms of protein that the average American consumes from the type of animal product given in the corresponding row of Column 1.

The total of Column 4 is 25.9 kilograms. Assume the vegan would have otherwise eaten this amount of protein in soybeans if she had not switched to a standard-American diet.

Multiply each entry of Column 3 by its corresponding entry of Column 4 and take the sum. The result is 295.3, which represents the total number of mammal and bird life-weeks prevented by I. For simplicity, I'll just assume that these life-weeks would have been lived by $\frac{295.3}{\ell_2}$ mammals and birds that would have had an average lifespan of ℓ_2 weeks.

Squirrels, rats, and deer seem like some representative mammals from the table in section 8.5 that might be supplanted by crop land. If we average the lifespans of these three mammals—weighting in proportion to their representation in road kill—we get 223 weeks. The table's average lifespan for birds was 72 weeks. [42, p. 585] assumes that mammals are 2.25 times as numerous as birds, which gives the following weighted-average value for ℓ_2:

$$\ell_2 = \frac{2.25}{3.25}(223) + \frac{1}{3.25}(72) = 177. \tag{36}$$

Thus, we assume that I prevented $\frac{295.3}{177} = 1.67$ mammal and bird lives (and, therefore, deaths):

$$\Delta U_2(I) = -295.3\overline{L_2} - 1.67\overline{D_2}. \tag{37}$$

$\Delta U_2(I) > 0 \Leftrightarrow \gamma_2 < 0.006$.

9.3 Insects: $\Delta U_3(I)$

I causes some amount of land to be devoted to crops for a year. As I did above, assume that I converts otherwise forest land into crop land for a period of 52 weeks [$T = 52$].

9.3.1 Estimating h_3:

I have no specific data, so I'll just assume $h_2 = 0.33$.

9.3.2 Estimating ℓ_3:

I give lifespans for a number of different types of insects and then estimate a rough middle value.[5]

Type of Insect	Lifespan (weeks)
Horn fly	2 [55]
Trichogramma Wasps	2 [6]
Stable fly	3 [55]
Black fly	~ 3 to ~ 20 [7]
Mosquito	3 to ~ 150 [7]
Damselflies	3 to 4 [36]
Drosophila	6 [64]
Dragonflies	6 to 8 [36]
Green lacewings	12 [6]
Ladybird beetles	48 [6]

Perhaps a (very rough) compromise age is to choose $\ell_3 = 5$ weeks.

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[5] The sources that I used for this table were not specific about whether the "average lifespans" that they reported included the large number of insects that die shortly after birth. I imagine that most of these figures only give the average lifespan of those individuals that make it past the first few days or weeks of age. Thus, these figures may severely *understate* the case for environmental destruction, perhaps by many orders of magnitude.

> Insects are capable of high rates of reproduction. Curtis Sabrosky provided an example in 1952 of the reproductive potential in house flies. Beginning with one pair of house flies in April, there would be a total of 191,000,000,000,000,000,000 flies by August if all the descendants of this pair lived and reproduced normally.
>
> Glenn Herrick found that the cabbage aphid had an average of 41 offspring per female and that the aphid had 16 generations from April to October. If all the descendants of one female aphid lived, there would be 1,560,000,000,000,000,000,000,000 aphids by the end of the summer. [5]

9.3.3 Estimating k_3:

Suppose pesticides are applied four times: once in late April [$t = 17$], once in late May [$t = 22$], once in late June [$t = 26$], and once in late July [$t = 30$]. For each t when pesticides are applied, $k_3(t) = 0.5\big(c_3(t)\big)_I$; *i.e.*, each time pesticides are applied, they kill half of the total number of insects that could live on the crop land.

$w = 8$ with $\tau_0 = 1$, $\tau_1 = 17$, $\tau_2 = 18$, $\tau_3 = 22$, $\tau_4 = 23$, $\tau_5 = 26$, $\tau_6 = 27$, $\tau_7 = 30$, $\tau_8 = 31$, and $\tau_9 := T = 52$. $k_3(\tau_\phi) = 0$ when $\phi = 0$, 2, 4, 6, 8, or 9, and $k_3(\tau_\phi) = 0.5c_3(\tau_\phi)$ when $\phi = 1$, 3, 5, or 7.

9.3.4 Estimating c_3:

Return to the table in 9.2. Multiply each entry of Column 2 by its corresponding entry in Column 4 and take the sum. The result, 1,890, is the number of square meters of land that are cultivated due to I.

When there isn't snow on the ground, forest land has an insect[6] density of 105,000 per square meter [5]. During the winter, this number might be—just as a guess—half as much. Suppose there's snow on the ground for 4 months out of the year. Then, a weighted-average value for the number of insects per square meter of forest is $\frac{4}{12}(0.5)(105,000) + \frac{8}{12}(105,000) = 87,500$. Multiplying by 1,890—the total number of square meters being considered—gives $1.65(10^8)$ $= c_3^{\text{forest}}$, the carrying capacity of the given land area when the land is forest land. Similarly let c_3^{crop} represent the number of insects that the given area of land could hold as crop land.[7]

$$\beta := \frac{c_3^{\text{crop}}}{c_3^{\text{forest}}}. \tag{38}$$

I'll try two different values of β. The first, $\beta = 1$, is a default assumption, while the second, $\beta = 0.5$ is probably more accurate. I say this because, intuitively, the ground of a forest is littered with decaying organic material for decomposition, while farm land—even when no pesticides are applied (the relevant condition for considering carrying capacity)—is more dry and barren.

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[6] Actually, the density I cite here refers to "arthropods." The density of actual insects is only a fraction of this amount. I use the label "insects" as a more familiar term by which to refer to arthropods as a whole.

[7] Note that $c_3^{\text{forest}} := (c_3)_{\neg I}$ and $c_3^{\text{crop}} := (c_3)_I$.

9.3.5 When $\beta = 1$

The carrying capacities under I and $\neg I$ are the same, so that (25) reduces to the familiar (32):

$$\begin{aligned}
\Delta U_3(I) = \Bigg[&\Big(\frac{\overline{L_3}^S + (\frac{1}{\ell_3} + 0.33)\overline{D_3}^S}{0.33}\Big)\left[\frac{1}{0.33}\sum_{\phi=0}^{w}\left(k_3(\tau_\phi)\Big((1-0.33)^{\tau_\phi} - (1-0.33)^{\tau_{\phi+1}}\Big)\right)\right] \\
&+ (\overline{K_3}^S - \frac{1}{\ell_3}\overline{D_3}^S)k_3(0) + \Big(\overline{K_3}^S - \frac{1}{\ell_3}\overline{D_3}^S - \frac{\overline{L_3}^S}{0.33} - \frac{\frac{1}{\ell_3}\overline{D_3}^S}{0.33} - \overline{D_3}^S\Big)\sum_{\phi=0}^{w}\Big(k_3(\tau_\phi)\big(\tau_{\phi+1} - \tau_\phi\big)\Big)\Bigg]_I \\
&= \Big(\frac{\overline{L_3}^S + (\frac{1}{5} + 0.33)\overline{D_3}^S}{0.33}\Big)\left[\frac{1}{0.33}\sum_{\phi=0}^{8}\left(k_3(\tau_\phi)\Big((1-0.33)^{\tau_\phi} - (1-0.33)^{\tau_{\phi+1}}\Big)\right)\right] \\
&+ (\overline{K_3}^S - \frac{1}{5}\overline{D_3}^S)(0) + \Big(\overline{K_3}^S - \frac{1}{5}\overline{D_3}^S - \frac{\overline{L_3}^S}{0.33} - \frac{\frac{1}{5}\overline{D_3}^S}{0.33} - \overline{D_3}^S\Big)\sum_{\phi=0}^{8}\Big(k_3(\tau_\phi)\big(\tau_{\phi+1} - \tau_\phi\big)\Big) \\
&= \Big(3\overline{L_3}^S + 1.6\overline{D_3}^S\Big)\Big(6.39(10^{-4})c_3^{\text{crop}}\Big) \\
&+ \Big(\overline{K_3}^S - \frac{1}{5}\overline{D_3}^S - 3\overline{L_3}^S - 0.6\overline{D_3}^S - \overline{D_3}^S\Big)\big(51c_3^{\text{crop}}\big).
\end{aligned} \tag{39}$$

In this case, $c_3^{\text{crop}} = c_3^{\text{forest}} = 1.65(10^8)$, so that (39) becomes

$$\Delta U_3(I) = -252(10^8)\overline{L_3}^S - 151(10^8)\overline{D_3}^S + 84(10^8)\overline{K_3}^S. \tag{40}$$

Finally, discounting by $\Pi_3 = 0.001$,

$$\Delta U_3(I) = -252(10^5)\overline{L_3} - 151(10^5)\overline{D_3} + 84(10^5)\overline{K_3}. \tag{41}$$

9.3.6 When $\beta = 0.5$

This time, we have to use (25) because $(c_3)_I \neq (c_3)_{\neg I}$. But part of the work we've already done, in the form of (39); the only difference this time is that $c_3^{\text{crop}} = 0.5c_3^{\text{forest}}$. All we need to do for this portion of the equation is to multiply the right-hand side of (41) by 0.5:

$$\text{First part of } \Delta U_3(I) = -126(10^5)\overline{L_3} - 76(10^5)\overline{D_3} + 42(10^5)\overline{K_3}. \tag{42}$$

The remaining portion takes the form

$$\begin{aligned}
\text{Remaining } \Delta U_3(I) = &\Bigg[\Big(\frac{\overline{L_3}^S + (\frac{1}{\ell_3} + h_3)\overline{D_3}^S}{h_3}\Big)\Bigg[-\sum_{\theta=0}^{v}\Bigg(c_3(\tau_\theta)\Big((1-h_3)^{\tau_\theta} - (1-h_3)^{\tau_{\theta+1}}\Big)\Bigg)\Bigg] \\
&- h_3\overline{D_3}^S c_3(0) + (\overline{L_3}^S + \frac{1}{\ell_3}\overline{D_3}^S)\sum_{\theta=0}^{v}\Big(c_3(\tau_\theta)\big(\tau_{\theta+1} - \tau_\theta\big)\Big)\Bigg]_I \\
&+ \Bigg[\Big(\frac{\overline{L_3}^S + (\frac{1}{\ell_3} + h_3)\overline{D_3}^S}{h_3}\Big)\sum_{\theta=0}^{v}\Bigg(c_3(\tau_\theta)\Big((1-h_3)^{\tau_\theta} - (1-h_3)^{\tau_{\theta+1}}\Big)\Bigg) \\
&+ h_3\overline{D_3}^S c_3(0) - (\overline{L_3}^S + \frac{1}{\ell_3}\overline{D_3}^S)\sum_{\theta=0}^{v}\Big(c_3(\tau_\theta)\big(\tau_{\theta+1} - \tau_\theta\big)\Big)\Bigg]_{\neg I} \\
&= \Big(\frac{\overline{L_3}^S + (\frac{1}{5} + 0.33)\overline{D_3}^S}{0.33}\Big)\Bigg[-\sum_{\theta=0}^{0}\Bigg(0.825(10^8)\Big((1-.33)^1 - (1-0.33)^{52}\Big)\Bigg)\Bigg] \\
&- 0.33\overline{D_3}^S\big(0.825(10^8)\big) + (\overline{L_3}^S + \frac{1}{5}\overline{D_3}^S)\sum_{\theta=0}^{0}\Big(0.825(10^8)\big(52-1\big)\Big) \\
&+ \Big(\frac{\overline{L_3}^S + (\frac{1}{5} + 0.33)\overline{D_3}^S}{0.33}\Big)\sum_{\theta=0}^{0}\Bigg(1.65(10^8)\Big((1-0.33)^1 - (1-0.33)^{52}\Big)\Bigg) \\
&+ 0.33\overline{D_3}^S\big(1.65(10^8)\big) - (\overline{L_3}^S + \frac{1}{5}\overline{D_3}^S)\sum_{\theta=0}^{0}\Big(1.65(10^8)\big(52-1\big)\Big) \\
&= -(3\overline{L_3}^S + 1.6\overline{D_3}^S)\big(0.553(10^8)\big) - 0.272(10^8)\overline{D_3}^S \\
&+ (\overline{L_3}^S + \frac{1}{5}\overline{D_3}^S)\big(42.1(10^8)\big) + (3\overline{L_3}^S + 1.6\overline{D_3}^S)\big(1.10(10^8)\big) \\
&+ 0.545(10^8)\overline{D_3}^S - (\overline{L_3}^S + \frac{1}{5}\overline{D_3}^S)\big(84.2(10^8)\big) \\
&= -40.5(10^8)\overline{L_3}^S - 7.27(10^8)\overline{D_3}^S \\
&= -40.5(10^5)\overline{L_3} - 7.27(10^5)\overline{D_3}.
\end{aligned} \tag{43}$$

Adding this result to (42),

$$\Delta U_3(I) = -167(10^5)\overline{L_3} - 83(10^5)\overline{D_3} + 42(10^5)\overline{K_3}. \tag{44}$$

9.4 Adding Them Up: $\Delta U(I) \equiv \Delta U_1(I) + \Delta U_2(I) + \Delta U_3(I)$

9.4.1 Harmonization Assumptions

- Usually, the sign of $\overline{L}$ is somewhat ambiguous and fairly close to zero. But $\overline{L_1}$ is strongly negative. Thus, it might be best compared against $\overline{D}$.

Suppose that a week spent in a factory farm is as bad as experiencing the pain of slaughter: $\overline{L_1} = \overline{K_1}$.

- The US Humane Methods of Slaughter Act (HMSA) requires that, except in cases of religious slaughter, animals must be "rendered insensible to pain by a single blow or gunshot or an electrical, chemical or other means that is rapid and effective, before being shackled, hoisted, thrown, cast, or cut" [33]. Stunning is not always effectual, and slaughterhouses regularly violate the HMSA—sometimes even dismembering animals while conscious [22, 69]. Moreover, poultry—which constitute over 95% of all terrestrial farm animals killed [31, p. 7]—and aquatic animals—10 million of which are caught each year [32]—are not covered by HMSA [3, p. 3]. Still, the average factory-farmed animal probably has a slightly better death than one in the wild, so I'll assume $\overline{K_1} = \frac{1}{2}\overline{D_2}$.
- Suppose that $\overline{D_3} = \overline{K_3} = \frac{1}{2}\overline{D_2}$.
- I define the average aggregated utility of living a bug's life to be α times as good or bad as living the life of wild mammals and birds: $\overline{L_3} := \alpha\overline{L_2}$. Insects are presumably less active than mammals and birds, so I'll assume $\alpha = 0.5$. Since I consider it likely that insects have *no* net balance of happiness over pain during the course of their lives, I'll also try $\alpha = 0$.

9.4.2 Results for $\beta = 1$

Adding together (35), (37), and (41),

$$\begin{aligned}\Delta U(I) &= 277\overline{L_1} + 32.4\overline{K_1} \\ &\quad - 295.3\overline{L_2} - 1.67\overline{D_2} \\ &\quad - 252(10^5)\overline{L_3} - 151(10^5)\overline{D_3} + 84(10^5)\overline{K_3} \\ &= 139\overline{D_2} + 16.2\overline{D_2} \\ &\quad - 295.3\overline{L_2} - 1.67\overline{D_2} \\ &\quad - 252(10^5)\alpha\overline{L_2} - 76(10^5)\overline{D_2} + 42(10^5)\overline{D_2}.\end{aligned} \tag{45}$$

The insect terms swamp everything else. We end up with

$$\Delta U(I) = \left(-295.3 - 252(10^5)\alpha\right)\overline{L_2} - 24(10^5)\overline{D_2}. \tag{46}$$

- When $\alpha = 0.5$, $\Delta U(I) > 0 \Leftrightarrow \gamma_2 < 0.09$.
- When $\alpha = 0$, $\Delta U(I) > 0 \Leftrightarrow \gamma_2 < 8,127$.

9.4.3 Results for $\beta = 0.5$

Adding together (35), (37), and (44),

$$\begin{aligned} \Delta U(I) &= 277\overline{L_1} + 32.4\overline{K_1} \\ &\quad - 295.3\overline{L_2} - 1.67\overline{D_2} \\ &\quad - 167(10^5)\overline{L_3} - 83(10^5)\overline{D_3} + 42(10^5)\overline{K_3} \\ &= 139\overline{D_2} + 16.2\overline{D_2} \\ &\quad - 295.3\overline{L_2} - 1.67\overline{D_2} \\ &\quad - 167(10^5)\alpha\overline{L_2} - 42(10^5)\overline{D_2} + 21(10^5)\overline{D_2} \\ &= \big(-295.3 - 167(10^5)\alpha\big)\overline{L_2} - 21(10^5)\overline{D_2}. \end{aligned} \tag{47}$$

- When $\alpha = 0.5$, $\Delta U(I) > 0 \Leftrightarrow \gamma_2 < 0.25$.
- When $\alpha = 0$, $\Delta U(I) > 0 \Leftrightarrow \gamma_2 < 7{,}111$.

10 Summary of Applications

In the following table, A denotes the set of all species affected by I. a specifies the specific species to which γ_a refers. For example, when incorporating changes in expected aggregated utility due to both insects and larger animals, yet we can arrive at an equation written just in terms of $\overline{L_a}$ and $\overline{D_a}$ for $a = \{$larger animals$\}$. The γ_a in the table, then, should thus *only* be compared against the actual value of γ for larger animals—even though it *incorporates* effects on insects, as well.

Section	I	A	a	Using weeks for $\overline{L_a}$, $\Delta U(I) > 0$ iff
9.1	Eating meat	Factory-farmed animals	Factory-farmed animals	$\gamma_a > 0.12$
8.7	Road kill	Larger animals	Larger animals	$\gamma_a < -0.005$
7.3	Asteroid	Wibbles	Wibbles	$\gamma_a < 0.004$
9.2	Eating meat	Wild mammals and birds	Wild mammals and birds	$\gamma_a < 0.006$
9.4.2	Eating meat	All animals, $\beta = 1$, $\alpha = 0.5$	Wild mammals and birds	$\gamma_a < 0.09$
9.3.6	Eating meat	Insects, $\beta = 0.5$	Insects	$\gamma_a < 0.25$
9.4.3	Eating meat	All animals, $\beta = 0.5$, $\alpha = 0.5$	Wild mammals and birds	$\gamma_a < 0.25$
9.3.5	Eating meat	Insects, $\beta = 1$	Insects	$\gamma_a < 0.27$
9.4.3	Eating meat	All animals, $\beta = 0.5$, $\alpha = 0$	Wild mammals and birds	$\gamma_a < 7{,}111$
9.4.2	Eating meat	All animals, $\beta = 1$, $\alpha = 0$	Wild mammals and birds	$\gamma_a < 8{,}127$

It would be misleading to take a mean of the values in the fifth column for two reasons:

- they don't represent any sort of random sample, and

- they represent different species in different situations; there isn't even a single actual value for γ against which I could compare this mean if I were to compute it.

I will note, however, that in all rows except the first two, *I* had a net good effect even if γ_a was vanishingly positive (*i.e.*, even if daily life was barely enjoyable). If suffering perfectly balances happiness during life before death, $\gamma_a = 0$. For a negative utilitarian, according to whom both life and dying are bad, $\gamma_a < 0$.

11 Is Life in the Wild Miserable?

11.1 A Neglected Topic

Many people go through life with conceptions of nature taken from children's books or Disney films [58, Ch. 4.32]. Even wildlife programs tend not to convey a full sense of the brutality of nature. Like action movies, they often focus on the excitement of a predator's chase of prey, rather than the gruesomeness of death. Rarely do these shows display scenes of sick, injured, or moribund animals.

> The antihunter has no less responsibility [than the hunter] for the pain of the animals, he has merely chosen to remain far away from it so that he does not have to see it or face up to his responsibility. Through his efforts to prevent controlled hunting he unwittingly dooms animals to a certain death by some other cause. [. . . Antihunters] have made the choice for the slower natural death which they can avoid seeing, but cannot avoid being responsible for. [35]

11.2 Life and Death in the Wild

During the reader's contemplation of this topic, she should consider the following question: "If I were given the choice between never having existed, or living for five weeks as a wild mammal or bird and then suffering a natural death, which would I choose?" If the reader's answer is that she would prefer nonexistence, then she thinks that her γ would be < 0.20. If this estimate applies to most wild mammals and birds, many of the environmental impacts in the table of section 10 would appear to be beneficial.

12 Objections

12.1 “But I find life enjoyable!”

If you were in a state of severe agony, you wouldn’t be reading this paper right now. And if you were currently enduring significant pain, you might have a different opinion.

Most of the time, we go through life in a euthymic state—one in which we have our basic needs satisfied and feel mildly content [58, Ch. 5.0]. We also make most of our moral decisions in this state, as probably we should, since severe pain makes us irrational. But it is important that we do not become complacent to suffering. We live comfortable lives in which we have food, shelter, warmth, and general health. We will never be killed by the jaws of a predator. We will never die outside the cold. We musn’t blindly assume that other organisms share our emotional state, and we must remind ourselves of what it’s like to suffer.

Several studies have demonstrated the psychological phenomenon of “depressive realism”—the finding that depressed people have more accurate perceptions than happy people, especially as regards their own abilities [15]. It seems plausible that humans would have a similar mechanism with respect to their assessments of how enjoyable life is. Such a mechanism would presumably have evolutionary benefits, inasmuch as people who don’t dwell on negative thoughts are usually more motivated and productive. Of course, this analysis is slightly complicated by the fact that positive delusions themselves actually make people happier, so that those who think that their lives are better *actually do* have better lives, *ceteris paribus*. Indeed, self-delusion can often be salutary for one’s health, productivity, and happiness. But when we are considering the question of whether life is worth living for wild animals, we should aim for accuracy, rather than the conclusion that will just make us feel good about the world. The sick moose that lies helpless on the ground, waiting to be torn apart by predators, is not helped by our desire to paint rosy Potemkin villages of the world.

12.2 Nature as sacred

There are at least two sources from which this sentiment emerges: creationism and general intuition.

12.2.1 Creationism

Some maintain that nature is sacred because it was created by God. I shall not endeavor to refute this claim here.

I will, however, note that creationism, combined with belief in a benevolent creator, leads to the "problem of evil." John Stuart Mill was one of many to note this:

> For however offensive the proposition may appear to many religious persons, they should be willing to look in the face the undeniable fact, that the order of nature, in so far as unmodified by man, is such as no being, whose attributes are justice and benevolence, would have made, with the intention that his rational creatures should follow it as an example. [47]

Some religious thinkers have responded by denying that life in the wild is actually brutal, asserting instead that nature contains only that small amount of pain needed to ensure organisms' survival [68, 27, 2]. Others acknowledge "the ubiquity of pain, predation, suffering, and death in the creative evolutionary process," but argue that the situation might be made "morally acceptable and coherent" by the suggestion that God suffers along with his creation, in much the same way that mothers suffer during the birthing of their children [57]. [43, p. 102] echoes this view: the wholeness of the universe "submits to such suffering presumably because there are simply no other ways of creating the required abundance and diversity of selves than those ways that have pain as their corollary [. . .]."

12.2.2 General Intuition

People feel a wonderful sense of awe when they spend time in nature. When we walk through a forest, we remark about the song of birds, the croaking of frogs, and the chirping of katydids. We fail to notice the thousands of arthropods upon which we are stepping.

13 Spreading Suffering to the Stars

There is a possibility that humans or post-humans will populate other planets with life—perhaps, in some cases, sentient life.

13.1 Terraforming

NASA is one of several organizations contemplating the logistics of "terraforming" mars—that is, making the planet more like Earth to facilitate colonization [65]. Part of the process would involve introduction of microbial life forms [20]. Presumably, humans would introduce other sentient life as conditions progressed. The utilitarian might hope that such life would have been engineered to experience only varying degrees of pleasure [58] or that it might take the form of sentient (and extremely happy) machines capable of performing ecological functions. Unfortunately, humans may not be especially motivated to ensure that this happens;[8] even if they were, these utilitarian approaches to ecopoiesis would probably not be in place by the time humans terraform mars.

13.2 Directed Panspermia

Probably an even greater increase in the amount of sentient life on other planets would come from "directed panspermia"—deliberate seeding of the galaxy with packages of life. The process appears feasible (see, *e.g.*, [44, 45]); moreover, the idea would probably enjoy a fair amount of popular support (perhaps more than dispersal of engineered happy animals). Some might view the seeding of space with life as the human race's manifest destiny, while others might consider it a natural extension of God's command to Noah and his sons: "And you, be ye fruitful, and multiply; bring forth abundantly in the earth, and multiply therein" [26, Genesis 9:7]. The Society for Life in Space maintains that directed panspermia is a paramount ethical goal [59].

14 How Many Extraterrestrial Life-Years?

What's the expected number of sentient extraterrestrial life-years in our galaxy? I use a modified Drake equation [17]:

$$N \approx R^* f_e f_l f_s n \Pi L B, \tag{48}$$

where

this symbol	stands for the
N	expected number of sentient extraterrestrial life-years that will ever exist in the future of our galaxy (excluding Earth and colonization of other planets by post-humans)
R^*	rate of star formation in our galaxy
f_e	fraction of stars with habitable planets
f_l	fraction of those planets on which life does emerge
f_s	fraction of those planets on which life reaches a level at which it's conceivably sentient (*e.g.*, insects are conceivably sentient, but plants are not)
n	average population of conceivably sentient organisms per planet with life
Π	weighted-average probability that those organisms are actually sentient
L	average duration for which the population n continues to exist
B	length of time for which R^* continues before the stars burn out

---

[8] Perhaps this is a partial argument in favor of promoting awareness of animal welfare. Distributing literature on vegetarianism would be one way to accomplish this [31, p. 3]. Maybe it would be best to emphasize (as this paper is doing) the suffering of animals in the wild, since this issue often fails to enter into the minds of even dedicated animal-welfare activists.

Estimating parameters:

- $R^* = 6$ stars/year.

  [18] puts R^* between 4 and 19. Drake's original 1961 paper put the figure at 10, while NASA and the European Space Agency recently estimated R^* at 6 [17]. I chose the last value.

- $f_e = 0.1$ [41, p. 60].

- $f_l = 0.9$.

  We can't simply say that, "since life evolved on Earth, the process must be likely" because of an observer-selection effect. [40] took this effect into account and found an expected f_l close to 1, which happened to be Drake's original estimate [17]. In addition, $f_l > 0.13$ with 95% confidence [40]; hence, I (somewhat arbitrarily) chose 0.9.

- $f_s = 0.01$.

  f_s might be fairly small. For instance, life on Earth began $4(10^9)$ years ago, but it was not until

  - $2.1(10^9)$ years ago that eukaryotes evolved
  - 10^9 years ago that multicellular life evolved
  - $0.6(10^9)$ years ago that animals evolved (*e.g.*, sponges, jellyfish, and flatworms)
  - $0.505(10^9)$ years ago that vertebrates developed
  - and $0.45(10^9)$ years ago that arthropods emerged [66].

  Indeed, there's no reason why conceivably sentient creatures should necessarily evolve at all. (To say that "sentience is likely because it happened on Earth" is once again to neglect observational-selection bias, since self-aware organisms are presumably more likely to be sentient.)

  Because of these difficulties—and because I can't find any concrete data—I suppose that $f_s = 0.01$.

- $n = 5(10^{17})$.

  I'll use Earth as a basis for my estimate. On Earth, insects outweigh all other possible sentient organisms by orders of magnitude, so I'll just count them: 10^{18} [63]. Perhaps Earth is slightly better situated for life than some other planets are, so perhaps I'll cut this number in half for my average: $n = 5(10^{17})$.

  I am assuming here that there will be no post-human-like extraterrestrial civilizations with massive populations.

- $\Pi = 0.001$, as before.

- $L = 1.65(10^9)$ years.

  Drake's original estimate was 10,000 years, but he was calculating the survival time of civilizations that are willing and able to communicate with Earth [17]. The length of time for which insects can survive is much longer. Indeed, even few catastrophic risks are capable of wiping them out.

  I use the expected lifespan of arthropods on Earth for L. Arthropods evolved $0.45(10^9)$ years ago and will probably last until the demise of Earth's biosphere in $0.9(10^9)$ to $1.5(10^9)$ [average $= 1.2(10^9)$] years [11].

- $B = 10^{14}$ years.

  Normal stars will stop forming in 10^{14} years [1, p. 367].

N comes out to be $4.455(10^{35})$ life-years.

15 Closing Quotations:

> The whole earth, believe me, Philo, is cursed and polluted. A perpetual war is kindled amongst all living creatures. Necessity, hunger, want, stimulate the strong and courageous: fear, anxiety, terror, agitate the weak and infirm. The first entrance into life gives anguish to the new-born infant and to its wretched parent: weakness, impotence, distress, attend each stage of that life: and it is at last finished in agony and horror.
>
> —Demea, in David Hume's *Dialogues Concerning Natural Religion*, 1751 [34]

> We might reject nature policing simply by regarding it as intrinsically bad. If this view is selected as an axiom, so be it. This paper could then be read as arguing that such an axiom is not compatible with other plausible axioms that we hold about animals, such as the view that their welfare matters, they deserve moral consideration, or that the painful death of an animal is a bad thing. [. . .]
>
> In casual discussion, I find that virtually all individuals find the conclusion of nature policing as one to be avoided. Indeed I set out to write this paper with that intuition in mind. I expected to find some clever twist that would resolve the issue and eliminate nature policing as a philosophically viable alternative. It is impossible to prove that such a clever twist does not exist, but at some point we need to consider modifying our original intuition, if the would-be twist proves sufficiently hard to find. Philosophy is in part about

> subjecting our intuitions to the scrutiny of reason and hoping to improve on them.
>
> —Tyler Cowen, “Policing Nature,” 19 May 2001 [14]

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