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Abstract

This paper seeks to articulate a causal explanation of the covid-19 pandemic by bringing into dialogue two seemingly unrelated works: *Leyes sin causa y causas sin ley en la explicación biológica*, by philosopher of biology Gustavo Caponi, and the essay "Another Silent Spring", by environmental historian Donald Worster. Caponi, whose book was written well before the pandemic, offers epistemological tools that underscore the relevance of both proximate and remote causes in biological explanation, emphasizing experimental intervention as a valid form of causal understanding, even in the absence of universal laws. This framework allows us to interpret public health measures enacted during the pandemic as epistemically meaningful actions. Worster, in turn, attributes the origins of the pandemic to humanity's long-standing efforts to dominate nature and treat its living and nonliving components as mere "natural resources." While Caponi's model helps us conceptualize intervention as explanation, this paper argues, following Worster, that these very impulses have produced what may be termed a paradox of control: the more we attempt to master natural systems, the more we generate ecological instability and systemic risk. The result is a global-scale, unintended experiment with potentially catastrophic consequences.

Key words

covid-19. SARS-COV-2. natural selection. artificial selection. social health.

1 INTRODUCTION

> The impulse to control natural processes may reflect an evolved cognitive adaptation of the human brain. From early childhood, we begin to grasp causal relationships in the surrounding world by acting upon them, through direct intervention or through imaginative simulation. We come to recognize, through both experience and hypothetical reasoning, certain regularities, physical, chemical, biological, and social, that structure our environment and guide our actions. This process of causal learning parallels the acquisition of language and emerges even before formal education begins. We explain by doing, or by envisioning what might happen under altered conditions, constructing counterfactual scenarios that allow us to test, mentally or materially, the causal structure of the world (adapted from Gopnik, *The philosophical baby*, 2009).

For many scientists and physicians working in human health, understanding biological phenomena requires integrating both proximate and remote causes (Gluckman et al., 2016; Stearns & Medzhitov, 2013; Williams & Nesse, 1991; Mayr, 1961). In the case of covid-19, the fundamental proximate cause is the SARS-CoV-2 coronavirus itself. Immediate biological factors, such as the structure of its viral envelope proteins and their affinity for human cellular receptors, also belong to this category. Additional immediate causes, including ecological and societal variables, further contribute to transmission dynamics. Conversely, the remote or distal causes are broader, historical, and more difficult to delimit. These include long-term evolutionary processes, environmental changes, and anthropogenic factors that shape the emergence of new species, adaptive traits, and zoonotic pathogens such as SARS-CoV-2.

Genetic analyses of SARS-CoV-2 samples collected from individuals infected with the pathogen have revealed a close phylogenetic relationship between this coronavirus and others found in bats of the Rhinolophus genus (Andersen et al., 2020; Quammen, 2022). A remote cause of the covid-19 pandemic thus lies in the ecological and evolutionary conditions that led to the emergence of SARS-CoV-2, related lineages in certain bat species over tens of millions of years. Notably, the immune systems of these flying mammals differ in key ways from those of humans and other non-flying mammals (Crespi, 2020; Apoorva & Singh, 2024). In his 2020 article "Evolutionary medical insights into the SARS-CoV-2 pandemic", published in Evolution, Medicine, and Public Health, Bernard Crespi proposes that the pandemic may be explained, in part, by a mismatch between human immune responses and viral infection. Mismatch is a foundational concept in Evolutionary Medicine, which Crespi explicitly adopts as the framework for his analysis. According to this approach, the covid-19 pandemic stems from three interacting factors: 1) The bat immune system, characterized by low levels of inflammation and a highly efficient interferon-based antiviral response. Interferons are proteins produced by immune cells in response to pathogens such as viruses, bacteria, or tumors. Their primary role is to signal nearby cells and initiate antiviral defenses, including immune cell activation and the inhibition of viral replication. In contrast to other mammals, bats rely minimally on inflammation as a first-line defense; 2) "Viral tatics", mechanisms that disrupt the human interferon response, thereby allowing extensive asymptomatic and pre-symptomatic transmission, a defining feature of SARS-CoV-2's pandemic potential; 3) An evolutionary trade-off between healing and harm, in which the costs of human immune responses exceed their benefits. In severe cases, this imbalance manifests as a "cytokine storm", an extreme immune reaction involving the uncontrolled release of inflammatory cytokines that can damage the body's own tissues (Crespi, 2020). Evolutionary mismatches, including those among viral adaptations, bat immune systems, and human defenses, should be understood as one component of a larger constellation of remote causes shaping the emergence, transmission, and pathogenicity of the virus. While identifying all remote causes of a pandemic is inherently complex, building a coherent explanatory model that accounts for both levels of causality is even more challenging, and yet essential for public health and scientific accountability

1.1 Framing the Question: Causality, Control, and Crisis

This study aims to bring into dialogue two texts from distinct disciplinary and epistemological backgrounds in order to examine key dimensions of causal explanation regarding the covid-19 pandemic. The first, Leyes sin causa y causas sin ley en la explicación biológica by Argentine philosopher of science Gustavo Caponi, was published in 2014 and thus contains no direct reference to the pandemic. Nonetheless, it offers a compelling epistemological framework grounded in an experimentalist or manipulationist conception of causality, one that proves valuable for interpreting the health crisis that began in late 2019. The second text, "Another Silent Spring", is a brief yet powerful essay by American environmental historian Donald Worster, published in April 2020, in the early phase of global lockdowns. In it, Worster reflects on the pandemic's remote/ultimate causes, calling for a fundamental reassessment of how we understand ourselves as a species and how we relate to others. Crucially, he argues that this rethinking must be informed by evolutionary theory and ecological awareness. According to Worster, our biological and cultural drive to control natural phenomena, especially as manifested in large-scale industrial agriculture and livestock production, systematically ignores, or willfully denies, the fact that we are embedded within broader evolutionary and ecological processes. By treating living and nonliving elements of the planet as mere "natural resources", we are altering our relationship to the biosphere in radical and destabilizing ways.

Naturally, other texts intersect with the present study. In May 2020, I came across a short article, more precisely, a correspondence piece, in the prestigious journal Nature, titled "The Proximal Origin of SARS-CoV-2" (Andersen et. al, 2020). As the title suggests, the article focuses on the proximate origins of the coronavirus responsible for the covid-19 pandemic. It does so by comparing SARS-CoV-2 with other phylogenetically related viruses, such as

SARS-CoV (linked to the 2002–2003 outbreak), MERS-CoV (2015), and a coronavirus isolated from pangolins, in order to argue that SARS-CoV-2 is unlikely to have originated from a laboratory incident. This article occupies a central position in the still-unresolved debate about the origins of SARS-CoV-2 (Chan & Ridley, 2021; Quammen, 2022; Frutos et al., 2021; Holmes, 2024; Domingo, 2024). For those engaged in this scientific and social controversy in good political and ethical faith, understanding how the virus emerged, how it crossed the species barrier, is essential for preventing future pandemics. Although the laboratory-leak hypothesis has been significantly weakened, the exact pathway by which the virus reached humans, likely from bats, possibly via intermediate species sold in live animal markets, remains unknown (Domingo, 2024; Holmes, 2024).

In the first part of this study, I examine Caponi's experimentalist conception of causality, drawing on a brief yet significant passage in which he addresses a health-related case. Building on this foundation, I propose a manipulationist account of the covid-19 pandemic, one that highlights our capacity to intervene in the dynamics of such crises. In the second part, I turn to Donald Worster's central claim: that humanity's compulsion to dominate natural systems, amplified by a massive population surge and the exponential increase in global mobility, has placed us in a precarious and unstable position. This condition, I argue, reflects a paradox of control, in which our efforts to master nature generate new vulnerabilities, including the conditions for pandemic emergence. For Worster, any attempt to resolve this dilemma must take seriously the relevance of evolutionary theory and ecology to human life. I conclude by suggesting that a meaningful explanation of the covid-19 pandemic must not only account for its causes, but also contribute to the prevention of future catastrophes. If, as Caponi suggests, explaining is inseparable from doing, experimenting, manipulating, intervening, then causal understanding becomes a tool for action. And if action without understanding risks deepening the crisis, then explanation must be oriented toward foresight, responsibility, and care.

2- DEVELOPMENT

2.1 Caponi meets Thagard: causal explanation without laws

Leyes sin causa y causas sin ley en la explicación biológica (Leyes sin causa hereafter), published in 2014 by Argentine philosopher of biology Gustavo Caponi, addresses core debates in the philosophy of biology, with a focus on causal explanation in evolutionary and ecological contexts. Caponi, a prolific scholar currently based at the Federal University of Santa Catarina in Brazil, has authored over 150 articles and more than a dozen books. In Leyes sin causa, he begins by examining the limitations of the Nomological-Deductive Model (NDM) when applied to biological phenomena. According to the NDM, a phenomenon is explained when it can be logically deduced from general laws and initial conditions (Hempel, 1942). Within this framework, causal explanation consists in the subsumption of events under general laws, allowing for the deduction, prediction, and logical reconstruction of outcomes.

Caponi critically engages with a wide array of philosophical literature, most notably drawing on James Woodward's (2003) interventionist model and Henrik von Wright's (1971) analysis of causality. He begins with a seemingly straightforward example from physics, Archimedes' law of buoyancy, which describes a causal relationship between the volume of a submerged object and the density of the fluid it displaces. This serves as a springboard for a broader reflection on the status of causal laws in the life sciences. A key distinction developed by Caponi concerns the difference between causal laws and consequential laws. Causal laws specify a direct connection between two events or states of affairs: a particular condition (the cause) leads to another (the effect). They provide explanatory power by identifying mechanisms that produce outcomes. Consequential laws, by contrast, express regularities or patterns observed in nature without implying a causal mechanism. They describe what tends to happen, but not why it happens.

This distinction between consequential and causal laws is particularly significant in biology, where many observed patterns, such as adaptations and species distributions, often reflect statistical tendencies rather than strict mechanistic laws. Caponi's analysis underscores the limitations of importing explanatory models from the physical sciences into evolutionary biology and argues for alternative frameworks of causal reasoning, more attuned to the historical and contingent nature of biological systems. Caponi identifies several difficulties faced by philosophers of science, especially those working in biology, when attempting to determine what qualifies as a causal explanation. Much of the challenge lies in the elusive nature of causal laws in evolutionary and ecological contexts, where phenomena are typically transient, historically contingent, and locally specific. These characteristics undermine the applicability of universal, exceptionless regularities as the foundation of scientific explanation.

From the outset, however, Caponi gestures toward a conceptual alternative, one that sidesteps the demand for universality while remaining philosophically coherent. On page 128 of Leyes sin causa, he draws on Paul Thagard's influential book How Scientists Explain Disease (1999), a classic in the philosophy of biology and medicine. Thagard analyzes the historical development of causal models for peptic ulcers, tracing the shift from psychosomatic explanations, stress and excess stomach acid, to the discovery that many cases are caused by infection with the bacterium *Helicobacter pylori*. Importantly, Thagard arrives at this explanation not simply by asserting biological mechanisms, but by offering a historically layered and epistemologically informed account of how explanatory models evolve. He uses diagrammatic schemas with relational concepts and arrows to show how causal complexity increases over time, especially as non-biological factors are incorporated. For Caponi, the case of gastric ulcers exemplifies how causal explanations in biology can be robust and operationally effective without appealing to universal laws:

> Pero, si existe un ejemplo de explicación causal biológica que definitivamente no encaja, ni en la idea de heteronomía explicativa, ni tampoco en el MND, ese ejemplo es el de la explicación de las enfermidades infecciosas. Tal es el caso de la explicación bacteriológica de muchas úlceras gástricas propuesta y aceptada bajo el imperio de la biología Molecular, pero atendendo a coordenadas típicas de la Microbiología

> Clásica: la Microbiología de Pasteur y de Koch. Sin tener que valer para todas las úlceras, ni siquiera para todas las posibles úlceras infecciosas, esa explicación estableció un invariante, muy estable aunque tal vez de aplicación muy restringida, que permite explicar y tratar un tipo particular de esa patologia
>
> But if there is one example of a biological causal explanation that definitely fits neither the idea of explanatory heteronomy nor the MND, it is the case of the explanation of infectious diseases. Such is the case of the bacteriological explanation of many gastric ulcers, proposed and accepted under the dominance of Molecular Biology, yet guided by coordinates typical of Classical Microbiology: the Microbiology of Pasteur and Koch. Without having to account for all ulcers, nor even for all possible infectious ulcers, that explanation established an invariant—highly stable, though perhaps of very limited applicability—that makes it possible to explain and treat a particular type of this pathology.
> (Caponi, 2014, p. 128) (Thagard, 1999, pp. 59-61).

In this context, explanatory heteronomy refers to the claim that "organic phenomena must be explained by resorting to laws originating in physics and chemistry" (Caponi, 2014, p. 33). Caponi explicitly rejects this view, while acknowledging that "we are all physicalists" (Caponi, 2014, p. 129) in the sense that "we accept that every causal relationship must be embodied or anchored in a physical substrate or support" (Caponi, 2014, p. 34). The concept of an invariant, central to Caponi's conception of causality, will be addressed shortly. Before that, it is important to clarify what constitutes a bacteriological explanation for many cases of gastric ulcer:

> En la década que va de 1985 a 1995, los médicos australianos Robin Warren y Barry Marshall consiguieron mostrar que Helicobacter pylori era el agente responsable de muchas de esas úlceras en virtud de tres conjuntos de datos: [1] evidencia clínica y epidemiológica de la asociación entre dicha bacteria y esa patología; [2] éxito en la producción experimental de la

> úlcera por inoculación de cepas puras, cultivadas experimentalmente, de la bacteria imputada; y [3] evidencia experimental y clínica creciente de cura de la úlcera por el uso de un antibiótico específico. Es decir: la úlcera se puede producir inoculando Helicobacter pylori, y se puede curar eliminando ese agente. Nadie precisa ninguna ley, y menos una ley física o química, para justificar las imputaciones causales que a partir de ahí puedan formularse sobre casos clínicos concretos (Caponi, 2014, p.128).
>
> In the decade between 1985 and 1995, the Australian physicians Robin Warren and Barry Marshall succeeded in demonstrating that Helicobacter pylori was the causal agent responsible for many of these ulcers, based on three sets of evidence: [1] clinical and epidemiological data showing the association between this bacterium and the pathology; [2] the successful experimental production of ulcers through the inoculation of pure, laboratory-cultivated strains of the implicated bacterium; and [3] growing clinical and experimental evidence of ulcer cure through the use of a specific antibiotic. In other words: ulcers can be produced by inoculating Helicobacter pylori and can be cured by eliminating this agent. No general law—least of all a physical or chemical law—is needed to justify the causal imputations that can be formulated from this point on in relation to concrete clinical cases.

The bacteriological explanation operates at a level of analysis distinct from the physical and chemical strata. Although materially grounded in these lower levels ("we are all physicalists"), it stands as a legitimate causal explanation without having to invoke them directly. According to Caponi, such an explanation does not require the statement "H. pylori causes peptic ulcers" to be supported by a universal, exceptionless law. Instead, it is validated by an invariant proposition linking cause and effect, positively tested, for example, when the bacterium is inoculated into experimental animals that subsequently develop the disease, and when antibiotics targeting H. pylori are administered to humans, leading to the disappearance of the ulcer. Through this specific intervention, Warren and Marshall discovered a method to experimentally manipulate the disease. "To explain is to discover a way to do: it is re-doing with thought" (Caponi, 2014, p. 73). For Caponi, manipulation constitutes "something like the primitive core, the seed from which the idea of causation has developed" (Caponi, 2014, p. 86). Causality, then, is not grounded in a universal law but in an invariant that enables consistent and relatively stable relationships between variables:

> La idea de control experimental conlleva una noción que es crucial en la concepción experimental de la causación: aludo a eso que Woodward (...) llama 'invariancia' (...). Intervención e invariancia son, em efecto, dos nociones estrechamente vinculadas. Los estados de una variable solo pueden ser controlados por intermedio de la manipulación de los estados de otra variable, que sea realmente distinta a la primera, si entre esos estados existe una asociación constante tal que pueda perverse la modificación que ocurrirá en la variable controlada en virtud de nuestro conocimiento de la modificación que introduciremos en lavariable de control (Caponi, 2014, p.87).

> The idea of experimental control entails a notion that is crucial to the experimental conception of causation: I refer here to what Woodward (…) calls 'invariance' (…). Intervention and invariance are, in fact, two closely related notions. The states of a variable can only be controlled through the manipulation of the states of another variable—one that is genuinely distinct from the first—if there exists a constant association between those states, such that we can predict the modification that will occur in the controlled variable by virtue of our knowledge of the modification we introduce into the control variable.

If I interpret Caponi's terminology correctly, to causally explain the pandemic would involve identifying both ontological conditions and counterfactual epistemological statements that imply the possibility of manipulating or experimentally controlling covid-19, serving as either empirical or mental tests of the phenomenon to be explained. Counterfactuals are "if...then" statements that describe alternative scenarios, ranging from general to highly specific, that did not occur but remain logically coherent within the system of variables. Invariances, whether local or more general, govern the behavior of variables under intervention. "Invariance under interventions" (*invariancia bajo intervenciones*) is the cornerstone of Caponi's argument: "To explain something causally always necessarily involves a counterfactual presumption about how things would have been if that which is identified as the cause had not occurred in the way it did". (Caponi, 2014, p. 85). How might the covid-19 pandemic have unfolded had no public health measures been implemented? What consequences would have followed, for instance, if masks had never been used?

There is, for example, a clear causal relationship, at the population level, between the variables "mask use" and "number of cases" (Eikenberry et al., 2020; Mitze et al., 2020; Abaluck et al., 2021). In most cases, increased mask use leads to a reduction in the number of infections, an example of an invariant relationship, or invariance. This consistency between intervention (mask use) and outcome (fewer cases) allows for effective manipulation of the epidemiological context. Although controlled experiments on humans are ethically impermissible and multiple variables influence infection rates, the effectiveness of mask use remains measurable through observational and statistical methods. This kind of idealized case supports the identification of causal agents of the pandemic, such as the virus itself and its transmission routes. In addition to mask use, interventions like social isolation, quarantine, contact tracing (particularly in the early phases of transmission, as noted by Frutos, 2021), testing, and vaccination alter both the viral environment and the human environment. These actions modulate the selection pressures acting on the pathogen and help control its transmission dynamics.

2.2 Caponi meets Worster: artificial selection and uncontrolled control

The key point in the dialogue I propose between Caponi and Worster is that natural and social phenomena are, to a significant degree, susceptible to control and manipulation. Caponi shows that evolutionary biology provides a compelling example, widely acknowledged but rarely analyzed in this particular framework, in which interventions targeting processes that constitute the so-called invariants of natural selection make it possible to control phenomena of major relevance to public health:

> La selección está más a mano de lo que algunos parecen creer. Y el hombre ha operado con ella desde que comenzó a seleccionar las variedades de las especies domésticas. La selección artificial es una presión selective ejercida por nosotros mismos: ella no es un fenómeno análogo a la selección natural, ella es selección natural. Como ha dicho Robert Brandon (...): "la selección artificial es solo un tipo de selección natural"(Caponi, 2014, p.86).

In other words, artificial selection is a method developed by humans to manipulate animal and plant populations, shaping their traits with far-reaching implications for the exploitation of so-called "natural resources" for human benefit. Agriculture and animal husbandry, each serving distinct purposes, are grounded in this practical knowledge: across generations, certain animal or plant individuals are selectively bred as progenitors of the next generation, thereby intervening in and controlling a natural process governed by invariances.

Artificial selection plays a pivotal ontological and epistemological role in Caponi's argument. It illustrates how humans have historically controlled the physical and behavioral characteristics of various animal, plant, and even microbial species, often without any awareness of their biological mechanisms, as in the cases of bread, beer, wine, cheese, and fermented foods (Katz, 2012).This manipulation of species relies on a causal relationship: by intervening in the controlling variable - selecting desirable traits observed in one generation - the outcome variable consistently responds with the recurrence and often enhancement of those traits in subsequent generations. The invariance expressed under these interventions is the process of selection, here, human selection, which must be sustained over time to maintain the desired characteristics.

The large-scale manipulation of species, now operating at mega-industrial levels, has triggered the unintended proliferation of species across distinct biological phyla, for instance, arthropods (e.g., insects), fungi, and various microorganisms (including virus), alongside vertebrates such as rodents and bats. Many of these organisms are classified as threats to agricultural productivity and are targeted for eradication. Caponi identifies the control of so-called "pests" as yet another instance of the manipulation of living organisms driven by economic and demographic imperatives:

> El control biológico de plagas y malas hierbas, lo sabemos, es una tecnología humana muy difundida y relativamente avanzada. Yo solo estoy refiriéndome a ella para destacar cómo, por medio de ese control, y en posible conjunción con el control de factores abióticos que también afectan a los seres vivos, es posible manipular y controlar no solo el crecimiento de ciertas poblaciones, sino también controlar, manipular, revertir o acentuar las presiones selectivas que pueden incidir sobre dichas poblaciones. Lo primero es un control puramente ecológico, pero lo segundo ya es un control de la evolución. Un control de los procesos evolutivos que nos habla de la estabilidad bajo intervenciones de la que gozan los invariantes selectivos que la Teoría de la Selección Natural nos lleva a identificar, para, conbase en ellos, explicar la generación de las presiones selectivas que citamos como causas de esos processos (Caponi, 2014, p.111).

> he biological control of pests and weeds, as we know, is a widely disseminated and relatively advanced human technology. I refer to it here only to highlight how, through such control—and possibly in conjunction with the control of

> abiotic factors that also affect living beings—it becomes possible not only to manipulate and regulate the growth of certain populations, but also to control, manipulate, reverse, or intensify the selective pressures that may act upon those populations. The first is a purely ecological form of control, but the second is already a control of evolution itself: a control of evolutionary processes that points to the stability under interventions enjoyed by the selective invariants that the Theory of Natural Selection leads us to identify, and on which we rely to explain the generation of the selective pressures we cite as causes of those processes.

For approximately 200,000 years, humans lived as hunter-gatherers, depending on hunting, fishing, and the gathering of fruits, nuts, and roots. The emergence of food production marked a fundamental transformation in human history, rooted in artificial selection and the domestication of plants and animals, processes that reshaped wild species to fulfill human purposes. Long before Darwin and Wallace formulated the theory of natural selection, early farmers, breeders, and naturalists applied techniques of selection and crossbreeding to propagate desirable traits across generations. Plant domestication began around 12,000 years ago, during the Neolithic Revolution, when human societies shifted from foraging to farming. Early agriculturalists systematically selected seeds from high-yield, resilient, and easily harvested plants, initiating independent centers of domestication in regions such as the Fertile Crescent, the Yangtze River Valley, and the Americas. This transition, facilitated by the climatic stability following the last Ice Age, led to the cultivation of staple crops like wheat, barley, rice, and maize, alongside the domestication of animals including sheep, goats, pigs, and cattle. The development of agriculture underpinned the rise of villages, cities, and complex civilizations, supported by technological innovations such as irrigation systems, plows, and crop rotation (Diamond, 1999; Mithen, 2003).

Agricultural practices have evolved over centuries. In medieval Europe, the introduction of the three-field system improved soil fertility and crop rotation. During the Renaissance, the arrival of

New World crops such as potatoes and maize expanded food availability and nutritional diversity. The Industrial Revolution marked a turning point, as mechanization, tractors, plows, and chemical fertilizers, greatly increased agricultural productivity. All of these elements are interlinked through long-distance transportation infrastructures that rely on the combustion of fossil fuels, an arrangement that extends human control over time and space, yet simultaneously deepens dependency on non-renewable resources and accelerates ecological instability. In the 20th century, the Green Revolution brought further intensification through high-yield crop varieties, synthetic fertilizers, and pesticides. While these innovations reduced hunger in many regions, they also accelerated soil degradation, resource depletion, and biodiversity loss. These transformations underscore the extent to which human activity has reshaped ecological systems and altered the trajectories of natural selection, generating both gains in productivity and long-term risks to environmental sustainability. The mid-20th century also marks what historians and scientists call the Great Acceleration, a phase of intensified industrial activity and resource extraction with profound and measurable impacts on climate and ecosystems. Some scholars argue that this epochal shift signals the beginning of a new geological era: the Anthropocene, defined by human-induced transformations of planetary systems and the emergence of environmental dynamics with increasingly unpredictable consequences (Bonneuil & Fressoz, 2024; Chakrabarty, 2021; Pfenning-Butterworth et al., 2024).

2.3 Donald Worster meets the Anthropocene

Donald Worster is widely recognized as one of the founding figures of environmental history. His scholarship investigates the ways in which human societies have interacted with the natural world over time, analyzing both ecological transformations and their cultural, economic, and social ramifications. Among his most influential works is Dust Bowl: The Southern Plains in the 1930s (1979), which examines how economic ideologies and land-use practices contributed to one of the worst environmental disasters in U.S. history. In Nature's Economy: A History of Ecological Ideas (1977), Worster traces the development of ecological thought from the Enlightenment to the contemporary era, offering a nuanced account of the interplay between ecological science and social values. Worster's approach is distinctly critical: he contends that the unchecked exploitation of natural resources has produced severe and often irreversible consequences for both ecosystems and human communities. His work challenges linear narratives of progress and modernization, advocating instead for a reconfiguration of human-nature relations grounded in ecological sustainability.

In April 2020, Donald Worster launched the virtual exhibition Another Silent Spring on the Environment & Society Portal (https://www.environmentandsociety.org/). The exhibit presents a curated collection of photographs and visual materials related to covid-19, accompanied by a sharply articulated essay by the environmental historian. At that point, more than 150,000 people had died across multiple countries on all five continents. City streets around the world stood empty, silenced by government interventions intended to halt the unchecked spread of a novel virus with no precedent in human populations, what Alfred Crosby (1976) might have described as a "virgin soil pandemic". Worster draws a poignant parallel between the spectral stillness of cities in 2020 and the ecological silence evoked by Rachel Carson's Silent Spring (1962), where the widespread use of pesticides threatened to erase the natural soundscape. In both cases, the quiet marks not peace but disruption, an absence shaped by human attempts to intervene in and control natural processes.

Silent Spring opens with a parable describing a rural American landscape rendered biologically barren, its domestic and wild species eradicated by chemical agents we now classify as herbicides and insecticides. Carson invites readers to imagine the haunting silence that envelops this fictionalized setting and, while acknowledging its imagined nature, draws attention to the widespread and very real application of chemical substances across American farmland. The book ignited a national debate over the risks posed by synthetic chemicals, prompting critical reassessment of their use and leading to the implementation of more rigorous environmental regulations. Silent Spring played a pivotal role in the eventual ban on DDT in the United States in 1972 and in the creation of regulatory institutions such as the Environmental Protection Agency. Carson emphasized the interdependence of living systems, demonstrating how human interventions can destabilize food chains and disrupt ecological cycles. Often regarded as a founder of the modern environmental movement, she catalyzed widespread environmental awareness and activism, underscoring the inseparability of environmental and human health.

In 1962, when Silent Spring was published, the global population was approximately 3 billion. Yet concerns over large-scale food production and distribution were already acute. The expansion of monoculture agriculture and industrial animal farming had created novel ecological niches, occupied by various insect species, other arthropods, small vertebrates, and, imperceptibly, by microorganisms. Carson does not oppose the underlying goal of managing pests in agriculture and livestock. Rather, she exposes the widespread biological destruction caused by chemical control methods, including the poisoning and death of countless non-target species and human beings, through both direct exposure and indirect contamination. In place of such reactive measures, Carson advocates for biologically informed strategies, including insect sterilization and the use of natural predators, methods aimed at restoring ecological balance rather than disrupting it.

The global human population has now surpassed eight billion, with projections indicating a rise to eleven billion by the end of the century (Rohr, 2019). Reflecting on the silence imposed by social distancing and quarantine measures during the early stages of the covid-19 pandemic, Worster underscores the profound food security challenges of our time, a crisis unfolding within a world fractured by unstable national borders and intensified by geopolitical and climatic upheavals. He identifies a critical trade-off between large-scale food production and the emergence of infectious diseases. The ecological simplifications inherent in what he refers to as "Agro", particularly in the livestock sector, create conditions conducive to the spillover of pathogens from both wild and domesticated species into human populations (Worster, 2020; Rohr, 2019; Wallace, 2016).

The ways in which humans manage plants, animals, and soil, transforming vast landscapes into monocultures and pastureland, contribute directly to climate change and introduce new selective pressures on human populations, on nonhuman animals, and on the vast microbial ecologies within and around them. These shifts have intensified since the mid-twentieth century, coinciding with the Green Revolution and the onset of what Earth system scientists have termed the "Great Acceleration" (Bonneuil & Fressoz, 2016; Chakrabarty, 2021). This acceleration is characterized by rapid economic, technological, and demographic expansion, tracked by a range of socioeconomic indicators (such as industrialization, energy use, urbanization, and global trade) and environmental indicators (including greenhouse gas emissions, deforestation, biodiversity loss, ocean acidification, and pollution). These interlinked transformations are now believed to have disrupted the Earth's climatic regime, inaugurating a new geological epoch: the Anthropocene (Bonneuil & Fressoz, 2024; Silva & Lopes, 2021; Chakrabarty, 2021).

For Worster, much of this transformation is rooted in contemporary food systems, particularly in how we produce, distribute, and consume food on a global scale. Central to this transformation is the widespread reliance on fossil fuels, arguably one of the most powerful tools ever devised by human ingenuity to extract energy and generate material wealth. The discovery, exploitation, and combustion of coal, oil, and gas enabled an unprecedented expansion of industrial agriculture, mechanized transport, refrigeration, and long-distance supply chains, all of which are deeply embedded in modern food systems (Bonneuil & Fressoz, 2024; Wallace, 2016). Yet this same system, while delivering abundance for some, has also deepened global inequalities and contributed significantly to ecological degradation. Fossil fuels epitomize the paradox of control: a form of mastery over nature that accelerates both economic accumulation and planetary instability:

> We pursue agricultural development (most recently the Green Revolution); every continent except Antarctica is now under its

> reign, and food abundance flows endlessly to the cities. So far the strategy has worked well for our kind; we now number nearly eight billion, most of us well fed, hale and hearty. More than half of us can now live in towns, cities, and megalopolises because our efficient world food system supports us (Worster, 2020, p.16).

However, the entire industrial apparatus behind the production and distribution of living organisms, both plant and animal based, has introduced conditions that would have been unimaginable in earlier times. What once appeared to be an unequivocal achievement, controlling the reproduction of domesticated species to enhance nutrition and abundance, now reveals its hidden costs, some of which include human lives:

> Agriculture, though born of necessity, is the essential foundation of civilization, including written languages, the state, and the city. Modern industrialization has built itself on the back of the farmer and cannot live without his food surpluses. As agricultural settlements began to trade with one another, they unwittingly spread viral mutations and cause other problems far from home. Thousands of years later, those busy with local concerns may not know the distant consequences of their actions (Worster, 2020, p.15).

Worster identifies industrial agriculture as an immediate driver of increased human contact with animals carrying viruses and other parasites that would otherwise remain largely confined to their wild reservoirs. At the same time, he points to the very emergence and development of agriculture as a more distant, structural cause, an expression of the enduring human impulse to control and manipulate natural processes. He articulates this point twice, the first through an analogy with Carson's Silent Spring:

> By driving agricultural production to new heights, consumers threatened their own health as well as the health of the planet. (Carson linked rising cancer rates and other modern diseases to

> the new pesticides.) The ultimate cause, therefore, was not simply a concentration of economic and technological power; it was a deeper and broader cultural drive to conquer nature. While it was true that some powerful agribusiness companies had led the creation of new agricultural chemicals, showing "no humility before the vast forces with which they tamper," ordinary people bore some responsibility too. Millions of people had gladly bought and used those chemicals or otherwise supported their use. The domination of nature was what they commonly sought, and chaos was what they got (Worster, 2020, p.6).

In the interpretation advanced here, this "deeper and broader cultural drive to conquer nature" is closely linked to Caponi's conception of causality as grounded in control, experimentation, intervention, and manipulation. From this perspective, the impulse to dominate natural systems can be understood as an evolutionary cognitive adaptation, particularly when considering how cultural behaviors may emerge and stabilize in response to long-term environmental pressures. As widely recognized, natural selection favors traits and behaviors that enhance survival and reproductive success. In the case of humans, the capacity to manipulate the environment, through tool use, agriculture, fire, shelter construction, and other techniques, represents a significant adaptive advantage. Cultures that promote the mastery of natural processes likely enabled human groups to survive in diverse and often inhospitable environments, facilitating the exploitation of resources at new scales. Over time, such practices became deeply embedded within cultural systems, evolving from immediate survival strategies into a broader cultural imperative, one expressed as the pursuit of progress, technological development, and dominion over nature. To the extent that these behaviors improved the fitness of populations, they may have been reinforced by natural selection, giving rise to culturally transmitted dispositions that now shape human relationships with the biosphere.

As observed in Carson's toxic and Worster's viral spring, the pursuit of control over "resources" has spiraled out of control, with catastrophic consequences. In this context, Worster argues that if we continue to disregard ecology and the theory of evolution by natural selection, we are doomed to repeat the mistakes that led us to covid-19:

> Yet most of us remain uneducated in the science needed to understand epidemic history: the Darwinian revolution has given us astounding new knowledge that can explain more profoundly than ever our history on earth. Yet even now, ignorance, or cultural resistance, characterizes many citizens, including some university professors, corporate executives, and even experts in public health. They simply haven't learned to think about disease in Darwinian terms, and thus they are doomed to repeat the ultimate causes of all the dying that keeps happening (Worster, 2020, p.17).

According to Worster, the significance of disciplines such as evolutionary biology and ecology lies, in part, in their emphasis on the interconnectedness of human life with the broader natural world. These fields challenge anthropocentric assumptions that soil, animals (including humans), and plants exist solely as resources to be exploited under capitalist and neoliberal logics (Bonneuil & Fressoz, 2024; Danowski & Viveiros de Castro, 2014). Once again, the impulse to control and manipulate natural processes, perhaps not an exclusively human trait, may be understood as an evolutionarily adaptive feature of the mind. Yet for Worster, this impulse has become maladaptive: by intensifying selective pressures on pathogens with pandemic potential, it contributes to conditions that favor spillover events and facilitate viral transmission. Random mutations that enable efficient human-to-human transmission now encounter highly favorable conditions in a densely populated and hyperconnected world, one characterized by frenetic human movement through airplanes, airports, stadiums, transport hubs, and commercial or domestic spaces across local, regional, national, and international scales. In effect, humanity has unintentionally designed an uncontrolled global experiment through its management of plants and animals. In seeking to dominate natural processes for human benefit, we have created ecological conditions that support the emergence and proliferation of novel pathogens with the potential to trigger future pandemics.

In his collection of essays Big Farms Make Big Flu: Dispatches on Infectious Disease, Agribusiness, and the Nature of Science, American phylogeographer Rob Wallace argues that the global system of agricultural production, driven by profit maximization, is a central force behind the emergence and spread of novel infectious diseases. According to Wallace, industrial farming practices create conditions for the accelerated evolution of more dangerous viral strains. High animal density, genetic uniformity, prophylactic medication, and chronically stressful environments foster the emergence of pathogens that are both more virulent and more resistant to treatment, increasing the likelihood of large-scale outbreaks in human populations. In Big Farms Make Big Flu, Wallace presents H5N1 as a paradigmatic case for illustrating the accelerated evolution of virulent strains in intensive monocultural environments. He traces the global migration of the virus to industrial farming practices and underscores the urgent need for public policy and alternative agroecological models capable of disrupting this pandemic-selection cycle. Unsurprisingly, one of today's most pressing epidemiological concerns is the potential emergence of an H5N1 variant capable of sustained human-to-human transmission, especially given the virus's ongoing spread among aquatic birds, marine mammals, and terrestrial wildlife.(Peacock, 2025)

Wallace proposes that smaller-scale, decentralized, and ecologically grounded models of food production, anchored in biodiversity and local autonomy, could significantly reduce the risk of future pandemics. The fact that industrial farms, particularly poultry operations, function as incubators for respiratory pathogens illustrates how the manipulation of animal reproduction under conditions of extreme confinement, crowded animals breathing the same air, amounts to an uncontrolled evolutionary experiment in virulence. Throughout his work, Wallace systematically identifies the corporate structures underpinning the global meat industry, exposing how they exploit traditional farmers and operate with substantial support from public subsidies. While it is well established that SARS-

CoV-2 did not originate directly from an industrial farm, its emergence is, as Worster argues, intrinsically linked to the ways in which humanity exploits so-called "natural resources".

3. PROBLEMATIC CONCLUSION

How did bat-borne viruses reach human hosts? And why did this one, in particular, achieve pandemic status? The precise transmission pathway of SARS-CoV-2 into human populations remains unknown. Yet even without identifying its exact origin, we were able to exert a degree of control over the virus's evolution and impact. Through quarantine, isolation, masking, vaccination, and other public health interventions, societies managed to mitigate the severity of the pandemic and reshape its trajectory. In this sense, the pandemic was causally explained in a philosophically coherent manner: through intervention in a complex biological and social phenomenon, we acted upon future outcomes, increasing the likelihood of improved public health. At the same time, our interventions may have inadvertently selected for viral variants better adapted to the conditions we imposed, altering the virus's evolutionary path. Despite these efforts, covid-19 now appears to be a disease that will remain with us for the foreseeable future, woven into the biological and social fabric of human life.

In New Pandemics, Old Politics, British sociologist Alex de Waal explores the militarization of public health through the recurring metaphor of war against microorganisms. Drawing on historical episodes in which infectious diseases have alarmed populations worldwide, from tuberculosis and the Spanish flu to HIV/AIDS and covid-19, he shows how the response to large-scale outbreaks has often been framed within a bellicose logic of conquering nature. According to de Waal, the metaphysical frameworks through which we interpret etiological agents shape our interactions with them (de Waal, 2021). The view of bacteria and viruses as hostile enemies to be eradicated neglects the fact that these organisms, even when pathogenic, are simply participating in the Darwinian struggle to maximize their own replication. In our zeal to eliminate them, we may unwittingly promote their evolution, an effect evident in the development of antibiotic resistance among bacteria and pesticide resistance among agricultural pests.

This adversarial stance obscures the ecological reality: bacteria, viruses, insects, arthropods, and countless other organisms form part of the intricate web of life to which humans also belong. By reducing them to economic or medical threats, we disregard their ecological roles and the broader systems upon which our own health depends. Drawing on the work of physician-anthropologist Rudolf Virchow, de Waal highlights what he calls the "indissoluble connection between medical science, economic interest, and political ideology." As Virchow famously stated, "medicine is a social science, and politics is nothing more than medicine on a large scale" (de Waal, 2020, p. 19). For de Waal, both medical science and political institutions must be critically informed by evolutionary theory and ecological understanding.

In a 2022 study, Bernstein and colleagues argued that the number of lives lost and the economic costs associated with viral zoonotic pandemics have increased markedly over the past century. In response, public policies in various countries have begun to prioritize strategies for detecting and containing emerging zoonotic threats. However, the authors contend that such interventions are typically implemented only after outbreaks are already underway, a reactive approach they fundamentally reject. Human populations maintain extensive contact with wildlife species known to harbor an astronomical number of microorganisms, including viruses to which the human immune system remains immunologically naïve, in the "virgin soil" sense described by Crosby (1976). Bernstein and colleagues examine the impacts of emerging viral zoonoses and, through a counterfactual lens, propose three actionable strategies that aim to manipulate key variables to prevent future pandemics: enhanced surveillance of pathogen spillover, including global databases for viral genomics and serology; improved regulation of wildlife trade, particularly illicit networks; and substantial reductions in deforestation. They conclude that the cost of implementing these primary prevention measures would amount to less than one-twentieth of the annual economic losses attributed to emerging viral pandemics (Bernstein et al., 2022). Yet, as with the agroecological reforms advocated by Wallace, pandemic prevention remains a politically fraught endeavor. It not only challenges entrenched economic interests but also suffers from a fundamental epistemological dilemma: how can policymakers convincingly demonstrate that a catastrophe has been averted? How can one prove that a pandemic would have occurred had we not restricted wildlife trade, reduced deforestation, or restructured industrial agriculture? This dilemma speaks to a broader existential challenge, one that demands resolution or threatens to overwhelm us. The commodification of animals, plants, and other so-called "natural resources", privatizing profits while socializing ecological and epidemiological risks (Wallace, 2016), has emerged as a profound threat to the health and well-being of both human and non-human life.

The connection between Caponi's and Worster's perspectives in the context of covid-19 lies in the tension between control as a means of mitigation and control as a root cause of crisis. Caponi's framework helps conceptualize experimental control as a rational, operational strategy for mitigating the effects of the pandemic, demonstrating how human intervention can alter the course of viral evolution. Worster, by contrast, underscores how unrestrained control, manifested in industrial food systems and the intensive exploitation of "natural resources", played a key role in precipitating the emergence of SARS-CoV-2. The pandemic thus crystallizes a paradox of control: while interventions grounded in causal understanding and experimental manipulation (such as vaccines and public health measures) proved essential for mitigating the crisis, the ecological and evolutionary destabilization brought about by global systems of biotic and abiotic extraction contributed to its origin. This duality underscores the urgency of rethinking how control is exercised, and of redesigning it in ways that respect ecological limits and evolutionary dynamics, in order to prevent future pandemics.

Data Availability Statement

No new data were generated or analyzed in support of this research.

Conflicts of Interest

The authors declare that they have no conflicts of interest concerning the research, authorship, or publication of this article.

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