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Exploring the Key Challenges Confronted by Quasi- Experimental Design in Establishing the effects of Biodiversity Change on Human Well-Being

A Literature Review

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Exploring the Key Challenges Confronted by Quasi-Experimental Design in Establishing the effects of Biodiversity Change on Human Well-Being: A Literature Review

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Table of Contents

List of Tables

List of Figures

Introduction

Today's overall species extinction rates are 1,000 higher than natural pre-human rates and they are accelerating (IPBES, 2019). This alarming trend affects all three dimensions of biodiversity: diversity within species, diversity between species and diversity of ecosystems (IPBES, 2019). The Dasgupta report emphasizes the critical role of biodiversity in supporting the stability of natural systems and at the end life prosperity. It states that "current economic activities decided by human poses serious threat to maintain biodiversity and eco-systems functions" (Dasgupta, 2021). Paradoxically, humankind depends on biodiversity. The nature is an essential foundation for human societies. For instance, 70 percent of the world major food crops depend, at least in part, on the extraordinary work of pollinators. Unfortunately, the vast array of services provided by biodiversity is not adequately incorporated into economic activities (Dasgupta, 2021).

The extinction rate and our dependency towards species place valuation of eco-systems as a key challenge. But quantifying biodiversity features and attributing them an economic value is complex: how do economic actors incorporate the work of pollinators in the price of fruits, vegetables, and nuts? First, species and ecosystems are wide and the interactions that occur within them are complex to understand and quantify. Second, biodiversity also encompasses non-market values such as the spiritual, cultural, scenic values. These are sometimes not meant to be economically quantified (E. G. Frank & Schlenker, 2016). Third, the uncertainty about the future we face makes it more challenging to accurately quantify the economic benefits of ecosystem functions.

Investigating the relationships between biodiversity and economic outcomes requires a methodological framework that carefully considers the complexities of the natural and human factors influencing biodiversity. Establishing a controlled study design raises challenges due to the influence of both environmental conditions and human activities on ecosystem services. Random assignment of a biodiversity change on two areas seems unpracticable.

Quasi-experimental design appears as an alternative technique to understand core environmental economic questions. The researcher will limit the scope by finding areas affected by the biodiversity change and similar areas (areas with the same observable and unobservable characteristics) that are not affected. Butsic et al. in 2017 demonstrate that quasi-experimental techniques enable stronger inferences on ecological economic questions, especially when starting with observational data. Still, "current knowledge about economic consequences of biodiversity change is not largely informed by quasi-experimental evidence" (E. Frank, 2022).

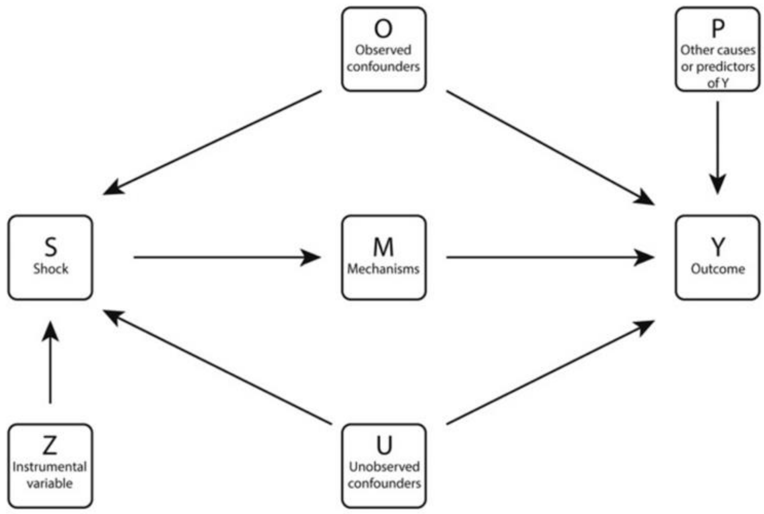
This literature review examines how quasi-experimental design can demonstrate causal link between a disruption of ecosystems and economic activity or human well-being. It sheds light on how current literature deals with obstacles to a solid causal relationship. This review aims at deepening our comprehension of the constraints and potentials of quasi-experimental design in this field. Thereby, I aspire to foster a more robust adoption of rigorous quasi-experimental practices. Ultimately, demonstrating the economic benefits of biodiversity can help policy makers in making informed decisions for a sustainable management of our footprint.

Chapter 1 - Quasi-experimental as a suitable approach

Featured in the Nature Journal, “The value of the world’s ecosystem services and natural capital” marked a significant milestone in advancing our understanding of the economic value provided by eco-systems (Costanza et al., 1997). This paper acknowledges that without the service of ecological systems, life could not be supported on this Earth. Consequently, attributing a value to the total Earth would result in an infinite estimation. Instead, searching for “marginal” services seems more meaningful. The paper in Nature provides an initial reliable estimation of value changes resulting from shifts in ecosystem services from their current levels. Since then, academic works have further explored marginal benefits of biodiversity. Part of the literature examines “how changes in biological features of the environment affect human well-being” using a special kind of experiment: quasi-experimental approach (E. Frank, 2022; E. G. Frank et al., 2022; E. Frank & Sudarshan, 2023; Horsch & Lewis, 2009; Jones, 2019). Quasi-experimental research seeks to establish a cause-and-effect link in a situation where a change in time and/or space reveals a relationship, but where the change (or treatment) is not randomly assigned like in Randomized Control Trials (RCT).

The use of quasi-experimental approach was originally developed to overcome the lack of a second identical world that could serve as a counterfactual. Biodiversity presence is determined by natural historical conditions: human intervention and environmental conditions. Climate, type of soil, topography will shape the elaboration of habitats for species. Historical land use, city development or even new conservation efforts also determine the presence of biodiversity. Furthermore, the profound dominance of the human species on the planet has permanently altered the intrinsic value and utility of other species. This raises the question of not just the current state of biodiversity but also the hypothetical maximum potential state it could have reached if human history had taken a different course. The initial state of biodiversity richness has such characteristics at baseline that will for sure influence the eco-systems services they provide. Furthermore, the large-scale and interconnected aspect of eco-systems makes it challenging to assign to nature a biodiversity change. Due to the absence of control over natural processes, the researcher is unable to assign an area to a specific biodiversity change. RCTs seems thus unethical, unpracticable, and complex. Therefore, quasi-experimental studies get leverage from real-world situations relying on observational data. It exposes the assignment to factors beyond the control of the researcher that influence the estimate, such as accidental events, institutional factors, and human behaviours (Greenstone & Gayer, 2009). These observed and unobserved confounders can distort the mechanism studied from a shock (biodiversity change) to the economic outcome (see Figure 1).

Figure 1: Causal relationship between a shock and an outcome



(Ferraro et al., 2019)

The presence of these factors introduces the potential for selection bias, where systematic differences between the treatment and the control group may cofound the estimation of the so-called "treatment effect". Consequently, this situation raises the issue of endogeneity. Further techniques to cope with problem of internal validity like matching, differences-in-differences, regression discontinuity design and instrumental variables will be explored.

The internal validity might be more easily compromised with quasi-experimental design compared with RCT. Thus, it is useful to first clarify the theory behind the chain of causal links and acknowledge the potential gaps. When assessing the direct relationship between a function of the biodiversity and an economic outcome, the causality attribution could be a big puzzle. Several intermediate causal links are used in quasi-experimental design to infer a plausible economic consequence from a biodiversity change. First, an exogenous event in the world leads to a biodiversity change. Secondly, the biodiversity change is linked to a functional loss or gain. The function losses or gains are mainly regulating services, material services and cultural benefits. Thirdly, a variation of the biodiversity function will finally lead to an economic consequence. Economic consequences include direct revenues from natural resources, labour market opportunities and health and life expectancy effects. It is crucial to unfold each link in order to explore each path, especially with eco-system services which encompass various direct and indirect benefits for a life-supporting Earth. The causal links elaborating the theory behind each paper analysed is disclosed in **Error! Reference source not found.**.

Table 1: Explored Connections Between Nature and Human Impact in Analysed Papers

Paper	Exogenous change	Biodiversity loss/gain	Functional loss/gain	Direct consequence	Socio-economic consequence
(Jones, 2019)	- Accidental transportation of invasive species (EAB)	- Forest canopy loss	- Less evapotranspiration - Less tree shade	- Higher extreme and average temperature	- Additional annual deaths - Additional emergency visits
(E. Frank & Sudarshan, 2023)	- Sudden cattle medicine use (diclofenac)	- Vultures die from infected carrions	- Removing less livestock carrion - Less competition with feral dogs and rats	- Water pollution - Infectious disease (rabies)	- Higher all-cause death rates
(Horsch & Lewis, 2009)	- Inadvertently spread of milfoil by recreational boats	- Less fish - Less plant species	- Limit native plant species to grow - Affect fisheries - Limit recreational activities	- Less attractive lake	- Reduced property/land values
(E. Frank, 2022)	- Sudden emergence of fungus disease (WNS)	- Mortality shock to bats	- No biological pest control (predation of agricultural insects)	- Less crop productivity	- Drop in crop revenues - Increase use of insecticides leading to increased human infant mortality
(E. G. Frank et al., 2022)	- Reintroduction/migration of wolves	- More wolves	- (direct) No additional livestock losses due to wolves - (indirect) Biological control (overabundant deers, coyotes)	- Small net reduction in livestock predation - Large reduction of animal-related vehicle collisions	- No decrease of livestock revenue or productivity - Less vehicle collision rates

Chapter 2 - Finding a proper control group

Despite having established a chain of causal links between a biodiversity change and an economic outcome, demonstrating its empirical evidence faces a path full of pitfalls. The key to a strong quasi-experimental model is the identification of valid treatment/affected and control group (Butsic et al., 2017). In the quest to distinguish between a group affected by a biodiversity change and an unaffected group, two main challenges arise. Primary, it is complex to find a group completely unexposed to the treatment. Then, it is tricky to locate a control group sharing the same characteristics as the treated group. We seek to confirm that the only different element is the treatment. There should be no differences in both observable and unobservable factors that might influence the outcome. Unfortunately, both challenges are colliding. Selecting a control area near the affected one will increase the similarities but at the same time lower the possibility to observe an area totally free of treatment. The researcher must balance both challenges.

2.1 Finding a zero-treatment control group

Generally, the group of study is an area: a county infected or not in the papers of Jones (2019) and E. Frank (2022), a "suitable" area for E. Frank & Sudarshan (2023), a lake for Horsch and Lewis (2009) or a forest. In the pursuit of an unaffected area, researchers must balance the trade-off between comparability and proximity. They strive to identify an unaffected region similar to the affected region, while simultaneously ensuring its independence from any indirect influence stemming from spill-over effects or contamination. However, when it comes to studying species populations, locating an area where the species in question has not established is challenging. It requires relevant and accurate data.

2.1.1 Spatial data

A primary obstacle is obtaining precise data on the **spatial location** of the biodiversity change. Numerous questions come into play: do we have enough species within the affected area? Is the monitoring comprehensively conducted across the entire area? Do we have data spanning multiple years? In their research about vultures, Frank and Sudarshan (2023) extract habitat ranges map to assess the effects of sudden and quasi-random occurrence of a vulture mortality event (see Table 1). The paper examines how the exogenous decline of vultures in India leads to sanitation problems and water pollution. It results in an increase of all-death rate in the counties they define as "suitable for vultures". They develop a dummy variable that translates a "suitable district", or "unsuitable district" based on habitat range map of vultures provided by BirdLife International[1]. Basically, habitat range map extracts ecological requirement and distribution patterns of the species to establish the potential of habitat for a certain species. The habitat range map overlaps with the district area to determine "high suitable" districts. This approach bears resemblance with the process employed to determine crop choices in agricultural production. The Global Agro-Ecological zones developed by the FAO assess a range of biologist-evidence characteristics that are suitable for the growth of a plant. These attributes encompass plant eco-physiological characteristics, climate requirement, soil composition (Fisher et al., 2021).

To construct the counterfactual form observational data, Jones (2019) uses another methodology. From detection of an invasive species, called emerald ash borer (EAB), he analyses the effect of the induced forest destruction on temperature increase (see Table 1). Emerald ash borer (EAB) is an insect that lays its eggs in holes of ash trees and gives tree tissues as food for the larvae. Instead of searching for "suitable" areas for the EAB, Jones uses areas more rapidly affected due to "nearly" randomisation of the apparition of invasive species. The possibility stems from the gradual establishment of the invasive species in the region, in contrast to the sudden disappearance of vultures. Unfortunately, the EAB detection lacks the "suitable" matching like in the paper about vultures. As the species is alien to the area of detection, it is not applicable to estimate a suitable habitat for invasive species. The strength of the "suitable" habitat range map is also to be independent of observational data that can easily be biased. When people are aware of a change in the presence of a particular species, they will put more effort in detecting it. For EAB, data collection is based on reporting by DNR Wisconsin subsequently verified by a taxonomist. This source of data is strongly dependent on human reporting.

Nevertheless, invasive species constitute a noteworthy case with matter to causal inference. Invasive species possess the trait of easily adapting to local climate conditions. Another distinctive feature of invasive species is their relentless expansion into various

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[1] http://datazone.birdlife.org/species/spcdistPOS

environments. This circumstance gives rise to a significant challenge: identifying an unaffected area. The author of the paper about EAB uses "not yet" affected counties as control group. The comparison group consists of regions where the invasive species has not been identified yet, but its detection is certain to happen in the next years. In this example, the methodology for detection is debatable: how to ensure that the area was not already affected last year but is affected only today? Along the years, the technique could evolve, becoming increasingly efficient and thereby leading to higher detection rates in the last years of the study. This would downward the estimated effect. Again, Frank and Sudarshan (2023) recognise in the case about vultures that an absolute zero-treatment area is not possible. Counties selected in control group detected "low suitable" might still be affected to some degree and this provides a lower bound of the effect. Therefore, the effect measures more a difference in the intensity of the collapse of vultures rather than the absolute loss of vultures.

2.1.2 Administrative borders

Another blocker to find the perfect zero-treatment control group is the spill-over tendency of species. There is no reason that emerald ash borer limits itself to the administrative district borders. Similarly, the case is true for vultures. Even in an area considered "unsuitable", the absence of vultures is not absolute, as their presence cannot be totally ruled out. Nevertheless, the suitable strategy minimizes this loss of information thanks to the overlapping method of habitat range and district borders.

One way to cope with the lack of respect for administrative borders for animals is explored in the paper about wolves (see Table 1). The authors analyses the economic impact of reintroducing wolves (E. G. Frank et al., 2022). They leverage from a natural discontinuity in presence of wolves to alleviate spill-over bias (regression discontinuity design). Wolves appear to stay only on the north part of Saint Lawrence River. We still must make sure the characteristics of the area are closely similar on each part of the river. In the case about bats, Frank (2022) refutes the spill-over effects (see Table 1). He demonstrates that only a small and insignificant portion of affected counties have centroid of population bats near control counties. He can thus state that it is unlikely that affected bats flight and eat pest in the control crop fields (E. Frank, 2022).

Despite implementing a meticulous sample delimitation process, an unsatisfactory sample size could hinder general inferences. For Horsch and Lewis (2009) in the article about milfoil, there are only nine lakes invaded by milfoil as treated group (see Table 1). The question about the stability and the statistical power of the model must be raised.

To sum up, there is a possible contamination between areas considering the non-resistance to administrative borders of animals or plants. The difference of biodiversity richness can be underestimated (or over-estimated) if we do not leverage reliable spatial data. It results in a biased evaluation of the economic outcome.

2.2 Finding a control group with the same characteristics

Following the collection of high-quality data and the verification of zero-treatment in one area, the second target is to get a close similarity between the treated and the non-treated area. The researcher seeks areas that share similar characteristics except for the treatment (or exposure). The two main threats are: one, the selection of exposed areas is not random and distorts the results via the selection bias; two, the presence of observed and/or unobserved variables influencing the outcome apart from the treatment (covariates). Addressing these two issues helps ensuring that the estimated effect is entirely and solely attributed to the exposure, enhancing the pursuit of accurate and credible inferences.

2.2.1 Selection bias

As we have seen, the random assignment of exposed areas is not possible, so the researcher will try to mitigate endogenous concerns. One approach is to approximate the attributes of a random assignment using an exogenous (i.e., external and unexpected) natural event. An illustrative example of this quasi-experimental instrument is the accidental introduction of invasive species within an area.

Case study: Invasive species

The invasion of ecosystems by non-native species is one of the direct pressures on eco-system services. Following the terminology of Iannone et al. in 2020, we define invasive species as a non-native species to the eco-system that is introduced and causes or is likely to cause environmental or economic harm. This broad definition immediately reveals a crucial point. The invasive species did not evolve initially in the area where it spreads. The invasive aspect shows that the organism will try everything it can to spread. Researchers would find this valuable when the introduction of the species is unintentional. It acts as a natural experiment where the change in the examined eco-system is exogenous. It claims randomness of the spread and partly ensures that there are no systematic differences between the treated and the control group. This intrinsic characteristic was explored by some researchers. In 2019, Jones used the accidental introduction of emerald ash borer in the United States of America. The EAB was exogenously introduced via trade transport from China to the USA. We can reasonably assume that the timing of the apparition and the place of introduction is accidental and not controlled by humans. Two factors strengthen the design: EAB was the main responsible of ash tree losses from 2002 to 2014 and, the spread of this invasive insect was randomly expansive.

Even out of invasive species, the biodiversity shock can be found to be exogenous. Frank and Sudarshan (2023) use the same argument in their paper about vultures. Via the sudden wide utilisation of a medicine for cattle, an unintentional large mortality shock happens to vultures in India. And again in the case of bats, the author uses "plausibly exogenous variation in biological pest control in the form of mortality shocks to bats caused by an invasive fungus species, which has spread to 36 states in the U.S" (E. Frank, 2022). In the case of wolves, the author only assumes it: "our identification relies on the migration of wolves being plausibly exogenous with respect to the outcomes we are studying". Wolves have generally not a migration behaviour. They are rather sedentary, staying on the same territory as long as there is enough prey to eat. Proving that prey non availability is not leading the wolves to migrate is more difficult. Human intention may have played a role. To sum up, three elements are essential to "partly" demonstrate randomness. First, the apparition of the species should not be determined by characteristics of the system but exogenous. Second, the biodiversity loss must be spread randomly on the environment. Third, the spread should not have effects on the outcome through another channel.

We said "partly" demonstrate randomness because still, invasive species could facilitate the spread in favourable environment. Also, the spread could be decided by human activities. In the work of Horsch and Lewis (2009), the interaction with human behaviour leads to unfulfillment of the first requirement. The spread is endogenous to the economic outcome we measure. The authors assess the impact of milfoil invasion on the property values around the invaded lake. They also measure the loss of recreational fishing. The authors state that unobserved lake-specific characteristics can affect the property value. The complexity originates from the connection between scenic views and fishing quality with the spread of the invasive species. Indeed, milfoil is spreading via sides of boats that flow on the lake. If a lake has great amenities like fishing quality and scenic view, the properties around the lake are attractive. At the same time, the lake has more chance to be visited by recreational boats. Consequently, these boats may inadvertently spread the milfoil. It ends up with popular lakes i.e., with high value properties, being more likely invaded through recreational boats. This scenario presents a case of endogeneity, wherein the exposure/invasion is correlated with the error term. One could check if the bias contradicts or amplifies the outcome. In this case, the bias goes against the effect of milfoil invasion. On the short term, spreading the milfoil increases property value because the spreading is physically materialised by more recreational boats coming. This increases the popularity of properties around the lake raising their price. Or, the researcher expects a negative consequences on property values. Hence, this biased effect goes against the results.

2.2.2 Observed and unobserved factors as covariates

While an exogenous shock can help mitigate endogeneity concerns and approximate the benefits of random assignment, it may not eliminate all potential confounding factors. Confounding factors are variables correlated with the explanatory variable of interest and exert an influence of the dependent variable. Under these circumstances, these variables may threaten the estimation of the true effect of the exposure (in this case, a biodiversity change). Possible confounding factors include climate and geographic conditions, soil composition, species distribution, population density, human inter-action, level of development, technology use and local economic fluctuations.

One issue lies in the fact that covariates fluctuate depending on the environmental conditions of the eco-system. For instance, forest destruction is mainly caused by deforestation and shifting agriculture in Latin America, Africa, and South Asia (tropical regions). In temperate regions like Europe and North America, the main causes are wildfires and forestry products (Curtis et al., 2018). So, depending on the region of the world, the covariates could be different on forest destruction. More specifically, when considering the functional activity of species, it is crucial to examine the environmental conditions. Weather conditions such as temperature and precipitation should be similar in both areas or at least not influencing the economic outcome.

A lot of covariates can exist between the exogenous change and the socio-economic consequences especially when the outcome is very complex like all-causes mortality, infant mortality, or emergency visits. The approach employed in the papers analysed is a kind of reduced form. It leverages economic and biological theory to demonstrate the relationship between the biodiversity change and the final economic outcome. Each underlying mechanism at play cannot be precisely demonstrated but authors in this review have presented an explicit cause-consequence pathway. The Table 1 at the end of Chapter 2 discloses the intermediate variables at play for the cases analysed.

In the case of the emerald ash borer (EAB) by Jones in 2019, a strong assumption is made: the biological perturbator automatically leads to the functional loss. The author assumes shade loss as a causal variable of temperature, but he does not present any correlation between a loss of shade within the country and the increased temperature. On the contrary, E. Frank and Sudarshan (2023) provide an in-depth illustration of the mechanisms at play. The paper unfolds how the death of vultures impacts sanitation through the connections with feral dogs, rabies and how it ends up in water pollution of the river. The author supports evidence for their sanitation channel by providing referenced data and previous studies on the behaviour of scavengers and on water quality. This enables to easily detect and include potential covariates.

Propensity-score matching can balance observable confounding variables we discussed (Butsic et al., 2017). The advantage of the propensity score approach is that it provides a realistic method to control the observables in a more flexible manner than with linear regression (Greenstone & Gayer, 2009). However, it is obviously unable to consider unobserved covariates like land use history.

To cope with unobserved variables, alternative quasi-experimental techniques such as differences-in-differences or instrumental variable allow for partial control over all the covariates (Greenstone & Gayer, 2009). The approach of most of the papers analysed in this review is a spatial difference-in-difference. The impact of the treatment is calculated by the change in outcome before and after the treatment subtracted by the change for the control group over time.

2.2.3 Time-variant unobserved factors as covariates

However, the differences-in-differences model assumes that in the absence of treatment, trends in outcome of both groups would have evolved the same. Unfortunately, this is not possible to verify. Time-variant unobserved factors, such as economic fluctuations, change in reporting methods and new infrastructure can potentially impact both the treatment and the outcome. One solution involves examining historical data prior to the exposure and compare the trajectories of outcomes of both groups. The study of Frank and Sudarshan (2023) on vultures adopts this strategy. The author found no systematic trend differences on the death rate of the population after considering the covariates. They even accounted for time-varying effects by including state-linear time trends and state-by-year fixed effects (E. Frank & Sudarshan, 2023). In the analysis of wolf recovery and its effect on animal-related vehicle collisions, Franks similarly employed state-by-year fixed effects. The author emphasizes the necessity of accommodating variations specific to each state. Since every state displays its own distinct trend trajectory of animal-related vehicle collision rates, it becomes crucial to consider varying trends attributable to factors like alterations in reporting methodologies and investments in road infrastructure.

Another often disregarded time-varying unobserved factor is the response of the ecosystem to a shock. This topic will be explored in the following chapter.

Chapter 3 – Ecosystems and their relationships

Analysed research papers tend to focus on one direct consequence from a decline of biodiversity, neglecting the network of interactions around it. The scope of the impacts of biodiversity loss can be extensive, yet authors frequently concentrate on specific aspects, resulting in a limited understanding of the overall effects. For instance, the study by Jones (2019) about EAB limits the investigation to the evapotranspiration and tree shade channel. It fails to consider other essential aspects such as carbon storage. The author explores this other ecosystem service in a different paper. To gain a comprehensive understanding of the consequences of biodiversity loss, researchers should adopt a holistic approach that considers multiple facets of ecosystem systems and appreciate the interconnectedness of biological elements. Emphasizing a broader range of impacts and accounting for interdependencies will facilitate better decision-making. Management and preservation of biodiversity can safeguard the health of our planet and human well-being.

3.1 Direct relationships within the eco-system

Assessing the broader ecosystem impacts holds great significance. When bats are removed, it can profoundly influence overall biodiversity, disturb vital ecological interactions, but also disrupt other essential ecosystem services. These interconnected systems can trigger cascading effects on crop productivity, extending the effects beyond the direct loss of pest control. Forest destruction is another example. The destruction may lead to the proliferation of new plants that attract birds as a food source. It creates a novel ecosystem. Moreover, certain species play a key role in defining the entire ecosystem due to their extensive and critical interactions. These species are known as keystone species, and their presence or absence can have far-reaching consequences for the stability and functioning of the ecosystem (Cardinale et al., 2012).

Case study: Keystone species

The loss of keystone species impacts in a large way the productivity of the eco-system it is part of (Koprowski, 2018 cited in E. Frank & Sudarshan, 2023). Moreover, the repercussions of keystone loss are manifold.

Inter-relations between species within an ecosystem can be explored using quasi-experimental design. Frank et al. (2022) look at the effects of a reintroduction program for wolves in the United States (see Table 1). Previously, overabundant population of deer and coyotes had had effect on the local eco-systems. Through the competition with coyotes, the population of wolves controls the overabundant wildlife populations. The authors demonstrates that the reintroduction of wolves in some states has increased the biological control of coyotes and deer. Frank again explores the network of interactions within an ecosystem in the paper about vultures (E. Frank & Sudarshan, 2023). While employing a reduced approach, this study examines two pathways through which the decline in vulture populations contributes to public health concerns. First, a decrease in vulture numbers results in reduced livestock carrions, leading to water contamination. Secondly, the absence of vultures permits scavenging by dogs and rats, which can harbour infectious diseases like rabies, posing risks to public health.

Inter-actions occur also with space. A change on a particular eco-system could impact neighbourhood eco-systems, creating difficulties to find a zero-treatment counterfactual (as developed in Chapter 3). When there is forest destruction, species lose their habitat and thus tend to migrate to another area (Larsen, 2012). The new zone may experience an intensification of species: competition for resources, changes in predator-prey dynamics and interactions between species, creating a deregulation known as the spill-over effect. This topic brings back the need to unfold the complex network of inter-relationships between species and identify any gaps or possible confounding factors.

3.2 Indirect relationships with humans

Beside directly affecting the function of an eco-systems, species and more particularly keystone species might have indirect relationships with humans. When studying the impact of reintroducing wolves, Frank explores the vehicle collision due to animal-related causes. Deer is an animal that is likely to crossroad and hit cars. By controlling the population of deer, the reintroduction of wolves displaces deer from roads. Consequently, the author can measure an economic gain in the decreased of animal-related collisions. This example shows the potential of unsuspected link between biodiversity and humans.

Apart from its indirect impact on humans, biodiversity loss can trigger response behaviours. For instance, regarding the loss of tree shade, individuals might react by purchasing more air conditioning units to mitigate an increase of temperature. In the case of vulture collapse, a government may initiate a street-cleaning campaign to address carrion concerns. These potential response behaviours must be taken into account when inferring a relationship between biodiversity loss and human well-being. Additionally, their emergence can offer valuable insights on the economic costs of ecological functions.

However, these behavioural responses can further harm the people. For instance, if a large number of people were to purchase air conditioning units, the energy consumption would surge significantly. The effect of cascading behavioural response is developed in the paper about bats. The author shows that following a sudden loss of bats population, farmers increased their pesticide use while still experiencing a drop in crop revenues (E. Frank, 2022). Frank considers that farmers compensate the service usually provided by the eco-system with more direct and cheap means like insecticides. He found an increased 35 percent use of insecticides resulting from bats drop off. From this case, Frank demonstrates that "increased use of fertilizer can compensate for soil degradation but can damage aquatic life and have negative health effects" (E. Frank, 2022). It resulted in a higher level of infant mortality. When a biodiversity loss results in a readily observable economic outcome, the way people react is likely to influence the calculation of the total effect. Consideration should be given to the substitutability of nature capital with human-produced capital.

These made-up examples highlight how biodiversity loss can lead to much higher indirect costs, sometimes even outweighing direct effects. Conversely, people tend to underestimate these connections and its underlying costs. Quasi-experimental design can reveal unexpected relationships between biodiversity and human well-being.

Discussion

While grasping the interrelations between humans and ecosystems appear straightforward, demonstrating the consequential impact of a biodiversity change on human well-being is full of pitfalls. This review has highlighted the main challenges encountered when applying quasi-experimental designs in this field.

The pursuit of a suitable counterfactual is of paramount importance. In the search for a zero-treatment group, the availability of precise and accurate data enables the isolation of the exclusive effect of a biodiversity change within a given area. Furthermore, acknowledging the inherent tendency of species to migrate from one area to another is crucial. In the search for control group with comparable characteristics, leveraging an exogenous change serves as a solid starting point for approximating a random selection. Subsequently, methods such as differences-in-differences help to balance the influence of covariates. One approach involves utilizing instrumental variables to estimate the treatment effect on a subset of the sample, followed by applying matching methods to compare similar treated and control units. This mitigates selection bias. Additionally, the presence of a breakpoint in the exposure merits investigation. Still, it is imperative to account for time-varying factors, as human systems and ecological systems evolve in response to each other.

Clearly, this review overlooks certain aspects. It fails to compare methodologies to attribute an economic value to ecosystem services. The analysed papers predominantly adopt a short-term perspective and do not encompass the entire network of ecosystem functions. It should be stressed that this study adopts an economic position. Biological features can be disregarded, as ecology is not inherently designed for economic valuation. Economists may not fully comprehend ecological systems due to inherent uncertainties and complex causal relationships, often accompanied by data gaps. Collaboration with biologists, botanists, and all environmental scientists appears insightful. Economists can enhance the communication efforts of environmental scientists to decision-makers. Indeed, quasi-experimental design offers an evidence-based assessment of the value of ecosystem services for human life support.

Our limited comprehension of all ecosystems strongly indicates that we underestimate the value of ecosystem services. Another indicator was shown in the paper about wolves. The indirect control of the overabundant coyote population outweighs the direct effect of wolves' predation on livestock. More, the quasi-irreversible aspect of invasive species or loss of keystone species informs us that natural capital cannot be restored easily.

In the times ahead, locating an unaffected control area due to biodiversity change could become increasingly challenging. Human activity has already left a lasting mark on the entire natural world, serving as an ongoing reminder of our presence. What would be the current value of bats in Europe if their role of pest control were still widely established in European and Russian fields? Informing the decision-makers about our dependency on natural capital is vital and urgent considering the earlier than expected ecological collapse (Willcock et al., 2023).

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