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Does Farmland Loss Increase Habitat for Conservation? A Counterexample from a Highly Industrialized Economy

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Abstract

A global peak in agricultural land use suggests that productive land can meet human food requirements while abandoned marginal farmland acts to conserve biodiversity. I tested this hypothesis by examining trends in economic, population, and farmland dynamics in Canada's highly industrialized province of Ontario. Farmland area decreased steadily since 1951 while the human population, urbanization and GDP increased. The result is a fatal hysteresis in which farmland consumed by urbanization and industrialization in such societies cannot be reclaimed by nature. The problem is compounded because remaining agricultural land is likely to require further intensification with less biodiversity if it is to meet human food requirements.

Keywords: biodiversity, Canada, conservation, farmland loss, food security, Ontario, urbanization

La perte de terres agricoles augmente-t-elle l'habitat pour la conservation ? Un contre-exemple d'une économie hautement industrialisée

Resumé

Un pic mondial d'utilisation des terres agricoles suggère que les terres productives peuvent répondre aux besoins alimentaires de l'homme, tandis que les terres agricoles marginales abandonnées contribuent à conserver la biodiversité. J'ai testé cette hypothèse en examinant les tendances de la dynamique économique, démographique et agricole dans la province canadienne hautement industrialisée de l'Ontario. La superficie des terres agricoles a diminué régulièrement depuis 1951, tandis que la population humaine, l'urbanisation et le PIB ont augmenté. Le résultat est une hystérésis fatale dans laquelle les terres agricoles consommées par l'urbanisation et l'industrialisation dans de telles sociétés ne peuvent pas être récupérées par la nature. Le problème est aggravé par le fait que les terres agricoles restantes nécessiteront probablement une intensification accrue, avec moins de biodiversité, si l'on veut répondre aux besoins alimentaires de l'humanité.

Mots clés : biodiversité, Canada, conservation, perte de terres agricoles, sécurité alimentaire, Ontario, urbanisation

1.0 Introduction

"As countries get wealthier from a poor baseline, natural lands are converted to agriculture at a rate that slows and then reverses." Taylor and Rising (2021, p.3)

The conservation of biodiversity depends on agricultural and other land-use practices that preserve or provide suitable habitat. In the USA (Lark et al., 2020) and elsewhere, cropland and other forms of farmland expansion destroy or displace natural habitats with severe negative consequences on native biodiversity (Benton et al., 2021; Tilman et al., 2001). The impact of farming on biodiversity may be ameliorating because, on a global scale, the world's peak in agricultural land may have passed (at about 5 billion ha in 2000, Ritchie, 2022). Yet, the area devoted to cropland continues to increase unabated (~ 1.6 billion ha in 2029, Ritchie, 2022; analyses in Goldewijk et al., 2017 yielded somewhat higher values while those in Taylor & Rising, 2021, yielded somewhat lower estimates; both retained the same general pattern). Even so, any amelioration will be patchy because patterns in land-use transitions are variable across the globe and depend, among other factors, on economies, population growth, and agricultural technology (DeFries et al. 2004).

A peak in agricultural land, and subsequent decline with economic development, might nevertheless help to tip the scales of land use in favor of conserving biodiversity (e.g., Taylor & Rising, 2021). Taylor and Rising's (2021) explanation for this effect is a version of density-dependent habitat selection (Fretwell & Lucas, 1969) that can be paraphrased as follows: When the population density and GDP of agrarian societies is low, farmers concentrate on the most productive land. As the population grows, ever more marginal land is converted to agriculture. Industrialization reverses the process. Marginal farmers move to cities where they simultaneously contribute to urbanization and the return of marginal farmlands to quasi-natural conditions that can harbor more biodiversity. Deficits in food production associated with urban migration are counter-balanced by technological advances and intensified agriculture on the 'best' croplands.

Tracking these trends through time, and associating the trends with economic development, reveals a global tipping point at approximately $5,000 US GDP per capita (Taylor & Rising, 2021). Prospects for conservation can be further enhanced by invoking best agricultural practices and policies to preserve semi-natural habitats such as field margins, fallow, and woodlots (Estrada-Carmona et al., 2022; European Commission, n.d.; European Environment Agency, 2022; Jeanneret et al., 2021; Morales et al., 2022). GDP varies among and within nation states, so although biodiversity is threatened while agricultural expansion displaces natural habitats in several countries, area for biodiversity appears to be increasing in others. The importance of GDP is highlighted by global analyses where it is a significant predictor of national threats to biodiversity for both birds and mammals (Morris & Kingston, 2002).

But limited area, continued economic expansion, and growing human populations suggest a supra-industrial period during which farmland is consumed by urbanization and its far-reaching industrialization of rural landscapes. The suggestion is bolstered by concerns on future food security (e.g., Canada, [Caldwell et al., 2022], USA [Francis et al., 2012], and China [Zhu et al., 2022] among others), and the role of farmland in either endangering or preserving residual biodiversity (Dudley & Alexander, 2017; European Commission 2019, n.d.; European Environment Agency, 2022; Wrzaszcz & Prandecki, 2020).

With these points in mind, I evaluate underlying mechanisms of farmland abandonment by examining long-term trends in farmland and the farming economy in the highly urbanized and increasingly industrial province of Ontario, Canada. I begin with a brief description of the methods I used to search for patterns in publicly available data. I use those data to describe the basics of the province's economy and record on biodiversity conservation in the 21st century. I explore a variety of social and industrial stressors on agricultural land and highlight government policies that endanger it. I describe the speed and patterns of farmland loss, evaluate the generality of patterns with comparisons to other Canadian provinces, and seek economic correlates that might explain those patterns. I conclude by revisiting tipping points in farmland area, discuss some of the consequences for food security and conservation, and finish with suggestions to limit the damage.

2.0 Methods

I searched a variety of publicly available government—primarily the Governments of Canada and Ontario including Canada's five-year agricultural census (list in Morris, 2024a)—and global (World Bank) datasets. I used the data to summarize the current and past state of Ontario's economy, biodiversity conservation, farmland, population size, and pattern of urban and industrial expansion. I supplemented these data with those included in (a) government audits, news briefs, reports, and appropriate legislative acts and activities; (b) summaries available from appropriate companies and industrial organizations; and (c) news reports. I did so at a variety of spatial and temporal scales, and merged data by time and space to evaluate patterns of farmland loss and changes in land use, and to search for possible causal relationships. In each case I used the longest time series for which data were available. I compared Statistics Canada data from Canada's other provinces to explore the generality of the Ontario pattern of farmland loss.

Canada's census of agriculture takes place during the national census at 5–year intervals. Complete data are available from 1951 to 2021, with sporadic data in earlier census periods. Most of my analyses thus use only the complete 1951 to 2021 data. The definition of a 'census farm' varied over time. For example, census periods between 1991 and 2021 defined 'farm' as an agricultural operation producing, for sale, at least one agricultural product (Statistics Canada, 2022a). In 2021 the definition was changed to a unit producing agricultural products that reported to the Canada Revenue Agency (Chen, 2022). Although this change should influence only small-scale farms, I guarded against bias by ensuring that data from the 2016 census documented the same pattern as those from 2021.

I used stepwise multiple regression to assess potential relationships between total farmland and the two dependent variables (human population size, area of cropland) available in the longest time series of 15 census periods (1951–2021; I could not use multiple regression to assess the relative importance of GDP because it was included in only nine census periods). I used linear and polynomial regressions to evaluate which provided the best temporal fits of data for croplands (15 census-period time series), fallow and pasturelands (a 10-census time series; 1976–2021) and GDP (a nine-census time series; 1981–2021). These regressions enable an assessment of whether trends are changing at constant, accelerating, or decelerating rates.

I used linear regressions to test whether land use was better related to GDP or human population size. I chose GDP over Taylor and Rising's (2021) preference for per capita GDP because GDP better represents the total economy, and because per capita GDP was well above the proposed tipping point of $5,000 US during the entire period under study. Using GDP also avoids the potentially confounding effects of population size and economic growth that determine per capita economic activity.

I attempted to gain deeper insights into the mechanisms underlying patterns of farmland loss by exploring the relationship between population size and GDP using annual Canada-wide statistics available from the World Bank. I reasoned that a strong positive relationship between population size and GDP would allow population size, as used in the multiple regression predicting farmland area, to serve as a surrogate for GDP. A strong relationship would allow me to use the surrogate (population size) to test Taylor and Rising's (2021) global association of farmland with GDP while also yielding a greater understanding of the joint effects of GDP and population size on farmland area. All statistical analyses were performed with Minitab® Version 20 and IBM® SPSS Statistics Version 28 software.

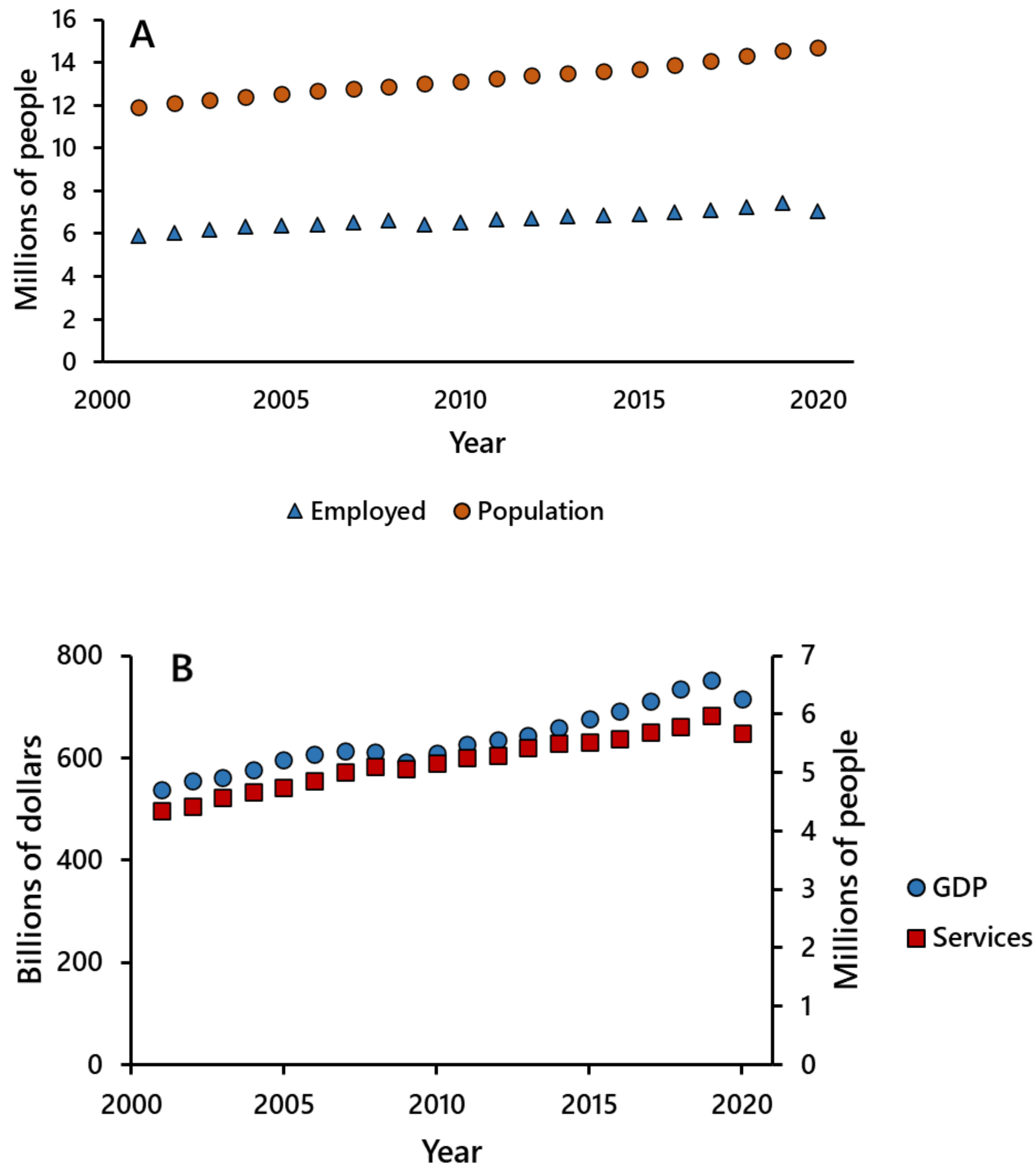
Ontario farmlands in the agricultural south contain the majority of the area's forested habitat, and thus play a significant role in conserving biodiversity. That role is diminished when portions of these remnant woodlots are converted to residential or other human uses. I quantified this effect by searching Google Earth satellite imagery (Google Earth, n.d.) in order to count woodlots with residences, or related human development such as clearings and driveways, in the province's most southerly and least-forested Essex County (Elliott, 1998). I excluded woodlots with extreme disturbances such as recreational areas, golf courses, quarries, and industrial complexes, as well as numerous strip developments along the county's waterways. I repeated the count for woodlots that revealed no intrusions by human infrastructure. I counted otherwise adjacent woodlots as separate entities if they were severed by roadways or clear property boundaries. My counts are nevertheless likely to represent a minimum estimate of human encroachment because I often observed multiple dwellings within a single counted woodlot.

3.0 Results

3.1 Overview of Ontario's Economy

Ontario is the workhorse of Canada's economy. The province contributes approximately 38% of the nation's GDP with a similar proportion of Canada's population (Statistics Canada, 2022b, c). Ontario's population has been growing at a more or less constant rate since 2001, but with an upsurge in growth beginning about 2015 (see Figure 1A). Total employment during that time has also been linear, albeit with minor discontinuities associated with the economic downturn of 2008 and the SARS-CoV-2 epidemic in 2020 (see Figure 1A). Total GDP mirrors both patterns with an overall linear trend marked by economic readjustments in 2008 and 2020 (see Figure 1B). The economy is highly diversified with most employment in an expanding services sector (80% in 2020, see Figure 1B). Employment in agriculture, although much more variable, is in decline and represents approximately 1% of the provincial workforce.

Figure 1. Ontario population and economic metrics through time. A, population size and employment. B, GDP and people engaging in service industries, Ontario's highest employment sector.



Sources: Statistics Canada Table 36-10-0402-01 Gross domestic product (GDP) at basic prices by industry, provinces and territories (× 1,000,000). Retrieved February 5, 2023, from https://doi.org/10.25318/3610040201-eng; Statistics Canada Table 14-10-0092-01 Employment by industry, annual, provinces and economic regions, inactive (× 1,000). Retrieved January 16, 2023, from https://doi.org/10.25318/1410009201-eng; Statistics Canada Table 17-10-0005-01 Population estimates on July 1st, by age and sex. Retrieved January 17, 2023, from https://doi.org/10.25318/1710000501-eng.

3.2 Ontario's Record on Conserving Biodiversity in the 21st Century

Ontario's Endangered Species Act (2007) requires the Committee on the Status of Species at Risk in Ontario to provide an annual report to the relevant minister of all newly classified species at risk (Section 6:1). The act further requires the 'Ministry official' to make and file the list as classified by the Committee on the Status of Species at Risk in Ontario (Section 7:1). That list of regulated species increased from 184 species in 2008 to 243 in 2018 (Office of the Auditor General of Ontario, 2021). No new regulated species were added in either 2019 or 2020 because the independent scientific committee responsible for classifying species "lacked quorum to function" (Office of the Auditor General of Ontario, 2021, p. 4).

The act allows automatic conditional exemptions that impact species at risk. The vast majority are issued for infrastructure and development. More than 2,000 conditional exemptions involved activities with potentially negative impacts on bobolinks (*Dolichonyx oryzivorus*) and nearly as many for eastern meadowlarks (*Sturnella magna*), both of which are listed as threatened and use farmland as breeding grounds (Office of the Auditor General of Ontario, 2021). Over 300 permits have been issued for activities that harm species at risk, and none has ever been denied (Office of the Auditor General of Ontario 2021, n.d.).

More generally, the Canadian Living Planet Index, a metric of biodiversity based on time series of population abundances, reveals a stable trend for all vertebrate species included but a concerning 59% decline by Canada's species at risk between 1970 and 2016 (World Wildlife Fund–Canada 2020; based on 629 populations of 139 vertebrate species deemed at risk by the Committee on the Status of Endangered Wildlife In Canada (COSEWIC). Many of those species' ranges include the southern regions of Canada, such as southern Ontario, where human activities and associated land use are most intensive (World Wildlife Fund–Canada, 2020). The percentage of farmland deemed of high or moderate quality for terrestrial vertebrates declined by nearly two-thirds from 1986 to 2011 (17.5% in 1986 to only 6.5% in 2011) while that considered of very low quality increased (from 38.5% in 1986 to 64.6% in 2011; Javorek et al., 2016). Increases in reduced tillage and no-till farming (Daneshfar & Huffman, 2016) may help to stabilize or reverse some of these trends, but those practices depend on effective herbicides that might have opposing impacts.

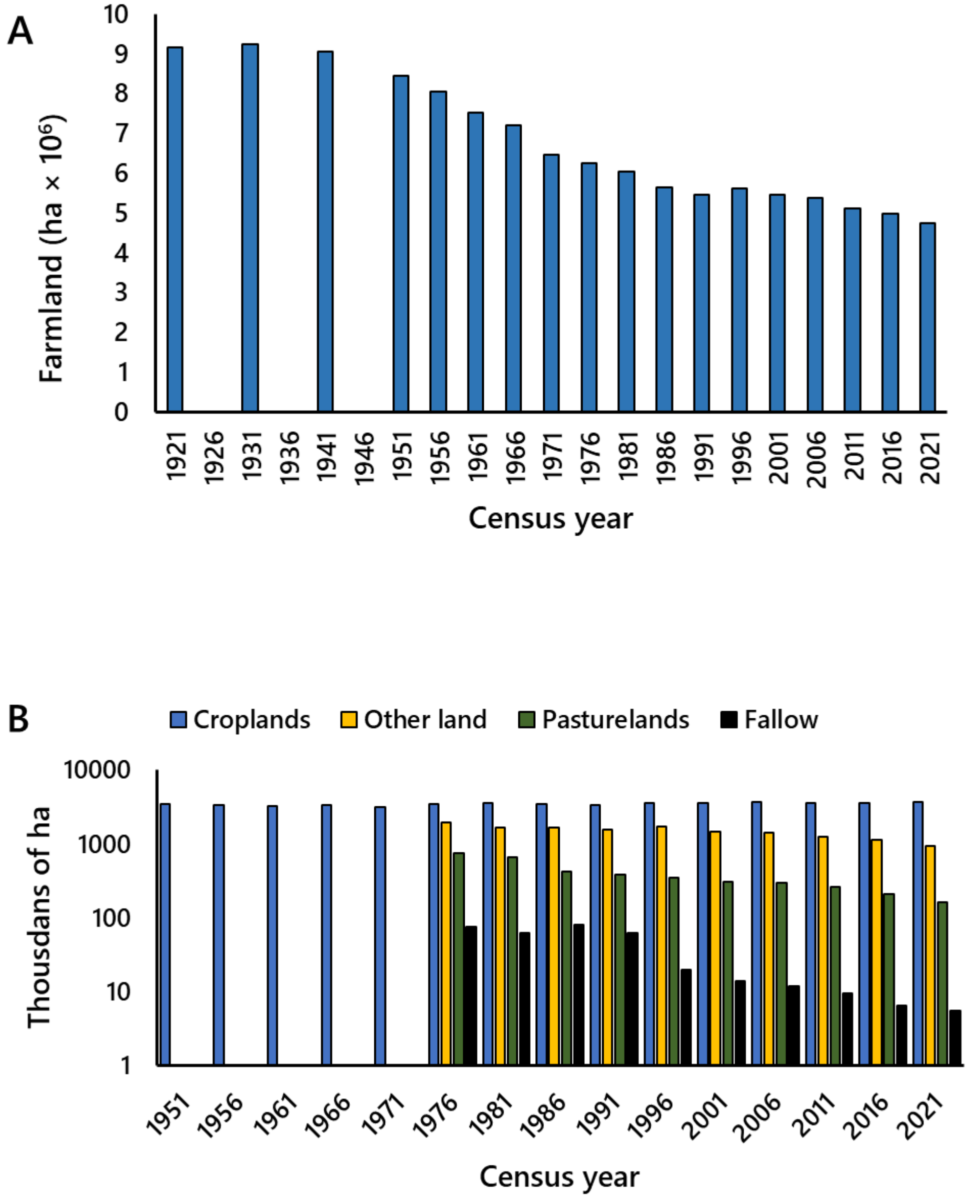
Less than 5% of the land area is covered by forest in Essex and Kent Counties (Elliot, 1998) that comprise the southernmost part of the province. A more recent estimate is close to 6% or 9,918 ha (Pannunzio, 2019), but that estimate includes wooded swamps and swamp woodlots unsuitable for human occupation. What little forest remains is highly fragmented by agriculture and suburban sprawl.

My Google Earth survey of Essex County revealed human intrusions (mostly residential) in 156 woodlots ranging in size from approximately 1 ha to approximately 25 ha. I observed no obvious human intrusions in 453 other woodlots (25.6% of all woodlots included human development).

3.3 Ontario's Record of Farmland Loss

Ontario's farmland area declined from approximately 9.2 million ha in 1921 to 4.8 million ha a century later (52% of the 1921 estimate), but complete 5-year census data are available only for the interval between 1951 and 2021. During that time, farmland area in Ontario decreased somewhat stepwise with a loss of approximately 1.24 million ha between 1951 and 1966 (226 ha daily); 1.01 million ha (110 ha daily) between 1971 and 1991, and 855,301 ha (94 ha daily) since 1996; mean daily loss since 1951 = 144 ha (see Figure 2A, and data in Morris, 2024b). The decline in the number of farms recorded by the census dropped even more dramatically from 149,920 in 1951 to only 48,346 (32%) in 2021. Two-thirds of the decline in farmland since 1976 is attributed to loss of 'other land' (includes categories such as woodlands, wetlands, natural grazing land, idle land etc.; the percentage decreased from 31% of the total farmland in 1976 to 20% in 2021, see Figure 2B). Croplands (e.g., maize, wheat, soybeans) that increased by 164,000 ha since 1951 appear to have plateaued with total cropland area more-or-less constant at 365,000 ha during the past two decades (see Figure 2B, Table 1; 56% of total farmland in 1976; 77% of the total in 2021). Although some of the 'other land' category has no doubt been converted to growing crops, much of the increase in cropland appears to have been achieved through dramatic declines in pasturelands and fallow (581,000 and 70,000 fewer ha in 2021 than in 1976, see Figure 2B and Table 1; the change in fallow is unlikely caused by reduced summer fallow that is practiced primarily in semi-arid regions of the Canadian prairies [Daneshfar & Huffman, 2016]). Pasturelands declined sharply between the 1981 and 1986 census periods (nearly 226,000 ha). Fallow lands underwent an even more precipitous drop of approximately 44,000 ha between the 1991 and 1996 census periods. Although both continue to decline, pastureland (3.4%) and fallow area (approximately 0.1%) were small fractions of the total farmland in 2021.

Figure 2. The temporal decline of agricultural land in Ontario. A. Total farmland (by 5-yr census period beginning in 1951). B. Four farmland categories (by 5-yr census period beginning 1976). Note the difference in scale.



Source: Statistics Canada Table 32-10-0153-01 Land use, census of agriculture historical data. Retrieved January 9, 2023, from https://doi.org/10.25318/3210015301-eng.

Table 1. *Summaries of Causal Relationships Influencing Farmland Loss*

Analysis[1]	**Dependent variable (Y)**	**Predictor variable(s) (X)**	**Statistically significant model**	***F* ratio**	***Df***	***P***	R^2_{adj}
Multivariate linear regression	Total farmland (ha)	Population size on 1 July (X1); cropland (X2; ha)	Y = 9488221 – 0.342 X1	119.9	1,13	< 0.001	0.866
Quadratic regression	Total farmland (ha)	GDP (chained 2012 dollars [millions])	Y = 12127484 – 19.03X + 0.000014 X2	246.8	2,6	< 0.001	0.984
			Linear term	136.5	1	< 0.001	
			Quadratic term	18.4	1	0.005	
Quadratic regression	Canada GDP (trillion $US)	Canada population (1997 - 2021)	Y = - 6.92 + 0.419X -0.005X2	510.7	2,22	<0.001	0.977
			Linear term	505.5	1	<0.001	
			Quadratic term	23.4	1	<0.001	
Univariate linear regression	Total farmland (millions of ha)	Per capita GDP (chained 2012 dollars)2	Y = 12.57 – 0.000167 X	113.79	1,7	< 0.001	0.934
Quadratic regression	Pastureland (ha)	Census (1976 = 0)	Y = 720550 – 117036 X + 6598 X2	63.47	2,7	<0.001	0.933
			Linear term	55.72	1	<0.001	
			Quadratic term	9.82	1	0.017	
Univariate linear regression	Fallow (ha)	Census (1976 = 0)	Y = 77072 – 9346 X	35.03	1,8	< 0.001	0.791
Univariate linear regression	Cropland (ha)	Census (1951 = 0)	Y = 3309686 + 26422 X	15.51	1,13	0.002	0.509

Notes: Multivariate linear regressions between total Ontario farmland and population and economic predictors, the shapes of relationships of total farmland with GDP and per capita GDP, Canada GDP and population size, and the shapes of reductions in pasturelands, fallow, and cropland across census periods.

[1] Shape estimates included both quadratic and univariate linear regressions. Only statistically significant models are included here. [2] Calculated as GDP/Population size on July 1; a quadratic term was marginally significant (P = 0.057) and yielded a model R^2_{adj} = 0.96.

It is not just Ontario that is losing farms and farmland at an alarming pace (see Table 2, and data in Morris, 2024b). In New Brunswick, the number of censused farms in 2021 was only 7% of the number censused in 1951. The percentage was somewhat higher in Newfoundland and Labrador (9.5%), Nova Scotia (11.7%), and Prince Edward Island (11.8%). The farmland area in New Brunswick in 2021 was approximately 20% of that in 1951; the percentage was marginally higher in Nova Scotia (23%). The general pattern is prevalent in other provinces but with higher percentages in the western prairies. The percentage of farmland reported in the 2021 census, relative to the peak during the preceding 70 years, varied between 85% (Alberta), 90% (Manitoba), and 91 % in Saskatchewan. Farmland area peaked during intermediate census periods in all western provinces (Manitoba 1986, Saskatchewan 1991, Alberta and British Columbia 2006). Substantial farmland losses also occurred in the USA (~ 26% loss from 487 million ha in 1951 to 362.3 million ha in 2021; USDA, n.d.).

Data on the number of farms and farmland area reported in 2021, other than the number of farms in Alberta (41,505 in 2021 *vs* 40,638 in 2016), were all lower in magnitude than those in 2016 (Morris, 2024b). Data reported in 2016 for all provinces were lower in magnitude than those reported in 2011. It thus appears that the data from 2021 were consistent with earlier trends even though the definition of ‘farm’ changed in that census.

Table 2. *Temporal Relationships of Numbers of Farms and Cropland Area*

Province	**Variable**	**Model**	**Change (max year)**	***F***	***P***	R^2_{adj}
NL	Farms	Quadratic (+)	-3282 (1951)	57.28	<0.001	0.889
	Area	None significant	-27351 (1991)	2.58	0.117	
PEI	Farms	Quadratic (+)	-8942 (1951)	370.45	<0.001	0.981
	Area	Quadratic (+)	-239020 (1951)	145.38	<0.001	0.954
NS	Farms	Quadratic (+)	-20774 (1951)	61.04	<0.001	0.896
	Area	Quadratic (+)	-992955 (1951)	93.55	<0.001	0.930
NB	Farms	Quadratic (+)	-24580 (1951)	53.15	<0.001	0.882
	Area	Quadratic (+)	-1126991 (1951)	86.47	<0.001	0.924

Table 2 continued

PQ	Farms	Quadratic (+)	-104956 (1951)	325.70	<0.001	0.979
	Area	Quadratic (+)	-3648636 (1951)	234.33	<0.001	0.971
ON	Farms	Quadratic (+)	-101574 (1951)	820.00	<0.001	0.992
	Area	Quadratic (+)	-3688298 (1951)	285.39	<0.001	0.976
MN	Farms	Quadratic (+)	-37840 (1951)	932.07	<0.001	0.993
	Area	Quadratic **(-)**	-811596 (1986)	45.60	<0.001	0.864
SK	Farms	Quadratic (+)	-77890 (1951)	563.26	<0.001	0.988
	Area	Quadratic **(-)**	-2476974 (1991)	41.96	<0.001	0.854
AB	Farms	Linear (-)	-42810 (1951)	197.97	<0.001	0.934
	Area	Quadratic **(-)**	-1202170 (2006)	27.25	<0.001	0.790
BC	Farms	Linear (-)	-10565 (1951)	9.23	0.010	0.370
	Area	Quadratic **(-)**	-549729 (2006)	20.85	<0.001	0.739

Notes: Most statistically significant general relationships between the numbers of farms reporting to Canada's Census of Agriculture and area (ha) of cropland during 5-year census periods between 1951 and 2021. Positive and negative signs in parentheses indicate the sign of the highest (usually quadratic) term in the model (all linear terms were negative in positive quadratic equations thus indicating a slowing rate of decline). Provinces are sorted from east to west. All relationships tested against linear and quadratic solutions. Quadratic solutions for MN and SK included non-significant linear terms. NL = Newfoundland and Labrador, PEI = Prince Edward Island, NS = Nova Scotia, NB = New Brunswick, PQ = Quebec, ON = Ontario, MN = Manitoba, SK = Saskatchewan, AB = Alberta, BC = British Columbia. Territories excluded because farmland area is limited.

3.4 Urbanization

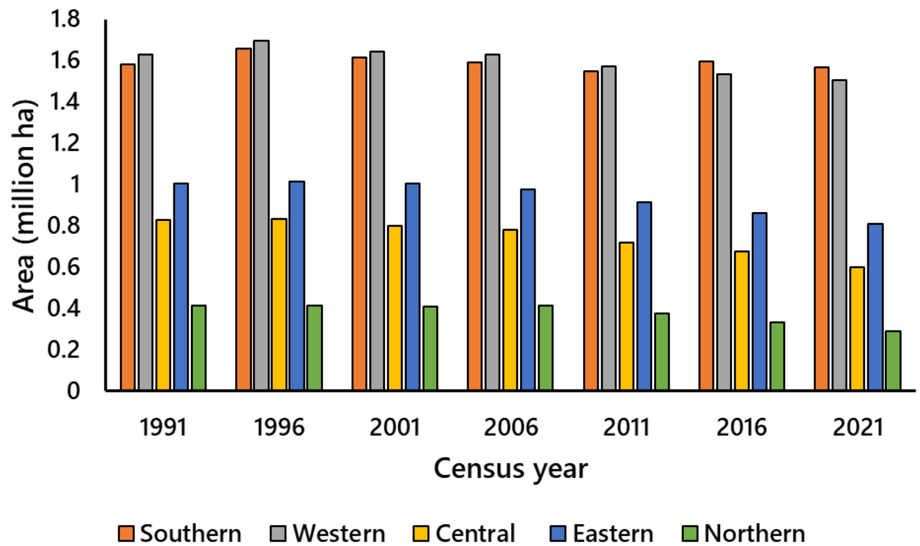
Canada's cities tend to be located on the most fertile farmland (Pope, 2016), and especially so in southern Ontario (Statistics Canada, 2016). Statistics Canada agricultural census data are insufficient to determine how much of the reduction in provincial farmland area represents land converted to non-agricultural uses such as urban expansion, highways, and other permanent non-agricultural land-uses. We can nevertheless estimate the effect from work by other researchers, and data on built-up areas in 13 census metropolitan areas located in southern Ontario. The area of those 13 metropolitan locations increased by 339,100 ha between 1971 and 2011 to a total exceeding 1 million ha (data from Table 2.2; Statistics Canada, 2016). The amount of urban area on dependable land (Canada Land Inventory classes 1 through 3) more than doubled from 1971to 2002 (from 6,900 km^2 to 14,300 km^2; Hofmann et al., 2005), continuing the pattern observed through 1996 (Hofmann, 2001). Estimates of losses of prime agricultural land for a much shorter period is substantially less (29,217 ha between 2000 and 2017) when using official plan amendments from southern Ontario municipalities (Caldwell et al., 2022).

Data based on Statistics Canada's Census of Agriculture record a total loss of 565,974 ha in the 'southern' part of the province (includes Statistics Canada classifications of Southern Ontario, Western Ontario, Central Ontario, and Eastern Ontario; see Figure 3) between 1991 and 2021 (~ 486,000 ha using the same boundaries as Caldwell et al., 2022 [Figure 1]). How much of that total can be ascribed to urbanization? We can generate a crude approximation using the mean annual percent increase in metropolitan areas between 1971 and 2011 (total increase of 150.8%/40 years = 3.77% annually; based on the increase of 339,100 ha through 2011 from the total of 224,800 ha in 1971; Statistics Canada, 2016 [Table 2.2]). Applying that value to the 1991 total of 446,400 ha yields a predicted 113.13% increase of 505,012 ha, a shortfall of ~ 60,000 ha from Statistics Canada's estimated loss of 565,974 ha.

Population growth and demand for space is not restricted to metropolitan areas, so I contrasted the rate of recent population growth in Ontario's 15 larger population centers (>80,000 residents) with that of smaller ones (1,000 to 80,000 residents; data from Statistics Canada, 2022d). The human population in large centers grew by 5.7% between 2016 and 2021 (from 9.53 million to 10.07 million). Growth in 281 smaller centers rose by 7.1% (from 2.1 million in 2016 to 2.26 million in 2021). It is reasonable to expect that lot sizes, including acreages, are larger in smaller centers and that the impact of associated infrastructure is also greater than in large urban centers. Rates of population growth are somewhat higher in the southern portion of the province that contains the majority of high-quality farmland.

Populations grew by 4.7% in even smaller communities (from 1.80 million in 2016 to 1.89 million in 2021), again with potential for larger lot sizes. One of the smaller centers, St. Thomas, received provincial authority to annex 607 ha of farmland for an industrial electric-vehicle mega-site battery manufacturing plant (Butler, 2023). Spin-off industries, houses, and other infrastructure are likely to increase farmland loss (Zandbergen, 2023). Other large-scale projects are converting farmland to industrial use elsewhere in the province (e.g., Fraser, 2024). It is thus likely that urban and industrial development in smaller centers can account for much, if not all, of the otherwise 'unaccounted' 60,000 ha of farmland loss noted above. It is also clear that built-up areas, including industry, suburbia, so-called *rurban* development (e.g., hobby farms and residential acreages on the outskirts of urban centers [Stobbe et al., 2009] and along rural roads) as well as their associated transportation, energy, and resource systems are increasing throughout the province at the expense of ever less total farmland.

Figure 3. Farmland area in five regions of Ontario from 1991 to 2021.



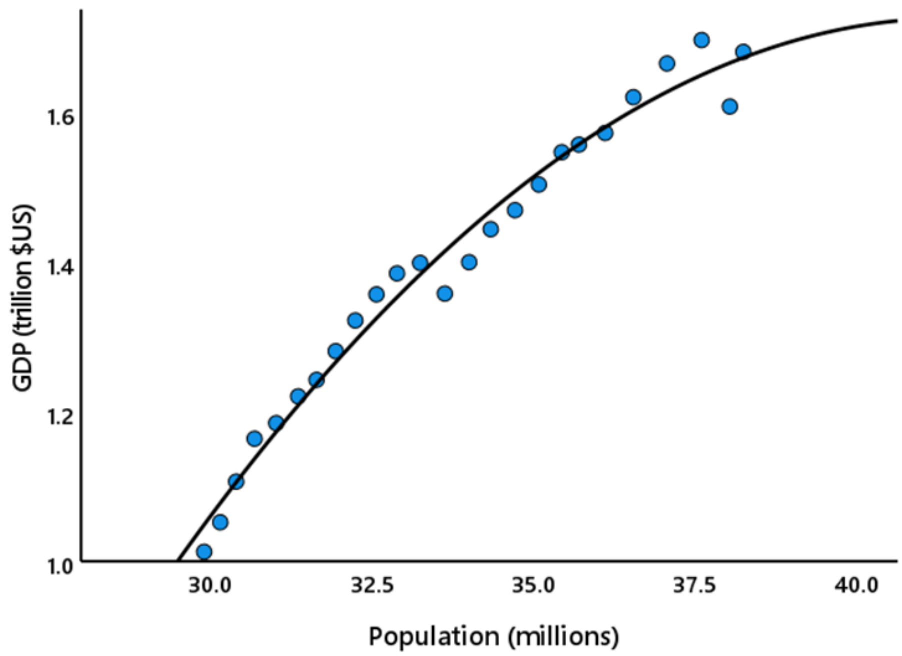
Source: The Ontario Data Catalogue census farm data collection (data based on the Statistics Canada Census of Agriculture). Retrieved January 16, 2023, from https://data.ontario.ca/dataset/census-farm-data-collection.

3.5 Correlates and Predictors of Farmland Loss

During the past two decades, human population size, rather than the area of cropland, was a highly significant negative predictor of farmland area (see Table 1; stepwise multiple linear regression). As expected from Taylor and Rising's (2021) analysis, Ontario's farmland area declined with increases in GDP during the nine census years when those data were available (see Table 1). But the decline, at least in the southern part of the province, appeared mostly due to urban and industrial expansion (above) rather than through abandonment of marginal lands. Intriguingly, the highly significant fit with GDP (quadratic) was slightly better than that with per capita GDP (linear, Table 1; also true for the linear terms, R^2_{adj} = 0.944 vs 0.934 respectively).

Data from the World Bank on Canada's annual GDP (constant 2015 $US) revealed that GDP increased dramatically from 1.01 trillion dollars in 1997 to a maximum of 1.70 trillion (68% increase) in 2019, but at a slowly decelerating rate (see Figure 4). Population size over the same interval increased from 29.9 million humans in 1997 to 38.2 million (28% increase) in 2021, but at a slowly accelerating rate (data from Statistics Canada reveal a dramatic 2.7% annual growth rate to 39.6 million on 1 January 2023; more than 42% of that growth occurred in Ontario, Statistics Canada, 2023a, 2023b). Taken together, these patterns produce a decelerating relationship between Canada's GDP and population size (see Figure 4 & Table 1). Although the overall fit is extraordinarily strong (R^2_{adj} = 0.98), clear departures are evident during the 2008 economic slowdown and the 2020 SARS-CoV-2 epidemic. Even so, the fit between GDP and population size verifies that the strong relationship between total farmland in Ontario and population size reported above corresponds with similarly general trends between total farmland and Ontario's GDP. Reductions in Ontario's farmland through time are tightly linked to the interdependence between human population size and GDP. Farmland is being consumed by the urban-industrial complex, not returned to quasi-natural habitat.

Figure 4. The quadratic relationship between Canada's GDP and population size from 1997 to 2021.



Source: World Bank. Retrieved February 1, 2023, from https://databank.worldbank.org/source/world-development-indicators.

4.0 Discussion

4.1 The Decline of Ontario and Canada's Farmland

Farms and farmland area in Ontario, and Canada's eastern provinces, have declined remarkably since 1951; a date that closely corresponds with the 1950 acceleration in human influences on the Earth system (e.g., the Anthropocene, Steffen et al., 2015). A similar decline in farm numbers occurred in the United States associated with broad-scale technological change (Dimitri et al., 2005). But in Ontario, at least, and even with rather crude calculations, the accusatory finger points toward ever increasing consumption of farmland by urban and industrial expansion. In southern Ontario, in particular, there is little farmland that can be abandoned without further compromising production of dominant human food items such as grains, oilseeds, roots, and tubers (e.g., Xia et al., 2022), and extensive agriculture required for livestock production. Greenhouses and vertical farming initiatives have significant potential to increase Ontario's production of some fruits and vegetables (Pereira et al., 2024), but with relatively high energy and fertilizer consumption and expanding infrastructure.

Declines are somewhat later in Canada's west following the northward extension of agriculture from the grasslands in the southern prairies to northern woodland soils (Hedlin, 1995). The same pattern of expansion into less optimal conditions is occurring to variable degrees across the high prairies in the Peace River regions of

Alberta and British Columbia (Bowen, 2002; Don Cameron Associates, 2014; Vanderhill, 1982). The patterns, in combination with rapid increases in human population size and GDP, cast a pall on the proposition (Taylor & Rising, 2021) that per capita GDP yields peak farmland and a return of unproductive land to a more natural state, at least in supra-industrial societies.

4.2 Does the Future Hold Promise for More Biodiverse Rural Landscapes?

There is no doubt that some of the decline in Canadian farmland includes abandonment of marginal farmland and its replacement by other uses, including quasi-natural habitat. But it is patently clear that urbanization, its industrial tentacles, and values based on myths of growth without limits, represent the greatest current threat to Ontario's farmland and its ability to harbor biodiversity. It is reasonable to assume that the same is likely in similar economies where the objective of ever--increasing human populations and GDP includes farmland conversion. Future food security in such economies is more likely to involve reconversion of marginal lands to agriculture, rather than setting them aside to conserve biodiversity. Even if it is possible and desirable to meet food requirements by returning abandoned marginal farmland to crop production, doing so will likely require more fertilizer and other inputs in order to approach the yields of fertile lands lost to urbanization and industrial infrastructure.

Conversion of marginal farmland may be insufficient in any case because increases in global farmland required to meet the needs of the world's growing human population (e.g. Haddad et al., 2015; Tilman, 1999) are compromised by the continuing and massive expansion of urban centers (Seto et al., 2012). The global urban population is expected to increase by 2.5 billion in only 30 years and, in combination with economic growth, will form the major drivers of urban land expansion (Mahtta et al., 2022). Early projections predicted that between 2000 and 2030, urban areas would consume approximately 30 Mha of Earth's most productive croplands, especially in Asia and Africa, and reduce crop production by about 4% (Bren d'Amour et al., 2017). Over a longer term, the preferred Shared Socioeconomic Pathway (SSP; O'Neill et al., 2017; Riahi et al., 2017) of sustainability (SSP1) projects an increase in urban area to about 2.6 million km^2 by 2100 (260 Mha, approximately triple the 0.83 Mha revealed by satellite imagery in 2013; Figure 1 in Li et al., 2021; less preferred options of regional rivalry [SSP3] and inequality [SSP4] project a doubling of urban area). If the projections hold, urban area in 2100 would be larger than the global area dedicated currently to wheat production (~ 230 Mha [Tilman, 1999])—a value of nearly 19% of Taylor & Rising's (2021; in Ritchie, 2022) estimate of 1.38 BHa of cropland in 2010.

Simulations of urban land demand paint a somewhat more optimistic future with a downturn in demand late in the current century (Chen et al., 2020). That optimism must be balanced against the inability to reconvert urban areas to productive agriculture, and the potential socio-economic disruptions that will ensue (Chen et al., 2020).

4.3 Implications for Food Production and Security

Urbanization and rural supra-industrial complexes portend further declines in Ontario's farmland area, food production, and agricultural biodiversity, particularly so in the southern portion of the province. Sadly, it is the south that contains the vast majority of the province's high-quality land with the most amenable climate for growing food, and the highest biodiversity. On a more positive note, northern

Ontario's clay belts, mostly forested legacies of large glacial meltwater lakes, could improve the province's food security if they were converted to farmlands. The northeastern portion's approximately 1.8 million ha of potentially viable agricultural land (Robinson et al., 2020) rivals that available in southern Ontario. The north's short growing season combined with harsh winters, and long distances to markets, create substantial but not insurmountable challenges for agriculture, albeit with far less diversity of crops and produce than are grown in the south. Agricultural expansion in the north risks infringing on the rights and territories of First Nation's peoples, creating negative impacts on the north's forest industries, and hindering the ability of northern forests to confront climate change and conserve boreal biodiversity. A far better option is to find ways to limit urban and industrial expansion into the south's productive agricultural heartland.

4.4 Horns of a Dilemma: Food Security or Conservation?

Some are nevertheless likely to suggest that opportunities to revert farmland to a quasi-natural state exist because farming in Ontario has not yet attained maximum production or efficiency. For example, year-round yields under the protective cover of glass and plastic greatly exceed the seasonal production available in open cropland. There is no doubt that greenhouse vegetables and fruits help to address Ontario's concerns about food security. But greenhouses cannot provide the bulk of human diets that are composed of field-grown grains and root crops. Nor can their continued expansion improve conditions for conserving species in the absence of efforts to make urban environments and residual farmlands more compatible with biodiversity.

Might it not be possible, even in the south, to allow some farmland to return to a more natural state that harbors more biodiversity, and to reclaim abandoned land elsewhere for agriculture? Perhaps, but setting aside agriculture for quasi-natural habitat while reclaiming the same habitat for farming in a different area represents a paradox that is unlikely to improve either food security or biodiversity. It is also an option that is unavailable in many regions and nations where virtually all arable land is already in use (DeFries et al., 2004, Foley et al., 2011). Even when it is an option, legacies of abandoned farmland often impinge negatively on biodiversity (Standish et al., 2008) and ecosystem services unless there is a commitment to restoration (Ustaoglu & Collier, 2018) and rewilding (Wang et al., 2023).

Setting land aside for biodiversity may not be viable even in Ontario. The province can no longer grow enough food for its population (Econometric Research Limited, 2015; Morris & Blekkenhorst, 2017). The province's farmland is disappearing, and its biodiversity is spiraling downward. It is long since time to stop the descent. But in order to do so we must look beyond patterns to causation: More people require more land, more food, and more resources. It is simply impossible to simultaneously increase human populations, 'grow' their economy, and conserve nature. Worse, it is also impossible to reverse our course. We cannot convert the impervious brown fields of cities and factories into safe and productive farmland. But we can, if we act now, preserve what is left. And we can change our practices so that other members of Earth's biodiversity persist in our presence.

4.5 The Promise of Changing Agricultural Practices: Climate Change

It is possible in many instances to replace conventional tillage and cropping practices that deplete soil organic carbon (e.g., Smith et al., 1997) with less intensive practices that reduce atmospheric CO_2. In Ontario, clay soils sequester carbon following conversion to 'no-till' farming and improved crop rotations (Van Eerd et al., 2014). Approximately 33% of southern Ontario land prepared for seeding in 2021 was no till (Statistics Canada, 2022e), suggesting a major role for farmland in carbon sequestration. Urban soils can also function as carbon sinks (e.g., Du et al., 2022), but their cumulative capacity is necessarily compromised by the urban dominance of impervious substrates.

4.6 The Promise of Changing Agricultural Practices: Biodiversity

Although species richness for many groups declines with urbanization (Svabó et al., 2023), non-native species can yield biodiversity hotspots that exceed the numbers of species in neighboring areas (e.g., McKinney, 2008). But conservation of native species will often depend on farmland that, if sufficiently complex, can retain large components of biodiversity (Estrada-Carmona et al., 2022), and especially so when it retains refuge habitats such as those afforded by field margins and semi-natural fragments (Plath et al., 2021). Understanding farmland's potential at conservation is vital because agriculture, on a global scale, is considered the primary threat to terrestrial vertebrates (Munstermann et al., 2022). But in Ontario, much of the diversity of life that remains in the southern industrialized zone depends on habitats afforded by agriculture. These habitats include grassland mimics such as pasturelands, hay fields, and cereal crops, but also residual habitats along the margins of rivers, creeks, streams, and rural roadways. Fencerows and remnant patches of forest provide crucial habitat for numerous resident and migratory woodland species. Other species benefit from the patchwork mosaic of field and forest. All these components are under threat by continued urban and industrial intrusions into Ontario's farmlands.

5.0 Conclusion

5.1 Who Is the Villain?

The Ontario pattern and relationship with GDP is dramatically different from that revealed in the global data analyzed by Taylor and Rising (2021). There is no peak and subsequent decline in the relationship between farmland area and GDP, no tipping point in land use, and no previous attainable state. Cropland area is mostly stable, not in decline, but is threatened by a fateful hysteresis with ongoing urban and industrial expansion. There is little land that can be returned to nature, and any attempt to do so will come at the expense of cropland and food production.

It is not GDP that is directly responsible of course, but instead the policies, including population growth, directed towards its continued expansion. Those policies, promulgated by ideologies of ever-increasing wealth, and myths of ever-growing sustainable economies, imperil food security and biodiversity. Worse, they will continue to do so until societies demand a full accounting of the externalities of economic and other policy decisions that include cumulative effects on our environment and other life forms (Carney, 2021; Dasgupta, 2021).

Policies that limit urban and industrial expansion in rural areas can help to preserve farmland but not necessarily biodiversity. Intensified agriculture alters rural landscapes and often results in removal of many of the habitats currently occupied by native species. Preservation of farmland and its biodiversity is thus likely to require thoughtful incentives to stakeholders that align with an increased public appreciation of biodiversity's irreplaceable value.

5.2 A Vital Need for Leadership and Policy

Farmland's role in conservation also requires that decision makers and planners understand the full panoply of contributions that farmland provides to public, provincial, and national objectives, including those related to biodiversity (Baudron & Giller, 2014, Baudron et al., 2021), climate change (European Environment Agency, 2022) and the circular economy (World Economic Forum, 2022). Many of Ontario's threatened species persist only in remnant habitats maintained by farmers in agricultural landscapes. If those species are to remain, land-use policies must discard the short-sighted socio-economic and political hubris that led to unfettered population and economic growth. We must replace the penchant for growth with a sustainable circular, steady-state economy (e.g., Daly, 1993). One way to do so is to incentivize urban planning and agricultural practices that make cities greener and more livable and retain farm landscapes that provide multiple benefits in food production, biodiversity, and climate stability. We need well-informed leaders who understand the limits of our fragile planet: Leaders who are alarmed to learn that "Canada does not have a comprehensive and coherent approach to agricultural land protection" (Food Policy for Canada, n.d.).

Patterns and processes in Ontario, mirrored in other provinces, are best viewed as a case study on humanity's inability to control growth, secure our future, and preserve the biodiversity that nurtured our ancestors as it does us. Generations of leaders and advisors have engaged in a foolhardy global tragedy of the commons (Hardin, 1968; Lloyd, 1833; Morris, 2019) with profligate spending and no plan to repay the accumulated debt other than continued economic and population growth. Those misinformed values and policies contribute to an ever-increasing deficit in Earth's ability to support its human population, and our cohabitants (Lin et al., 2018; Morris, 2019; Vitousek et al., 1986).

All species possess the potential to over-exploit the resources that sustain their populations. Those that do always experience negative consequences on their own population growth (e.g., Vourinen et al., 2021), including extinction (e.g., Gyllenberg & Parvinen, 2001; Parvinen, 2005). Populations must thus be subject to mechanisms that prevent most species from wildly over-exploiting their resources (Vourinen et al., 2021). The same can undoubtedly be true for humans if we understand and adopt similar limiting processes. Promising approaches include finding equitable ways to limit access to common-pool resources and cooperative management of those resources by groups with clear 'territorial' boundaries (Ostrom, 1990; Vuorinen et al., 2021). More generally, our collective challenge is to better understand how feedback mechanisms that regulate natural populations can be applied to modern humans whose technological and medical advances decoupled the ecological and evolutionary feedback on human population growth.

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