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The Ecosystem Service Benefits of Lab-cultured and Insect Meat

Research Article

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Keywords

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Abstract

Background: Population and income growth are expected to augment meat demand, and consequently, the conversion of natural ecosystems into pasture. Promising alternatives to livestock, particularly lab-cultured and insect meats, use about 1% as much land. Utilizing these technologies could reduce pasture expansion and maintain natural ecosystem service values. This paper investigates: what is the value of the ecosystem services potentially maintained by reducing agricultural expansion through the adoption of cultured and insect meat?

Methods: Total global livestock-associated agricultural expansion by 2050 was predicted using FAO livestock projections (1) multiplied by the average land-use per kilogram of meat (2) yielding 194Mha. This expansion was partitioned among ecosystems according to threat scores derived from past expansion (3). Changes to annual ecosystem service values were calculated using average global values from Costanza et al. (4) multiplied by predicted expansion per ecosystem.

Results & Conclusion: Tropical forests and east-Asia were the most threatened ecosystem and region, respectively, by both area and value. The net loss in annual ecosystem service values in 2050 due to predicted livestock-associated agricultural expansion was calculated to be $732bn/yr, translating to a NPV of $6.62tn to 2050. The potential to save such large ecosystem services value justifies increased research and promotion of these protein production methods.

Limitations: This research does not identify exact ecosystems that are both targeted by agricultural meat expansion and that yield large ecosystem benefits because it is not sufficiently spatially explicit. Thus, it should not be used as a reference for new ecosystem conservation zones.

Introduction

Considering the extent to which current agricultural practices are land-intensive and the risk they pose to natural ecosystems, this research looks at two promising meat production alternatives—lab-grown meat and insect farming—and investigates their potential to mitigate agricultural expansion and loss of ecosystem service value.

Current Protein Production Methods

Current industrial farming activities contribute to many environmental problems including greenhouse gas emissions, the decimation of pollinators, water pollution and waste creation. (5,6,7) These externalities will be exacerbated by the foreseen increase in demand for meat. (8) This increase is due to global population, which is expected to grow from 6.5 billion in 2007 to 9.3 billion by 2050, and per capita consumption of meat across the world, predicted to increase by over 25% in the same period. (1)
In order to respond to the changes in demand, meat production will have to significantly increase, and perhaps double: according to recent predictions, global meat production could reach 524 million tons worldwide by 2050, from 258 million in 2007. (1) With current practices, this translates into more land being used for agriculture as 79% of global agricultural land is used for pasture and cropland for feed. (1) Land use expansion occurs at the cost of natural ecosystems and their ecosystem services.

Added pressure on food systems, and more generally on the environment, prompts questions of sustainability. This creates an interest in alternatives to conventional meat production that could respond to the demand for protein, improve food security and mitigate the externalities of food production.

New Protein Production Methods

Though many meat substitutes exist, we focus on cultured and insect meat as they both have a large potential to reduce the negative impacts associated with livestock farming. In addition, they could respond to global demand as they are each better suited for different relative inputs of land, labor, and capital. Though cultured meat can be a realistic option in developed countries, it is likely to be hard to implement in developing countries as it is currently very capital intensive. Insect farming, on the other hand, may be a more viable solution in those regions where entomophagy (the eating of insects) and vegetarianism are more common culturally.

Producing meat in laboratories from animal stem cells is a novel idea and its potential is being examined with considerable interest. Several studies (9),10,11) and an anticipatory life cycle analysis (12) have been conducted to better assess the benefits and challenges of cultured meat. These have pointed to the promising environmental advantages of such a production method but have also highlighted many uncertainties such as the plausibility of a shift towards the technology. Since creating a market demand for such a product seems to be a primary concern, some consumer surveys have been conducted to further understand and evaluate the future potential of cultured meat. (13) Despite possible challenges with respect to consumer adherence, cultured meat is being looked at as a potential solution with optimism. It will likely be far more resource and pollution efficient: it emits less greenhouse gases and uses significantly less land and water. (11)
Insect meat is an older idea but has been regaining attention over the past few years as food system externalities and food security are entering the popular discourse. Like cultured meat, its production is much more energy efficient and requires significantly less land to produce a kilogram of protein. (14) The document prepared by the Food and Agriculture Organization, Edible Insects (14), summarizes the benefits of using insects as a protein source. Other papers, such as Edible insects: Traditional knowledge or western phobia? by Alan L. Yen, (15) highlight the challenges of marketing insects in western societies while emphasising the potential positive impacts.

As we have seen, both alternatives use considerably less land than conventional livestock farming. The interest of this research is to look at cultured meat and insect farming as possible options to diminish the need for land expansion and to value the natural ecosystems that could be maintained.

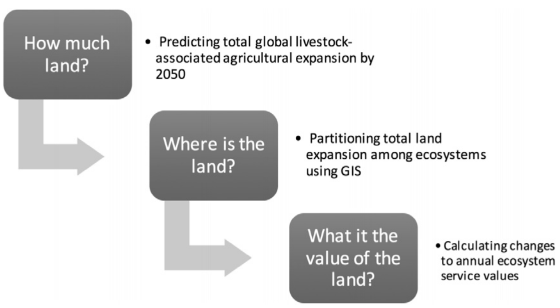
Market Forces

The impacts of cultured meat and insect farming on agricultural expansion will be highly dependent upon the size of the market share they can command. As briefly mentioned above, this depends on various market forces. Primarily, the demand for these alternative meats is highly reliant on sensory expectations, i.e. the ability to mimic conventional meat,16 price, and policy regulations. The supply relies on investment, technological progress, production costs, and policies such as carbon taxes. The evolution of these production methods is dependent on chaotic human systems, justifying the exploration of a variety of scenarios reflecting the myriad of possible futures.

Research Question

The purpose of this research is then to analyse the value of increasing the land efficiency of protein production through technology. The research will look at two alternatives to industrial livestock—cultured meat and insect farming—and the potential environmental benefits that adopting these modes of protein production could lead to, depending on different possible market forces and their interactions.
This study seeks to answer the following question: what is the potential value of the ecosystem services maintained by reducing agricultural land expansion through the adoption of cultured meat and insect farming? This is achieved by identifying the ecosystems at risk due to agricultural expansion and calculating their ecosystem service values. The back-of-the-envelope scenarios help express the long-term value that could be maintained by increasing the market shares of alternatives meat.

Methods



Our methodology consisted of answering three main questions: How much land is predicted to be converted for agricultural purposes? Where is this land expansion predicted to occur? And what is the value of this land in terms of ecosystem services?

The first step of our research involved separating the globe into six geopolitical regions and predicting how much beef, lamb, poultry and pork will be produced in each region by the year 2050. The six geopolitical regions were: East Asia, South Asia, Near East/North Africa, Sub Saharan Africa, Latin America and the Developed Countries.

We used projections from the FAO1 on the number of livestock that are predicted to be produced from 2007 to 2050. This data was provided by geopolitical region. We then multiplied these livestock counts by the predicted edible weight of each animal for each geopolitical region. (1) This yielded the total amount of edible weight that will be produced in 2050 by geopolitical region and species. We then multiplied these total weights by the estimated land use required to produce one kilogram of each type of meat. (2) Cattle and buffaloes use an average of 22 m^2/kg, sheep and goat require 12 m^2/kg, pigs require 10 m^2/kg and poultry require 5 m^2/kg. This yielded the total increase in agricultural land required to match the increase in livestock production in each geopolitical region. We corroborated our estimate with a second calculation and an additional source, which suggest similar values (see Appendix I).

The second step used Geographic Information Systems (GIS) programs to partition the total land expansion calculated in the first step into ecosystems within the geopolitical regions. This requires us to know where agricultural land is expected to expand. This information was found in James Oakleaf and his research team's article A World at Risk: Aggregating Development Trends to Forecast Global Habitat Conversion (3) Oakleaf's research team produced the map shown in Figure 1, which depicts the locations in which agricultural expansion is predicted to occur until the year 2030.

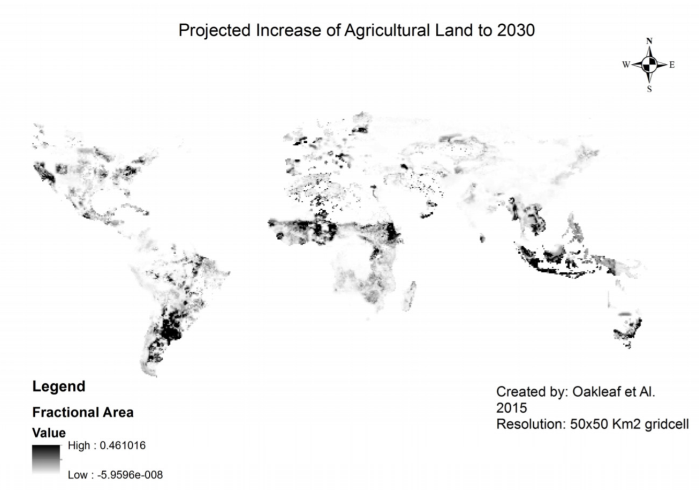


Fig. 1. Projected Increase of Agricultural Land to 2030

The map in Fig. 1 was created using a linear extrapolation from known agricultural land expansion between 2000 and 2011. Each 50x50 km grid cell contains a value between 0 to 0.46, which corresponds to the fractional area of that grid cell that is predicted to be converted to agricultural uses by 2030 after accounting for other trends such as urbanization and mining. (3) This map was used to predict the location of agricultural expansion. However, the specific increase in area calculated from this method is not used directly for two reasons. First, the map only extrapolates until 2030 whereas this research projects until 2050. Secondly, the map includes land used for all types of agriculture, not just livestock and feed production.

The agricultural expansion map was compared with an ecosystem map (17) and a map of country borders. We separated the map of country borders into the six regions defined by the FAO1 in the first step. Next, the ecosystem map was separately clipped to each geopolitical region. This resulted in separate regional maps where each geopolitical region was composed of ecosystems rather than countries. These regional ecosystem maps were then clipped with the agricultural expansion map. GIS software (Arcmap) tools such as "spatial join" and "summary statistics as a table" made it possible to calculate the expansion predicted in each ecosystem and geopolitical region. We then scaled these calculated areas to match the area predictions found in the first step for each geopolitical region.

Costanza et al. Categories	Value (2007$/ha/yr; 2011 values)
Tropical Forest	$5,382.00
Temperate/Boreal Forest	$3,137.00
Grass/Rangelands	$4,166.00
Tidal marsh/Mangroves	$193,843.00
Swamps/Floodplains	$25,681.00
Lakes/Rivers	$12,512.00
Desert	$0
Tundra	$0
Ice/Rock	$0
Cropland (without food production)	$3,244.00

Table 1. Selected average global ecosystem service values, from Costanza et al. (4)

Having calculated predicted land expansion for each ecosystem, the more specific WWF ecoregion categories18 were reclassified into those used by Costanza et al. (4) (See Appendix II.) The predicted change in each (reclassified) ecosystem, was multiplied by the corresponding per-area ecosystem services value from Costanza et al. shown in Table #1. (4) All natural ecosystems lost area and were replaced by an equal amount of cropland. Note that the value of food production was removed from cropland in the analysis. This assumes that, no matter what proportion of future growth in meat demand is satisfied by the proposed alternative meats, the same value of food will be produced as in the baseline prediction of full livestock expansion. This allows us to compare the costs and benefits of protein production scenarios. Also note that the land-use of alternative meats is assumed to be zero in the calculations. In reality, it is about 1% of the land-use of conventional livestock, but that land-use is expected to be in vacant urban areas, where it does not threaten natural ecosystems. (11,14)

Results

Step 1

The total global increase in agricultural land required to meet the increase in livestock production from 2007 to 2050 was calculated to be 194 million hectares. The spatial patterns of predicted land use are shown in Figure 2. The largest increase is predicted to occur in East Asia.

Step 2

The total livestock-associated land expansion from Step 1 was partitioned into nine ecosystems as shown in Fig. 2. Over half of the expansion is predicted to occur in Tropical Forests.

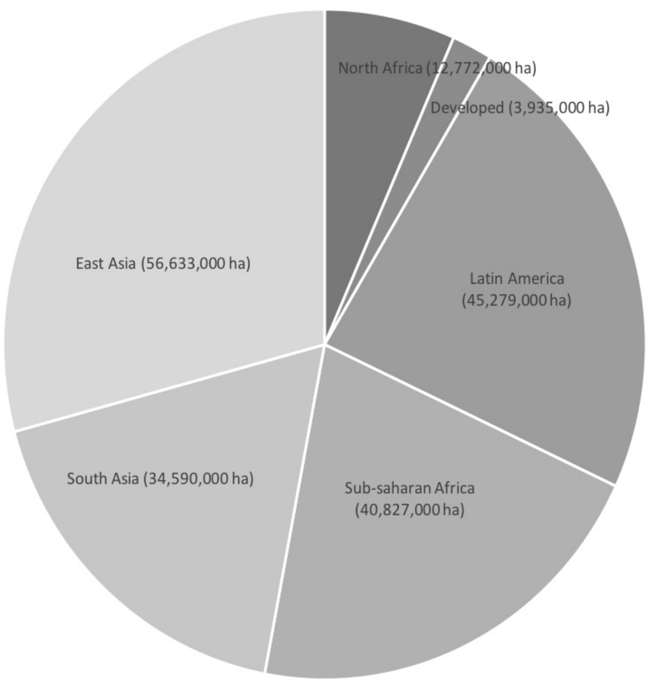


Fig. 2. 2050 Livestock-Associated Agricultural Increase by Geopolitical Region

Step 3

We found the net loss in annual ecosystem service values for 2050, should the predicted livestock increases occur, to be $732 billion dollars each year. In the following tables, this value was divided among geopolitical regions and ecosystems, along with their respective areas.

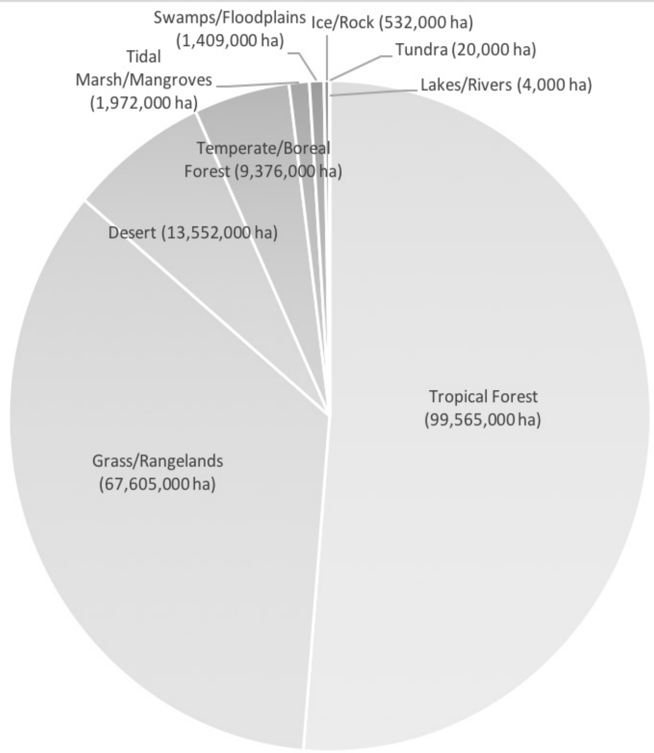


Fig. 3. 2050 Livestock-Associated Agricultural Increase by Natural Ecosystem

Discussion

Table 2 shows how the $732bn/yr and 194Mha are divided among geopolitical regions. Interestingly, North Africa and the Developed Countries have increased ecosystem service values. This is partly because their converted areas are so small, and also because the natural ecosystems that are expected to be expanded upon have lower values than cropland (i.e. deserts and tundra) even without food production values. The region that has the most value and area at risk is East Asia, particularly Indonesia.
In Table 3, the $732bn/yr and 194Mha are divided among ecosystems. While tropical forests are the most threatened in terms of area and value, the next most valuable ecosystem is tidal marsh and mangroves despite the small area under threat. Much of these mangroves are in the east-Asian archipelago.

Net Present Value of Ecosystem Services

Although $732bn/yr is an interesting number, it is only useful for making decisions today if expressed as net present value (NPV). For comparison, global GDP (19) is about $75tn/y and global agricultural subsidies are about $500bn/y (20). As mentioned, there are many human factors that will influence how meat production will evolve, the modeling of which would have been infeasible. Instead, we looked at how ecosystem service values would change depending on how widespread these alternative meats and their production methods become.

Thus, we stated that by 2050, either none of the growth in meat demand will be satisfied by cultured and insect meat with a resulting 194Mha agricultural expansion; all of it will be, resulting in no agricultural expansion; or somewhere in between, resulting in an expansion of some fraction of 194Mha. Using these total land and ecosystem service changes by 2050 we interpolated their change, assuming it to be linear, between now and then. Using a discount rate of 3%, we calculated the net present value of the lost ecosystem service values under the different scenarios. With 0% cultured or insect meat and full pasture expansion, 6.62 trillion dollars are lost in ecosystem service values as net present value to 2050; when tidal marshes and mangroves are conserved, 40% of the 6.62 trillion dollars is

Table 2. Change in total ecosystem value and area by geopolitical region

saved. If cultured and insect meat satisfies half of the growth in demand, 50% of 6.62 trillion dollars is saved. For every 25% of total growth in meat demand that is satisfied with cultured meat, we save a net present value of 1.65 trillion dollars.

Geopolitical Region	Net Ecosystem Service Value (2016$/yr)	Change in Natural Ecosystem Area (ha)
North Africa	+$4,670,768,504.41	(12,772,500)
Developed	+$1,777,353,527.95	(3,935,320)
Latin America	-$85,502,151,066.15	(45,279,080)
Sub-Saharan Africa	-$109,099,358,800.03	(40,827,400)
South Asia	-$162,572,757,215.45	(34,590,280)
East Asia	-$381,731,014,132.53	(56,633,290)
World	-$732,457,159,181.80	(194,037,870)

Table 2. Change in total ecosystem value and area by geopolitical region

Ecosystem Type	Net Natural Ecosystem Service Value (2016$/yr)	Change in Ecosystem Area (ha)
Grass/Rangelands	-$324,352,509,693.33	(67,605,228)
Tidal Marsh/Mangroves	-$440,279,305,089.42	(1,972,258)
Swamps/Floodplains	-$41,683,356,700.56	(1,409,407)
Tropical Forest	-$617,114,831,039.67	(99,565,295)
Temperate/Boreal Forest	-$33,872,824,698.85	(9,376,107)
Lakes/Rivers	-$62,796,196.56	(4,358)
Desert	$0.00	(13,552,285)
Tundra	$0.00	(20,337)
Ice/Rock	$0.00	(532,590)
Total Natural Ecosystems	-$1,457,365,623,418.39	(194,037,870)
Cropland (without food production)	+$724,908,464,236.59	194,037,870

Table 3. Change in total ecosystem value and area by ecosystem type

Financing Investment and Conserving Ecosystems

Expressed as net present value, we should be willing to invest similar sums of money to prevent these ecosystem service value losses. Thus, the upper-bound of socially-optimal investment in alternative meats, if only considering the loss of ecosystem services, is $6.62tn. Such investment would only be socially optimal if it is enough to allow alternative meats to satisfy all growth in the demand for meat, which is unclear. Thus, a fee of around $2 per kilogram of livestock meat would generate a total revenue with NPV of $6.79tn after 10 years to be invested in alternative meats.

According to our analysis, mangroves are the second most threatened ecosystem by value, but fifth by area. As these ecosystems are being converted for aquaculture, mangrove conversion is a plausible trend. (21) However, tidal marshes and mangroves only occur on the coasts: their high value and narrow, precise locations make the results of spatial analyses such as ours very sensitive to imprecision related to our raster resolution. Thus, we need to be cautious when interpreting the mangrove estimates.

Assuming the accuracy of these results, if we could conserve all threatened mangroves we would maintain 30% of threatened ecosystem service value by protecting only 1% of threatened area. This alone would reduce the net loss of annual ecosystem services to $292bn/yr by 2050 and a NPV of $2.64tn, the equivalent of satisfying between 50% and 75% of the growth in meat demand with alternative meats. If we view the threat to mangroves as an error due to our raster resolution we can interpret the $292bn/yr and $2.64tn as the values of the baseline scenario of full livestock expansion.

Limitations of the Data and Further Research

Crucial to our initial calculation of 194Mha were our estimates of the land needed to produce one kilogram of livestock meat, which were quite conservative (2). This was done for several reasons. First, it is predicted that future livestock production will mostly be intensive, thus requiring less land to produce a kilogram of meat.1 Second, there are no robust estimates for how land requirements differ by geopolitical region, thus a standard value had to be chosen for each species. Therefore, our results may be inaccurate where land use per kilogram is significantly different from our selected values. In particular, pasture expansion may be underestimated where ranching is common. This makes our final value of $732bn/yr a conservative estimate of threatened value, ceteris paribus. Further research could improve our results by using different per-kilogram land-use values for specific locations.

The partitioning of total expansion among ecosystems relied on a raster dataset with cell resolution of 50x50km (3). As discussed above, while this is suitable for large tracts of tropical forest and rangelands, ecosystems such as mangroves occur in very precise and narrow locations. If a cell had seen high past expansion, resulting in a high threat-score, our calculations assume that future expansion will occur in all ecosystems present in that cell according to their relative areas. A coastal cell in which there has been much expansion into tropical forests, but none into its mangroves, would nonetheless be predicted to lose mangroves. These errors could be rectified by further research in various ways. Raster resolution could be improved; polygons could be used to display separate ecosystems with more precise boundaries between them; or data on threatened ecosystems could be used directly, eliminating the need to overlay threat score data with ecosystem data.

Finally, it is widely argued that Costanza et al. (4) makes fundamentally flawed assumptions about the nature of total versus marginal value, particularly when asserting that the value of the world's ecosystem services is $145 trillion annually. However, for the purposes of this research, we must assume that the changes to ecosystem services we consider are small enough to be marginal, such that they do not change the scarcity and value of each hectare of a natural ecosystem. Further, as these are global averages, they are appropriate for our global analysis; we do not use them to claim that a particular hectare of land has a specific value. However, assuming that each hectare of, say, mangroves has the same value causes errors even in such a global analysis. While we might be confident in the average ecosystem service values of mangroves from Costanza et al., we don't know how the values of the specific mangroves that we expect to be threatened differ from this average. Further research could improve our results by having spatially explicit data on ecosystem service values, rather than global averages for ecosystem types.

Conclusion

By 2050, 194 million hectares of natural ecosystems may be converted to raise livestock. Tropical forests and east-Asia are the most threatened ecosystem and geopolitical region, respectively, both in terms of area and value. If this expansion occurs and the natural ecosystems are lost, it would represent a loss of $732bn per year in ecosystem services in 2050, cumulating in a net present value of $6.62tn.

Though this research cannot be used to identify which areas are at risk as it is not sufficiently spatially explicit, other similar studies could be replicated in greater detail, locally, and at finer scales to account for spatial heterogeneity in order to better inform the policy-making process. The human systems that will influence market forces and the uptake of alternative meats can be studied and perhaps modeled, to identify the pressure points within these human systems.

However, the large value of threatened ecosystem services demonstrates the potential of these technologies and can be used to influence market forces that can further advance these alternatives. It can encourage further research and development in the specific science and technology of cultured and insect meat. It can also inform public policy if governments recognize the potential to save ecosystem service value by preventing agricultural expansion through alternative meats. It may even encourage new investment within protein industries as there are yet opportunities for first-mover advantages in seizing market share. This would not only include investment in the technologies themselves, but also marketing campaigns and public awareness. Lastly, the dissemination of the ecological benefits of cultured and insect meat may increase market demand for such commodities, while also spreading awareness of the concept of ecosystem services. Consumers respond more favorably to the alternative meats when they understand their personal and societal benefits.13 Even as individuals we can influence how cultured meat expands its market share. Perhaps the most effective way to promote lab-cultured and insect meat, relative to effort, is to purchase cultured meat when it becomes available, and discuss it with others to reduce the stigma against it.

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