Journal of Public Health Policy (2026) 47 (Suppl 1):S120–S134
https://doi.org/10.1057/s41271-026-00646-5

RESEARCH

Households under pressure: a systems framework for modeling the "watch" famine archetype

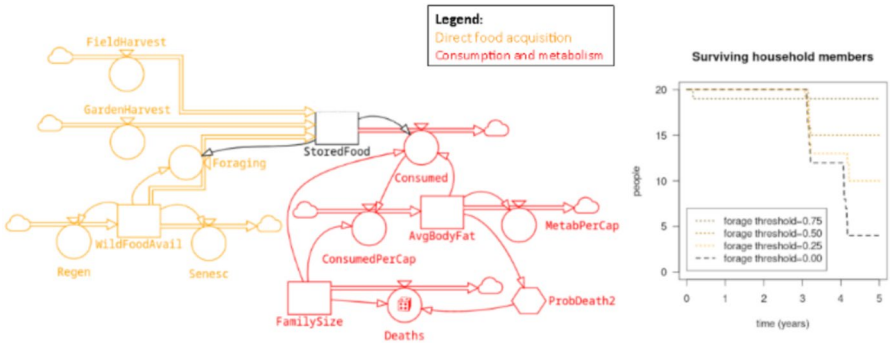
Alexandra M. Thorn[1]

Received: 23 September 2024 / Accepted: 26 May 2026 / Published online: 12 August 2026
© The Author(s) 2026

Abstract

Famines are complex systems that change over time, and in which outcomes differ by household situation and livelihood. The "watch" famine system archetype occurs when populations engage in coping strategies to deal with a hunger gap, such as between agricultural harvests, which can interfere with future food production and mask the existence of a crisis to outside observers. I present a framework for modeling household responses to hunger. I used a partial prototype model for agrarian, horticultural, or foraging livelihoods to simulate the role of rationing and foraging as coping responses to insufficient food. Although not all dynamics were included, simulations suggested that while coping mechanisms can improve outcomes, rationing may also produce negative outcomes, due to the increased chance of death with lower energy reserves. I discuss next steps for a more complete framework, generalization to other famine systems, and implications for monitoring and responding to famine systems.

Graphical abstract



✉ Alexandra M. Thorn
Alexandra.thorn@tufts.edu

[1] Tufts University, Medford, MA, USA

Key messages

- A simple systems dynamics modeling framework can help to understand household coping strategies in response to interruptions in food supply, either seasonally or during a crisis, for example, rationing or foraging supplemental wild food sources
- Preliminary simulations suggest that in a closed horticultural-agrarian system, rationing may increase survival in some situations but contribute to mortality in others
- Simulations without accounting for time and labor suggest that foraging wild resources provide a consistent advantage, but this pattern might not hold when tradeoffs are included
- The framework presented can be adapted to more open or market-based systems and by incorporating specific ethnographic data may also be applied to specific famine systems

Keywords Famines · Starvation · Households · Livelihoods · System dynamics · Modeling

Introduction

In our changing world, with increasingly unstable climate conditions, rising conflicts, ramifying economic shocks, and the possibility of global pandemics such as COVID-19, the risk of famine and food and nutrition crises represents an ever-growing challenge. According to the United Nations, there has been a substantial increase in humanitarian needs over the past decade [1]. Yet resources for humanitarian assistance are consistently insufficient for addressing these needs [2], with the largest gap between requirements and funding occurring in 2023 [3]. Furthermore, demands on resources from donor countries may increase as they face some of these same global trends within their populations.

Given this context, it is critical to better understand the dynamic processes of famines to help identify ways to optimize the timing of humanitarian assistance and make efficient use of limited resources. The Integrated Food Security Phase Classification (IPC) defines acute food insecurity into one of five phases, based on the combined assessment of causal factors (vulnerability of households and acute or ongoing circumstances), several metrics of food security, first-level outcomes (changes in food consumption and livelihoods), and ultimately second-level outcomes (nutritional status and mortality) [4]. The IPC defines Phases 3 to 5 of acute food insecurity as crisis levels calling for urgent action. Evidence for Phases 3 (Crisis) and Phase 4 (Emergency) can include either second-level metrics (nutrition status and mortality) or first-level outcomes (livelihood changes and coping strategies that will interfere with long-term sustainability). Phase 5 (Catastrophe/Famine) is the most severe level of acute food insecurity, defined by > 20% of households with significant

food gaps, > 30% of children acutely malnurished, and crude death rate of at least 2 per 10,000 per day. The IPC notes causal linkages among these factors, including the feedbacks between contributing factors and outcomes that drive accelerated degradation of livelihoods as populations approach Phase 5, but also notes that there is not always a strong correlation among the first-level outcomes, such that evidence must be contextualized for each crisis. Tools for interpreting the underlying dynamics that cause indicators to correlate in some systems but not others could facilitate the development of more sophisticated frameworks for prioritizing interventions and determining the most suitable actions for managing a food crisis. Systems thinking and systems dynamics modeling may provide particularly useful tools.

To illustrate the potential for systems thinking for understanding famine systems, Howe [5] defined famine system archetypes to describe the interactions of human behavior with seasonality of resource availability to shape the timing of onset of famine conditions. Famine systems may be described as 'open' or 'closed,' depending on the ability of populations to move outside of the area initially affected by famine, or to trade resources, or receive aid from outside [6]. Howe's archetypes include the following: the 'watch' in which households and communities use coping strategies to manage the impact of shocks; 'price spirals' when attempts to buy food and sell assets lead to deteriorations in the terms of trade; and 'aid magnets' when populations migrate out of the affected area and congregate in camps where they are exposed to disease and mortality increases [5]. To translate these frameworks into specific predictions about real-world systems, quantitative simulation modeling is required.

One approach is to work toward the development of models for national or population level dynamics, as exemplified by ongoing work by Sanga (current issue) to model the 2011–2012 famine in Somalia. However, micro-scale dynamics oriented toward processes at the household level could yield complementary insights. Food insecurity does not affect all segments of the population in the same way, and the IPC famine definition is based on evidence of deprivation for one in five households in a population [4]. Walker et al. famously observed that famines have both victims and beneficiaries, with outcomes highly dependent on a person or household's economic status and social relationships [7]. The trajectory for each household differs depending upon their situation entering the famine and their ability to access resources to facilitate coping mechanisms.

The present paper lays out a framework for quantitatively modeling the dynamics of household behavior under the watch famine archetype from Howe [5] (Fig. 1a). Under the watch, households experiencing famine adopt coping strategies to feed themselves during the gap between agricultural harvests. Common strategies for coping with hunger gaps include rationing [8], foraging for wild foods [9, 10], borrowing resources, engaging in outside labor, sale of livestock and assets, and emigration [11]. Such strategies can interfere with long-term food acquisition [6, 11] and can also mask the approaching famine as perceived by outside observers [5]. For example, during the crisis in southern Sudan in 1998, deaths in February were below the historical average, causing some observers to conclude that disruptions to food production would not result in famine (Fig. 1b). In reality, mortality increased dramatically later in the year as short-term coping mechanisms failed [5, 12]. Although



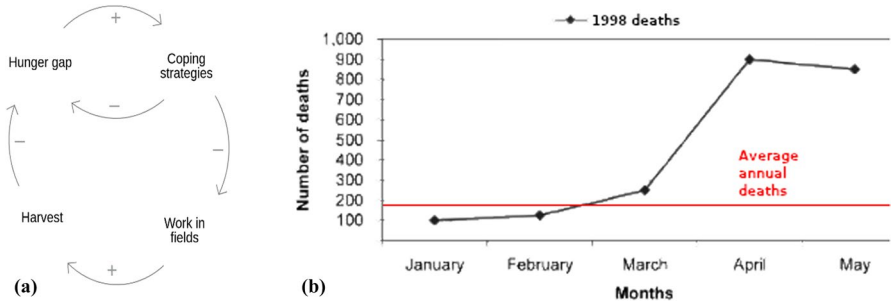


Fig. 1 The 'watch' archetype, illustrated with 1997 deaths from Southern Sudan. In this archetype, households experiencing famine must find ways to feed themselves during the hunger gap between agricultural harvests, and these activities may interfere with future harvests. **a** Causal loop diagram for the watch archetype. In this 'shifting the burden' archetype, a hunger gap between harvests causes communities to adopt coping strategies that simultaneously mitigate the hunger gap and reduce labor for working in the fields to ensure the next harvest; **b** Monthly deaths in early 1998 for Grogrial County in southern Sudan (image adapted from Ref. [5] with data originally from Ref. [12])

initially described for an agrarian population [5], these dynamics may occur in any famine system where resource availability is highly seasonal.The purpose of the current paper is to describe a framework for modeling of household dynamics in the watch archetype. To illustrate this framework, I present a partial prototype for a generalized quantitative model for several aspects of household dynamics in a closed system. I simulated food storage, nutritional energy balance, and mortality for several subsistence livelihoods, both under baseline conditions with stable food production and under scenarios where food production is disrupted. The prototype model focuses on three modes of direct food acquisition: an annual field crop, a perennial home garden, and foraging naturally regenerating wild resources, and with two responsive mechanisms for coping with food shortage: rationing and (in the case of agrarian or horticultural livelihoods) supplemental foraging of wild food resources when agrarian and horticulture food supplies run short. I report results for specific scenarios of either chronic food shortfall or crisis interruptions in food supply through failures of field crops and discuss next steps for model development the potential for model generalization to other livelihoods and dynamics.

Modeling framework

Howe's framework for the 'watch' archetype ([5], Fig. 1a) can be subdivided into numerous subcomponents, including household food resources, nutritional outcomes, and market dynamics (Fig. 2). As a first step toward modeling the dynamics of household decision-making, the current paper describes a partial prototype model, focusing on stored food storage, consumption, and production (Fig. 3), implemented in StochSD 2022.01.02 as a stocks and flows model (Fig. 4).

Details on the modeling framework and the description of the partial model used for the present manuscript can be found in the Supplemental Materials.

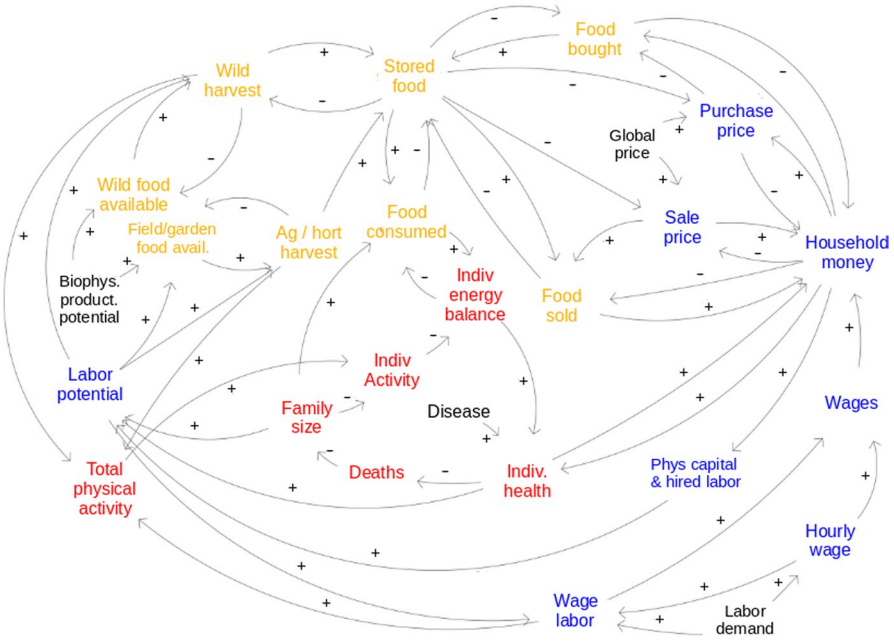


Fig. 2 Causal loop diagram illustrating the system components and their relationships for resource management in a subsistence household. Influence of one component on another is indicated by an arrow connecting the components, with a plus sign ('+') indicating a positive influence and a minus sign ('–') indicating negative influence. Health, survival, and energy balance outcomes for members of the household (shown in red) depend on sufficiency of food and food production (shown in orange), which may change depending on market dynamics (shown in blue). Outside influences are shown in black (Color figure online)

Scenarios

To illustrate model dynamics, I ran 5-year simulations for a number of different scenarios, varying by livelihood (agrarian, horticultural, horticultural and agrarian, or wild foraging) (Table 1). For each livelihood, I simulated outcomes with different values for a subsistence ratio parameter (S), which defines the amount of food obtained from field and garden relative to annual metabolic needs. I then ran additional simulations for the combined horticultural-agrarian (hort-agrarian) livelihood to investigate the potential role of rationing and foraging to mitigate food shortfalls and to respond to disruptions in the form of failed field crop harvests for intervals of 0.5–2.5 years.

Household outcomes during a food crisis strongly depend on social and economic positionality [13], and under the IPC definition, famine occurs when 20% of the population experience acute food insecurity [4]. Thus, a very severe food crisis can occur while the majority of households remain food secure. Starvation and deaths are concentrated among the most vulnerable, and I therefore simulated scenarios that focus on households with low food security (S = 1 or lower) under baseline



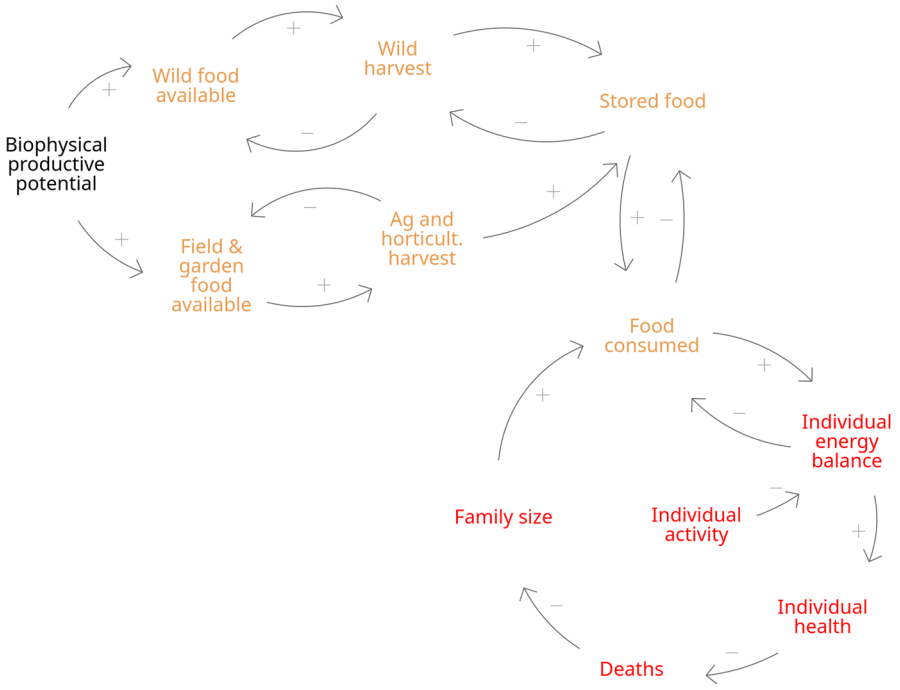


Fig. 3 Causal loop diagram illustrating the components of the household system that are included in the partial prototype model. Influence of one component on another is indicated by an arrow connecting the components, with a plus sign ('+') indicating a positive influence and a minus sign ('–') indicating negative influence. Health, survival, and energy balance outcomes for members of the household (shown in red) depend on sufficiency of food and food production (shown in orange). Exogenous influences are shown in black (Color figure online)

conditions. Simulated household mortality is therefore expected to be much higher than community mortality in real-world famines.

Results

Results for scenarios without disruptions are in Supplementary File 1.

Production disruption × adaptive responses

Survival of household members in simulated periods of crop failure ranging from 0.5 and 2.5 years was sensitive to adaptation strategies adopted. With no adaptation strategies, a single year of missed harvests resulted in the deaths of three fourths of household members by one quarter of the way through the subsequent year, with similar trajectories for longer intervals of crop disruption (Fig. 5a). With rationing, outcomes for the single year of crop failure improved such that half of household members survived to the end of the simulation (3 years after start of crop failures),

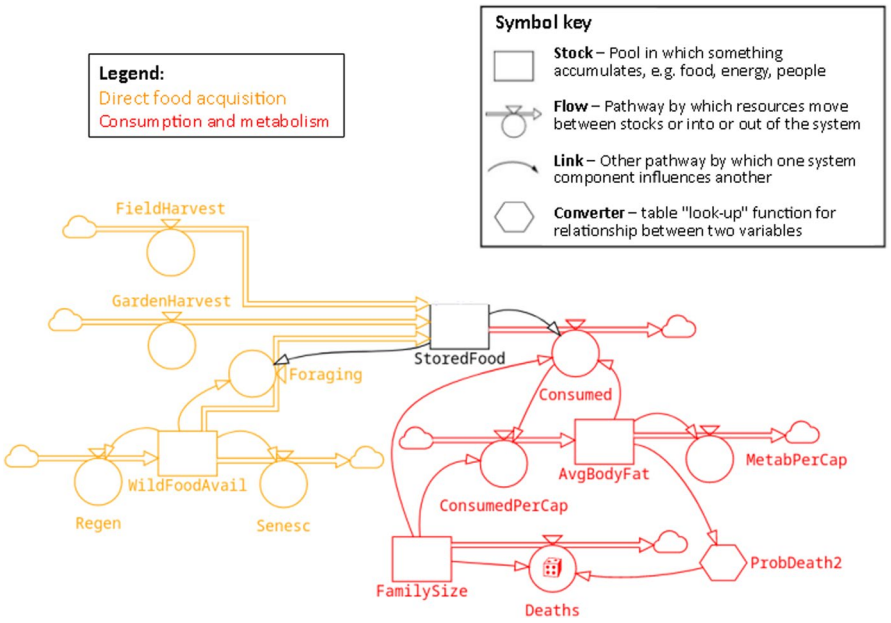


Fig. 4 Stocks and flows diagram for household famine model. Modes of direct food acquisition include "FieldHarvest" of an annual crop, year-round harvest from a home garden ("GardenHarvest"), and "Foraging" from the wild foods pool ("WildFoodAvail"), which regenerates at a rate defined by "Regen" and declines (senesces) at the rate "Senesc." The rate of food consumption "Consumed" depends on the number of people in the household ("FamilySize") and the metabolic needs per capita ("MetabPerCap"), which depend on body status ("AvgBodyFat"). When body fat is too low, the probability of death ("ProbDeath2") increases

but extension of the period of crop failure beyond a year reduced 3-year survival to fewer than two household members (Fig. 5b). Inclusion of wild foods foraging improved survival for all durations of crop failure (Fig. 5c). Foraging combined with rationing produced better outcomes than rationing alone, but generally worse outcomes than foraging alone (Fig. 5d).

Discussion

The framework presented here illustrates the potential of household simulation models to help understand famine dynamics when coping mechanisms are adopted to mitigate hunger and starvation. Although the prototype model presented does not include all system components, the simulations are consistent with literature on the high value of home gardens in improving food security, nutrition, and economic wellbeing [14, 15] and point to higher resilience afforded by food acquisition spread out over the year as opposed to concentrated in the single harvest events of annual field crops. The results also indicate a role for supplemental food sources—harvesting of wild foods in these scenarios—in improved outcomes, both in cases of



Table 1 Parameter definitions for simulated scenarios

Scenario	S	G_{frac}	$t_{wild,K}$	f_{ration}	$f_{rationlevel}$	f_{forag}	$t_{poor,length}$	$f_{pooryield}$
No adaptative responses								
Agrarian	1.0, 0.95, 0.90	0.0	–	0	–	0	0	–
Horticultural	1.0, 0.95, 0.90	1.0	–	0	–	0	0	–
Hort-agrarian	1.0, 0.95, 0.90	0.5	–	0	–	0	0	–
Foraging	0	–	80, 76, 72	0	–	1	0	–
With adaptative responses								
Hort-agrarian, rationing	1.0, 0.95, 0.90	0.5	10	1	0.7	0	0	–
Hort-agrarian, foraging	0.90	0.5	10	0	–	0.25, 0.50,0.75	0	–
Hort-agrarian, rationing + foraging	0.90	0.5	10	1	0.7	0.25, 0.50,0.75	0	–
Production disruption × adaptive responses								
Hort-ag. disruption, no adaptation	1.0	0.5	–	0	–	0	0.5, 1.0, 1.5, 2.0, 2.5	0
Hort-ag. disruption, rationing	1.0	0.5	–	1	0.7	0	0.5, 1.0, 1.5, 2.0, 2.5	0
Hort-ag. disruption, foraging	1.0	0.5	10	0	–	1	0.5, 1.0, 1.5, 2.0, 2.5	0
Hort-ag. disruption, rationing + foraging	1.0	0.5	10	1	0.7	1	0.5, 1.0, 1.5, 2.0, 2.5	0

Values are specified for the subsistence ratios (S), the fraction of cultivated harvest that comes from the garden (G_{frac}), the number of days of wild food available at the carrying capacity ($t_{wild,K}$), the rationing parameter (f_{ration}), the rationing level ($f_{rationlevel}$), and the foraging parameter (f_{forag}). A dash ('–') indicates that a parameter is not relevant for a particular scenario



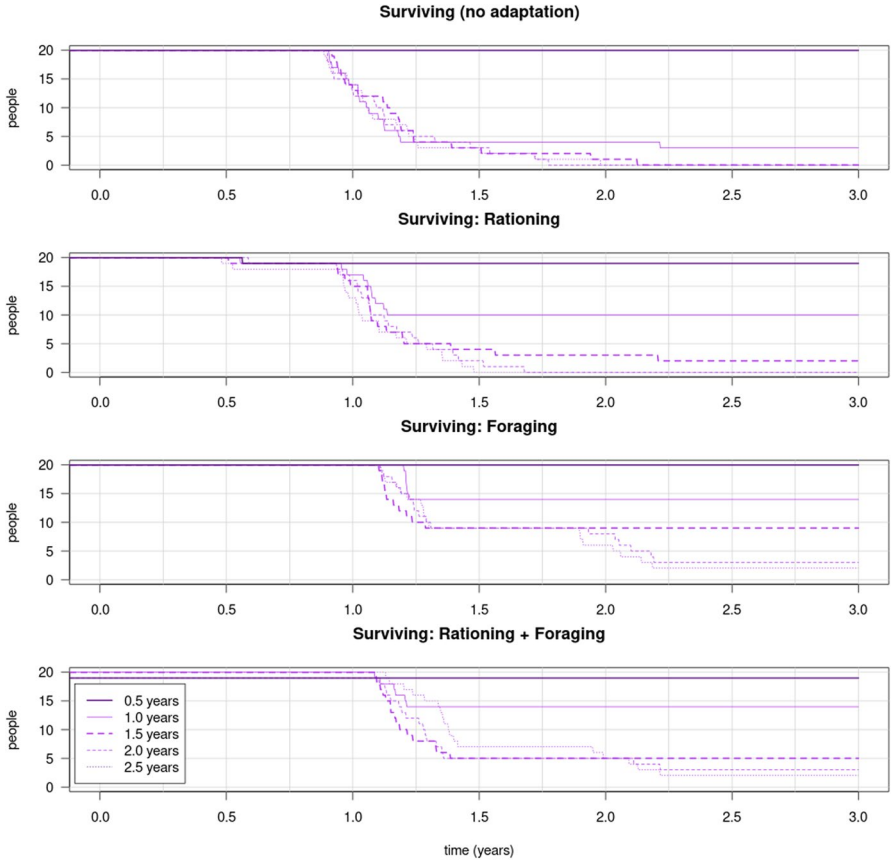


Fig. 5 Survival outcomes for varying intervals with complete failure of field crops, following two years of baseline conditions (0.0 years on the plot marks the start of the first year with crop failure). Results are shown for no adaptive behaviors (top panel), rationing alone (second panel), foraging alone (third panel), and rationing + foraging (bottom panel)

chronic food shortfall with crisis disruptions of primary food acquisition. Caution should be taken in interpretting this result, however, because the prototype model does not yet include labor tradeoffs and the opportunity cost diminished farm or garden yields if time is dedicated to foraging rather than cultivation.

An important insight from the simulations is the potential for household-level rationing to either increase or decrease mortality, depending on other circumstances. While the specific quantitative results should be interpretted with caution, the simulated pattern reflects the physiological reality that rationing results in caloric deficiency, which can increase the chance of mortality, whether directly or indirectly (see Thorn and Fitzpatrick [44], current issue). In real-world famine systems, one trajectory that can occur is for food intake to be limited early in the crisis, before infrastructure breakdown or displacement has lead to increased vulnerability to disease and other stressors, and for the depleted stores of body energy to compound



risks if subsequent broader breakdown occurs [16]. The potential for rationing as a short-term coping mechanism to threaten long-term survival exemplifies the potential costs of coping mechanisms as described in Howe's [5] "watch" archetype.

More generally, the simulations suggesting that access to wild foods as a supplemental resource can delay onset of high mortality (by up to 3 months according to some simulations) illustrate the ways in which "the watch" dynamics can mask an ongoing crisis. Also, the role of supplemental food sources or rationing in enabling households to survive during chronic shortfall of food from primary sources may illustrate less visible differences in vulnerability among households. A household closer to "the edge" may appear to flourish under baseline conditions if supplemental resources are sufficient, but quickly succumb to disruptions if they are already fully exploiting available resource streams.

Policy implications

While the quantitative household model is highly preliminary, the model outputs do shed light on important metrics to be emphasized in humanitarian responses to food crises. The results show how household coping behaviors can enable households to survive a crisis, while simultaneously masking their degree of vulnerability. For households close to 'the edge,' rationing (Supplementary Figure S6) and/or foraging (Supplementary Figure S7) can enable long-term survival even if their baseline food production falls short of their annual needs. When existing vulnerability is compounded by a major disruption in food production, such households will be unable to exploit these strategies moving forward. This observation underlines the importance of behavioral metrics for vulnerability and resilience, such as the Coping Strategies Index (CSI) and the simplified reduced Coping Strategies Index (rCSI), which uses coping behaviors as indicators of chronic or acute food insecurity [17, 18]. The CSI and rCSI are commonly used—typically alongside other metrics—both in primary research [19–23] and as monitoring metrics for humanitarian organizations such as the World Food Program, UN Food and Agriculture Organization, and the IPC acute food insecurity classification [24].

A notable challenge in measuring food insecurity is that despite strong supporting evidence for various metrics, the metrics themselves are not always correlated, and the IPC advocates contextualization of metrics [4]. Maxwell et al. compared the performance of the CSI, rCSI, Household Food Insecurity Access Scale, Household Hunger Scale, Food Consumption Scale, and other metrics and concluded that areas of weaker correlation reflected the difference in underlying aspects measured, combined with the challenges of establishing arbitrary cutoffs, and importantly that different metrics are most at different levels of insecurity [24]. The IPC manual notes that "a defining characteristic of Phases 3 and 4 is that food consumption might reflect a lower phase, but only because households are using negative crisis or emergency coping" [4].

A more complete systems dynamics model for household resource management could help to elucidate the progression through known indicators of food insecurity, aiding in the development of more consistent combined metrics for crisis severity,



using the underlying temporal process to help diagnose changing conditions, including the inconsistent overlap between existing metrics highlighted by Maxwell et al. [24]. Focusing on household dynamics could be particularly valuable for developing metrics incorporating diversity of livelihood and social position within a famine system, better reflecting Sen's entitlements framework [13]. The relatively simple modeling framework described here is well suited for incorporation of into agent-based models, such as have previously been developed for various rural economies [25–30], would enable simultaneously accounting for differences in livelihoods, finances, and social position, as well as interactions among diverse households.

Before applying the framework and modeling approach described here to real-world systems, however, it will be crucial to incorporate additional components Fig. 2 into the quantitative model, particularly labor tradeoffs and market dynamics.

Limitations and areas for improvement

As noted above, the prototype model does not account for the interference of time spent foraging with future garden or field productivity, nor is there a mechanism for the reduction in labor capacity expected as the body's energy reserves are depleted. The only adverse consequences of the simulated coping mechanisms are increased mortality due to weight loss, and the draw-down of resources (food in storage, fat stores on the body, and wild food sources), which reduces the ability of the household to absorb future shocks. Thus, the model does not fully capture the interference with future harvests described in the "watch" archetype from Howe [5]. A more complete model for the "watch" should include rules for calculating labor effort available and allocating labor between food acquisition activities (Supplementary Figure S8). A challenge in implementing labor tradeoffs will be determining the correct definitions for time-delayed returns on labor investment, whereas investment of labor in foraging will produce food in the immediate term, loss of field or garden labor early in the growing season is expected to reduce harvest at the end of the season, which could be defined either by a simple mathematical definition converting labor input into expected harvest or by a detailed crop model, such as those reviewed in [31], explicitly accounting for management actions taken at different stages of plant development. Incorporation of crop models (and ecological models) would provide the added benefit of facilitating appropriate coupling productivity for field, garden, and wild systems based on climate conditions, but would also require more specific model inputs with regard to land use and yield potential.

Relatedly, the logistic growth model used to simulate wild food regeneration does not account for biodiversity or differences in the nutritional value of different plant tissue types. Whereas the logistic model assumes immediate growth responses to biomass removal, the plant tissues highest in macronutrients (mostly starch and protein, with some oils) include seeds, fruits, and tubers [32]. These tissues are unlikely to contribute to plant population growth or regeneration until a future generation or season. Examination of the biology of specific famine food plants would be valuable in model refinement.



In addition, while the current model centers on direct subsistence food production, this livelihood is not common, and the model furthermore focuses on households in a closed famine system, a situation typically combined with additional stressors. In his classic book *Poverty and Famines*, Sen notes that individual outcomes during a famine depend upon economic and social inequalities, which he frames as different forms of entitlements [25]. Furthermore, Corbett identifies numerous financial and transactional strategies for dealing with periods of hunger, including borrowing resources, selling assets, and engaging in outside labor [11]. Inclusion of market dynamics could therefore enhance model realism (Supplementary Figure S8). Such dynamics could either be predetermined (such as with a cosine model for seasonal fluxuations in price) or be dynamically simulated by adapting existing economic models [34–36]. The focus of the model on energy balance and direct food acquisition may also not reflect the realities of closed famine systems. Closed famine systems are most often occur in the context of armed conflict [6], a scenario in which violence, infrastructure breakdown, displacement, and environmental exposure may be of particular importance to mortality. The model presented may be most appropriate for the early stages of closed famine systems. Modifications for more open systems, for example, by including market dynamics, could broaden the applicability.

Another facet of open famine systems is the ability of household members to relocate to places with employment prospects or better access to humanitarian aid [6]. To incorporate population mobility into the described modeling framework, one approach would be to model the household members as two connected 'stocks' representing different locations or livelihoods with access to different livelihoods and risk profiles.

The prototype also assumes all household members have the same physiology, whereas real households are of course composed of people of different ages, genders, and body types that contribute to household livelihood in different ways. Modification of the model to include diverse household members would improve realism.

The current metabolic submodel is also extremely simplified. As noted by Thorn and Fitzpatrick (current issue), a realistic starvation model should account for loss of lean weight, not just body fat, and to model starvation during a famine, interactions with personal and maternal history, disease, malnutrition, and other stressors should be considered. Adaptation of more physiologically based starvation models such as Hall [33] could improve the household modeling framework in its current form and inform further model development incorporating physiological determinants of capacity for labor.

Finally, while coping strategies in the current model are largely reactive, real-world coping mechanisms are well documented to be pro-active, drawing on traditional knowledge to plan well in advance of when food supplies run short [7]. The system of threshold-based decisions described in the current modeling framework might not sufficiently capture the sophistication of real-world decision-making. To appropriately apply the framework described here to a real-world system, mathematical functions for coping responses should be descriptive of documented human behaviors, ideally including location-specific ethnographic studies of household resource management.



Conclusions

The framework and partial prototype model described illustrate a promising framework for simulating household resource management and adaptive coping strategies during food crises and periods of food insecurity and how these behaviors could shape the temporal dynamics of weight loss and mortality. Although the quantitative model is incomplete and describes narrowly defined dynamics, the simulated scenarios show how rationing and foraging could significant loss of life for a vulnerable subsistence household from around a month to close to a year, exemplifying the role of coping strategies in masking the effects of an ongoing crisis in the watch archetype [5]. More complete future variants on the same framework, incorporating labor tradeoffs and market dynamics (Supplementary Figure S8), as well as the smoothing effects of gift exchange [14–43], could be the basis for improved metrics for responding to food crises.

While the partial prototype model described here focuses on rural agrarian households, a more complete model based on the same framework could be adapted to represent more diverse livelihoods (Supplementary Figure S9). Furthermore, adaption of this single-household framework into a more complicated agent-based framework, tracking the behavior of multiple households over time, could also be valuable for delving into the role of social positionality in Sen's entitlements framework for famine systems [13]. However, when adapting this type of framework to additional contexts, researchers should consider the tradeoffs between simpler models, which are easier to analyze, and more complicated models, which can more closely model real-world conditions. Especially if the framework is to be applied to specific real-world systems, it will be crucial to ensure that the mathematical functions and submodels reflect geographically specific dynamics. Enhanced data sharing and engagement of modelers with practitioners and ethnographers are crucial for real-world applicability.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1057/s41271-026-00646-5.

Acknowledgements I thank colleagues Paul Howe, Elena Naumova, and Udita Sanga for feedback during the early stages of model development. I thank an anonymous reviewer and Paul Howe for useful feedback during the resubmission process.

Author contributions A.M.T. developed the model and modeling framework and wrote all parts of the manuscript.

Data availability All simulation outputs were generated using the StochSD (.ssd) model attached as Supplementary material. Readers seeking to replicate the results may download the.ssd file and open it using StochSD software, which can be either downloaded or run online via the StochSD home page (https://stochsd.sourceforge.io/homepage/#/home). A zip file containing.csv files of outputs from the sensitivity analysis is also attached as Supplementary material.

Declarations

Conflict of interest The authors declare no competing interests.



Open Access This article is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License, which permits any non-commercial use, sharing, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if you modified the licensed material. You do not have permission under this licence to share adapted material derived from this article or parts of it. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by-nc-nd/4.0/.

References

1. OCHA. Global humanitarian overview 2024. 2023. Available from: https://www.unocha.org/publications/report/world/global-humanitarian-overview-2024-enarfres. Cited 2024 Sep 18.
2. Relief Web. 2024, a challenging year for the humanitarian world. ReliefWeb. 2024. Available from: https://reliefweb.int/report/world/2024-challenging-year-humanitarian-world. Cited 2024 Sep 22.
3. OCHA. Financial Tracking Service. 2024. Available from: https://fts.unocha.org/home/2024/plans/view. Cited 2024 Sep 18.
4. IPC Global Partners. Integrated food security phase classification technical manual version 3.1: evidence and standards for better food security and nutrition decisions. Rome; 2021. Available from: https://www.ipcinfo.org/fileadmin/user_upload/ipcinfo/manual/IPC_Technical_Manual_3_Final.pdf. Cited 2024 Nov 27.
5. Howe P. Archetypes of famine and response. Disasters. 2010;34(1):30–54.
6. Howe P. Famine systems: a new model for understanding the development of famines. World Dev. 2018;105:144–55.
7. Walker P. Famine early warning systems: victims and destitution. London: Routledge; 2013. p. 210.
8. Cordero-Ahiman O, Santellano-Estrada E, Garrido A. Food access and coping strategies adopted by households to fight hunger among indigenous communities of Sierra Tarahumara in Mexico. Sustainability. 2018;10(2):473.
9. Erskine W, Ximenes A, Glazebrook D, da Costa M, Lopes M, Spyckerelle L, et al. The role of wild foods in food security: the example of Timor-Leste. Food Sec. 2015;7(1):55–65.
10. Moore M, Alpaugh M, Razafindrina K, Trubek AB, Niles MT. Finding food in the hunger season: a mixed methods approach to understanding wild plant foods in relation to food security and dietary diversity in southeastern Madagascar. Front Sustain Food Syst. 2022. https://doi.org/10.3389/fsufs.2022.929308/full.
11. Corbett J. Famine and household coping strategies. World Dev. 1988;16(9):1099–112.
12. Deng LB. Famine in the Sudan: causes, preparedness and response—a political, social and economic analysis of the 1998 Bahr el Ghazal Famine. University of Sussex: Institute of Development Studies; 1999. (IDS Discussion Paper).
13. Sen A, editor. Poverty and famines: an essay on entitlement and deprivation. Oxford University Press; 1983. https://doi.org/10.1093/0198284632.001.0001.002.002.
14. Ogutu SO, Mockshell J, Garrett J, Labarta R, Ritter T, Martey E, et al. Home gardens, household nutrition and income in rural farm households in Odisha. India J Agric Econ. 2023;74(3):744–63.
15. Whitney CW, Luedeling E, Hensel O, Tabuti JRS, Krawinkel M, Gebauer J, et al. The role of homegardens for food and nutrition security in Uganda. Hum Ecol. 2018;46(4):497–514.
16. Young H, Jaspars S. Nutrition matters. London: Intermediate Technology Publications 496 Ltd.; 1995.
17. Maxwell D, Caldwell R, Langworthy M. Measuring food insecurity: can an indicator based on localized coping behaviors be used to compare across contexts? Food Policy. 2008;33(6):533–40.
18. Maxwell D. The coping strategies index: field methods manual second edition. Cooperative for Assistance and Relief Everywhere, Inc. (CARE); 2008.
19. Zingwe DE, Banda AE, Manja LP. The effects of remittances on household food nutrition security in the context of multiple shocks in Malawi. Cogent Food Agric. 2023;9(1):2238440.

20. Brander M, Bernauer T, Huss M. Improved on-farm storage reduces seasonal food insecurity of smallholder farmer households—Evidence from a randomized control trial in Tanzania. Food Policy. 2021;1(98):101891.
21. Huss M, Brander M, Kassie M, Ehlert U, Bernauer T. Improved storage mitigates vulnerability to food-supply shocks in smallholder agriculture during the COVID-19 pandemic. Glob Food Sec. 2021;1(28):100468.
22. Ilboudo Nébié EK, Ba D, Giannini A. Food security and climate shocks in Senegal: who and where are the most vulnerable households? Glob Food Sec. 2021;1(29):100513.
23. Macheka L, Manditsera FA, Ngadze RT, Mubaiwa J, Nyarugwe S, Bangira C, et al. Agro-ecological distribution and consumption of wild harvested edible insects, fruits, and vegetables in rural Zimbabwe. Future Foods. 2022;1(6):100187.
24. Maxwell D, Bapu V, Coates J. How do indicators of household food insecurity measure up? An empirical comparison from Ethiopia. Food Policy. 2014;47:107–16.
25. Musayev S, Mellor J, Walsh T, Anagnostou E. Application of agent-based modeling in agricultural productivity in rural area of Bahir Dar, Ethiopia. Forecasting. 2022;4(1):349.
26. Sanga U, Park H, Wagner CH, Shah SH, Ligmann-Zielinska A. How do farmers adapt to agricultural risks in northern India? An agent-based exploration of alternate theories of decision-making. J Environ Manage. 2021;15(298):113353.
27. Tracy M, Cerdá M, Keyes KM. Agent-based modeling in public health: current applications and future directions. Annu Rev Public Health. 2018;39:77–94.
28. Dobbie S, Schreckenberg K, Dyke JG, Schaafsma M, Balbi S. Agent-based modelling to assess community food security and sustainable livelihoods. JASSS. 2018;21(1):9.
29. Dobbie S, Balbi S. A model to unravel the complexity of rural food security v1.1.0. CoMSES computational model library. 2018. Available from: https://www.comses.net/codebases/5170/releases/1.1.0/. Cited 2024 Jan 31.
30. Naivinit W, Le Page C, Trébuil G, Gajaseni N. Participatory agent-based modeling and simulation of rice production and labor migrations in Northeast Thailand. Environ Model Softw. 2010;25(11):1345–58.
31. Jin X, Kumar L, Li Z, Feng H, Xu X, Yang G, et al. A review of data assimilation of remote sensing and crop models. Eur J Agron. 2018;1(92):141–52.
32. Turner NJ, Łuczaj ŁJ, Migliorini P, Pieroni A, Dreon AL, Sacchetti LE, et al. Towards a more sustainable agriculture. Crit Rev Plant Sci. 2011;30:198–225.
33. Hall KD. Modeling metabolic adaptations and energy regulation in humans. Annu Rev Nutr. 2012;32:35–54.
34. Mitra S, Boussard JM. A simple model of endogenous agricultural commodity price fluctuations with storage. Agric Econ. 2012;43(1):1–15.
35. Lagi M, Bar-Yam Y, Bertrand KZ, Bar-Yam Y. Accurate market price formation model with both supply-demand and trend-following for global food prices providing policy recommendations. Proc Natl Acad Sci USA. 2015. https://doi.org/10.1073/pnas.1413108112.
36. Schewe J, Otto C, Frieler K. The role of storage dynamics in annual wheat prices. Environ Res Lett. 2017;12(5):054005.
37. Townsend RM. Village and larger economies: the theory and measurement of the Townsend Thai project. J Econ Perspect. 2016;30(4):199–220.
38. Olken BA, Singhal M. Informal taxation. Am Econ J Appl Econ. 2011;3(4):1–28.
39. Bhattamishra R, Barrett CB. Community-based risk management arrangements: a review. World Dev. 2010;38(7):923–32.
40. Lybbert TJ, Barrett CB, Desta S, Layne Coppock D. Stochastic wealth dynamics and risk management among a poor population. Econ J. 2004;114(498):750–77.
41. Fafchamps M, Lund S. Risk-sharing networks in rural Philippines. J Dev Econ. 2003;71(2):261–87.
42. Cox D, Jimenez E. Risk sharing and private transfers: what about urban households? Econ Dev Cult Change. 1998;46(3):621–37.
43. Townsend RM. Financial systems in Northern Thai villages. Q J Econ. 1995;110(4):1011–46.
44. Thorn AM, Fitzpatrick M. Modeling the dynamics of human starvation: incorporating lessons from famines past and present. J Public Health Pol. 2026.

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.