ETHNOBIOLOGY LETTERS

Perspectives

Astro-Ethnobiology: Insects, Identity, and the Design of Food Systems in Space

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Abstract Astro-ethnobiology—an explicitly interdisciplinary framework connecting ethnobiology and astrobiology—treats space food systems as cultural and ecological interfaces, not just technical solutions, by integrating engineering, bioregenerative ecology, and human factors. As humanity prepares for long-duration missions beyond Earth, these systems must support not only survival, but also identity, multispecies relations, and emotional resilience. Drawing on historical provisioning strategies, from maritime voyages to polar expeditions, we examine how animals fulfilled multifunctional roles in sustaining morale, routine, and ecological balance under extreme conditions. Insects, in particular, emerge as promising candidates for space-based life support due to their efficiency in nutrient provision and recycling as well as waste conversion. Beyond their biological utility, insects may contribute to psychological well-being and cultural continuity through care-based routines, storytelling, and sensory engagement. While cultural acceptance of insects as food remains a challenge in some parts of the world, historical dietary shifts show that unfamiliar foods can gain acceptance through ritual and shared experience. Astro-ethnobiology invites us to see space food not as a technical product, but as a shared practice shaped by care for other species, cultural meaning, and symbolic connection.

Received July 27, 2025
Accepted October 9, 2025
Published November 20, 2025

OPEN ACCESS
DOI 10.14237/ebl.16.1.2025.1970

Keywords Astrobiology, Bioregenerative life support systems, Gastronomic ethnobiology, Mini-livestock, Food system resilience, Multispecies spaceflight, Space food

Introduction

As space agencies prepare for long-duration missions beyond Earth, the question of how humans will procure food in extraterrestrial environments has become increasingly urgent. This issue intersects with key themes in ethnobiology, such as human–nonhuman relationships, food symbolism, and the adaptive use of resources in constrained settings. Gastronomic ethnobiology helps us understand how food systems are shaped by ecology and nutrition, but also by history, culture, and daily practices (Pieroni et al. 2016). A particularly relevant area of study is the history of travel diets and how food was sourced, prepared, and sustained during long-distance expeditions under harsh and isolated conditions (Nagai 2023). The provisioning strategies developed for maritime voyages and polar explorations provide instructive analogies for today's efforts to design food systems for space. Technology and environments may differ, but the core challenge is the same: how to sustain health, morale, and resource use in isolated settings.

Current strategies from space agencies emphasize the development of self-sufficient, closed-loop life support systems for the Moon and Mars (European Space Agency 2022; National Aeronautics and Space Administration 2023). These systems must minimize waste, operate autonomously, and support well-being under confinement. Fiction like *The Martian* celebrates the cleverness needed in space survival (Weir 2014). But real historical expeditions, from sixteenth-century naval voyages to nineteenth-century Arctic missions, reveal the complex realities of provisioning, including dependence on animals, preserved food, and symbolic familiarity (Carpenter 1986; Spalding 2014).

In this perspective, we introduce *astro-ethnobiology* as a conceptual lens that expands the scope of ethnobiology into extraterrestrial environments. This emerging framework combines ethnobiology, astrobiology, and systems thinking to view food as more than sustenance—as a shared cultural and ecological practice. Through the case of insects, we examine how future provisioning systems may support not only physiological needs, but also emotional resilience, symbolic continuity, and multispecies care. We argue that understanding future food systems requires attention to cultural adaptability and relational practices that sustain more than nutrition alone. Astro-ethnobiology is explicitly interdisciplinary: it links engineering design and bioregenerative ecology with human factors, psychology, and cultural analysis. In this sense, the framework bridges the technical and the lived dimensions of space exploration—much as insects in our case study bridge ecological performance, provisioning, and cultural meaning (European Space Agency 2021; National Aeronautics and Space Administration 2023; Wolverton 2013).

We begin by examining historical provisioning strategies from maritime and polar expeditions, highlighting the multifunctional roles of animals in sustaining life under extreme conditions. Next, we explore current approaches to bioregenerative space food systems, focusing on insects as ecologically efficient yet culturally complex candidates. Finally, we introduce astro-ethnobiology as a conceptual lens to reframe food in space not just as sustenance but also as a relational and symbolic practice.

Astro-ethnobiology is proposed here as a bridging framework that draws from ethnobiology's attention to multispecies relationships and cultural knowledge, and from astrobiology's orientation toward life beyond Earth. Unlike gastronomic ethnobiology, which emphasizes food as a cultural and ecological interface within terrestrial systems (Pieroni et al. 2016), astro-ethnobiology expands this analysis into closed, artificial, and culturally unfamiliar environments such as spacecraft and planetary habitats. It focuses not only on what can be eaten but also on how provisioning practices support identity, care, and symbolic continuity in extreme isolation.

Lessons from Historical Expeditions

Historical provisioning strategies developed during scientific and exploratory expeditions offer valuable insights for future space-based life support (Table 1). During the Age of Sail, spanning roughly the sixteenth to mid-nineteenth century, maritime voyages faced considerable challenges related to nutrition, logistics, and crew morale (Patrick et al. 2019). To extend autonomy at sea, vessels often carried livestock such as pigs, goats, and chickens. These animals supplied meat, milk, and eggs and were selected for their resilience in cramped conditions (Spalding 2014). Pigs were particularly valued for their efficient feed conversion, while goats and chickens diversified the diet and could subsist on food waste (Weibust 1969). Occasionally, unfamiliar species like land and sea turtles were collected from islands such as Ascension and the Galápagos to supplement provisions (Haworth and Russell 2023). Despite being novel to many European sailors, such animals were generally accepted as food, especially under necessity. Their nutritional value, including mitigation of vitamin deficiencies such as scurvy, was considerable in diets otherwise dominated by salted and dried foods (Carpenter 1986). Livestock brought on board were not only sources of nutrition, but they also provided much-needed comfort during long journeys. Pigs, for example, could be treated as pets (Weibust 1969).

However, including animals created additional challenges. They required space, feed, and care, introduced risks of zoonoses, and added to crew workload (Spalding 2014; Swanson and Morrow-Tesch 2001). In polar expeditions, where livestock was impractical, sled dogs played multifunctional roles, offering both transportation and, at times, an emergency food source (Strecker and Svanberg 2014). Later provisioning innovations, such as canned food, aimed to reduce reliance on live animals but introduced new concerns, including toxicity, suspected in the case of lead-soldered cans used during Sir John Franklin's 1845 Arctic expedition (Millar et al. 2015). These practices illustrate how provisioning involved more than logistical problem-solving. Familiar foods and animals contributed to psychological stability and social cohesion. The presence of recognizable species and caregiving routines provided continuity and structure in otherwise unpredictable and isolating conditions (Hurley 1925). Even animal waste, manure from shipboard livestock, was at times repurposed for small-scale gardening, an early example of circular nutrient use under constrained conditions (Spalding 2014).

Cultural frameworks also played a significant role in shaping food acceptance during expeditions and beyond. While seafarers and polar explorers

Table 1 The roles of animals in historical expeditions and potential role in future space missions. This highlights how past use of livestock can inform insect-based systems for sustainable, multifunctional provisioning in space.

Aspect	Historical Exploration	Space Exploration	Lessons for the Future
Animal roles	Livestock (pigs, goats, chickens) provided food, milk, and emotional comfort to sailors (Patrick et al. 2019; Spalding 2014).	Insects like crickets and mealworms offer nutrition, waste conversion and caregiving roles (Ko et al. 2016; van Huis and Tomberlin 2017).	Insects can serve multifunctional roles similar to livestock, blending utility with emotional support.
Space constraints	Compact livestock such as pigs were chosen for efficiency aboard cramped ships (Spalding 2014).	Insects require minimal space and can utilize waste as feed, fitting autonomous systems (Berggren et al. 2025).	Practices with livestock and insects inform compact, regenerative systems for long-duration space travels.
Waste management	Livestock waste created logistical burdens and sanitation challenges on ships (Spalding 2014).	Insects help close nutrient loops by consuming organic waste and producing plant fertilizer (van Huis and Tomberlin 2017).	Insect-based systems can transform waste into value, improving sustainability.
Psychological impact	Animals like cats, dogs, and goats offered routine, companionship, and familiarity (Strecker and Svanberg 2014).	Humans can gain psychological resilience by caring for insects and the benefits of animal companionship (Ko et al. 2016).	Care-based interactions with insects can support mental well-being in space.
Cultural and ethical factors	Food choices historically aligned with cultural norms; some species rejected even during famine (Svanberg and Nelson 1992).	Unfamiliarity can be a hinder, but norms can be reshaped through ritual and framing (Oshaug 1985; Svanberg and Berggren 2021).	Acceptance depends on aligning nutrition with culture and dignity in closed environments.
Symbolic and ritual roles	Animals held symbolic meaning, pigs, goats, and dogs were seen as companions and food rituals helped foster crew cohesion and morale (Hurley 1925; Svanberg and Nelson 1992).	Insects also carry symbolic meaning: pets strengthen emotional well-being, and insects can play important roles in spiritual practices (Ko et al. 2016; Quezada-Euán et al. 2018).	Recognizing the symbolic and relational potential of insects can support emotional resilience during long-duration missions.
Logistical challenges	Maritime provisioning involved dried meats, canned goods, and livestock, all resource-intensive and vulnerable (Carpenter 1986; Millar et al. 2015).	Space provisioning must prioritize self-sustaining, automated and resilient systems (Berggren et al. 2025; European Space Agency 2021).	Learning from historical provisioning inefficiencies can drive innovation in life support system design.

sometimes relied on unfamiliar foods, their willingness to consume these often depended on cultural framing and necessity (Nagai 2023). Similar dynamics were evident during terrestrial famines, when broader societies were encouraged to adopt alternatives such as lichens, mushroom bread, or bark flour. The acceptance of these substitutes was not purely a matter of survival, it often hinged on prevailing social norms, taboos, and symbolic associations (Svanberg and Nelson 1992). This interplay between pragmatism and cultural negotiation parallels the kinds of adaptation likely to be required in space-based food systems, where unfamiliar or unconventional food sources must be integrated into daily life. Taken together, these historical examples, both from exploratory expeditions and societal crises, highlight key themes relevant to future life support: the multifunctional use of organisms, cultural flexibility, symbolic continuity, and circular resource use. These themes underscore that food systems for long-duration space missions must address not only biological and logistical challenges, but also the cultural, psychological, and multispecies dynamics that shape how humans relate to food in unfamiliar environments.

Insects in Life Support Systems

Space imposes a hard boundary on provisioning:

volume, mass, and energy are tightly constrained, and resupply is impractical beyond low Earth orbit (European Space Agency 2021). While historical expeditions relied on a mix of stored, preserved, and sometimes live food sources, space provisioning must follow a different logic. Food systems must be integrated into closed-loop ecological infrastructures, where even minor failures can threaten system function and crew well-being (National Aeronautics and Space Administration 2023). Bioregenerative life support systems offer a promising model. They aim to establish closed to semi-closed ecological cycles that recycle waste, regenerate air, and produce food—treating life support not as isolated engineering tasks but as interdependent processes (European Space Agency 2021). This approach draws on analogues like Lunar Palace, Biosphere 2, and other Earth-based experiments, though maintaining stable multispecies environments remains a significant challenge. For example, Laboratory Biosphere trials achieved high-yield, closed-system soil crops (Nelson et al. 2005; Silverstone et al. 2005). In parallel, a range of biological strategies for in situ food production is under exploration. Earth-based circular-bioeconomy research shows that nitrogen can be recirculated into food proteins via insects, algae, and fungi (Siddiqui et al. 2023). Higher plants offer oxygen generation, carbon fixation, and sensory familiarity, but demand substantial resources and time (Wheeler 2010). Algae and cyanobacteria produce biomass quickly and contribute to gas exchange but are generally unpalatable and culturally unfamiliar. Cultivated meat and microbial electrosynthesis remain energy-intensive and are unlikely to meet crews' psychological or symbolic needs in the near term (Matassa et al. 2016). Most strategies address discrete functions like nutrition, air quality, or morale, but few integrate ecological performance with symbolic or emotional relevance.

Insects as mini-livestock offer a rare convergence of these domains (Table 1). They convert organic side streams into edible protein with minimal water or space, and their frass can fertilize crops (Cammack et al. 2021). Species like yellow mealworm (*Tenebrio molitor*), house cricket (*Acheta domesticus*), and black soldier fly (*Hermetia illucens*), tolerate high-density rearing and environmental variability and are already used in food and feed production systems on Earth (Berggren et al. 2019; van Huis and Tomberlin 2017). *A. domesticus* has a long dietary history and cultural familiarity in parts of Asia and Europe, while *H. illucens* is efficient for bioconversion but is predominantly used for feed and waste management (Cammack et al. 2021; van Huis and Tomberlin 2017). Insects can be reared modularly, adapted to different rearing scales and complement plant systems by processing inedible biomass. Presently significant knowledge gaps remain in how insects would cope with the environment in space. Microgravity, radiation, and altered microbial dynamics may affect insect development, behavior, and reproduction (Berggren at al. 2025; Guidetti et al. 2025). Their integration into bioregenerative life support systems needs to be studied holistically to ensure ecological stability and avoid unintended feedback. Importantly, insects may serve more than biological functions. Like animals on historical expeditions who provided food, labor, companionship, and symbolic continuity, insects may contribute to psychological stability. Their care and responsiveness may anchor routines, provide tactile contrast, and support emotional well-being, particularly in confined, artificial environments. From a systems perspective, insects embody a rare combination of ecological utility, logistical efficiency, and cultural adaptability. They point toward food infrastructures that offer more than sustenance: systems that are also meaningful, participatory, and emotionally resonant.

Insects, Meaning, and Multispecies Care

As human spaceflight extends in duration and autonomy, the organisms selected for life support systems must contribute across ecological, operational, and psychological domains. Insects, while often viewed through a technical lens, may also carry symbolic, emotional, and relational value—particularly in the confined and isolating environments of space (Table 1). Historical expeditions offer instructive analogues. Animals on board were not only eaten but also named, cared for, and used to mark time. Dogs, goats, pigs, and monkeys accompanied travelers as sources of food, labor, companionship, and emotional continuity (Spalding 2014). These relationships were not incidental; they formed part of the social and psychological architecture of survival. Insects could serve similar functions in space. Beyond their ecological role, they may offer opportunities for multisensory engagement and ritualized care. Feeding, observing, or interacting with insects can introduce rhythm, contrast, and purpose into highly controlled environments. In long-duration missions, such routines may support well-being and psychological continuity (Barbour et al. 2024).

This potential is grounded in cultural precedent. Across societies, insects are embedded in symbolic and ritual life. In pre-Columbian Mesoamerica, stingless bees (*Melipona* spp.) were cultivated for honey and ceremonial use (Quezada-Euán et al. 2018). In many African and Asian cultures, edible insects form part of a wider ethnozoological landscape that includes medicinal uses, ceremonial practices, and social memory (van Huis 2022). Globally, people eat more than 2,000 insect species—from mopane caterpillars (*Gonimbrasia belina*) in southern Africa to chapulines (*Sphenarium* spp.) in Mexico and weaver ants (*Oecophylla* spp.) and giant water bugs (species of *Belostomatidae*) in Southeast Asia—so entomophagy is a long-standing norm rather than a novelty (van Huis 2021). In East and Southeast Asian traditions, insects symbolize resilience, rebirth, or spiritual presence (Duffus et al. 2021). They also appear in folk medicine, seasonal rituals, children's games, and household cosmologies (Duffus et al. 2021; Meyer-Rochow 2004). These practices suggest ways future crews might weave insects into the cultural and emotional fabric of space life. Naming, storytelling, and caregiving routines can build emotional relationships with nonhuman cohabitants. These multispecies ties need not be nostalgic projections; they may evolve into new, mission-specific rituals that help astronauts navigate uncertainty, isolation, or interpersonal tension. Insects may thus serve as symbolic anchors: small, tangible beings that connect crew members to Earth-bound traditions or emerging space cultures.

However, cultural acceptance of insects as food or companions is not universal. Though widely consumed in parts of the world (Lesnik 2017; van Huis and Tomberlin 2017), insects are often rejected elsewhere due to disgust, unfamiliarity, or colonial legacies (Svanberg and Berggren 2021). Yet dietary norms are fluid. History shows that foods once regarded as revolting have been normalized through repetition, ritual, and collective adaptation (Svanberg and Berggren 2021). Food in space has always required negotiation—between technical feasibility and cultural acceptability, between standard rations and personal taste. Future crews will likely be multinational, and what is considered edible, offensive, or sacred will differ across individuals, shaping both diet and social dynamics (Hartmann et al. 2015). Astro-ethnobiology helps anticipate and navigate these divergences by foregrounding cultural entanglements with food, animals, and care. Designing systems with symbolic flexibility could support both personal identity and intercultural cohesion on long missions. By attending to symbolic, ritual, and affective dimensions, astro-ethnobiology invites a broader view of provisioning. Insects in space may be edible, but also nameable, narratable, and care-receiving. They offer a bridge between ecological function and emotional resilience, between engineered systems and cultural meaning.

Toward Astro-ethnobiology: A Conceptual Lens

Much of the current discourse on space food systems is dominated by technoscientific framings prioritizing efficiency, automation, and caloric adequacy. These approaches are essential, especially in resource-constrained environments. However, they often underplay the relational, symbolic, and emotional aspects of food that are central to human adaptation. As past expeditions have shown, survival depends not only on inputs and outputs, but on rituals, shared purpose, and care.

Astro-ethnobiology builds upon established subfields such as gastronomic ethnobiology (Pieroni et al. 2016), which explores the cultural and symbolic dimensions of food systems, and the broader ethnobiological tradition of examining human–biota relationships in specific ecological contexts (Wolverton 2013). While ethnobiology is typically grounded in terrestrial, localized systems, astro-ethnobiology extends this focus to extraterrestrial settings and spaces defined by isolation, artificial ecologies, and cultural heterogeneity. It reframes provisioning as a cultural-ecological process shaped not only by survival and logistics but by shared purpose, care, and relational ethics. Unlike conventional astrobiology, which often focus primarily on biochemical conditions for life, astro-ethnobiology emphasizes how multispecies relationships, symbolic practices, and cultural continuity evolve in space-based living systems. This orientation aligns with emerging strands of applied ethnobiology that address future-oriented challenges, such as food system resilience, multispecies adaptation, and ecosystem design.

The integration of insects into future provisioning systems is not merely a technical possibility—it is an entry point into *astro-ethnobiology*, a perspective that rethinks how humans relate to food, species, and ecological processes in unfamiliar environments.

Building on the lessons of historical expeditions and the emerging complexities of bioregenerative systems, astro-ethnobiology offers a conceptual framework that draws from ethnobiology, history, and systems thinking to explore human–nonhuman relationships in space-based life support. Ethnobiology has traditionally focused on dynamic interactions between people and biota within localized, terrestrial contexts. It examines not only practical knowledge systems such as foraging, cultivation, and animal husbandry, but also the symbolic and cultural dimensions of these practices. Astro-ethnobiology extends these concerns into the extraterrestrial domain. It invites reflection on how food systems beyond Earth will be shaped not only by engineering constraints and biological requirements, but also by deeply human needs for meaning, continuity, and cultural expression. For instance, anthropologist Hugh Raffles (2010) highlights the complex and emotional ways in which humans and insects interact, emphasizing the intricate relationships between humans, even within closed systems.

This perspective emphasizes that space food systems cannot be reduced to calculations of calories, mass, or technical efficiency. Like their historical antecedents, the systems will be shaped by emotional attachments, daily rituals, symbolic meanings, and cultural negotiation. Insects exemplify this multidimensional role: they function as ecological recyclers and nutrient sources while also enabling care-based routines. Their presence shifts provisioning from passive delivery toward active cultivation and interaction with other organisms. *Astro-ethnobiology* also encourages inclusive thinking about the makeup and diversity of future space crews. As international missions expand, provisioning systems must reflect the cultural preferences, taboos, and culinary identities of their members. Insects, already integrated into many terrestrial food traditions, have the potential to offer a culturally adaptable and scalable component of these systems, particularly when their use is guided by ritual, storytelling, and participatory practice. While their technical inclusion requires rigorous study, their symbolic potential invites a broader conversation about what counts as acceptable, comforting, or meaningful food in unfamiliar worlds. By linking historical models of provisioning with emerging technologies and multispecies systems, *astro-ethnobiology* invites us to understand future food design not just as engineering, but as an ongoing cultural and ecological negotiation. It does not offer definitive solutions, but a lens for asking richer questions: How do humans co-create life support with other organisms? How are identity, care, and tradition sustained in space? And how can food systems reflect not only survival, but ethical adaptation and relational depth beyond Earth?

Conclusion

Designing sustainable food systems for space requires more than technological innovation. It calls for an understanding of food as a multispecies, multidimensional practice. Drawing on historical analogies and ethnobiological insights, this perspective has emphasized that provisioning is never purely functional. From early seafarers and polar explorers to future astronauts, food systems have shaped routines, relationships, and resilience under conditions of isolation. Insects exemplify this complexity. As efficient biological processors, they can transform waste into nutrients within life support systems. But like the pigs, goats, and sled dogs of earlier expeditions, their value may extend beyond calories to include symbolic, emotional, and relational roles. Insects embody a kind of multifunctionality that is ecological, psychological, and cultural. There are, of course, a number of network effects of human-animal relations in the spacecraft environment (Kirsey and Helmreich 2010). The insects brought along also require care, which can offer psychological benefits, including by alleviating the isolation and stress that space travelers are exposed to. In this way, insects have a number of other functions that benefit human fellow travelers, which protein-rich fungi and microalgae do not have.

The conceptual lens of astro-ethnobiology helps articulate this shift. It highlights the cultural, historical, and ecological dynamics that shape how food systems are designed, interpreted, and lived. Rather than viewing provisioning as a technical pipeline, astro-ethnobiology encourages us to consider food systems that also support ritual, meaning, and identity.

This approach invites researchers, engineers, and mission planners to imagine provisioning models that are not only efficient and sustainable, but also culturally resonant and emotionally sustaining. As humanity ventures beyond Earth, we are not just solving problems of nutrition and logistics, we are shaping new ecologies of life and meaning in unfamiliar worlds. The lessons of ethnobiology and the versatile roles of insects suggest that future food systems can support not only survival but creativity, continuity, and ethical adaptation in space. Ethically, an ethnobiology lens stresses care, reciprocity, and biocultural stewardship. It helps avoid extractive, colonial patterns and complements planetary-protection rules by adding attention to cultural as well as biological impacts (Coustenis et al. 2021).

Declarations

Permissions: None declared.

Sources of funding: This study is the extension of a research project on insects in circular systems in Space funded by the European Space Agency (ESA) 'Potential of Insects as Nutritional Food in Spaceflight (PINS)' no. 4000136088.

Conflicts of Interest: None declared.

References Cited

Barbour, B. N., K. Twardowska, N. Favero, P. Ghoddousi, and P. Hodkinson. 2024. Biopsychosocial Health Considerations for Astronauts in Long-duration Spaceflight: A Narrative Review. *Wilderness and Environmental Medicine* 36:123S–137S. DOI:10.1177/10806032241289106.

Berggren, Å., A. Jansson, and M. Low. 2019. Approaching Ecological Sustainability in the Emerging Insects-as-Food Industry. *Trends in Ecology and Evolution* 34:132–138. DOI:10.1016/j.tree.2018.11.005.

Berggren, Å., A. B. Jensen, D. Copplestone, R. Guidetti, M. Heer, and P. Pittia. 2025. Insects in Bioregenerative Life Support Systems: Unlocking Their Role in Space Sustainability. *Frontiers in Physiology* 16:1–11. DOI:10.3389/fphys.2025.1621099.

Cammack, J. A., C. D. Miranda, R. Jordan, and J. K. Tomberlin. 2021. Upcycling of Manure with Insects: Current and Future Prospects. *Journal of Insects as Food and Feed* 7:605–619. DOI:10.3920/JIFF2020.0093.

Carpenter, K. J. 1986. *The History of Scurvy and Vitamin C*. Cambridge University Press, Cambridge.

Coustenis, A., N. Hedman, and G. Kminek. 2021. COSPAR Policy on Planetary Protection 2021. *Space Research Today* 211:12–25. DOI:10.1016/j.srt.2021.07.010.

Duffus, A. L. J., N. Harrison, and A. Choo. 2021. Insect Cultural Services: How Insects Have Changed Our Lives and How Can We Do Better for Them. *Insects* 12:377. DOI:10.3390/insects12050377.

European Space Agency. 2021. ROADMAP #11: Bio-regenerative Life Support Systems in Space: Space Biotechnology and Space Agriculture. European Space Agency. Available at: https://esamultimedia.esa.int/docs/HRE/11_Biology_Bioregenerative_LifeSupport.pdf. Accessed on September 9, 2025.

European Space Agency. 2022. Terrae Novae 2030+ Strategy Roadmap. Available at: https://destination-orbite.net/documentations/Terrae_Novae_2030+strategy_roadmap.pdf. Accessed on September 9, 2025.

Guidetti, R., A. B. Jensen, D. Copplestone, M. Heer, P. Pittia, L. Rebecchi, and Å. Berggren. 2025. Insects in Outer Space: Assessing the Effects of Microgravity on Edible and Model Insect Species for Spaceflight Food System. *Frontiers in Physiology* 16:1622401. DOI:10.3389/fphys.2025.1622401.

Hartmann, C., J. Shi, A. Giusto, and M. Siegrist. 2015. The Psychology of Eating Insects: A Cross-Cultural Comparison between Germany and China. *Food Quality and Preference* 44:148–156. DOI:10.1016/j.foodqual.2015.04.013.

Haworth, D., and L. Russell. 2023. Islands, Oceans, Whaling Ships, and the Mutable Ontologies of the Galápagos Tortoise. In *Maritime Animals: Ships, Species, Stories*, edited by K. Nagai, pp. 13–37. Pennsylvania State University Press, University Park, PA.

Hurley, F. 1925. *Argonauts of the South: Being a Narrative of Voyagings and Polar Seas and Adventures in the Antarctic With Sir Douglas Mawson and Sir Ernest Shackleton*. G. P. Putnam's Sons, New York.

Kirsey, E., and S. Helmreich. 2010. The Emergence of Multispecies Ethnography. *Cultural Anthropology* 25:545–576. DOI:10.1111/j.1548-1360.2010.01069.x.

Ko, H-J., C-H. Youn, S-H. Kim, and S-Y. Kim. 2016. Effect of Pet Insects on the Psychological Health of Community Dwelling Elderly People: A Single-blinded, Randomized, Controlled Trial. *Gerontology* 62:200–209. DOI:10.1159/000439129.

Lesnik, J. J. 2017. Not Just a Fallback Food: Global Patterns of Insect Consumption Related to Geography, Not Agriculture. *American Journal of Human Biology* 29:1–8. DOI:10.1002/ajhb.22976.

Matassa, S., N. Boon, W. Verstraete, and I. Pikaar. 2016. Microbial Protein: Future Sustainable Food

Supply Route with Low Environmental Footprint. *Microbial Biotechnology* 9:568–575.

Meyer-Rochow, V. B. 2004. Traditional Food Insects and Spiders in Several Ethnic Groups of Northeast India, Papua New Guinea, Australia and New Zealand. In *Ecological Implications of Mini-Livestock*, edited by M. G. Paoletti, pp. 385–409. Science Publishers, Enfield, NH.

Millar, K., A. W. Bowman, and W. Battersby. 2015. A Re-analysis of the Supposed Role of Lead Poisoning in Sir John Franklin's Last Expedition, 1845–1848. *Polar Record* 51:224–238. DOI:10.1017/S0032247413000867.

Nagai, K. 2023. Introduction. In *Maritime Animals: Ships, Species, Stories*, edited by K. Nagai, pp. 1–14. Pennsylvania State University Press, University Park, PA.

National Aeronautics and Space Administration. 2023. NASA's Moon to Mars Strategy and Objectives Development: A Blueprint for Sustained Human Presence and Exploration Throughout the Solar System. Available at: https://www.nasa.gov/moontomarsarchitecture-strategyandobjectives/. Accessed on September 9, 2025.

Nelson, M., W. F. Dempster, S. Silverstone, A. Alling, J. P. Allen, and W. van Thillo. 2005. Crop Yield and Light/Energy Efficiency in a Closed Ecological System: Laboratory Biosphere Experiments with Wheat and Sweet Potato. *Advances in Space Research* 35:1539–1543. DOI:10.1016/j.asr.2005.01.016.

Oshaug, A. 1985. The Composite Concept of Food Security. In *Introducing Nutritional Considerations into Rural Development Programs with Focus on Agriculture: a Theoretical Contribution*, edited by W. B. Eide, pp. 6–15. Institute for Nutrition Research, University of Oslo, Oslo.

Patrick, W., J. A. Hayes, B. Matthews, B. Allaire, and P. Holm. 2019. European Naval Diets in the Sixteenth Century: A Quantitative Method for Comparative and Nutritional Analysis. *Historical Methods: A Journal of Quantitative and Interdisciplinary History* 52:195–212. DOI:10.1080/01615440.2019.1580170.

Pieroni, A., L. Pawera, and M. S. Shah. 2016. Gastronomic Ethnobiology. In *Introduction to Ethnobiology*, edited by U. P. de Albuquerque and R. R. N. Alves, pp. 53–62. Springer, Cham, Switzerland. DOI:10.1007/978-3-319-28155-1_9.

Quezada-Euán, J. J. G., W. D. May-Itzá, and L. M. Medina. 2018. Stingless Beekeeping: A Historical Perspective. In *Pot-Honey: A Legacy of Stingless Bees*, edited by P. Vit, S. R. M. Pedro and D. Roubik, pp. 3–16. Springer, Cham, Switzerland. DOI:10.1007/978-1-4614-4960-7_1.

Raffles, H. 2010. *Insectopedia*. Pantheon Books, New York.

Siddiqui, S. A., D. Pleissner, A. Pentjuss, J. Gołaszewski, A. Karwowska, E. Dace, M. Pahmeyer, S. Van Miert, L. Frooninckx, L. Broeckx, V. Heinz, and S. Smetana. 2023. Biological Nitrogen Recirculation to Food Protein – A Review. *Cleaner and Circular Bioeconomy* 6:100056. DOI:10.1016/j.clcb.2023.100056.

Silverstone, S., M. Nelson, A. Alling, and J. P. Allen. 2005. Soil and Crop Management Experiments in the Laboratory Biosphere: An Analogue System for the Mars on Earth Facility. *Advances in Space Research* 35:1544–1551. DOI:10.1016/j.asr.2005.06.008.

Spalding, S. 2014. *Food at Sea: Shipboard Cuisine from Ancient to Modern Times*. Rowman and Littlefield, Lanham.

Strecker, L., and I. Svanberg. 2014. Dogs in the Arctic. In *Antarctica and the Arctic Circle: A Geographic Encyclopedia of the Earth's Polar Regions*, edited by A. Hund, pp. 231–238. BC-CLIO/Greenwood, Santa Barbara, CA.

Svanberg, I., and Å. Berggren. 2021. Insects as Past and Future Food in Entomophobic Europe. *Food Culture and Society* 24:624–638. DOI:10.1080/15528014.2021.1882170.

Svanberg, I., and M. C. Nelson. 1992. Bone Meal Porridge, Lichen Soup, or Mushroom Bread: Acceptance or Rejection of Food Propaganda 1867–1868. In *Just a Sack of Potatoes? Crisis Experiences in Past and Present Societies*, edited by A. J. Häkkinen, pp. 119–147. Societas Historica Finlandiae, Helsinki.

Swanson, J. C., and J. Morrow-Tesch. 2001. Cattle Transport: Historical, Research, and Future Perspectives. *Journal of Animal Science* 79:E102–E109. DOI:10.2527/jas2001.79E-SupplE102x.

van Huis, A., and J. K. Tomberlin. 2017. Future Prospects of Insects as Food. In *Insects as Food and Feed: From Production to Consumption*, edited by A. van Huis and J. K. Tomberlin, pp. 430–445. Wageningen Academic Publishers, Wageningen. DOI:10.3920/978-90-8686-849-0_24.

van Huis, A. 2021. Prospects of Insect as Food and

Feed. *Organic Agriculture* 11:301–308. DOI:10.1007/s13165-020-00290-7.

van Huis, A. 2022. Edible Insects and Their Roles in Food Culture, Medicine, and Symbolism in Sub-Saharan Africa. *Journal of Ethnobiology and Ethnomedicine* 18:27. DOI:10.1186/s13002-022-00524-w.

Weibust, K. 1969. *Deep Sea Sailors: A Study in Maritime Ethnology*. Nordic Museum, Stockholm.

Weir, A. 2014. *The Martian*. Del Rey, London.

Wheeler, R. M. 2010. Plants for Human Life Support in Space: From Myers to Mars. *Gravitational and Space Research* 23:25–35.

Wolverton, S. 2013. Ethnobiology 5: Interdisciplinarity in an Era of Rapid Environmental Change. *Ethnobiology Letters* 4:21–25. DOI:10.14237/ebl.4.2013.11.