Article

Nature and Space

EPE: Nature and Space
0(0) 1–25

DOI: 10.1177/25148486211000746
journals.sagepub.com/home/ene
SAGE

Nonscalability and generating digital outer space natures in *No Man's Sky*

Emma R Tait and Ingrid L Nelson
University of Vermont, USA

Abstract

This article examines the generation of digital outer space natures in the space exploration game, *No Man's Sky*. Using procedural generation, *No Man's Sky* offers nearly infinite planets, flora, and fauna on the fly. With the rapid development of gaming technology and tools, game developers and others are attempting to diversify the representation of various forms of nature in gaming content and to expand the use of games in behavioral change, education, conservation, and other fields. Many scholars argue that games offer promising ways for various publics to understand their place and their interconnectedness with microbes, ecosystems, planet Earth, and beyond. We examine how *No Man's Sky* struggled to coproduce digital outer space natures at the two scalar extremes of the vast expanse of outer space and of the embodied player relating within complex biomes. Our results from an in-depth, qualitative analysis of the initial version of the game, of player world-building experiences in *No Man's Sky*, and of subsequent developer modifications to the game demonstrate that nonscalability theory is useful for studying what digital outer space natures do in games. We also argue that nonscalability theory would benefit from a more robust engagement with the digital. *No Man's Sky* was initially scalable to such an extreme that it made players into objects without an origin story, broader purpose or way to build meaningful relations in the game. For a brief period, this game undermined players' interplanetary colonial imaginaries. Subsequent updates to the game introduced a limited scope of nonscalability, but only to the extent of satisfying gamers' desires to become more impactful agents of exploration. We see great potential for analyzing the role of innovations in computing and game design in linking multiscalar digital, outer, and earth spaces, which as other scholars have shown, bear significantly on our understanding of multiple worlds and natures.

Keywords

Digital game natures, feminist political ecology, outer space, scale, world building

Corresponding author:
Ingrid L. Nelson, Department of Geography and the Environmental Program, University of Vermont, 94 University Place, Old Mill Building 200, Burlington, VT 05405, USA.
Email: ilnelson@uvm.edu

Introduction

Promises of infinite exploration in a new digital gaming universe titillated many in the computer gaming community ahead of the release of the open world game, *No Man's Sky* (NMS) (Hello Games, 2016a). Developers of NMS aspired to satisfy gamers' voracious demands for complex new landscapes and features by automating labor-intensive game environment design (Tach, 2015). Through procedural generation, NMS would offer an impressively scalable game terrain with nearly infinite planets, flora, fauna, atmospheres, and other components of navigable worlds on the fly using a set of algorithms. The premise of the game involves players crash-landing their spaceship on a distant planet. Before traveling to some of the game's 18 quintillion other planets, players must explore the landscape to collect resources necessary for repairing their spaceship. Advertisements for the game displayed complex exoplanetary landscapes teeming with diverse terrestrial and aquatic wildlife.[1] Upon NMS' release in 2016, however, game critics and the broader gaming community expressed profound disappointment and outrage (Caldwell, 2017). Sony had promoted NMS with its other major titles of the year—a first for an independent game—which increased pressure on the game's development team by expanding media coverage and by advertising features absent from the initial release (Hello Games, 2016a; Khatchadourain, 2015; Parkin, 2014). Developers often under-deliver to some extent, but many players argued NMS' failures were unparalleled (Caldwell, 2017).

We understand NMS as a powerful example of contemporary technological, cultural, and political innovation that informs imaginaries of interplanetary futures. Political geographers and others in related fields have contributed extensively to discussions of coloniality, imperialism, and frontier imaginaries shaping outer space geopolitics (see Dunnett, 2019; Kleinberg, 2007; Leib, 2015; Ormrod and Dickens, 2016; Redfield, 2002; Sage, 2008; Sammler and Lynch, 2019). Geographers have most extensively published works on outer space in the journal *Geopolitics* (some exceptions include Dunnett et al., 2019; Kopack, 2019; MacDonald, 2007). To a limited extent, select political geographers, science, technology, and society (STS), and environmental humanities scholars have focused on various outer space environments and ideas of nature (Messeri, 2016; Olson, 2018), the "environmental geopolitics of outer space" (see Klinger, 2019), and the ethics of contemporary co-constitutive earthbound and outer space worlding (see Kearnes and van Dooren, 2017; Saperstein, 2020).

Rather than attempting to expand work on outer space geopolitics, our goal is to encourage *political ecologists* to study interplanetary political ecologies. This interdisciplinary field has largely been silent on discussions of outer space natures. We note, following feminist STS scholarship (see Haraway, 1989; Messeri, 2016; Olson, 2018; Shaw, 2004), that preparing for interplanetary existence involves cultural and symbolic work through science fiction literature and other media, including digital games. The return of popular desires for interplanetary exploration has brought a resurgence of paternalistic and colonizing tropes critiqued decades ago by feminist scholars. For example, Carolyn Merchant (1980, 1995, 2006) and Donna Haraway (1989) demonstrated the specific patriarchal and power-laden features of frontier desires and the gendered and racialized assumptions within scientific writings about discovering nature's secrets on and beyond earth. According to Haraway (1989, 136–137):

> . . . the wilderness of Africa is coded as dense, damp, bodily, full of sensuous creatures who touch intimately and intensely. In contrast, the extraterrestrial is coded to be fully general; it is about escape from the bounded globe into an anti-ecosystem called, simply, space. Space is not about "man's" *origins* on earth but about "his" *future*, the two key allochronic times of salvation

> history . . . Space and the tropics are both utopian topical figures in western imaginations, and their opposed properties dialectically signify origins and ends for the creature whose mundane life is outside both: civilized man. Space and the tropics are "allotopic"; i.e., they are elsewhere," the place to which the traveler goes to find something dangerous and sacred.

In rereading Haraway's analysis, we note the importance of *scale* in her discussion of colonizing embodied earthbound relations and unbounded space.

Developers of NMS promised players intimate encounters with exotic creatures and an escape into a vast universe, while also asking players to form a relationship with that digital universe. For game studies scholars such as Alenda Chang (2019: 90–91), games offer promising ways for various publics to understand their place and their interconnectedness with microbes, ecosystems, planet Earth and beyond:

> Although games inevitably participate in flows of material and capital and so-called attention economies that place them squarely within the ongoing debate over local, as opposed to global, modes of thinking and living, games, especially digital ones, can obviate the perceived choice through multiscalar play. The local and the global are, after all, only imagined extremes, beyond which lie countless microorganisms, elementary particles, and most of the known universe. If we could . . . escape the anthropomorphic drag of the local-global dualism, perhaps our Earth-friendly bumper stickers would urge us to "think galactically, act microscopically."

Chang (2019: 98) argues further that, "Games . . . are inherently multiscalar—melding the quantitative and the qualitative, the experiential and the analytic, the computational and the graphical—and a universe of questions awaits." Like Chang, we think NMS's multiscalar aspirations and production merit sustained analysis. While "think galactically, act microscopically" is a great slogan, a more-nuanced understanding of multiscalar relationality is necessary to understand what digital outer space natures (DOSNs) do in digital games.

We strengthen our understanding of multiscalar relationality through Anna Tsing's (2019) concepts of scalability and nonscalability. Tsing (2019: 143) defines scalability as "the ability to expand—and expand, and expand—without rethinking basic elements." We aim to "notice" what Tsing (2019: 147), refers to as "nonscalable phenomena" within broader legacies of persistent capitalist, patriarchal and colonial logics underpinning popular desires for conquering "new world"[s]. Tsing (2019: 148) argues:

> European sugarcane plantations of the New World . . . gave us the equivalent of pixels for the land. But unlike pixels these plantations did not come into being through an already developed aesthetics of scalability. Instead they stumbled into history and only afterward became a model for further scalable designs. Attention to their stumbling—that is, the contingencies and conjunctures that informed their design—is the 'nonscalable' approach I take to seeing where their plans failed to meet their own expectations . . . If the world is still diverse and dynamic, it is because scalability never fulfills its own promises . . . Instead of taking scalability for granted as a necessary tool of progress, nonscalability theory attends to the work of contingency and failure.

Digital games such as NMS are a kind of scalability project of generating nearly infinite DOSNs.

The concepts of scalability and nonscalability help us to understand what the built game environment, developers, algorithms, code, and players coproduce, particularly in terms of embodied relationships with DOSNs. Players experience scalability and nonscalability in NMS through their attempts at *world building*: the practices that coproduce game space as

players go about understanding their role in a game's narrative and their physical, social, cultural, and political relationship to the gaming environment, thereby establishing a sense of place and belonging. Specifically, we found that NMS was initially so scalable that players became sugarcane-like scalable objects with no origin story and no broader narrative purpose or way to build meaningful relations in the game. This kind of scalability project prevented effective world building. For a brief period, this colonial exploration game undermined players' interplanetary colonial imaginaries, rendering endless discovery and resource extraction as so boring that many players stopped playing. Subsequent NMS updates introduced a limited scope of nonscalability, but only to the extent of satisfying gamers' desires to become impactful agents of exploration. Our analysis also demonstrates that Tsing's nonscalability theory would benefit from a more robust engagement with the digital. Tsing contrasts the presumed "aesthetics of scalability" of the digital pixel with the messier attempts to render earth-bound sugar cane clones into scalable plantations. Digital natures consist of much more than a simple, binary, discrete, pixel structure.

We conducted three phases of empirical analysis. First, we examined the structure and design of NMS through document analysis of promotional material and of articles about NMS for gaming communities and broader audiences (e.g., Khatchadourain, 2015; Peckham, 2016, and others). In our second phase, we played through the game to contextualize our document analysis and further explore its production of DOSNs. We also asked six gamers to play the game and record their experiences in a digital diary. We interviewed them before and after their playthrough concerning their expectations and impact on game play as well as how they coproduced DOSNs. Our third research phase examined which aspects of the game the developers changed and whether and how they addressed nonscalability. We conducted a document analysis of the patch notes from each of the NMS updates released between August 2017 and November 2019 and we analyzed the implementation of those updates with a further 20 hours of play.

Drawing on nonscalability theory, we contextualize our analysis within two areas of scholarship: (1) feminist digital geographies (extending this to digital natures) and (2) digital games studies. The first area of scholarship situates our feminist approach to studying games and digital natures and the second contextualizes the study of games as a space where DOSNs are coproduced. We then detail our methods further, and present and discuss our findings. We conclude with the implications of our analysis, which extends the fairly narrow treatment of *nature* in digital natures political ecology scholarship to include DOSNs, and we call for further feminist scholarship on digital natures that draws from game studies and other approaches.

Feminist digital geographies and digital natures

Feminist geographers critically analyze many aspects of digital technology. Sarah Elwood and Agnieszka Leszczynski (2018) examine power structures, violence, and social difference in and through digital spaces in their overview of feminist engagements with digital technologies and geographies. They question the assumptions that enable or complicate affective digital encounters and add crucial methodological insights, which we engage in the subsequent section of this article (Leszczynski, 2018). Feminist theory invites us to examine world-building failures from a multitude of positionalities and perspectives and to interrogate the power dynamics, social differences, and identity issues involved in these encounters (see Downhour, 2016; Gigliotti, 2016; Nelson, 2017; Tsing, 2019; Wirman, 2014). The robust and dynamic field of feminist digital geographies, however, has not yet engaged extensively with debates concerning digital natures (see Nelson, 2017). A new feminist digital natures

research agenda could focus specifically on encounters with, assumptions about, and coproduction of variously defined digital "naturecultures" (see Haraway, 2016) on and beyond Earth.

We see DOSNs as key sites of emerging feminist political ecologies of linked fears about climate crisis and hopes invested in making humans interplanetary (see Olson and Messeri, 2015). In the coming decades, far more people are likely to experience novel forms of place making in *digital* outer space than on the elite space flights imagined by wealthy space exploration entrepreneurs. Recent work by political geographers demonstrates that desires for material investments in space exploration produce contested environmental geopolitics involving toxic geographies of rocket launch sites and falling debris in vulnerable environments and communities (Klinger, 2019; Kopack, 2019). The colonial logics and desires in the scientific and political cultures of space exploration merit sustained critical attention (see Cosgrove, 1994; Dittmer, 2007; Messeri, 2016). Political ecologists have largely ignored outer space natures, with some preferring instead to study digital natures, focusing primarily on conservation and social media (Büscher, 2016; Büscher et al., 2017).

Only a few political ecologists study digital games (see Sandbrook et al., 2015). One example is Robert Fletcher's (2017) analysis of two children's digital conservation games alongside his experiences leading a group of US-based university students on a program in the southern Peruvian Amazon. He aimed to understand the connections, tensions, and divergences between digital tropical rainforests and "direct encounters" in neotropical rainforests (2017: 160). Digital games and other media are often celebrated for their potential to help broader publics connect with various natures without physically trampling such natures or increasing ecotourism-linked resource consumption. Such games and media present rainforests as pleasant, "romanticized" or "Disney-like" in stark contrast with forests full of "inescapable and sweltering heat," and the "incessant attack by mosquitos and other biting insects" experienced by Fletcher's (2017: 157) students. He doubts conservation games can achieve ostensibly positive environmental and social change, based on the limited kinds of individual, consumer-centered solutions to environmental degradation narrated in these games, such as encouraging awareness, charitable giving, and purchasing various eco-certified products. Beyond how specific games narrate normative arguments about saving nature, we draw from games studies scholarship for a more robust understanding of the kinds of digital natures that digital games coproduce at multiple scales.

Understanding digital game encounters

Playing games is a productive practice in which games and players reinvent spaces to perpetuate particular narratives or gaming objectives (Boellstorff, 2008; Rutherford and Bose, 2013). Players are active agents in game content (Aber, 2008; Ash, 2009, 2015; Shaw and Warf, 2009; Thrift, 2000). Game studies scholar Ian Bogost (2008: 121) argues video games, "create new possibility spaces" for exploring the material world processes they represent, enabling exploration of "possibility spaces through play," in which the player encounters the game's meanings (see also Fernández-Vara, 2011). Geographer Daniel Bos (2018: 62) argues that play is "a complex event . . . conditioned by the spatial context, practices and socio-technical relations," including the social relations in many players' family rooms and bedrooms where they connect with game spaces, and extending these physical space engagements via mobile gaming apps.

Game mechanics are key to understanding possibility spaces of play. Miguel Sicart (2008) defines game mechanics as "methods invoked by agents, designed for interaction with the game state." As such, they are available both to the player through jumping, running, and

other actions, or to other non-player elements such as gravitational effects. Game mechanics are designed to facilitate the gameplay towards developers' goals. Players, however, often use a game's mechanics to ignore the game's goals and engage in activities outside the game story, such as mining mineral towers to make caves in the context of NMS. As Stephanie Rutherford and Pablo Bose (2013: 5) elaborate, "while the game designer may intend a particular understanding of the world, the player might have oppositional, subversive or rogue readings." It is a game's level of abstraction—overlap between the rules of a game and the game world, and the ways that players can interact with the visually rendered content—at different scales that shapes the scope of what players can do in terms of subversive or rogue engagement with game mechanics (Fernández-Vara, 2011). According to Fernández-Vara (2011: 137), "choosing the right level of abstraction is a fundamental tool to establish how much room the player has to fail and experiment." Players' probing of the possibility space to determine correct actions "produces an experience of back-and-forth, of fine-tuning one's behavior in relation to an environment" (Driessen et al, 2014: 93).

Games are most scalable along the trajectory of their stories. There are various opportunities for nonscalibility to arise, sometimes within the story but also as players play outside the scope of these trajectories, and when game mechanics, bugs, glitches, and levels of abstraction cause failures in world building. As Tsing (2019: 148) argues, "nonscalability theory attends to the work of contingency and failure." Player exploration of the level of abstraction and game mechanics is essential for world building and this is how players encounter scalability and nonscalability. Developers want as many players as possible to be able to world build so as to enjoy and play through the game's storyline effectively. NMS developers promised unprecedented scalability, which we argue they achieved to a fault because of how scalability prevents world building. We examine which aspects of DOSN coproduction and world building—despite their assumed scalability in NMS—are in fact scalable and which are not, and their implications for interplanetary scalability projects.

Methods: Researching DOSNs in digital games

We conducted an in-depth, qualitative analysis of the initial version of NMS and subsequent developer modifications to the game. Oona Morrow and colleagues (2015) highlight how research in/of digital space raises questions about the tendency for researchers to place greater weight on face-to-face interactions. Standard research methods such as document analysis, interviews, and participant observation are valuable for studying digital spaces, but how to do so requires sustained critical epistemological reflection (Leszczynski, 2018). Rather, as a site of ethnographic research, digital space is less about physical location than the coproduction of place as a set of encounters, interactions, communications, events, and networks that contribute to a particular phenomenon or community (Bos, 2018; Crang and Haji Bin Mohamed, 2016; Lenihan and Kelly-Holmes, 2016; Massey, 2005). Contemporary geography of games, game studies, and feminist digital geographies scholarship highlights nuanced productive relations in and with digital spaces and furthers debates regarding the problematic binaries of virtual/real and virtual/material spaces (Boellstorff, 2008; Hine, 2000; Morrow et al., 2015). We agree with this extensive scholarship that experiences, relationships, and encounters are no less "real" for being manifested in digital space, and that digital spaces coproduce particular kinds of interaction, communication, and world building (Boellstorff, 2008; Graham et al., 2014; Haraway, 2004). We, therefore, use the term *digital* to articulate the technical structure of the NMS game space through specific software and algorithms that require careful consideration through textual

analysis and observing what happens within/through the spaces themselves (Fernández-Vara, 2019).

Our analysis occurred in three phases. The first began in 2016 and focused on the structure and design of NMS. We conducted a qualitative document analysis of 23 gaming community articles in addition to NMS' promotional materials, including published interviews with the game's lead developers. Our textual analysis of these materials focused on developer narratives regarding their personal experiences, and understandings of nature and of outer space, as well as references to technical design choices regarding game physics and assumptions written into the game's algorithms, noting what developers explained with great detail (coded as new and interesting from the developers' perspectives) compared with game features with little to no explanation (coded as routine or obvious from the developers' perspectives). Emma—who identifies as a gamer—then played NMS for 30 hours to systematically assess the procedurally-generated environments within the game and "what the technologies themselves are doing" (Rose, 2016: 291).[2] Emma generated screenshots of planetary landscapes, game stages, instructions, and dashboard content, noting the level of detail provided at different spatial scales. Each NMS playthrough varies greatly depending on the choices and preferences of the player due to the game's structure. Emma played on "normal" mode (if she died, she would return to her last save point, with any progress made since that point being lost).[3] We were interested in world building within NMS and as such, approached the game from an exploratory perspective, driven primarily by curiosity and attention to the depth of player–environment interactions. When given choices, Emma chose the options which seemed likely to foster positive or neutral relationships with non-player characters (NPCs). We focused on five formal game elements: (1) abstraction, (2) values and procedural rhetoric, (3) representation and identity, (4) the relationship between the rules and the fictional world, and (5) the gap between the player and the game (see Table 1) (Fernández-Vara, 2019). We concluded our first phase by reexamining NMS promotional materials, gaming community forum articles and developer interviews to elaborate aspects of NMS that were insufficiently described.

Our second research phase examined player interactions within the game. We recruited six adult self-identified gamers who play digital games regularly and are actively involved in gaming communities to play at least 10 hours of NMS and to record their reactions and experiences in text- and image-based digital journals.[4] Their ages ranged from 18 to 30 years, they had completed at least some higher education, and the racial and gender diversity of the group broadly reflected that of the larger gaming community. They primarily played action–adventure games, real-time and turn-based strategy games, and massively multiplayer online games (MMOs). We conducted 30- to 90-minute semi-structured interviews with each participant before and after game play, asking what they had heard about the initial release of NMS, what they expected to experience, and what they actually experienced. We analyzed the resulting interview transcripts and player-created text and images regarding DOSNs iteratively in the context of our structural analysis of NMS. We noted convergences and divergences regarding player expectations of DOSNs, their experiences of and responses to DOSNs that scaled with relative ease, and nonscalable encounters that challenged their world-building capabilities. The results of this phase revealed world building failures at the two scalar extremes of the vast expanse of outer space and the individual, embodied player relating within complex biomes.

Our third research phase focused on how the developers changed the game to improve world building, and whether and how they addressed nonscalability. We conducted a document analysis of the patch notes from each NMS update released between August 2017 and November 2019. Emma played through these updates for a further 20 hours, recording

Table 1. Research phases, formal elements, methods, and questions.

Study phase	Formal elements	Methods	Driving questions and sub-questions*
I. Analyze game design and structure	*(1) Abstraction*	• Critical game play (Emma), 30 hours, including screen captures and notes	• How did the limits of player interactions with DOSNs influence experiences of world building? (PRQ1)
	(2) Values and procedural rhetoric	• Document analysis of developer interviews and game development articles	• What tropes and ideologies regarding various natures did the developers deploy to facilitate the game's storyline? (PRQ2) • What assumptions about digital natures did players bring into the game? (PRQ3)
	(3) Representation and identity		• Who is the player character? (SRQ1) • How does the player identify with/as this character? (SRQ2) • How does this character relate to player understanding of themselves in relation to digital natures and play of the game? (SRQ3)
II. Player–game interactions with DOSNs	*(4) Relationship between the rules and fictional world*	• Player ($n = 6$) pre-play interviews • Player diary and image analysis from their minimum 10 hours of play • Player ($n = 6$) post-play interviews • Second analysis of developer interviews and game development articles to add omitted/unexplained details and observations	• How did the game convey expected behavior to the player? (SRQ4) • What assumptions about natures and players did the game rely on to do this? (SRQ5) • How did players respond to signals for expected behavior (were these signals effective)? (SRQ6)
	(5) Gap between the player and game		• What is the perspective of the player and how does this impact their ability to understand and enact their role in the game's story? (SRQ7)
	(1) Abstraction		• PRQ1 (see above)
	(2) Values and procedural rhetoric		• PRQ3 (see above)
	(3) Representation and identity		• SRQ1-3 (see above)

(continued)

Table 1. Continued.

Study phase	Formal elements	Methods	Driving questions and sub-questions*
III: Developer modifications to NMS based on player reviews and actions	*(2) Values and procedural rhetoric* *(4) Relationship between the rules and fictional world* *(3) Representation and identity*	• Document/text analysis of patch notes and game community post release articles • Critical game play (Emma), 20 hours including screen captures and notes	• How did the developers change their use of tropes and ideologies regarding various natures in response to player reviews and complaints? (PRQ4) • How did the developers modify the rules and assumptions about natures used to convey expected player behavior in response to player actions? (PRQ5) • How did the developers adjust player representation and identity building within the game based on player actions? (PRQ6)

*Primary research questions (PRQs) and secondary research questions (SRQs) as labeled.

screenshots of different planetary landscapes, game stages and instructions, and dashboard content, noting the level of detail provided at different scales of the game. Our results demonstrate the importance of both gamers' and game developers' assumptions and strategies regarding ecological processes, game physics, and issues of embodiment at different DOSN scales.

Findings: Being disembodied in nearly-infinite DOSNs

As a small British indie game development company founded in 2008, Hello Games released its first game, *Joe Danger*, in 2013 as a side-scrolling game with platform and racing components, in which the player plays as the daredevil titular character (Hello Games, 2013). Their most recent game, *The Last Campfire* (Hello Games, 2020) is a puzzle game in which the player is a small sack-like creature lost between worlds who must help other lost souls to move on while searching for a way back to its own world (Barbosa, 2020; Watts, 2020). This game offers a vibrant world similar to that of NMS, but with a smaller narrative scope that provides emotional depth, a clear goal, and beautiful, surreal aesthetics celebrated in recent game reviews (Ibid.). In contrast with Hello Games' other titles, NMS is significantly larger in narrative scope, ambition, and technical complexity due to its use of procedural generation and the stress that Sony's promotion fomented.

The universe-sized NMS game space does not require each game element to be stored on a player's computer for processing through the computer's memory and graphics processing unit. Instead, game elements are generated using a "seed" (pseudorandom number) upon launching the game. According to Khatchadourain (2015),

> The seed defines the over-all structure of the galaxy, and the random numbers spawned from it serve as digital markers for stars. The process is then repeated: each star's number becomes a seed that defines its orbiting planets, and the planetary numbers are used as seeds to define the qualities of planetary terrain, atmosphere, and ecology . . . the system combines entropy and structure: if two players begin with the same seed and the same formulas, they will experience identical environments.

Formulas only create the planets, plants, and other objects in visual game space or computer memory as the player encounters them. This creates an interesting temporal relationship: "In one sense, because of the game's procedural design, the entire universe exists at the moment of its creation. In another sense, because the game only renders a player's immediate surroundings, nothing exists unless there is a human there to witness it" (Morin, 2016).

Procedural generation could, therefore, *technically* cocreate nearly infinite DOSNs. In the initial NMS release, players could only experience the game through a first-person perspective, without any sense of or reference to one's digital body. Players lacked an explicit origin or contextualizing story other than having crash landed their ship and pursuing three basic categories of activities: resource extraction, navigating to other planets, and discovering and naming flora and fauna. Players being from nowhere, without a body and with no larger purpose at scalar extremes—unable to world build—meant that they quickly stopped playing the game. Both nonscalability and scalability can contribute to successful and unsuccessful world building. We read players' experiences of world building in NMS for scalability and nonscalability and illustrate how these concepts map unevenly to each other.

Frontier narratives in quasi-infinite DOSNs

Sean Murray, the lead developer of NMS, drew from his childhood experiences in the Australian outback as he designed the game to make players feel alone and insignificant (Hall, 2017). He and his colleagues also invoked emotive frontier imaginaries and enduring settler–colonial desires for outer space exploration. The online game description (Hello Games, 2019a) invokes a limitless frontier:

> A truly open universe: If you can see it, you can go there. You can fly seamlessly from the surface of a planet to another, and every star in the sky is a sun that you can visit . . . Exploration is seeing things that no-one else has ever seen before. Every creature, geological formation, plant and spaceship is unique . . . Survive on a dangerous frontier: You are alone and vulnerable, and will face threats everywhere, from deep space to thick forests, barren deserts to dark oceans.

NMS developers invited players to explore planets and discover species through narratives of the frontier, individuality, and legacy across scales.

Players were drawn to these discovery narratives, but during actual play, the structure of the game confronted their desires. The promise to "explore uncharted solar systems and catalogue unique new forms of life . . . never before encountered" rang hollow when players found "the same" flora and fauna on planets with vastly different ecosystems. Participants expected to encounter completely different species of flora and fauna on a planet with icy tundra and on a different planet with tropical forests. To their disappointment, these life forms seemed to be "the same" but with different names (see Figures 1, 2, 3(a), and 3(b)). Julian explained:

> The jungle world was probably the best because there was the most teeming amounts of life everywhere. And yet, it still had caves and in the caves, there was still these pink or green or yellow flowers that gave off light and as you destroyed them they still gave you the same resource, atrium . . . There was this one bloody plant, that looked like this large fiddlehead that would always whip you as you walked by it on every single planet. It was always the

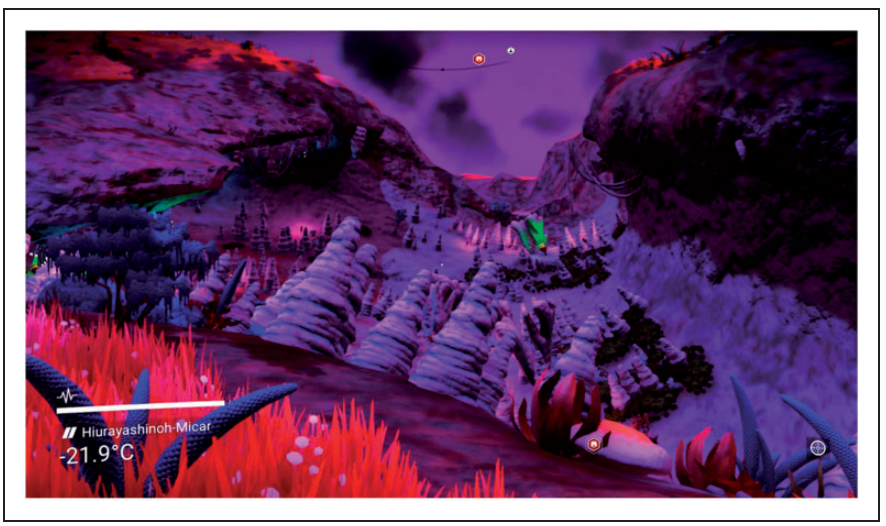

Figure 1. Screen capture of glowing flowers on a planet explored by Emma (Hello Games, 2016a, Fair Use).

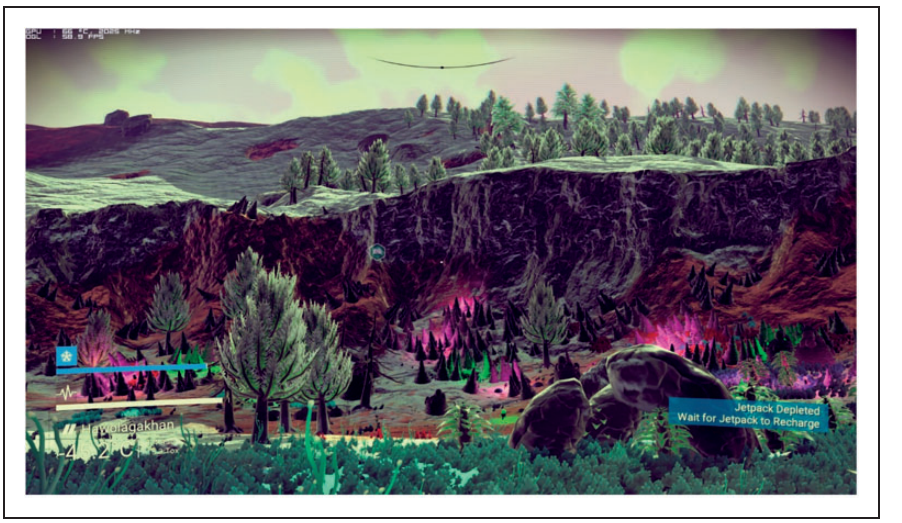

Figure 2. Screen capture of glowing flowers on a planet explored by Julian (Hello Games, 2016a, Fair Use).

> same green, but it always had a different name. Even on the snowy Hoth world, there would still be this whip-like thing that would just get you as you walked by . . . Everywhere I went, I got my platinum from the same blue flower, I got my [Thamium] from the same red flower.[5]

Val agreed: "it was just all the same . . . Even if they were different they were still the same." Jessica explained, "the planets were all very, very similar. Even the climates . . . they all kind of reminded me of neon Dr. Seuss." Several participants also lamented the fact that every planet consisted of only a single climate and a couple of ecosystems. No participant encountered a planet containing both frozen landscapes and humid jungles.

Though technically unique in NMS, every creature derives from the same set of base templates, which might—as is the case on Earth—lead to subtle differences that are not apparent to most players. The resulting game ecosystems contained life forms that originated with the same few hundred "ancestors" or base archetypes (Duncan, 2015). The mathematics and algorithms used to build NMS were based upon concepts in astrophysics, meteorology, geomorphology, and plant genetics (Khatchadourain, 2015; Morin, 2016). The scope of NMS is what makes its use of procedural generation unique. Not only has it managed to prevent a devolution into chaos—common in uses of procedural generation—but the player can explore everything generated (Chang, 2019; Fernández-Vara, 2019; Khatchadourain, 2015; Peckham, 2016). To do this, the artists created basic architecture for all elements of the game based on mathematical theories such as Astrid Lindenmayer's (1968a, 1968b) L-systems Theory (Khatchadourain, 2015; Morin, 2016; Warren, 2015). The algorithms randomly mutate the architecture based on a set of rules (i.e., trees must have a trunk, branches, and leaves, and animals must have skeletons) to create new flora, fauna, atmospheres, and planetary climates (Khatchadourain, 2015; Tach, 2015).

Earth physics also informed the algorithm that generated the game's planets. Planets positioned closest to their sun had hot, arid landscapes. Planets further away from their suns had frozen or tundra-like landscapes and those positioned between these extremes were most likely to support abundant life (Wiltshire, 2015). These programmed instructions extended to moisture content and sky color, depending on the particles in the atmosphere and the type of star at the center of each solar system, with wildlife tailored to these guiding

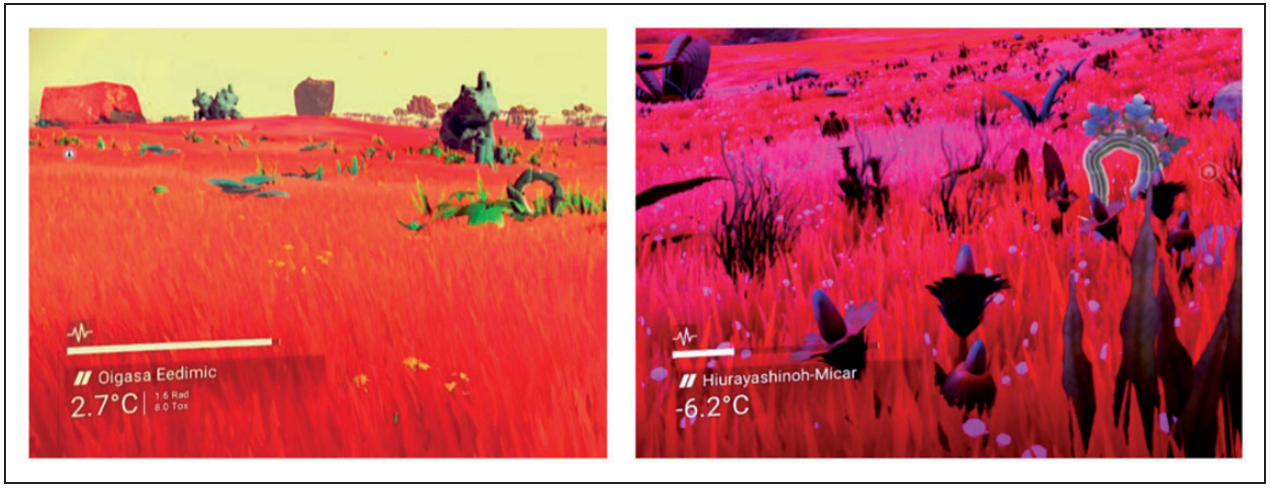

Figure 3. (a) Screen capture of a plant (upper right) on a toxic planet explored by Jake. (b) Screen capture of "the same" plant (upper right) on a planet explored by Emma (Hello Games, 2016a, Fair Use).

planetary attributes (Wiltshire, 2015). Planets programmed with a "hostile" environment featured fauna with "hostile" spikes and horns (Duncan, 2015). Such ecosystem detail largely went unnoticed by players in our study and by many of those posting NMS reviews in gaming forums.

Players were willing to have their desires for an interplanetary existence confronted in limited ways, and they held contradictory expectations of DOSNs. For example, participants expected species, ecosystem, and landscape variation to be displayed as variations in color, regardless of whether such color combinations violated principles of the physics of visible light. The algorithms that generate the colors of the planets and their environments in NMS rely on principles of the physics of light refraction. Artists and programmers considered which gases and particles reflect or emit which wavelengths in order to make planet atmospheres with different colors (Morin, 2016). The planets and their flora and fauna have color palettes with allowable variations in hue, tint, and shade (Duncan, 2015). The algorithms that make them include rules for understanding basic color theory so that procedurally generated planets have flora and fauna that cohere with the local environment in ways that appeal to gamers (Duncan, 2015; Tach, 2015). Changing the color of a digital landscape can fascinate and excite players while allowing them to easily reproduce relationships with others through familiar categories. Eddie explained:

> I feel like plants are kind of like this universal thing. Like, grass is grass. You can make grass purple, but it's still really its grass . . . Beyond them being different colors . . . there's not a whole lot you can do. If a planet supports life, that's what we think life is going to look like.

Players expected infinitely variable DOSNs to satisfy their desires for new and exotic encounters, but they were disappointed with the diversity that NMS procedurally generated. Jake described the extreme outer space natures he encountered: "they [planets] basically seemed to fall into four different categories . . . they were fine and nothing was trying to kill me . . . it was too cold and I was freezing to death, it was too hot and I was burning to death, or it was toxic and I was getting poisoned." The lack of recognizable plant and animal variety and complex ecosystems in the digital natures of NMS was a world-building failure resulting from the scalability of the algorithms that produced those digital natures. As Chang (2019: 121) notes, "our perceptual apparatus somehow registers excessive uniformity as artificial." Those same algorithms, however, also enabled successful world building by creating recognizable landscapes and categories (grass is grass, even if it's purple). Without a more detailed understanding of the 'rules' for the algorithms that procedurally generated planets, players were not able to world build effectively.

By providing a minimal storyline, developers of the game also assumed incorrectly that players' desires for exploration and discovery of exotic outer space worlds would be sufficient to sustain their interest. The promise of an endless frontier became boring. Julian felt like "a bystander in a functioning system that would go on playing itself without you" noting that in MMOs:

> You can have a direct impact on what is going on around you even though the game itself is enormous and can take a ton of time. [*NMS* is] just too big and the player doesn't have enough impact on where they are or on the settings. I don't know, once I left a planet there was no point to ever go back to it even though I had named everything on there.

NMS lacked a compelling story for players to enact. Storylines are some of the most important elements of digital games because they generate what gamer and streamer Day[9] calls

"emotional resonance" (Plott, 2019), helping players understand and contextualize their goals, actions, and decisions. Eddie critiqued NMS' lack of storyline, "there's no sort of sense of linear progression." Julian explained, "There also didn't seem to be any real point . . . they could have used that loading screen to talk to you, to give you some kind of feedback to what you are or where you are or anything." Julian and Eddie's frustrations highlight their sense of insignificance in a vast universe where they are unable to develop the relationships necessary across scales to understand their purpose and place. This is a world-building failure caused by generating nearly-infinite DOSNs at the level of the vast expanse of outer space in that these digital encounters, and the players themselves, were too scalable.

The game's developers also translated player time into game time for space travel and resource extraction poorly. These actions advance a game's storyline or broader purpose. In the contemporary gaming market, players can access more content—within quite specific gaming genres—than they can feasibly experience in a long lifetime. On the Steam platform alone, which distributes more than 30,000 games, there were over 8,000 games released in 2019 at an average of 176 games per week (Galyonkin, 2019; Meer, 2019). With abundant content availability, players develop preferences regarding the kinds of affordable gaming experiences worthy of their time. NMS was the first game to offer endless content within a single game, but its developers failed to consider rapidly changing player preferences regarding time-worthy play. Regarding travel time, Petra explained her experience: " . . . So, you see something and it's . . . 10 minutes away, and you're like 'oh cool, 10 minutes in the game, that's nothing, right?' *No*. No, they mean 10 *real* minutes" (emphasis hers). NMS provides a shortened sense of the time required to travel vast distances between planets in players' quests for ever more frontier discovery, but not short enough. This is a key temporal scalability issue in that NMS devalues the player's time, which is also a way of impeding world building.

In digital games, resource extraction often facilitates a player's progression through the game's story. Natural resources serve as raw material for crafting and upgrading tools, buildings, modes of transportation such as spaceships, and other strategic items, allowing players to expand their capabilities. Players refer to the process of repeating actions to progress in a game as "grinding." Julian complained:

> . . . you go to a planetary system [and] you scan the planets. You see what has the mineral that you need. You go down and you get the mineral. Maybe there's other minerals or elements that will sell on the auction house but that's it. That's the entire game . . . You might not be able to do it in one planetary system, but when you do get to the center there's no ending. It just sticks you back on another world, somewhere else and says alright, start over. There's no point. There's no end game.

On the one hand, the player is technically the only agent of change in the NMS universe. On the other hand, the player feels irrelevant because the sociality of that change is meaningless. Another player, Jake, commented "There was lots of environment. Too much environment some might say." Petra had a similar experience: "I started with mining resources and then I found a mountain of gold. So, I spent a long time actually completely decimating that. And then I was super rich 'cause I sold all of that gold. And then I . . . bought a new spaceship and was flying around in circles'." The procedurally- generated resources in NMS reflect a technical, mathematically-infinite diversity based on a limited set of templates within accepted categories such as grasses, trees, vertebrates, mineral resources, etc. The extreme scalability of DOSNs in NMS and player's sense of insignificance within them resulted in world-building failures, despite the categorical familiarity of the flora and fauna. World building

appears to require a different mix of DOSNs and a more compelling storyline than resource extraction and naming nearly-infinite exotic places and life forms.

Nonscalability and interplanetary digital bodies

World-building failures in NMS also occurred at the level of the body. Until the 2018 release of the NMS NEXT update (1.5) the game did not give the player an avatar: a digital body that the player chooses or creates to represent them in the game. Players experienced the game in first-person perspective with the computer screen serving as the player's eyes. Thus, a player never saw their in-game body, with their in-game identity entirely up to the player's imagination. Players relied on other game elements to locate and contextualize themselves within the game, especially players' interactions with the game's digital environment.

Participants in our study complained that the NMS game environment did not operate according to consistent applications of physics. They were most concerned about gravity not being universally applicable. For example, Julian remarked:

> When there were big pillars of like the blue [heridium] or gold or copper, and then you cut just the bottom out, the whole thing would just stay floating in the air. There was no gravity and yet if I jumped into the air with my jetpack, gravity would always bring me right back down . . . it was a little janky with gravity (see Figure 4).

Eddie explained that his "first experiment was, well ok did they put physics into this? And I was sadly disappointed. Because I cut the bottom off of things all the time just to see if they would fall over and they didn't . . . I wasn't exactly expecting that level of realism, but you know, it would have been nice." The uneven application of gravity in the game environment impacted players' abilities to understand the physical boundaries and limitations of the worlds in which they played. The way that gravity was applied in NMS produced world-building failures because players expected gravity to be congruous across all game DOSNs at all scales. These problems only scratch the surface of what anthropologist David Valentine (2017) identifies as the centrality of gravity for understanding humanness on

Figure 4. Screen capture of a mined heridium tower with a floating piece (upper center) by Emma (Fair Use).

and beyond earth such as sense of bodily motion and direction vis-à-vis landscapes and spacecraft with different orientations, curvatures, and gravitational forces. NMS also utilized physics that players did not understand to be correct. For example, its planets rotate on their axes, which creates a distinct night and day cycle. If a player flies down to a planet from a space station and then flies directly back up into space, they will not find that station due to the planet's rotation (Morin, 2016). On discovering this "true to physics" feature, many players complained that this was a bug in the system (Morin, 2016; Wiltshire, 2015).

Physics in online games are controlled by a set of mathematical equations that determine how objects interact with each other (Eberly, 2004). The more complex the movement of objects the more complex the mathematics required to define how those objects relate and interact (Eberly, 2004). Game physics govern how objects move, gravity, friction, and what happens when objects collide (Eberly, 2004; Millington, 2007). The game must specify which object is being acted upon and the requisite inputs for physics calculations (Millington, 2007). If a player throws a ball, the physics engine will calculate the gravity, force, and velocity only if it can identify the object and its necessary attributes such as its mass. In most games, the physics engine applies calculations within a skybox: a cube that contains the illustration of the game within which the player plays (Morin, 2016). Players always view the game environment through the skybox, moving between skyboxes to simulate changes such as day and night. Physics engines in skyboxes require a significant part of the landscape to be pre-generated in order to perform calculations such as water flow (Khatchadourain, 2015). NMS cannot operate in this way because the player must be able to move between billions of environments created on the fly requiring equally nimble game physics (Morin, 2016). These rules and algorithms must jointly navigate the problems that arise from the procedural generation of the game elements (Hall, 2017; Khatchadourain, 2015; Morin, 2016; Whittaker, 2015). The sheer scope of NMS required considerable innovation to calculate and render physics within the game, yet participants in our study experienced the physics as incomplete or incongruous.

Some of the physics and gravity issues occurred because players did not have an avatar to illustrate their relationship to game environments, and they had trouble understanding how their body related to, and could interact with what was around them in the initial game release. The lack of an avatar also left players without a distinct way of knowing themselves in the game. In an interview in *The Atlantic* (Morin, 2016) NMS lead developer, Sean Murray, stated:

> In most games, you begin by choosing a character . . . but that might be before you decide how you really want to play. We want to let people have their imagination. They can be whoever they want to be. They might be an alien if that's what they want to believe. I quite like that.

Most of the participants in our study, however, did not like this idea. The ambiguity caused players to question how they were represented to others within the game. As Eddie remarked, "I had no idea what I was supposed to be, going through this game. Like, am I a Robot? . . . Am I an alien to these aliens?" The ambiguity of the player's body in relation to NPCs troubles the otherwise clear colonial narratives of the frontier and discovery. Eddie's experience raises the question of who and what is discoverable by and for whom? Players attempted to situate themselves within the game's spaces through other means, such as their interactions with the landscape and with other species. Without a body, players were technically extremely scalable, with their identity left to their own imagination, but this level of abstraction meant that players could not relate to places or world build effectively. World building with DOSNs across scales requires some form of digital embodiment, despite NMS

game designer's fantasies and assumptions otherwise. Finally, in our analysis of the *initial version* of NMS we did not encounter examples of nonscalability that *enabled* successful world building. These may have existed without us or other players noticing them.

'Fixing' DOSNs nonscalability

The world-building failures of NMS at the scalar extremes of a vast outer space frontier and of player bodies embedded in complex ecosystems, guides our analysis of game developers' chosen improvements to NMS' game physics, embodiment, and ecosystem generation. By selectively 'fixing' problems and by specifying elements previously left to the player's imagination, the game's developers improved players' world building while also curtailing other nonscalable possibilities for co-generated DOSNs. Player desires for and assumptions about DOSNs confronted the limitations of a procedurally-generated universe. For example, the Pathfinder (1.2) update enabled players to co-build communities in NMS, increasing the potential for nonscalable encounters that facilitate world building (Hello Games, 2016b). When NMS developers announced plans for the Atlas Rises update (1.3) in August 2017, players realized the update would use a new "seed," which would not remove player-generated content but would rebuild the entire universe (e.g., planet locations and characteristics) (Hello Games, 2017). Archaeologist, Andrew Reinhard (2017, 2018), studied the Legacy Hub, the abandoned original home of the Galactic Hub, a player-built community in NMS with its own government, laws, capital planet, and economic and social structure. The Hub player community hosted events to celebrate their many creations and made plans for the looming "end of the world" update (Reinhard, 2017, 2018). The entire Hub moved to a new star system abandoning the player-made content on the Legacy Hub (Jackson, 2017). The Hub's capital planet transformed from a tropical paradise into a frozen wasteland, and the Hub's community mourned their co-created places and the extinction of fauna in the digital landscape, yet that remained in their records of prior discoveries (Reinhard, 2017). The story of the Galactic Hub is a story of a digital culture living a nonscalable digital interplanetary existence in a broader context of ongoing extinction debates in the Anthropocene.

The July 2018 NEXT update (1.5) added the choice of first-person or third-person player view and appearance customization, including choice of "race." In his review of this update, Justin Clark (2018) notes, "the third-person camera not only grants the game a sense of scale, but also gives you a better understanding of exactly who you are in the universe." This change improved world building by contextualizing the player within the game DOSNs and story. The developers added hazardous flora, improvements to animal behavior algorithms, and unique resources and weather phenomena based on planetary biomes, which developers claimed, "is more diverse than ever with colour palette variety, dense forests and large trees . . . " (Hello Games, 2018a). The update added multiplayer capabilities and the chance to "excavate buried ruins . . . to unearth locked ancient treasures" (Hello Games, 2018a). The November 2018 Visions update (1.75) produced new lifeform categories such as "strange alien rock creatures" and a more "diverse set of science fiction aesthetics" (Hello Games, 2018b). The updates diversified the DOSNs while retaining the scalability of the algorithms, which improved world building within a sustained narrative of colonial encounters with others.

According to the developers, the August 2019 Beyond update (2.0) was the largest since the game's initial release (Hello Games, 2019b). It included NMS Virtual Reality (VR), which provides further embodied connection for players in co-generated DOSNs (Hello Games, 2019b). Players can participate in an in-game social hub, visit each other's bases

and embark on joint missions as they enjoy new technologies, recipes, planetary charts, and a galaxy map "added to alleviate grinding" (Hello Games, 2019b). Creatures can be tamed with bait, some can be ridden, and others "peacefully harvested" for products (Hello Games, 2019b). Industrial bases extract resources while the player is offline and run on "fueled biogenerators, or self-sustaining solar panels" (Hello Games, 2019b). Through these updates, the developers introduced nonscalability in ways that ensured successful world building by taking on some of the labor of the resource "grind," enabling team play and allowing players to build a home base and more meaningful relationships with each other and with NPCs. Recent reviews of the game are largely positive.[6] These updates and subsequent player and reviewer responses address some of the more popular player feedback and concerns by adding more nuance and complexity, but they do not change the fundamental frontier narrative of NMS. By adding more opportunities for diverse encounters, yet refusing to change the core premises of the game, the developers are attempting to rectify player desires for successful world building through nonscalable phenomena and relations within a digital game project that insists on the scalability of DOSNs more broadly. Finally, in our review of the developer updates to NMS we did not find examples of *world-building failures* resulting from scalability or nonscalability. Again, we—and other players—may not have noticed these.

Discussion

Compelling games make space for nonscalability through successful world building where the player feels like they can transform worlds and be transformed through meaningful and purposeful relationships. The game's nearly infinite DOSNs undermine players' ability to transform worlds relationally (e.g., nonscalability). The NMS algorithms operate in the same way for a single planet as they do for a universe of 4 quintillion planets. In the initial release of NMS, players became modularized components of a scalable system. They were insignificant, "abstract labor" (Tsing, 2019: 156) reproducing narratives of expansion and "growth" (until updates allowed for multiplayer community formation and improved world building). Tsing (2019: 145) argues that "scalability is possible only if project elements do not form transformative relationships that might change the project as elements are added . . . Scalability projects banish meaningful diversity, which is to say, diversity that might change things." Developers and players require some scalability to enable them to satisfy their desires for exploration, resource discovery, and extraction, yet NMS also illustrates how to render colonial tropes of discovery and extraction as boring (offering a brief opportunity for some players to question the desirability of such colonizing tropes).

While Tsing's (2019) discussion of nonscalability draws from the material and critical history of earthbound colonial sugar cane plantations, scalability, and nonscalability are also useful concepts for studying what DOSNs do in digital games. Tsing describes the aesthetics of scalability by referencing scalable pixels. Pixels, however, are only the visual representation of a digital environment, and do not encapsulate the entirely of the digital realm where digital natures are proliferating. We argue that nonscalability theory would benefit from a more robust engagement with the digital. NMS initially flopped because it was too scalable and because it challenged players' expectations about interplanetary existence to such an extent that they were not able to engage in world building until the developers updated the game and introduced limited forms of nonscalability.

Players having avatars and a sense of digital embodiment is essential for nonscalability and world building. Feminist geographers, feminist political ecologists, and others note the centrality of the body in place making (Gururani, 2002; Harcourt and Nelson, 2015;

Longhurst, 1995; Nightingale, 2011; Rose, 1995; Sundberg, 2004) which we argue extends to digital bodies co-creating DOSNs. The generalness of outer space or interplanetary existence became both meaningless and boring without the specificity and perceived relevance of the embodied individual in NMS. World building in digital games is a project of subject making through particular desires (Boellstorff, 2008). Player disappointment in NMS stemmed largely from world building failures that were a combination of player expectations of and desires for outer space natures, the application of game mechanics, and the extreme scalability of NMS. Nonscalability theory is an anti-colonial theory. In studying DOSN nonscalability in NMS, it is not our aim to declare this game as good or bad by highlighting the coloniality of NMS. Rather, coloniality is the context of much of the gaming industry (see Byrd, 2018), of many outer space exploration projects, and of Tsing's argument about scalability and nonscalability. We are most interested in what procedurally-generated DOSNs *do* in terms of the digital "naturecultures" (Haraway, 2016) that emerge during play.

Conclusion

There are several promising implications of our analysis. We extend the fairly narrow treatment of *nature* in digital natures political ecology scholarship to include DOSNs, and we call for further feminist scholarship on digital natures that draws from game studies and other approaches. What has changed since the feminist interventions of Merchant, Haraway, and others is the substantial role that *digital natures* play in emerging understandings of environmental politics and more-than-human worlds. We agree with Chang (2019: 144) that, "As Tsing [2013, 33] cautions, and games effectively teach us, 'we might not always be in charge. We might get to know other-than-human worlds in which we participate, but in which we don't make the rules'." Chang (2020) is hopeful that projects such as NMS, "demonstrate the potential for media to provide the intellectual and aesthetic interface between widely separated scales of activity and domains of knowledge" (p. 103), and "in the place of action, speed, and god's-eye surveillance, games may also invite you to feel small, do little, and take your time doing so" (p. 71). We are disappointed, but not surprised by the choices made by NMS developers in their modifications to the game. We see the intersections of DOSNs co-produced in games as sites of troublesome and hopeful forms of "sf" for thinking and relating.

We also see an urgent need to trouble scalability projects such as NMS and contemporary space exploration projects through a feminist digital natures lens. We are interested in the emerging role of procedural generation in game design in the context of the contemporary space race. We are intrigued by the work of feminist STS scholars and political geographers that have elaborated how the Earth is a basis for imagining potential interplanetary human futures. We do not treat digital space as fully imaginary and Earth space as entirely material or non-imaginary. Geographers, STS, and other scholars have done extensive research on the material dependencies of digital space (see Chang, 2019; Starosielski, 2015) and of how Western scientists and others imagined the earth as a globe before photographs of earth from space were possible (see Cosgrove, 1994, 2003) and the impacts of these photographs on environmental thinking and action (Jasanoff, 2001). Our findings compliment the work of Messeri (2016) and Olson (2018), to illustrate some of the different expectations of what emerging outer space natures might become, as both extreme environments and as potentially knowable and livable places.

As for the limitations of this study, we did not ask how players saw their existence as interplanetary and we did not ask scientists working with NASA, SpaceX, or others to play

NMS, but we think these kinds of questions are worth pursuing. Our analysis across multiple NMS updates reminds us that longitudinal digital research methods are also an area where a feminist digital natures approach would offer unique insights. We would have preferred to follow our participants longitudinally along with the game's updates, to learn more about participant personal stories and experiences with the updated game versions, but this was not possible as ours was not a longitudinal study at the outset (given the initial flop, it was not clear that NMS would persist through as many updates and as it has). As feminist political ecologists, we also see VR technology as a fruitful future area of research on digital embodiment and digital natures. By way of concluding, we see great potential for analyzing the role of innovations in computing and game design in linking digital, outer, and earth spaces, which as other scholars have shown, bear significantly on our understanding of multiple worlds and natures.

Highlights

- A feminist digital natures approach can inform debates about interplanetary futures.
- Digital games such as NMS coproduce DOSNs.
- Digital natures exhibit nonscalability despite their assumed scalability.

Acknowledgements

The authors thank Lesley-Ann Dupigny-Giroux, Brandon Ogbunugafor, Natalie Koch and Harlan Morehouse for feedback on earlier versions of this article. We also thank Pablo Bose for introducing us to this game and providing a copy for initial playtesting. We would also like to thank the player participants for their time and insights and the anonymous reviewers for their detailed and thorough feedback.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The authors disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: Emma Tait received a College of Arts and Sciences (CAS) Academic Programs for Learning and Engagement (APLE) award (University of Vermont) to purchase copies of NMS for the research participants to play.

ORCID iDs

Emma R Tait https://orcid.org/0000-0002-3970-7914
Ingrid L Nelson https://orcid.org/0000-0001-5589-1347

Notes

1. See an example promotional video on the PlayStation YouTube Channel: PlayStation. 2014. *No Man's Sky Gameplay Trailer| E3 2014| PS4*. 9 June 2014. Last Accessed 1 June 2019 at https://youtu.be/nLtmEjqzg7M.
2. We share our analysis, but Emma conducted the playthroughs.
3. The game saves when the player exits their ship or interacts with waypoints dispersed across planets.
4. Participants also played at least ten hours of a second game, the results of which we analyze separately. We incentivized participation by purchasing the two games for participants.

5. We use pseudonyms for all research participants.
6. According to Steam analytics (https://store.steampowered.com/app/275850/No_Mans_Sky/), NMS had 47,107 negative reviews and 21,854 positive reviews in the first three months of its release in 2016, which is a "flop" in the gaming industry. Subsequent game updates resulted in shifts to a clear majority of positive reviews.

References

Aber J (2008) Spatial scales of the arcade collecting community: A photo essay. *Aether* 11(1): 61–70.

Ash J (2009) Emerging spatialities of the screen: Video games and the reconfiguration of spatial awareness. *Environment and Planning A: Economy and Space* 41(9): 2105–2124.

Ash J (2015) *The Interface Envelope: Gaming, Technology, Power*. New York: Bloomsbury Academic.

Barbosa A (2020) The last campfire review—One step at a time. GameSpot. Available at: https://www.gamespot.com/reviews/the-last-campfire-review-one-step-at-a-time/1900-6417559/ (accessed 6 December 2020).

Boellstorff T (2008) *Coming of Age in Second Life*. Princeton, NJ: Princeton University Press.

Bogost I (2008) The rhetoric of video games. In: K Salen (ed) *The Ecology of Games: Connecting Youth, Games, and Learning*. Cambridge, MA: The MIT Press, pp. 117–139.

Bos D (2018) Answering the call of duty: Everyday encounters with the popular geopolitics of military-themed videogames. *Political Geography* 63(1): 54–64.

Büscher B (2016) Nature 2.0: Exploring and theorizing the links between new media and nature conservation. *New Media and Society* 18(5): 726–743.

Büscher, B, Koot S and Nelson IL (2017) Introduction: Nature 2.0: New media, online activism and the cyberpolitics of environmental conservation. *Geoforum* 79: 111–113.

Byrd JA (2018) Beast of America: Sovereignty and the wildness of objects. *The South Atlantic Quarterly* 117(3): 599–615.

Caldwell B (2017) The broken promise of no man's sky and why it matters. *Rock Paper Shotgun*. Available at: https://www.rockpapershotgun.com/2016/08/17/broken-promises-of-no-mans-sky/ (accessed 26 May 2017).

Chang AY (2019) *Playing Nature: Ecology in Video Games*. Minneapolis, MN: University of Minnesota Press.

Clark J (2018) No man's sky next review: You are not alone. *GameSpot*. Available at: https://www.gamespot.com/reviews/no-mans-sky-next-review-you-are-not-alone/1900-6416952/ (accessed 26 June 2018).

Cosgrove D (1994) Contested global visions: One-world, whole-earth, and the Apollo space photographs. *Annals of the Association of American Geographers* 84(2): 270–294.

Cosgrove D (2003) *Apollo's Eye: A Cartographic Genealogy of the Earth in the Western Imagination*. Baltimore: Johns Hopkins University Press.

Crang M and Haji Bin Mohamed SM (2016) Researching Virtual Communities. In: Clifford N, Cope M, Gillespie T, et al. (eds) Key Methods in Geography. London: SAGE, pp. 270–284.

Dittmer JN (2007) Colonialism and place creation in Mars Pathfinder media coverage. *Geographical Review* 97(1): 112–130.

Downhour MD de C (2016) *Decolonizing The Videogame: "Never Alone," Storytelling, And Native Cultural Identity*. MA Thesis. San Francisco, CA: San Francisco State University.

Driessen C, Alfrink K, Copier M, et al. (2014) What could playing with pigs do to us. *Antennae* 30: 79–102.

Duncan G (2015) No man's sky: How I learned to love procedural art. *Game Developers Conference 2015*. Available at: https://www.youtube.com/watch?v = vcEA41eBOGs (accessed 18 April 2017).

Dunnett O (2019) Imperialism, technology and tropicality in Arthur C. *Clarke's geopolitics of outer space*. *Geopolitics* 1–21. https://doi.org/10.1080/14650045.2019.1569632

Dunnett O, Maclaren AS, Klinger J, et al. (2019) Geographies of outer space: Progress and new opportunities. *Progress in Human Geography* 43: 314–336.

Eberly DH (2004) *Game Physics*. Amsterdam: Elsevier.

Elwood S and Leszczynski A (2018) Feminist digital geographies. *Gender, Place & Culture* 25(5): 629–644.

Fernández-Vara C (2011) From "open mailbox" to context mechanics: Shifting levels of abstraction in adventure games. Proceedings of *the 6th international conference* on the foundations of digital games, FDG 2011, 131–138. DOI: 10.1145/2159365.2159383.

Fernández-Vara C (2019) *Introduction to Game Analysis*. 2nd ed. New York: Routledge.

Fletcher R (2017) Gaming conservation: Nature 2.0 confronts nature-deficit disorder. *Geoforum* 79(1): 153–162.

Galyonkin S (2019) SteamSpy. Available at: https://steamspy.com/year/ (accessed 19 December 2019).

Gigliotti C (2016) Aesthetics of a virtual world. *Antennae* 37(1): 7–20.

Graham M, Zook M and Boulton A (2014). Augmented reality in urban places: Contested content and the duplicity of code. *Transactions of the Institute of British Geographers* 38(3): 464–479.

Gururani S (2002) Forests of pleasure and pain: Gendered practices of labor and livelihood in the forests of the Kumaon Himalayas, India. *Gender, Place & Culture* 9(3): 229–243.

Hall C (2017) In the beginning, no man's sky was flat. *Polygon*. Available at: http://www.polygon.com/2017/3/2/14790028/no-mans-sky-was-flat-procedural-world-generation-maths (accessed 18 April 2017).

Haraway DJ (1989) *Primate Visions: Gender, Race, and Nature in the World of Modern Science*. New York: Routledge.

Haraway DJ (2004) *The Haraway Reader*. New York and London: Routledge.

Haraway DJ (2016) *Staying with the Trouble: Making Kin in the Chthulucene*. Durham and London: Duke University Press.

Harcourt W and Nelson IL (eds) (2015) *Practicing Feminist Political Ecologies: Moving Beyond the 'Green' Economy*. London: Zed Books.

Hello Games (2013) Joe Danger. Hello Games, UK.

Hello Games (2016a) No man's sky. Hello Games, UK and Sony Computer Entertainment, USA.

Hello Games (2016b) No man's sky: 1.2 Pathfinder. Available at: https://www.nomanssky.com/ (accessed 20 March 2017).

Hello Games (2017) No man's sky: Atlas rises. Available at: https://www.nomanssky.com/atlas-rises-update/(accessed 3 April 2017).

Hello Games (2018a) No man's sky: Next. Available at: https://www.nomanssky.com/next-update/ (accessed 19 December 2019).

Hello Games (2018b) No man's sky: Visions. Available at: https://www.nomanssky.com/visions-update/(accessed 20 December 2019).

Hello Games (2019a) No man's sky press kit. Available at: https://www.nomanssky.com/ (accessed 25 June 2019).

Hello Games (2019b) No man's sky: Beyond. Available at: https://www.nomanssky.com/beyond-update/(accessed 19 December 2019).

Hello Games (2020) The last campfire. Hello Games, UK.

Hine C (2000) *Virtual Ethnography*. London: SAGE Publications.

Jackson G (2017) No man's sky players who colonized a galaxy now have to find a new home. *Kotaku*. Available at: https://kotaku.com/no-mans-sky-players-who-colonized-a-galaxy-now-have-to-1798357453 (accessed 24 June 2019).

Jasanoff S (2001) Image and Imagination: The Formation of Global Environmental Consciousness. In Edwards P and Miller C (eds) *Changing the Atmosphere: Expert Knowledge and Environmental Governance*. Cambridge, MA: MIT Press, pp. 309–337.

Kearnes M and van Dooren T (2017) Rethinking the final frontier: Cosmo-logics and an ethic of interstellar flourishing. *GeoHumanities* 3: 178–197.

Khatchadourain R (2015) World without end: Creating a full-scale digital cosmos. *The New Yorker*. Available at: http://www.newyorker.com/magazine/2015/05/18/world-without-end-raffi-khatch adourian (accessed 17 April 2017).

Kleinberg H (2007) On war in space. *Astropolitics* 5: 1–27.

Klinger JM (2019) Environmental geopolitics and outer space. *Geopolitics*. DOI: 10.1080/14650045.2019.1590340.

Kopack RA (2019) Rocket wastelands in Kazakhstan: Scientific authoritarianism and the Baikonur Cosmodrome. *Annals of the American Association of Geographers* 109(2): 556–567.

Leib K (2015) State sovereignty in space: Current models and possible futures. *Astropolitics* 13: 1–24.

Lenihan A and Kelly-Holmes H (2016) Virtual ethnography. In: Hua Z (ed*) Research Methods in Intercultural Communication: A Practical Guide*. West Sussex, UK: Wiley & Sons, pp. 255–267.

Leszczynski A (2018) Digital methods I: Wicked tensions. *Progress in Human Geography* 42(3): 473–481.

Lindenmayer A (1968a) Mathematical models for cellular interactions in development I: Filaments with one-sided inputs. *Journal of Theoretical Biology* 18(3): 280–299.

Lindenmayer A (1968b) Mathematical models for cellular interactions in development II: Simple and branching filaments with two-sided inputs. *Journal of Theoretical Biology* 18(3): 300–315.

Longhurst R (1995) Geography and the body. *Gender, Place & Culture* 2(1): 97–105.

Longhurst R (2016) Semi-structured interviews and focus groups. *In: Clifford N, Cope M, Gillespie T, et al*. (eds) *Key Methods in Geography*. *London: SAGE*, pp. 143–156.

MacDonald F (2007) Anti-astropolitik—Outer space and the orbit of geography. *Progress in Human Geography* 31: 592–615.

Massey DB (2005) *For Space*. London and Thousand Oaks: SAGE.

Meer A (2019) Half of all games on steam came out since 2017. *Rock Paper Shotgun*. Available at: https://www.rockpapershotgun.com/2019/01/15/how-many-games-are-on-steam/ (accessed 19 December 2019).

Merchant C (1980) *The Death of Nature: Women, Ecology, and the Scientific Revolution*. San Francisco, CA: HarperCollins.

Merchant C (1995) *Earthcare: Women and the Environment*. New York: Routledge.

Merchant C (2006) The scientific revolution and the death of nature. *Isis* 97(3): 513–533.

Messeri L (2016) *Placing Outer Space: An Earthly Ethnography of Other Worlds*. Durham, NC: Duke University Press.

Millington I (2007) *Game Physics Engine Development*. San Francisco, CA: Elsevier.

Morin R (2016) Inside the artificial universe that creates itself. *The Atlantic*. Available at: https://www.theatlantic.com/technology/archive/2016/02/artificial-universe-no-mans-sky/463308 (accessed 19 April 2017).

Morrow O, Hawkins R and Kern L (2015) Feminist research in online spaces. *Gender, Place & Culture* 22(4): 526–543.

Nelson IL (2017) Interspecies care and aging in a gorilla 2.0 world. *Geoforum* 79: 144–152.

Nightingale AJ (2011) The Embodiment of Nature: Fishing, Emotion and the Politics of Environmental Values. In Brady E and Phemister P (eds) *Human-Environment Relations: Transformative Values in Theory and Practice*. Dordrecht: Springer, pp. 135–147.

Olson V (2018) *Into the Extreme: U.S. Environmental Systems and Politics beyond Earth*. Minneapolis, MN: University of Minnesota Press.

Olson V and Messeri L (2015) Beyond the anthropocene: Un-earthing an epoch. *Environment and Society: Advances in Research* 6(1): 28–47.

Ormrod JS and Dickens P (eds) (2016) *The Palgrave Handbook of Society, Culture and Outer Space*. London: Palgrave Macmillan.

Parkin S (2014) No man's sky: A vast game crafted by algorithms. *MIT Technology Review*. Available at: https://www.technologyreview.com/s/529136/no-mans-sky-a-vast-game-crafted-by-algorithms (accessed 19 April 2017).

Peckham M (2016) Inside "No Man's Sky," the Most Innovative Game in Years. *TIME*. Available at: https://time.com/no-mans-sky/ (accessed 19 April 2017).

Plott S (2019) Day[9]'s day off—Legends of Runeterra P2. Available at: https://www.youtube.com/watch?v = HmZvW_IyKlw (accessed 24 November 2019).

Redfield P (2002) The half-life of empire in outer space. *Social Studies of Science* 32: 791–825.

Reinhard A (2017) The lost city of D: Archaeology in the legacy hub of no man's sky. *Archaeogaming*. Available at: https://archaeogaming.com/2017/09/15/the-lost-city-of-d-archaeology-in-the-legacy-hub-of-no-mans-sky/ (accessed 24 June 2019).

Reinhard A (2018) *Archaeogaming: An Introduction to Archaeology in and of Video Games*. New York: Berghahn Books.

Rose G (1995) Geography and gender, cartographies and corporealities. *Progress in Human Geography* 19(4): 544–548.

Rose G (2016) Rethinking the geographies of cultural 'objects' through digital technologies: Interface, network and friction. *Progress in Human Geography* 40(3): 334–351.

Rutherford S and Bose PS (2013) Biopower and play: Bodies, spaces, and nature in digital games. *Aether* 12(1): 1–29.

Sage D (2008) Framing space: A popular geopolitics of American manifest destiny in outer space. *Geopolitics* 13: 27–53.

Sammler and Lynch only has a doi available (it was published online, but appears not to have been assigned a volume or issue number or pages. https://doi.org/10.1080/14650045.2019.1569631

Sandbrook C, Adams WM and Monteferri B (2015) Digital games and biodiversity conservation. *Conservation Letters* 8(2): 118–124.

Saperstein JD (2020) Opening the black box of outer space: The case of Jason-3. *Geopolitics* 1–18.

Shaw DB (2004) Bodies out of this world: The space suit as cultural icon. *Science as Culture* 13: 123–144.

Shaw IGR and Warf B (2009) Worlds of affect: Virtual geographies of video games. *Environment and Planning A: Economy and Space* 41(6): 1332–1343.

Sicart M (2008) Defining game mechanics. *Game Studies: The International Journal of Computer Game Research* 8(2). Available at: http://gamestudies.org/0802/articles/sicart (accessed 18 June 2019).

Starosielski N (2015) *The Undersea Network*. Durham, NC: Duke University Press.

Sundberg J (2004) Identities in the making: conservation, gender and race in the Maya Biosphere Reserve, Guatemala. *Gender, Place & Culture* 11(1): 43–66.

Tach D (2015) No man's sky is so big, the developers built space probes to explore it for them. *Polygon*. Available at: http://www.polygon.com/2015/3/3/8140343/no-mans-sky-space-probes-gdc-quintillion-worlds (accessed 19 April 2017).

Thrift N (2000) *Afterwords. Environment and Planning D: Society and Space* 18(2): 213–256.

Tsing AL (2013) More-than-human-sociality: A call for critical description. In: K Hastrup (ed) *Anthropology and Nature*. New York: Routledge, pp. 27–42.

Tsing AL (2019) On nonscalability: The living world is not amenable to precision-nested scales. *Common Knowledge* 25(1–3): 143–162.

Valentine D (2017) Gravity fixes: Habituating to the human on Mars and Island Three. *HAU: Journal of Ethnographic Theory* 7(3): 185–209.

Warren J (2015) How no man's sky creates a universe! PBS Game/Show. PBS Digital Studios. Available at: https://www.youtube.com/watch?v=2KlmY7zxAp0 (accessed 18 June 2019).

Watts R (2020) The last campfire is a whimsical adventure that is worlds away from no man's sky. PC Gamer. Available at: https://www.pcgamer.com/the-last-campfire-is-a-whimsical-adventure-that-is-worlds-away-from-no-mans-sky/ (accessed 6 December 2020).

Whittaker C (2015) No man's sky treads new ground in game design. *Popular Science*. Available at: http://www.popsci.com/No-man's-sky-treads-new-ground-in-game-design (accessed 16 April 2017).

Wiltshire A (2015) 41 Amazing things about no man's sky. *PlayStation Blog*. Available at: http://blog.us.playstation.com/2015/08/03/35-amazing-things-about-no-mans-sky (accessed 17 April 2017).

Wirman H (2014) Games for/with strangers—Captive orangutan (Pongo Pygmaeus) touch screen play. *Antennae* 30(1): 103–113.