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ARTICLE

Algorithmic Maps and the Political Geography of Early-modern Japan

Mark Ravina[1]

[1] The University of Texas at Austin

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Many of our conventional mapping practices are ill-suited to the complexities and nuances of pre-modern politics, especially in the non-Western world. Choropleth maps suggest that political borders are clear and uniform, but early modern politics was characterized by ill-defined and overlapping political spheres. This study uses interactive maps to explore the case of composite state borders in early modern Japan. Using points, rather than polygons, to represent villages, we reproduce how Tokugawa-era officials understood political space primarily as population nodes, not as clearly defined polygons. In lieu of conventional borders, we calculate Voronoi polygons to show where political authority was spatially fragmented. Using logit analysis we show that increased spatial contiguity allowed lords (daimyo) to establish monopolies and tax their holdings more intensively. Other factors, such as the lord's rank, figure prominently in the historiography, but can not be substantiated in our analysis.

Introduction

Farmers in early modern Japan paid taxes to a welter of political entities, ranging from large, consolidated warrior suzerainties down to tiny religious seigneuries. How can we measure and map this complex and fragmentary political landscape? How can we assess the impact of composite-state geography on political power? This essay argues that computational methods provide both new ways of visualizing political spaces, and new ways of evaluating the spatial component of political authority. Digital interventions, such as "born digital" maps, can help us with two distinct tasks: reconstructing Japan's early modern spatial imaginaries (how period actors understood space) and evaluating the relationship between space and political power. New maps can advance both the emic project of understanding Tokugawa conceptions of space and the etic project of understanding how spatial consolidation affected political control.

Conventional maps of early-modern Japan (e.g., Nishioki and Hattori 1956) are choropleth and divide the landscape into neat, color-coded blocks. But that "jigsaw-puzzle view of discrete, bounded territories" (Lewis and Wigen 12) reflects a modern post-Westphalian European view of sovereignty rather than period Japanese understandings of political space. That disconnect between our conventional cartographic practice and period concepts of space is not unique to Japan. Choropleth maps are ideal for visualizing modern territoriality, the division of landscapes into exclusive, bordered spaces. But such clearly-bounded polygons are ill-suited to the political landscapes of much of the premodern and non-Western world. As noted by Charles Maier, "despite our taking it as a given for so long, territoriality has not been a timeless attribute of human societies. It is a historical formation, and its political form was also historical, that is, it has a beginning and an end." (Maier 806-807) The specific case of Tokugawa-era Japan thus highlights major conceptual challenges in cartographic practice.

How might we map political spaces without tacitly imposing modern territoriality? One solution is to avoid entirely "jigsaw-puzzle" polygons. As Peter Bol has observed, premodern Chinese maps routinely emphasized points over polygons, beginning with the world's oldest extant grid map, the *Traces of Yu Map* 禹跡圖 (1136 CE). "The near total absence of gazetteer maps showing boundaries," Bol argues, suggests that the cartographers understood political space as "nested hierarchies of places" rather than neatly bounded territories. In Song-dynasty China, as in the Tokugawa case, "although local governments had a concept of boundaries, and knew where they were on roads between administrative seats . . . there was no need to be exact about boundaries if the taxpaying villages were identified." Accordingly, he suggests discarding the choropleth or jigsaw model in favor of a network model of connected points (Bol, "Mapping China's History"). Merrick Lex Berman concurs: "Does the evidence found in pre-modern historical sources justify spending a great deal of time trying to reconstruct estimated boundaries? My answer is no." (Berman)

For the European case, Luca Scholz has argued that the polygon convention creates anachronistic spatial contiguities. "Polygon-based maps" of the Holy Roman Empire are problematic "not just because reliable information on the boundaries of territories and districts is hard to come by, but also because polygon-heavy maps obscure the entangled, ambiguous, and dynamic nature of old-regime spatial orders." Revisiting the work of Karl Brunner on the Electoral Palatinate, Scholz finds that Brunner's polygon maps radically overstate how successfully the Palatinate reasserted its authority after the Thirty Years War (Scholz). Our best historical maps, he concludes, might neglect borders entirely.

An alternative approach is to repurpose polygons, developing a new visual vocabulary to match our linguistic vocabulary. Our analyses of space now include concepts such as "middle ground," "contact zones," "thirdspace," and borderlands. Researchers have also developed typologies of borders, such as Gülzau and Mau's five-level scale: "no-man's land" borders, landmark borders, checkpoint borders, barrier borders, and fortified borders (Gülzau and Mau). Yet our visual vocabulary remains strikingly mired in convention. The maps of the Roman Empire in the *Oxford Classical Dictionary*, for example, use a single red line to depict radically different imperial "borders". In Britain, the edge of the empire was defined by Hadrian's Wall, but in the North African and Arabian deserts, borders were largely undefined. Nonetheless, the Oxford maps use the same modern visual lexeme, a solid red line, to represent these radically different phenomena. What alternative visual vocabularies might better represent these divergent spatial adjacencies?

This essay maps early modern Japan using two strategies: both points and polygons. The "points over polygons" strategy is valuable, first, because it is truer to period spatial concepts. The shogunate's major regional maps, for example, ignored village borders and depicted villages with simple oval marks. Points also help us visualize population densities, which were higher in the coastal plains and low in the mountains. Further, we can use points to calculate spatial statistics and engage the rich historiography on the relationship between space and political authority. Did, for example, size and spatial cohesiveness support greater political authority? This study argues that it did: large, contiguous domains exerted greater control over the local economy. What other factors shaped political economy? Many historians have argued that *fudai* ("allied") lords, who could serve in the shogun's administration, governed differently than *tozama* ("outside") lords, who could not. This study argues that any such differences were minor.

Given the value of mapping points, why use polygons? This study re-purposes polygons to circumvent their limitations. The central failing of chorolopleth maps is how they impute modern territoriality to the borders of Tokugawa (and other pre-modern) political spaces, which were often vague or complex. Simple borderlines cannot depict, for example, the shared usufruct rights and ill-defined edges of forests. But polygons are better than points for showing spatial adjacency. Where, for example, did clusters of villages pay harvest taxes to the same holder? Intriguingly, while points are best useful for calculating adjacency, polygons are more effective for visualizing those clusters.

This study uses a standard algorithm, Voronoi tessellation, to depict such neighboring villages as same-colored blocks. As detailed below, Voronoi tessellation creates a grid of polygons by drawing lines equidistant between points. As mathematical artifacts, the polygons in this study are not reconstructions of period "borders" and they do not take account of period checkpoints. In essence, this study inverts standard practice, wherein historians draw clear borders even where period borders were ill-defined or undefined. This study, by contrast, argues that since Tokugawa-era village borders are often poorly defined or difficult to reconstruct, we can rely instead on an algorithmic alternative, a formal, standardized method for inferring pseudo-borders. As mathematical artifacts, Voronoi polygons are like isobars on a topographic map. When hiking we do not expect to see numbered, curved lines on the ground as we ascend or descend a hill. Rather we recognize isobars as a tool for visualizing elevation changes. Accordingly, we appreciate how isobars have regular increments (e.g. 100 meter intervals) although the actual elevation changes are continuous. Topographic maps help us understand terrain precisely because they mathematically abstract elevation changes into a regular, visual gradient. In the same way, we can use Voronoi polygons to visualize spatial patterns in tax authority, e.g. compactness and coherence vs fragmentation. As empirically grounded abstractions, such polygons can represent the spatial extent of power without presuming to depict exact borders.

Political Spaces in Early-modern Japan

Tokugawa-era political authorities were ambivalent about borders. The shogunate was concerned primarily with the location on roads of villages and checkpoints, and only secondarily with borders between provinces. A striking example is the official 1838 shogunal map (*kuniezu* 国絵図) for Iyo province (伊予国) (Figure 1). Like all *kuniezu,* the map depicts villages as points rather than polygons and specifies the location of border checkpoints using mileage markers on key roads. Between those points, however, the entire border was labelled as undefined (*kunizakai aishirazu* 国境不相知): the shogunate's border between Iyo and Tosa provinces was thus a "checkpoint border." The provincial borders of Shikoku were uniquely ill-defined, and other provincial borders were often marked by rivers and roads. Nonetheless, *kuniezu* reveal how the shogunate was concerned with controlling the movement of people at key nodes, not with establishing comprehensive territorial boundaries. Indeed, although *kuniezu* show aspects of physical geography, such as forests, they are primarily maps of people, represented as population nodes. Accordingly, *kuniezu* borders do not conform to our modern sense of territoriality and are ill-suited to conventional choropleth mapping.[1]

The ambiguity of Tokugawa-era borders reflects a coherent vision of political space rather than a technological limitation: the shogunate could have created vastly more accurate maps. Indeed, the shogunate had more accurate maps in its own archives, the product of Inō Tadataka. In 1800, Inō, a wealthy and successful sake brewer and rice merchant, ceded his family business to his heir in order to focus on his avocation, surveying and cartography. For the next seventeen years, until his death in 1818, Inō traveled the length and breadth of Japan, some 35,000 km, compiling geospatial measurements of unprecedented accuracy. Using a quadrant, Inō was able to measure latitude to within seconds of a degree. His longitude measurements were less precise, since he lacked a reliable portable timepiece, but are still useful. After Tadataka's death, his friends and students completed his mapping project and in 1821 they presented the shogunate with a massive atlas of 225 maps, detailing the Japanese archipelago at scales ranging from 36,000:1 to

1 For an incisive and concise discussion of *kuniezu* see Sugimoto 2016. For greater detail see Kuniezu Kenkyūkai 国絵図研究会編 2005.

432,000:1. The small-scale maps included graticules (longitude and latitude lines), with the ruins of the ancient imperial observatory in Kyoto serving as a prime meridian.[2]

The shogunate received the gift and seems to have recognized the military value of accurate physical geography. But the government made no use of Inō's work in its official cartography. Instead, for its final series of provincial maps (1835-1838), the shogunate reproduced the style and format of its original series, compiled between 1696 and 1702. Since the shogunate deliberately ignored innovations in cartography, we need to interpret the "inaccuracies" of *kuniezu* as part of a coherent, native understanding of political space.

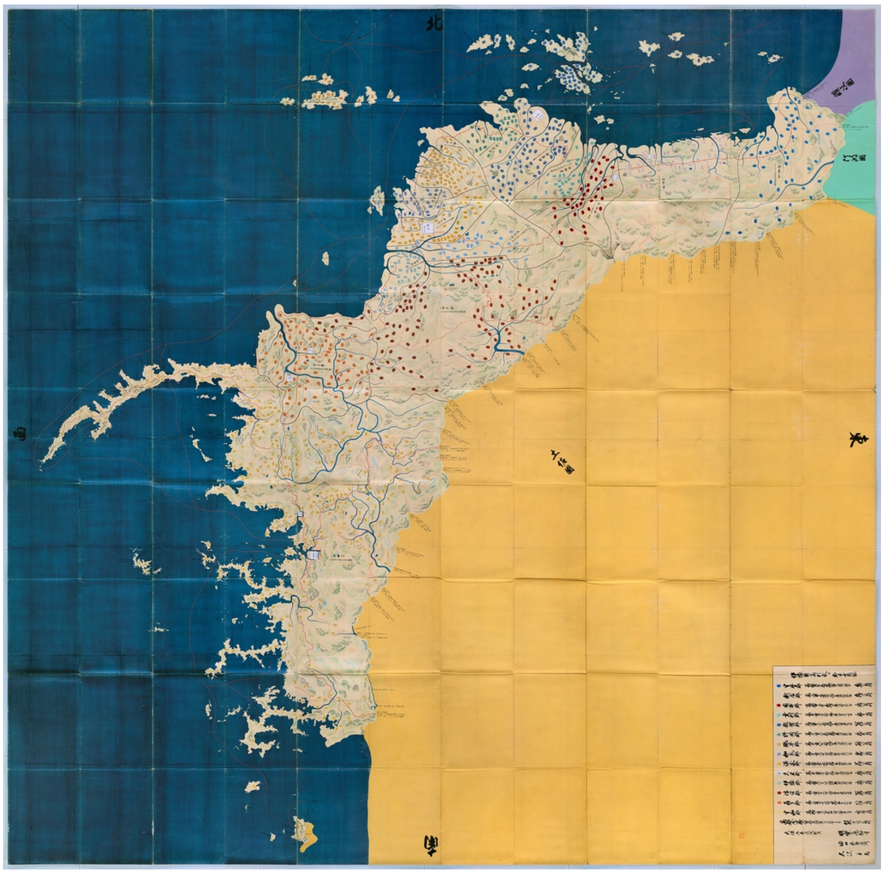

Figure 1. Shogunal Map of Iyo province, 1838

Daimyo mapped their domains only rarely and those maps commonly follow shogunal practice, focusing on villages as population nodes with little emphasis on borders. Ōzu domain in modern Ehime prefecture, for example, compiled detailed maps in 1770 and again in 1814. Like the shogunate's *kuniezu*, the Ōzu maps give detailed information for village harvest yields and border crossings on roads, but are impressionistic for general borders. The 1814 map (Figure 2) is especially stylized: villages are represented by rounded

2 Suzuki 2016

rectangular labels, while the surrounding mountains are flowing green swirls. The overall perspective is top down, but the mountains are drawn in an ad hoc mix of landscape perspectives. As with shogunal maps, we need to understand this lack of detail as a distinct political vision.

Figure 2. Ōzu Domain Map, 1814

The absence of absolute coordinates in the 1814 map is especially striking since the cartographer, Azuma Kanji 東寛治, included graticules and precise surveyors notes in a separate series of maps. Azuma was directly influenced by Inō, who visited Shikoku in 1808 and shared both data and techniques with Azuma. In appreciation of Inō's guidance, Azuma drafted 17 maps of the Ōzu coastline and sent them to Inō (Figure 3). Despite his addition of graticules, Azuma continued the *kuniezu* practice of ignoring comprehensive borders in favor of checkpoints. The red diagonal lines at the far left and right of the map mark the borders of the village of Konbō 今坊 with Kushi 串 (to the East) and Kuroda 黒田 (to the West), but those "border lines" are just parallels extending from border points on the coastal road. As straight lines, they do not follow the hilly terrain and do not represent borders in any modern sense. While Azuma painstakingly measured linear distances along major roads, and elegantly depicted houses and fields, he made no attempt to define Kondo as a fully bordered space. Accordingly, Azuma defined the size of Konbō as its length along the coastal road (38 chō 28 kan and 4 shaku, approx. 4,237 m), a line between two border points, rather than as an area defined by a polygon.

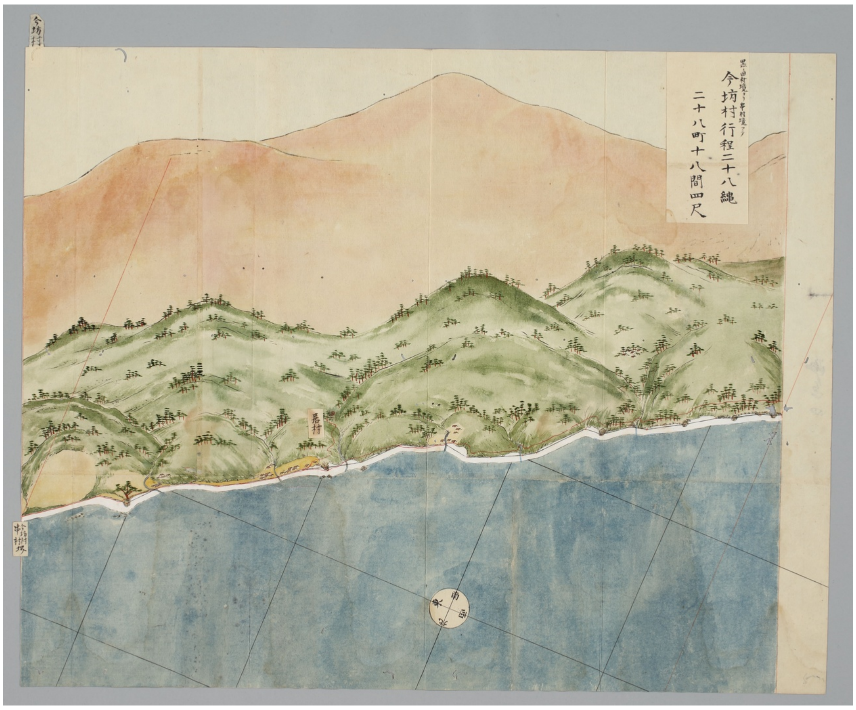

Figure 3. Map of Konbō village on the Ōzu coastline by Azuma Kanji 東寛治, early 19th C.

Because modern territoriality idealizes comprehensive geospatial coordinates, Tokugawa-era political maps seem "inaccurate." But *kuniezu* are "inaccurate" only if we misuse them. Tokugawa political maps were schematic rather than geospatial. They simplified and abstracted unimportant (or secondary) details. A helpful analogy is the modern mass transit map. Consider, for example, two modern maps of the Sendai City subway system. Figure 4 depicts the system as two simple perpendicular lines, intersecting at the Sendai central station.

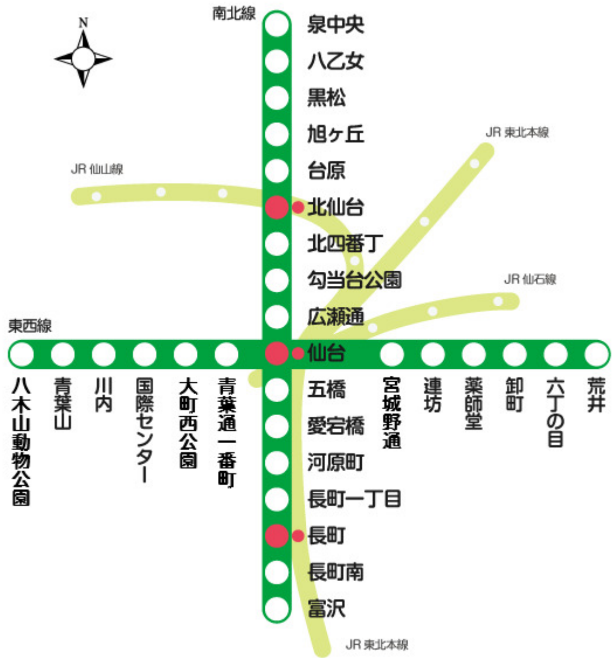

Figure 4. Sendai Subway Map

[Figure 5](#) allows for more complexity and shows that, in places, the North-South line (in green) actually runs from east to west.

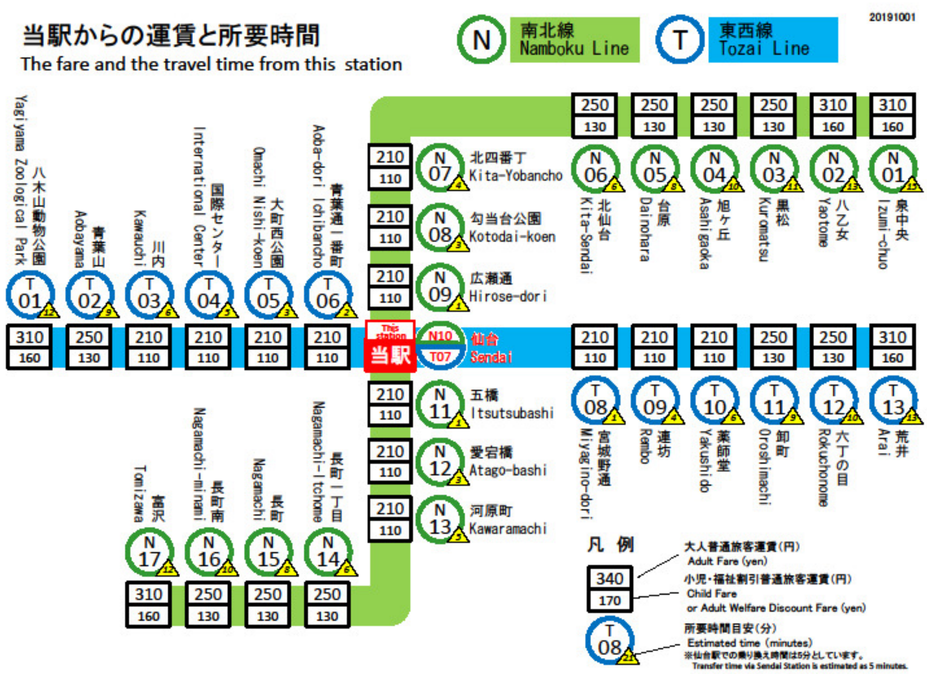

Figure 5. Sendai Subway Map

But both maps radically simplify the shape of the rail system, so they are geospatially "inaccurate." For example, at its western edge (from Aobayama 青葉山 to Yagiyama Zoological Park 八木山動物公園), the East-West line briefly reverses direction and runs to the southeast rather than the west.

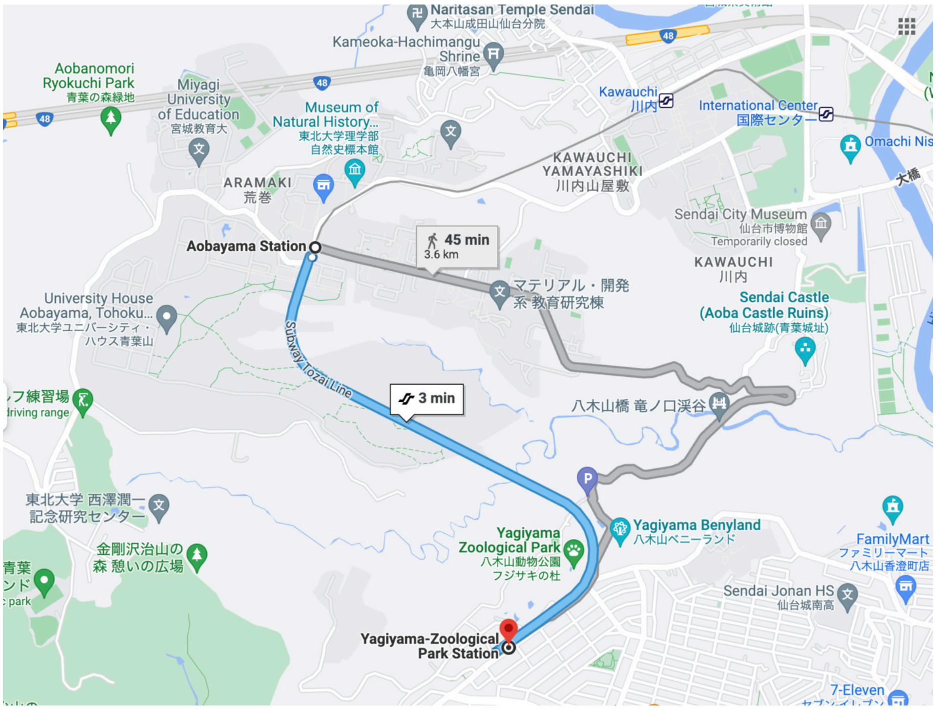

Figure 6. Google Maps image of Sendai Subway

By contrast, Google Maps is geospatially accurate and shows the absolute geographic coordinates of the stations (Figure 6). But the Google map is usable only because we can interactively highlight the desired details. A map showing all possible rail, bus, vehicular, and pedestrian routes from Aobayama to Yagiyama Zoological Park would be impenetrably dense. That interactive dimension of Google maps suggests how we might rethink historical cartography, creating maps that combine modern interventions with the reconstruction of historical epistemologies of space.

Because the conventions of transit maps are familiar, we do not treat these schematic abstractions as "inaccuracies." We know not to use a map of the London Underground to boat on the Thames. And we accept how schematic maps simplify secondary details (e.g., the spatial grid locations of the stations) in favor of primary information: the sequence of stations on each line (relative locations), travel time between stations, and the fare schedule.

Like subway or railway maps, *kuniezu* and domain maps were focused and task-specific. *Kuniezu* focused on village harvest yields and relative positions on roads, but simplified details that the cartographers considered secondary, such as borders through forests. By detailing the taxable harvest and relative location of villages, the *kuniezu* foregrounded a key aspect of political authority: lords measured their wealth and status in bushels of rice and restricted the mobility of their subjects. If we read *kuniezu* like transit maps, we can appreciate their schematic focus: simplified lines make both *kuniezu* and transit maps more legible. *Kuniezu* are jarring because they fuse practices that, in modern cartography, belong to different genres, mixing details of physical geography and schematic abstraction.

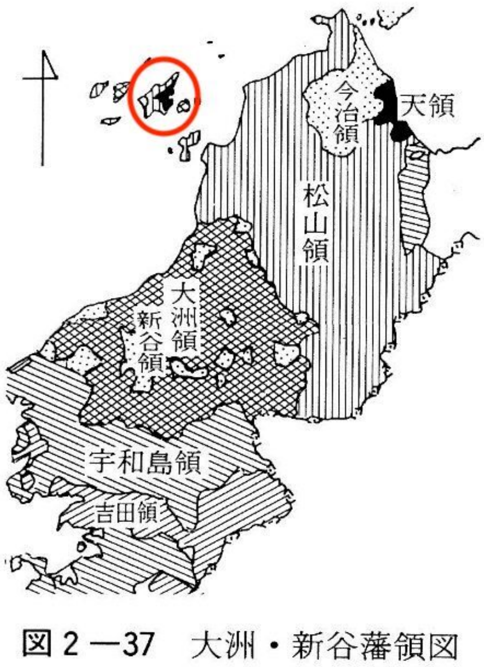

Figure 7. Domains of Ehime Prefecture from *Ehime-ken shi*

Choropleth and Beyond

Conventional cartographic practice ignores differences between Tokugawa and modern spatial epistemologies. Consider, for example, a map of Ōzu (Figure 7) and surrounding territories from the official *History of Ehime Prefecture* (*Ehime-ken shi* 愛媛県市). The map divides the prefecture into neat, domain-based blocks, but the evidentiary bases for those shapes are not revealed. How and why did the cartographers establish those borders? Which primary and secondary sources were consulted? Again, following convention,the text itself is silent.

Upon careful inquiry, it becomes clear that the *Ehime-ken shi* map depicts with clarity and certainty data that are by turns, unclear, contested, and unknowable. The map gives Ōzu clear land borders to the southeast, but those are explicitly marked on shogunal maps as unknown. At a more granular level, consider two contrasting depictions of Nakajima Island 中島 from *Ehime-ken shi* (circled in red above) and from Ōzu domain's 1814 map (Figure 8). First, the two maps disagree on who controlled four villages: Obama 小浜村, Ōura 大浦村, Awai 粟井村, and Uwama 宇和間村. On the *Ehime-ken shi* map, the eastern and western sides of the islands are colored black, suggesting that those villages were shogunal holdings (天領). On the 1814 Ōzu map, however, the villages (labelled with burnt orange ovals) are described as the holdings of Ōzu domain. That conflict reflects the nuances of early-modern territorial control: the villages were simultaneously Ōzu holdings and shogunal holdings. Those villages had once been divided. In Ōura in the mid-1700s, for example, 116 families were under shogunal administration but 87 paid taxes to Ōzu. That division

Figure 8. 1814 Map of Nakajima and Nuwajima

was a perennial source of tension. Did Ōzu villagers and shogunal villagers have the same forest rights? And should they pay regular taxes at the same rate? Beyond those practical matters, villagers under Ōzu domain jurisdiction complained that their neighbors under shogunal jurisdiction were arrogant and contemptuous. In 1780, Ōzu domain surrendered its parts of those four villages to the shogunate as part of a larger exchange of territories. But in 1813, the shogunate granted Ōzu administrative control over the four villages. Those shogunal parcels were henceforth *azukaridokoro* 預所, or "loaned lands": the shogunate claimed the villages's tax yield, but entrusted administration to Ōzu domain. Nonetheless, village control remained unresolved. In 1843, the shogunate reversed itself and reasserted direct authority, and then in 1850 returned control to Ōzu.[3] Choropleth maps are ill-suited to such fluid and contested borders.

Second, the polygons of *Ehime-ken shi* suggest that Nakajima Island was divided into two clear and well-delineated political zones: a shogunal region (solid black), and the holdings of Matsuyama domain (vertical lines). But the island had several overlapping and contested internal borders. The border between Obama and Ōura was left unresolved when the villages were separated in the 1580s and became a source of perennial conflict. In 1789, the villagers of Obama protested by decamping en masse to the neighboring village of Nagashi in Matsuyama territory. Local clergy helped arbitrate the

3 Nakajima Chōshi Shiryōshū Henshū Iinkai, 161-167 and Nakajima Chōshi Henshū Iinkai, 175-180. Nakajima has also historically been known as Kutsunajima 忽那島

dispute, and Ōzu promised to resolve the border dispute. The border of Awai village was similarly complex. Awai and the neighboring village of Hatari (畑里村) were divided in the 1430s but the forest in-between was held in common (*iriaichi* 入会地). While villagers could not cut timber there, both Awai and Hatari collected other vegetation as food, feed, and fertilizer. The problem of *iraichi* is especially acute for Nakajima because common lands included other neighboring islands. The two nearby islands of Ōtabachijima 大館場島 and Kotabachijima 小館場島, for example, were once the common land of four villages — Uwama, Kumata 熊田, Yoshiki 吉木 and Nyō 饒 — but the islands were then divided: Ōtabachijima was given to Nyō and Yoshiki and Kotabachijima to Uwama and Kumata. Uwama villagers thus shared common lands on multiple islands with villagers of different lords.[4]

Finally, cardinal directions in the 1814 Ōzu map are strikingly inconsistent. For the main territory of Ōzu on Shikoku, south is up, but for several islands in the Inland Sea, south is down. Because of that inconsistency, villages on Nakajima are on the wrong side of the island: Awai and Ōura, for example, were on the long, peninsular, northeast end of the island, but they are depicted instead on the flat, southwest end. That "error" reflects the intentionally schematic nature of most early modern Japanese maps. We can contrast, for example, the depiction of Nuwajima in the bottom right of Figure 8 with Azuma's personal map from the same period (Figure 10). In the latter, Azuma focused on physical geography and included a compass rose and the calculated circumference of the island, while the former is a more schematic representation of political authority.

All these factors militate against using period maps to create modern choropleth polygons. We can, however, re-purpose polygons as explicitly analytical interventions. We can use polygons, like isobars, not as direct representations but as fruitful abstractions. In the words of William Sewell, "the powerful abstracting, abbreviating, and summarizing techniques of quantitative reason" can help us see regularities that are obscure at the granular level (Sewell 350).

Polygons beyond Choropleth

For both points and polygons, this essay draws on data from a neglected source, the *Kyūdaka kyūryō torishirabechō* 旧高旧領取り調べ帳, (KKT), literally "Survey of old tax yields and old investitures." The KKT is essentially an autopsy of the Tokugawa shogunate (1600-1868): a comprehensive survey of landholding compiled by the new Meiji government as it dismantled the old regime. The KKT recorded the size, holder name, and village name for over 95,000 parcels in over 60,000 individual villages. This study combines

4 FIX FIX add note to Nakajima Chōshi Shiryōshū Henshū Iinkai FIX FIX ####

Figure 10. 1814 Map of Nuwajima Island 怒和島 by Azuma Kanji 東寛治, early 19th C.

the KKT data (as edited and digitized by the National Museum of Japanese History, or *Rekihaku*) with geolocation search engines to estimate the location of the villages. Many of the villages and hamlets in KKT disappeared as independent political units in 1889, when the Meiji state undertook a massive administrative consolidation, amalgamating 71,314 cities, towns, villages, and hamlets (市町村) into 15,859 larger units.[5] Although that consolidation eliminated some 55,000 administrative units, we can approximate the locations of those lost villages and hamlets because the toponyms survive in other forms, such as the names of modern "small statistical areas" (*kochiiki* 小地域),[6] and vestigially in the names of schools, civic centers, parks, businesses, bus stops, and even highway interchanges (details of the geolocation process are in the Appendix). Those coordinates are decidedly approximate. Different researchers using different reference works and different search engines produce results that vary, often by a few kilometers. Rather than attempt to resolve that "fuzziness," this study builds on it. At the individual village level, the imprecision of coordinate locations reflects the imprecision of Tokugawa-era maps, detailed below. At

5 The principle behind the 1889 consolidation was to create administrative districts with between 300 and 500 households. Beginning in 1956, the government began merging villages with less than 8000 residents. As of 2022, there are only 1718 remaining districts. https://www.soumu.go.jp/gapei/gapei2.html

6 Many toponyms survive as the names "small statistical areas" (*kochiiki* 小地域), spatial units introduced by the government in 1995. The creation of "small statistical areas," like the merging of villages, was a response to rural depopulation. Consolidating villages into larger districts reduced administrative costs, but also created regions too large and diverse for meaningful data analysis. The administrative district of Matsuyama city (松山市), for example, now includes the relatively densely populated prefectural capital itself, but also sparsely populated and unpopulated islands in the Inland Sea. The single administrative region is thus subdivided, as of 2021, into 725 "small statistical areas" with populations ranging from 0 to 7620. Many of those *kochiiki* retain the names of Tokugawa-era hamlets, but the borders are modern constructs. This study therefore uses *kochiiki* to derive central points rather than polygons.

the aggregate level, with over 60,000 villages, small village-level variations wash out as statistical noise. Indeed, the statistical conclusions in this study hold even if we artificially add "noise" to the data, shifting the village locations in small random increments.[7]

Using those approximate coordinates, we can create hybrid maps that capture the political geography of Tokugawa-era Japan but allow for interactivity and spatial statistics. Figure 11, which can be downloaded here, uses basic HTML and JavaScript to overlay both points and polygons on satellite images. The "villages" layer reproduces the Tokugawa-era convention of villages as points. Instead of cartouches, the map uses mouseovers and on-click popups to relate details such as village name, harvest yield, and tax claimants. Those interactive elements allow for a high density of information. In order to convey village-level details, Tokugawa-era maps were enormous. The 1814 Ōzu map is 117cm x 173cm (46in x 68in), and the *kuniezu* of Iyo is 714cm x 706cm (281in x 278in). Interactive maps capture a similar level of detail in a more manageable format. Using pop-ups, for example, the map includes notes on "loaned lands" on Nakajima and the common lands of Ōtabachijima and Kotabachijima.

The "Voronoi borders" layer relies on an algorithm, Voronoi tessellation, to create pseudo-borders. Rather than relying on period records or maps to create village borders, Voronoi tessellation generates lines equidistant between pairs of points, and those serve as pseudo-borders. Nodes are created where those lines meet and those points are equidistant between three or more villages.[8]

How does this map improve on conventional chorolopleth maps like those in *Ehime-ken shi*? The points layer reveals how valleys and littorals were densely populated but mountain regions were not. Matsuyama, Uwajima, and Toyohashi (a branch of Uwajima) domains, for example, appear not as homogeneous spaces, but as c-shaped, with large empty spaces in the high mountains and dense clusters of villages along rivers and seas. Ōzu and Niiya, by contrast, are more evenly populated at moderate densities.

The Voronoi cells, by contrast, reveal spatial contiguities: where were villages closest to villages with the same lord? Where were neighboring villages beholden to a different lord? Voronoi cells reveal those relationships through adjacent colored blocks. Unlike conventional choropleth maps, Fig. 11 makes

7 Technically, this study relies on the Law of Large Numbers and the Central Limit Theorem. Less technically, we can treat the noise in village locations as a game of chance. A fair coin toss will produce 50% heads and 50% tails, but it is impossible to see that outcome in a single toss. The "law of averages" appears only with multiple trials. A more suitable analogy for the spatial case might be a target shoot. Even if different archers, shooting under different conditions, all miss the bullseye, we can assume that the bullseye lies at the rough center of their cumulative attempts.

8 Polygons were calculated using the R package **ggvoronoi** r.0.8.5, which relies on Rolf Turner's **deldir** package.

no attempt to represent exact borders since many of these were undefined. Rather, the regular spiderweb pattern of cells, like the regular, nested loops of a topographic map, is an empirically grounded abstraction.

Finally, the map is highly reproducible. The point and polygon data are all included in the HTML file and are also available in simple txt format. The principles behind the polygons (Voronoi tessellation) are well known, and the relevant code can be readily shared. The map is almost entirely self-contained in a single file: the points, polygons, and metadata (mouseover and on-click text) are all in the HTML file and require no special software or server. The only external dependency is zooming the satellite image base maps, which requires an internet connection, although more limited base maps could be stored in a single folder. In short, Fig. 11 is a "born digital" spatial visualization rather than an incremental modification of static maps.

Quantifying Spatial Fragmentation and Political Power

The raw geospatial data behind "born digital" maps also allows us to explore the relationship between space and power. How did spatial fragmentation affect the excercise of political control? How can we measure the spatial consolidation (or fragmentation) of early-modern Japanese domains? Such measurements are complex because we need to account for many factors. Individual villages could have multiple holders. Alternatively, some villages had a single holder, but were surrounded by villages owing taxes to different lords. Some daimyo holdings formed a single contiguous territory around the lord's castle, while other holdings were fragmented into scattered parcels. Villages at the periphery of a lord's holdings might be close to another lord's or separated by forests, lakes, or rivers.[9]

A simple but powerful metric for these multiple factors is the Simpson index, a widely used metric of diversity developed by Edward H. Simpson in 1949. The basic formula is simple: the sum of the squared proportions. For example, in an area divided by two holders as 90% and 10%, the index is $0.9^2 + 0.1^2 = 0.82$, but for a 50%-50% split the index is $0.5^2 + 0.5^2 = 0.5$. The Simpson index ranges from 0 to 1, with 0 as infinite fragmentation and 1 as complete consolidation. The index, or similar variants, are used in a range of disciplines (including ecology, political science and economics) to measure diversity and competitiveness.[10]

9 There is an enormous bibliography on how to measure gerrymandering, but electoral districts are contiguous districts while daimyo domains were often non-contiguous.

10 Formally, where x_i is the tax yield, (*kokudaka*) allocated to each unique holder, and X is the total kokudaka, Simpson = $\sum_{i=1}^{n} \left(\frac{x_i}{X}\right)^2$. Closely related metrics include the Gibbs-Martin and Blau indexes in sociology, psychology and management studies, and the Herfindahl index or the Herfindahl–Hirschman index (HHI) in economics. For an overview of diversity metrics see Chiarucci, "Old and New Challenges."

We can calculate Simpson indices for any areal unit: a village-level Simpson index would include all holders within a village, while a county-level index would include all holders within a county. This study relies on Simpson indices for a 5km radius around each village. Consider, for example, the Simpson index for a 5 km radius around Sakamoto village (坂元村) near Kagoshima Castle. The village was held entirely by the Shimazu daimyo house, as were all the surrounding villages, so the Simpson index is 1 because $1^2 = 1$. At the opposite extreme is the most fragmented village in the KKT, Saiin village (西院村) in Kadono county (葛野郡), now a part of central Kyoto. The largest holder was Tōji Temple, which claimed roughly 22% of the village, but it shared Saiin with 165 other holders (households, temples, and shrines). A 5 km radius around Saiin encompasses another 125 villages and raises the total unique holders to 408. Because many of those holders claimed only a tiny portion of the yield, the Simpson index for the area is 0.02.[11] The largest holder in the radius was the "former administrative holding of the Kyōto military commissioner" (元守護職役知) which held 4,244 *koku* or 8.28% of the total yield. The second largest holder was " administrative holding of the Kyōto military commissioner" (守護職役知) which held 2,219 *koku* or 4.33% of the total yield. The third largest holder was "former imperial house holdings" (元御料) which held 1,938 *koku* or 3.78% of the total yield. The first three elements of the Simpson index are therefore $0.083^2 + 0.043^2 + 0.038^2$.

We can calculate the Simpson index for a domain by calculating the average of the 5 km Simpson indices for villages in which the domain was the primary holder. The Simpson index for domains ranged from a high of 0.98 for Kagoshima domain 鹿児島藩 to a low of 0.08 for Takaoka domain 高岡藩.[12]

Large, highly consolidated domains exercised greater control over their people than smaller domains with scattered holdings. Political control is a complex phenomenon to quantify, but we can measure one key facet through the presence (or absence) of domain monopolies. Historians have found records of hundreds of domain monopolies and monopsonies, covering commodities as diverse as rice, salt, tea, sugar, lumber, cotton, indigo, ceramics, ink stones, eggs and gelatin (寒天 *kanten*). The goals of such monopolies were as diverse as the target products. Often the objective was to directly increase government revenue by fixing prices. In other cases, the domain had the

11 For the 5km radius Simpson index for Saiin village, the total yield for the area was 51,270.75 *koku*.

12 This analysis omits Nanbu domain 南部藩, which was radically altered in the early Meiji era, and domains whose holdings in KKT were under 10,000 *koku*

broader objectives of promoting economic development through quality control and reliable distribution networks. In all cases, domains needed extensive political power in order to establish monopoly control.[13]

Which domains established monopolies? Monopolies were supported by two factors: size and consolidation. As shown in Figure 12, the likelihood of establishing a monopoly rose with size and mean Simpson index (5 km radius). For example, only 15% of domains under 50,000 koku ran monopolies, in contrast to 97% of domains over 200,000 koku.[14] Similarly, 8% of domains with a mean Simpson index under 0.25 ran monopolies, in contrast to 74% for domains over 0.75. In other words, the likelihood of establishing a monopoly rose with each factor. We can formally specify those relationships with a logistic regression (logit) model, and estimate the underlying probabilities. In Figure 12, the dashed diagonal line marks the calculated threshold above which the model predicts a domain monopoly: points above the line are expected to have a monopoly and those below not. That model predicts with roughly 82% accuracy whether a domain established a monopoly. In some situations, accuracy is a misleading metric of model performance, but in this case it points to a robust conclusion: large consolidated domains were much more likely to run monopolies than small, fragmented territories (Model details are in the Appendix).[15]

While the technical details of logit modelling are complex and beyond the scope of this essay, the basic principles are straightforward and are illustrated in Figure 13. In that graph the x-axis is the degree of fragmentation and the y-axis is the likelihood of a monopoly for each domain. The black points mark the observed values: 1.00 (or 100% likelihood) for a monopoly and 0.00 (or 0% likelihood) for no monopoly. The red curve represents the hypothetical likelihood of a monopoly for a given level of fragmentation. The curve is a sigmoid (S-shaped) because the effect of fragmentation (or size) must be asymptotic: even a huge, consolidated domain cannot have a monopoly likelihood above 100%. The term "logit" derives from the specific mathematical form of the sigmoid, the logistic function. Logit models adjust or "fit" the sigmoids to the observed data, trying to get the "S" as close as possible to the observed points. Thus, logit does not directly maximize

13 Data on domain monopolies and monopsonies is from Yoshinaga 1973

14 Koku was measure of volume (roughly 5 bushels, or 180 liters), narrowly used to measure grain, but more widely used as a currency of account. A landholding of 50,000 koku, for example, was understood as a parcel with an annual harvest valued at 50,000 koku of rice

15 The mean Simpson index (5km radius) was calculated for all villages where the target domain was the largest holder. Similar results obtain for other metrics. The text above reports model accuracy, although it can be a problematic measure for unbalanced data sets. Consider, for example, the prediction of a rare event, such as the crash of a commercial airplane. We can build a model that is extremely "accurate" simply by predicting "no crash" for all cases. If the crash rate is 0.000001% then the model can be 99.9999% accurate even without any additional information, a nearly perfect "no-information rate." The problem, of course, is that such a model will have a "false negative" rate of 100%, failing to predict any aviation problems. Accordingly, we often need metrics that account for "accurate" but useless predictions. Fortunately, the domain monopoly data is much more balanced: 63.64% of domains ran monopolies, so the "no information accuracy" of the model is also 63.64%. Using data on size and fragmentation, we can raise that accuracy to 82%, or roughly halfway to perfect accuracy. The value of the model is also confirmed with more robust metrics, such as AUC = 0.88

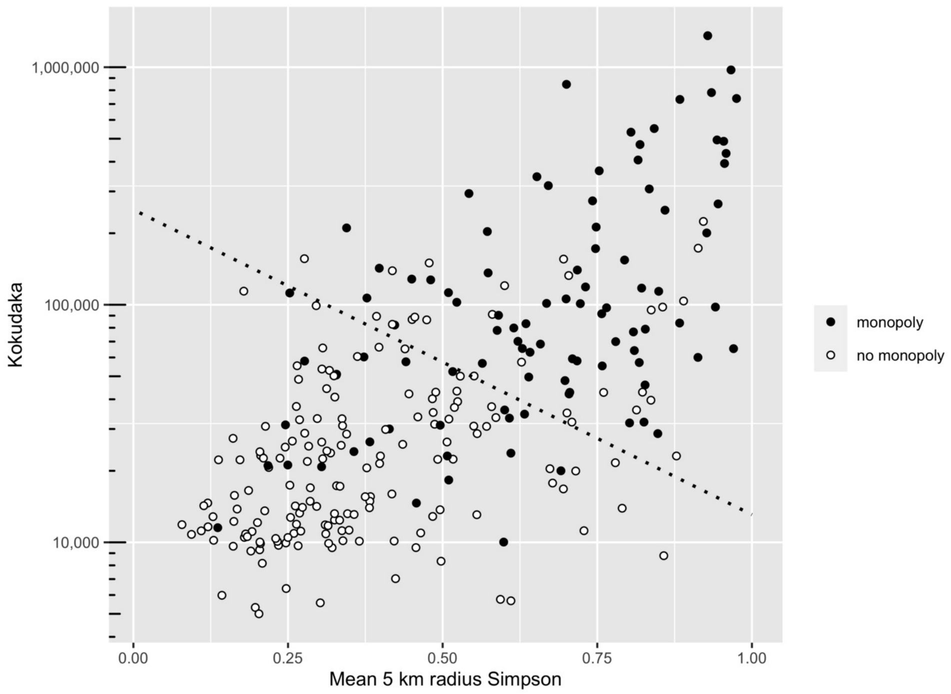

Figure 12. Domain monopolies as a function of fragmentation and size

accuracy, but rather maximizes the fit of the likelihood curve. For the simple case of one variable (e.g., predicting monopolies with the Simpson metric as in Figure 13), the relevant scatter plot is fairly simple. The threshold in that model, where the red line hits a likelihood of 0.5, is at roughly 0.625. Thus we will expect domains with Simpson indices above 0.625 to have monopolies. More complex models (such as the two and three independent variable models explored below) are difficult or impossible to visualize, requiring three or more dimensions, but the principles are the same.[16]

How good a result is 82% accuracy? If size and fragmentation fully determined the presence of monopolies, we might reach 100% accuracy. By contrast, the floor for predictive accuracy, the "no information rate" for this model is 64%. For binary choices (in this case "monopoly" or "no monopoly"), the larger category is used as the default prediction and 64% of domains did not run monopolies. Data on domain size and fragmentation (82% accuracy) thus gets us roughly halfway from "no information" (64% accuracy) to perfect information (100% accuracy). Those formal calculations aside, the impact of size and fragmentation is clear from Figure 12: there are no domains with monopolies in the bottom left, and no domains without monopolies at the top right. That conclusion is also confirmed by the parameter values (e.g. ß) in the Appendix.

16 To be exact, logit models minimize a loss function $-y\log(p) - (1-y)\log(1-p)$, where y is the observed values and p the estimated likelihood. Parameter values were estimates using the default method in the R **glm** package, iteratively weighted least squares. In the interests of reproducibility, we share a sample of 25,000 villages from the complete data, and that sample produces effectively identical logit parameters. Effectively identical results were also obtained using gradient descent.

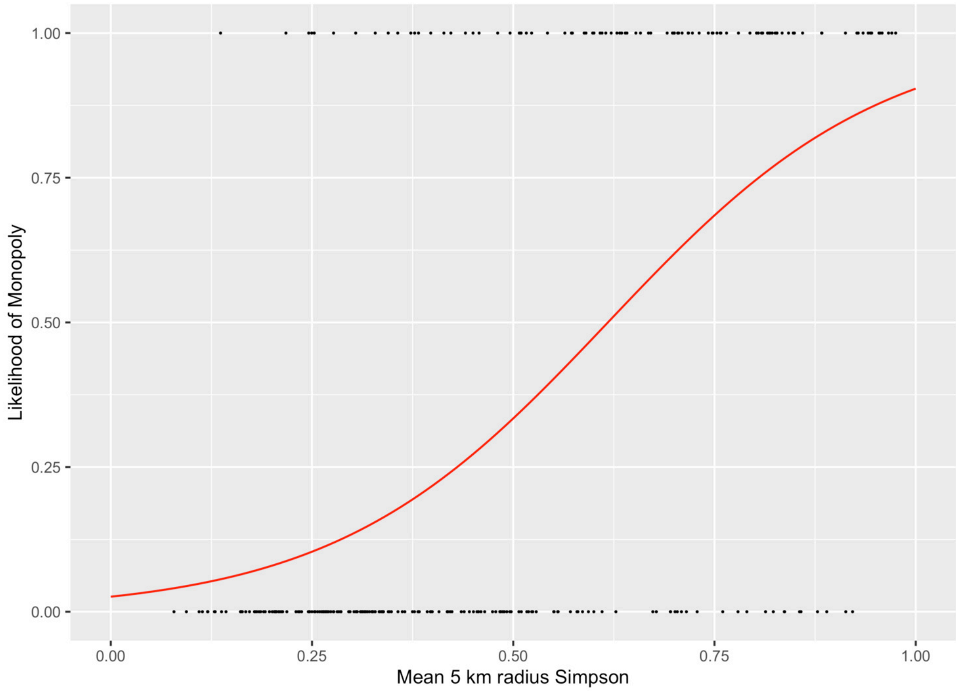

Figure 13. Domain monopolies as function of fragmentation

These findings confirm the seminal work of Yasuoka Shigeaki. In 1959 Yasuoka asserted that spatial fragmentation and cohesiveness were key to explaining an apparent paradox in Japan's 1868 Meiji Restoration. Why, he asked, was the Restoration led by the southwestern domains of Satsuma and Chōshū, rather than by domains in the more economically developed Kinai region (the Osaka area)? Yasuoka posited a discrete, binary distinction between the "territorial holdings" (領国 *ryōgoku*) of the southwest, which were large and consolidated, and the "non-territorial holdings" (非領国 *hiryōgoku*) of the Kinai, which were smaller and spatially fragmented. For Yasuoka, the size and fragmentation of Kinai domains undermined their ability to formulate and execute consistent economic policies, and thereby stopped them from converting relative economic advantage into political power (Yasuoka 1959).

At one level, the logit model results are unsurprising: it seems intuitive that size and spatial contiguity would enhance state capacity. In that context it is valuable to explore where the model fails as well as where it succeeds. For example, which small and fragmented domains ran monopolies, contrary to expectations? While the model correctly classified 226 domains, it failed to predict the appearance of monopolies in 20 cases. What factors did those domains have in common?

Many such "false negatives" involved goods with highly localized production, so the monopolies did not require control over extensive, contiguous holdings. Kanō domain 加納藩, for example, was divided into two distinct clusters, one in modern Gifu 岐阜県 and one in modern Ōsaka 大阪府, producing a low Simpson score (0.25). The domain ran a monopoly on umbrellas, but umbrella production was limited to the Gifu cluster. Thus, while Kanō holdings were fragmented, umbrella production was not.[17] In similar fashion, the small and fragmented domain of Toyooka (豊岡藩) successfully ran a monopoly on a type of wicker trunk (*yanagikōri* 柳行李) because production was limited to the domain castle town. In some cases, production was localized because of natural forces.[18] Mori domain (森藩) in Kyushu appears too small (23,732 koku) and fragmented (0.61) to have run a monopoly. Contrary to expectations, Mori ran a monopoly on potassium alum (myōban 明礬), used both as a medicinal and in fine leather work. The model misclassifies Mori because the alum salts were obtained solely from a hot spring in Tsurumi village (鶴見村), so maintaining the monopoly did not require extensive spatial control. Rather, establishing a domestic monopoly required lobbying to limit imports of Chinese potassium alum into Nagasaki.[19]

What of "false positives," the 26 large and consolidated domains that did not run monopolies? It is, of course, difficult to explain the absence of a domain initiative, but some instances are suggestive. The largest domain to lack a monopoly was Shōnai domain 庄内藩 (listed in KKT as Ōizumi domain 大泉藩). Shōnai was distinguished by its heavy reliance on a wealthy commoner financier house, the Honma, for financial support. The Honma regularly extended credit to Shōnai, and then forgave the loans in return for political access (Ravina 60). That financial support likely blunted the need for a monopoly as a revenue source.

What other factors supported the ability to run monopolies? In both Japanese and English historians have often looked to the status of the lord. *Fudai* lords were descendants of the first shogun's more trusted vassals and were therefore, by hereditary privilege, eligible to serve in the shogun's administration. In the conventional view, the shogunate entrusted *fudai* with smaller, scattered parcels and frequently changed their holdings. Those measures helped to ensure their dependence on the shogunate and their reliability as shogunal agents. *Tozama* lords, by contrast, were the descendants of the first shogun's less trusted vassals, including those who had sworn fealty only after defeat in 1600. In the conventional view, they had large, contiguous holdings, commonly at the periphery of Japan, far from the shogun's major cities and key castles. A smaller, third category, *kamon*, constituted daimyo with close kinship ties to the shogunate. In the sample for this study 107 domains were *tozama* (38.91%), 140 domains were *fudai* (50.91%), and 22 domains were *kamon* (8.00%)

17 Okamura and Shinma 1929

18 Toyooka-shi 1981, 301-305

19 Ōita mirai shin'yō kinkō 2002, 30-33

In the 1960s and 1970s, Conrad Totman and Harold Bolitho sparred over these *tozama-fudai* distinctions. Totman argued that *fudai* domains were markedly different from *tozama* holdings. *Fudai* lords who served as Tokugawa officials, for example, had more fragmented holdings because their parcels were increased or decreased based on their service to the shogun. "Even after 1700," he observed, "the process of rewarding officials undermined the integrity of the domains involved." While some older *fudai* domains enjoyed territorial integrity, many *fudai* holdings were "artificial creations at best, not political units proved by survival." In Sakura domain, for example, the Hotta house had holdings scattered over six provinces and had only limited control over parcels far from their castle. That fragmentation "made the Hotta hostage to the Tokugawa system" (Totman, *Politics in the Tokugawa Bakufu, 1600-1843*, esp. 156-59)

Bolitho counter-argued that *fudai* holdings were, in general, indistinguishable from those of *tozama*. He rejected as a "stereotype" the claim that *fudai* were more fragmented than other domains. Cases of extreme fragmentation, such as Sakura domain, were uncommon, as was the relocation of *fudai*. Although few *fudai* held the same fief in 1868 as in 1630, the rate of relocation dropped in the late 1600s, so that most *fudai* remained in place after the 1730s. Bolitho rejected as "without substantial basis in fact" the argument that *fudai* lacked strong ties to their holdings because of frequent relocation. (Bolitho, *Treasures Among Men*, esp. 44-56)

The *tozama-fudai* distinction figures prominently in Japanese historiography as well. Building on Yasuoka's work, historians developed a "regional society 地域社会" approach that seeks to integrate local and national history. In the words of Yamasaki Yoshihiro, "regional society theory 地域社会論" seeks to formulate a "grand theory" (*gurandō seorī*) of Japanese history that encompasses local specificities within a national framework of differences. Many "regional society" studies include the *tozama-fudai* distinction.[20]

Did *tozama* and *fudai* domains differ markedly in landholding and did that shape how they exercised power? The observation that *tozama* domains were large and consolidated, in contrast to small and fragmented *fudai* holdings, holds for extreme values. The largest consolidated domains were indeed *tozama* while the smallest and most fragmented were *fudai*. But the vast majority of both types of domain lay in between those extremes. We can visualize the *tozama-fudai* distinction by combining a scatter plot with convex hulls (Figure 14), revealing how extensively the two types of lord overlapped but not at extreme values. This graph reveals the "one picture is worth a thousand words" potential of quantitative analysis. Visually, it

20 The "regional society theory 地域社会論" bibliography is enormous. Key works include Yamasaki 2020; Ōshima 2008 and 2009; Iwaki 2003; Ono et al. 2001. Quote from Yamasaki 2020, 226.

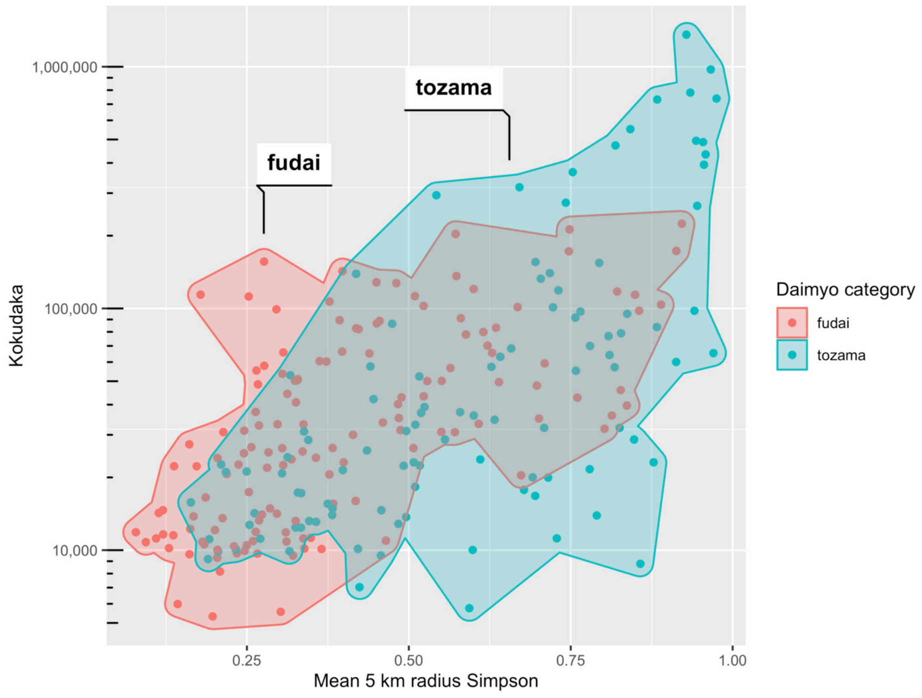

Figure 14. Tozama and fudai domains

becomes clear that Totman's argument focuses on the corners of the plot, while Bolitho's focuses on the overlapping area at the center. The two arguments are less in conflict than they are complementary.

What then, of domain monopolies? Following the conventional distinction between *tozama* and *fudai*, we would expect *tozama* to have been more independent and form monopolies at a higher rate. The logit modelling hints at such a "*tozama* effect," but it is relatively small and statistically tenuous. Model 2 below contrasts *tozama* with both *fudai* and *kamon*. The results suggest that, for a mid-sized domain, *tozama* status increased the likelihood of running a monopoly by roughly 15% over a comparable *fudai* domain, but that estimate has a high margin of error. Indeed, the raw accuracy of the model with a "*tozama* effect" (Model 2) is actually incrementally lower than that of the base model (Model 1). Other model specifications, such as dropping *kamon* domains from the sample, reduced all measures of model performance. As a check for robustness, we conducted a parallel analysis using the **caret** package for a tenfold cross-validated decision tree. The results were effectively the same: fragmentation and size were important split nodes while *tozama* dropped out. Finally, we arrived at a similar conclusion through simple arithmetic: comparing 32 domains in a band around the median values in the scatter plot, specifically between the 35th and 65th percentiles. Within that band, 16.7% of *fudai* and *kamon* ran monopolies, compared to 21.4% of tozama, a difference of 4.8%. In short, the *tozama* effect on monopoly formation was small to none.

The shogunate's political control, like that of the domains, was attenuated by spatial fragmentation. Most Tokugawa holdings were in the Kinai or Kanto, and were relatively scattered. But in areas where Tokugawa holdings were consolidated, the shogunate functioned much like a contiguous, consolidated domain, extracting revenue through monopolies. In the seventeenth century, the shogunate established spatially coherent control over key resources, including the Iwami Silver Mine, the Aikawa gold and silver mines on Sado Island, and the forests of Hida Province.

As in daimyo domains, spatial fragmentation diminished the shogunate's governmental capacity. The fragmentation of the Kanto and the Kinai regions reflect a central tension in the shogunate's spatial authority. The shogunate was a national government, with authority and responsibility across the archipelago, but its own holdings were fractured, especially around its major cities. As a result, the shogunate was a strangely weak government in its own heartland. The commercial development of the Kanto in the later Tokugawa period exacerbated those spatial problems. Pushed by poverty and drawn by greater opportunity, villagers left their homes for larger towns and the Edo metropole. That labor mobility commonly involved movement between legal jurisdictions, creating a surge in people described by authorities as *mushuku* 無宿, literally "homeless," but more accurately "unregistered," or "lacking a legally actionable domicile." The growing market economy generated increased demand for entertainments, including theater, gambling, and prostitution and many *mushuku* were involved in those legally marginal or illegal activities. Those displaced by the volatility of market forces were also drawn into criminal gangs, which engaged in extortion and brigandage, as well as gambling and prostitution. Because the gangs could move freely between legal jurisdictions, the shogunate found it difficult to suppress them. The shogunate also struggled with poverty relief since the poor also moved across jurisdictions (Howell; Botsman).

Period observers considered the fragmentation of Tokugawa holdings an impediment to Tokugawa rule. The problem was discussed, for example, by Hoashi Banri 帆足万里 (1778——1852), essayist and domain elder (karō 家老) of Hiji 日出 domain. According to Hoashi, the fracture of shogunal holdings diluted government authority and reduced shogunal agents to mere tax farmers, incapable of enforcing edicts. He evocatively described the political geography of the Kanto as a "houndstooth" pattern (*kenga* 犬牙). Hoashi recommended the radical reapportionment of lands to consolidate Tokugawa holdings around Edo and Osaka.[21] The Tokugawa senior councilor Mizuno Tadakuni attempted such a bold move in 1843, when he ordered the consolidation of all lands within a 10 ri 里 (approx 39.3 km) radius of

21 See Hoashi's 1843 essay "Tōsenpuron" 東潜夫論 in Hoashi Kinen Toshokan, 1:35-81, esp. 47-48. The curious title, literally "Thesis by an Eastern Recluse," is a reference to an essay by Later Han scholar Wang Fu 王符 (82 CE-167).

Edo and Osaka castles. Daimyo and hatamoto with holdings within those areas would receive new, equivalent parcels, further out from the castle towns. Mizuno's edict prompted a furious reaction that cut across class lines. Daimyo and samurai did not want to be relocated, while commoners feared that the transfers would trigger new land surveys and discover unreported or under reported yields. The opposition was so intense and widespread that Mizuno abandoned the transfer plan and resigned as chair of the shogunal council of elders.

While neither Hoashi nor Mizuno's bold plans were realized, the shogunate did manage less dramatic spatial consolidation. Most notably, it created the Kanto Itinerant Inspectors (*Kantō Toshimari Deyaku* 関東取締出役), a new constabulary force authorized to cross conventional jurisdictions within the eight provinces of the Kantō region.[22] The force also cut across status boundaries: samurai intendants were allowed to deputize commoner posses in pursuit of criminals. The force, commonly known as the *Hasshū mawari* 八州廻り, was effective in suppressing both banditry and popular uprisings. In 1866, the *Hasshū mawari* was deployed during the Busshū Revolt, a massive protest against rising prices that spread across three provinces. That presaged the Meiji state's mobilization of commoners in its military and police. But the reform also had the unintended consequence of exacerbating conflict within the commoner estate, since posse members were often the local elite. Thus, in Japanese popular culture, the *Hasshū mawari* are commonly depicted as corrupt and unjust while the thieves, gamblers, and rebels they pursued are portrayed as noble anti-heroes.[23] Most important, for present purposes, the deployment of the *Hasshū mawari* reflects how the shogunate attempted to resolve the problem of spatially fragmented authority.

Conclusions

In early-modern Japan, spatial coherence enhanced political power. Ruling authorities were able to exert greater control when their holdings were exclusive and contiguous. Shogunal officers such as Mizuno Tadakuni appreciated that spatial dimension of political control, as revealed by their reform efforts. Nonetheless, Tokugawa-era political authority did not correspond to modern territoriality. In their emic cultural framework, period agents did not conceptualize contiguous spaces as discrete "jigsaw puzzle" blocks of land, but as clusters of villages. Standard choropoleth maps of Tokugawa-era Japan obscure that spatial sense by treating polygons as period borders, rather than as a modern, etic interventions. By contrast, polygons based on Voronoi cells are explicitly interpretive and illustrate spatial contiguities without imputing modern territoriality or assuming it *a priori*.

22 The term *deyaku* 出役 is also read as *shutsuyaku*.

23 Sippel. For a lively introduction to the *Hasshū mawari* see Ochiai 2002. For greater detail see Tokuzo 1947

Standard, static maps require cartographers to make a choice between points and polygons. Interactive maps, by contrast, allow us to simultaneously deploy both. Two further advantages of such maps are transparency and reproducibility. In conventional historical maps, the creative process is undocumented and unreproducible. The smooth arcs of rivers and borders produced by GIS and mapping software are based on complex calculations, such as the Bernstein polynomials used in Bezier curves. Those calculations, however, are hidden, so the process is both obscured and naturalized. With Voronoi tessellation, by contrast, the process is transparent and polygons can be reproduced from the point data.

As a challenge to conventional GIS practice, this essay echoes broader calls for new approaches to historical maps. Anne Kelly Knowles has advocated for a humanistic GIS that can "broaden the range of geographical methods for visualizing the spatiality of human experience." While historians may want to rely on coordinate-based maps, they also need to explore alternatives: "GIS is ideal for studying representations of space but has limited utility for studying spatial practice." (Knowles et al.) David J. Bodenhamer has called for "deep maps", which link "geographic and cultural representations of a place" and "are visual, multilayered, and inclusive, offering multiple perspectives of a small area of the earth" "Traditional GIS," he argues, "is not the means for constructing a deep map. But it is part of the solution, especially when linked to recent advances in spatial multimedia." (Bodenhamer) The maps in this study are more conventional than the expansive reconceptionalizations offered by Knowles and Bodenhamer. But this study reveals how humanistic GIS and quantitative inquiry can be mutually supportive. If we reject the limiting association of quantitative methods with exactitude, we can use computational techniques such as Voronoi polygons as alternatives to precise borders. We can use aggregate statistics to overcome the noisiness of geolocation data. Modern computational methods can thus lead us towards, rather than away from, Tokugawa-era spatial experiences.

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Appendix

Geolocation procedures: This study relied on Rekihaku's digitized version of KKT, especially the administrative codes (市町村コード) added in 1990. By reversing those codes, we were able to place hamlets/villages within modern administrative units and create pseudo-addresses. We then used search engines and databases (Google Maps, Bing, Mapion, the CODH Geoshape Repository, and the Japanese government's e-Stat spatial data) to geolocate those addresses. We employed two checks for possible errors. First, we investigated duplicated coordinates (multiple hamlets with the same location), and second we checked that villages in the same county comprised a contiguous spatial unit. Errors were corrected by referring to reference works such as *Kadokawa Nihon chimei daijiten* 角川日本地名大辞典 and *Nihon rekishi chimei taikei* 日本歴史地名大系 and generating new search strings. We are continuing to "clean" this data set, but after testing various subsamples of the data, we find that the remaining data errors can be treated as random statistical "noise." Notably, our conclusions are the same whether we use our most recent, "cleanest" data or earlier, "noisier" versions.

	Model 1				Model 2			
	ß	odds ratio	marginal effects at mean	mean marginal effects	ß	odds ratio	marginal effects at mean	mean marginal effects
Constant	-14.965***	-	-		-16.246***	-	-	
Simpson 5km	3.486***	32.642	0.736	0.464	2.888 **	17.955	0.611	0.379
log10(kokudaka)	2.715***	15.112	0.573	0.361	3.002***	20.130	0.635	0.394
tozama					0.682 *	1.978	0.148	0.148
n	272				272			
AIC	232.14				230.812			
AUC	0.88				0.884			
Wald test χ^2	74.279***				71.819***			
No Information Rate	63.97%				63.97%			
Raw Accuracy	82.18%				81.45%			
Precision	0.84				0.84			
Recall	0.89				0.90			

SUPPLEMENTARY MATERIALS

Figure 11. Interactive map of Iyo Province and select islands

Download: https://culturalanalytics.org/article/84860-algorithmic-maps-and-the-political-geography-of-early-modern-japan/attachment/174413.html

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