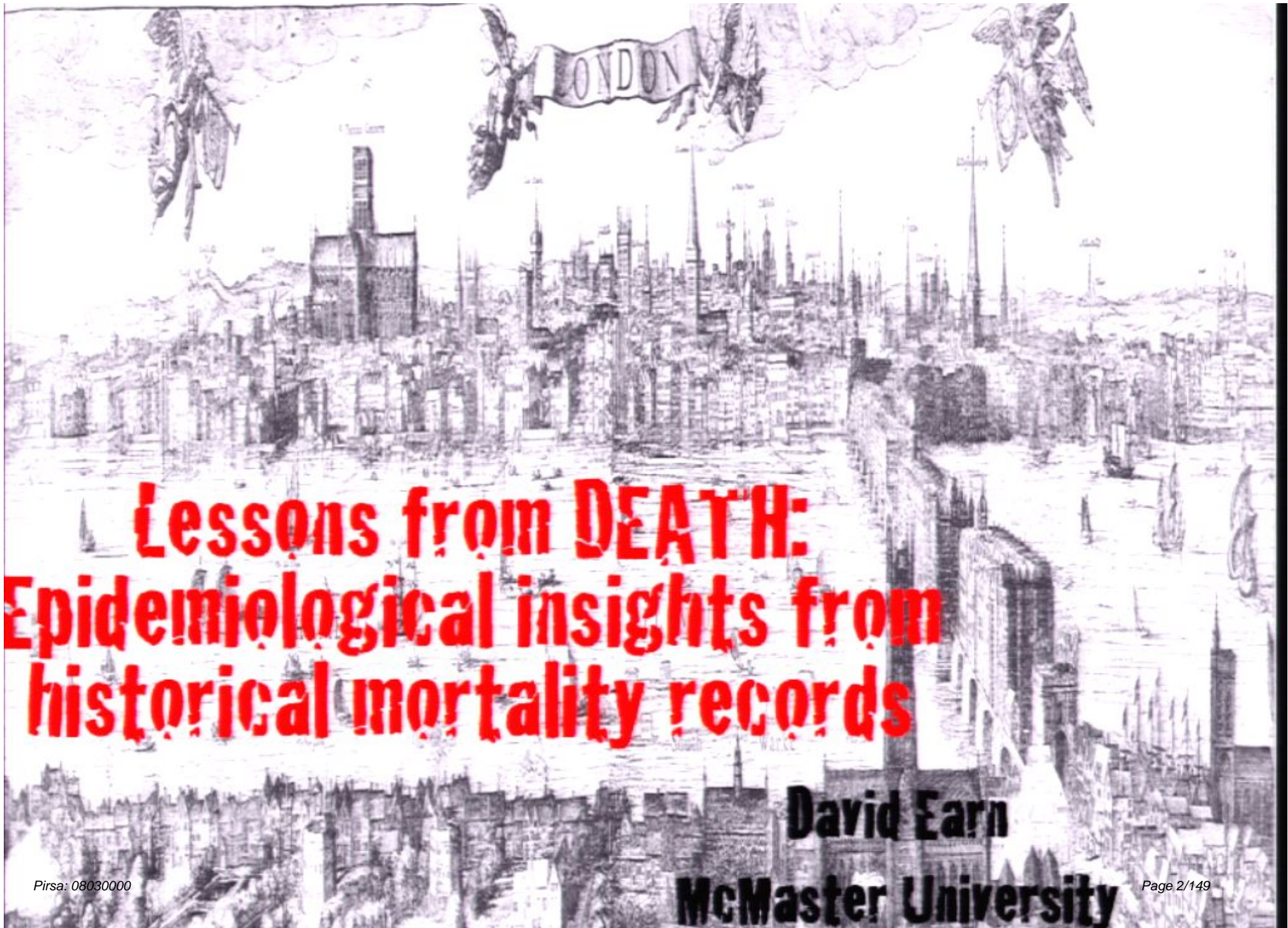


Title: The Great Plague of London

Date: Mar 26, 2008 02:00 PM

URL: <http://pirsa.org/08030000>

Abstract: The Great Plague of London, which claimed the lives of one fifth of London's population in 1665, is one of the most famous epidemics of all time. We have recently digitized the mortality records for London during the Great Plague, yielding weekly data for each of the 130 parishes. I will describe the temporal and spatial dynamics of the plague, and discuss our efforts to estimate the transmissibility of the infectious agent. I will also briefly describe other projects in progress inspired by disease-specific mortality records for London over the past 650 years.



**Lessons from DEATH:
Epidemiological insights from
historical mortality records**

David Earn

McMaster University

Why study Ecology and Evolution of Human Infectious Diseases?

Why study Ecology and Evolution of Human Infectious Diseases?

- Public health significance
 - Develop better control strategies
 - Gain insights for response strategies for new pathogens

Why study Ecology and Evolution of Human Infectious Diseases?

- Public health significance
 - Develop better control strategies
 - Gain insights for response strategies for new pathogens
- Ecological significance
 - Remarkably rich datasets provide windows into host-parasite ecology / dynamics / evolution
 - Infectious disease systems are much simpler than typical ecosystems
 - No complex "food webs": Infectious individuals don't seek out other species if everyone around them is immune

Mathematical and Computational Methods Can Help

- **Quantify pathogen transmissibility**
 - Final size of epidemic
 - Optimal control strategies
- **Describe/predict/demystify dynamics**
 - Seasonality
 - Frequency
 - Spatial structure
 - Evolution



The Great Plague of London

David Earn and Junling Ma

The Great Plague of London in 1665

- **What was the pathogen?**
 - Was it really bubonic plague? pneumonic plague?
- **Was it as transmissible as people thought?**
 - Could we control it if it arose today?
- **Is this disease relevant in 2007?**
 - Bubonic/pneumonic plague is considered a serious bioterrorist threat

The Great Plague of London in 1665

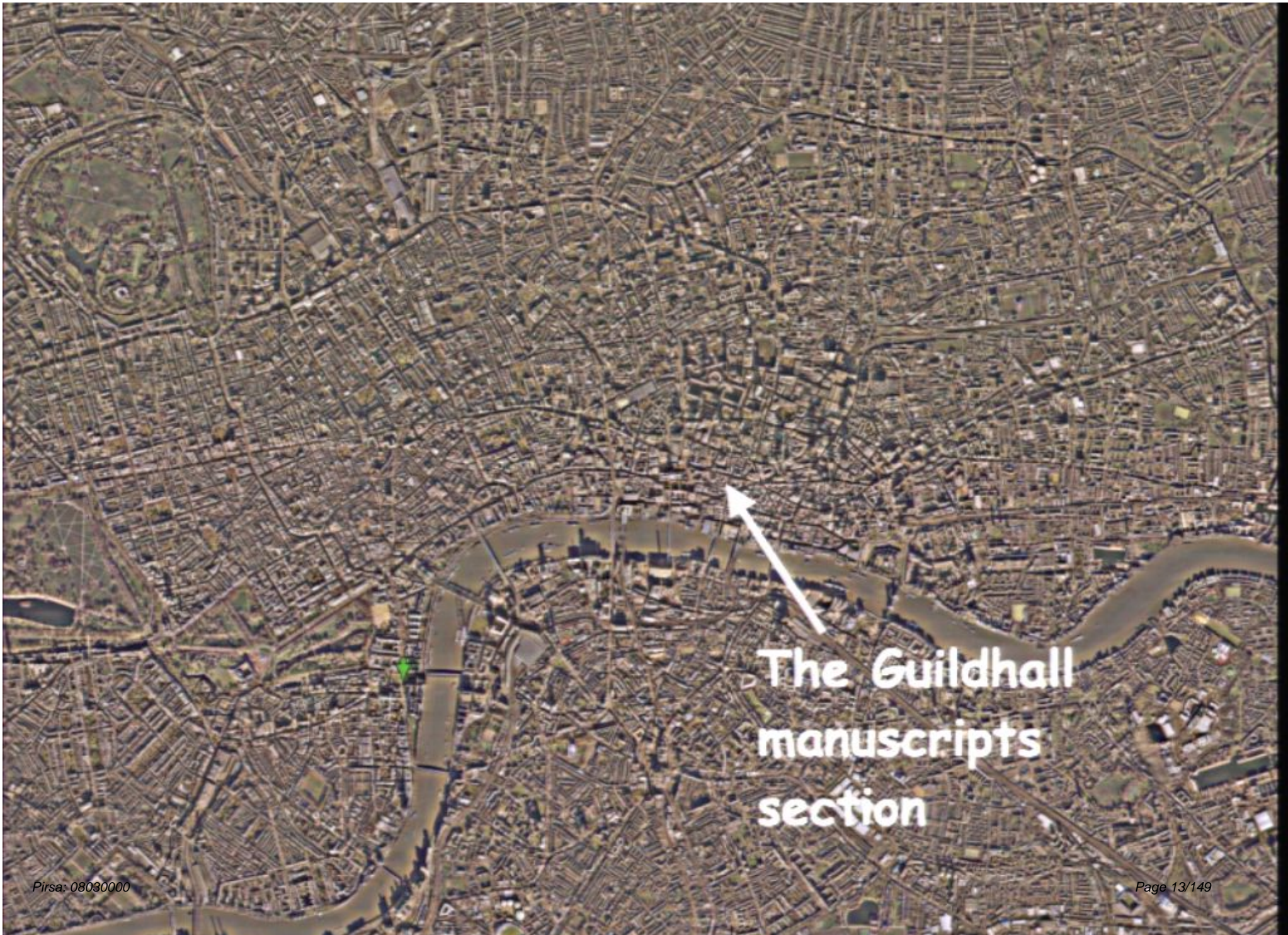
- Location
- Data sources
- Temporal pattern
- Spatial pattern
- Transmissibility

The Great Plague of London in 1665

- Location
- Data sources
- Temporal pattern
- Spatial pattern
- Transmissibility





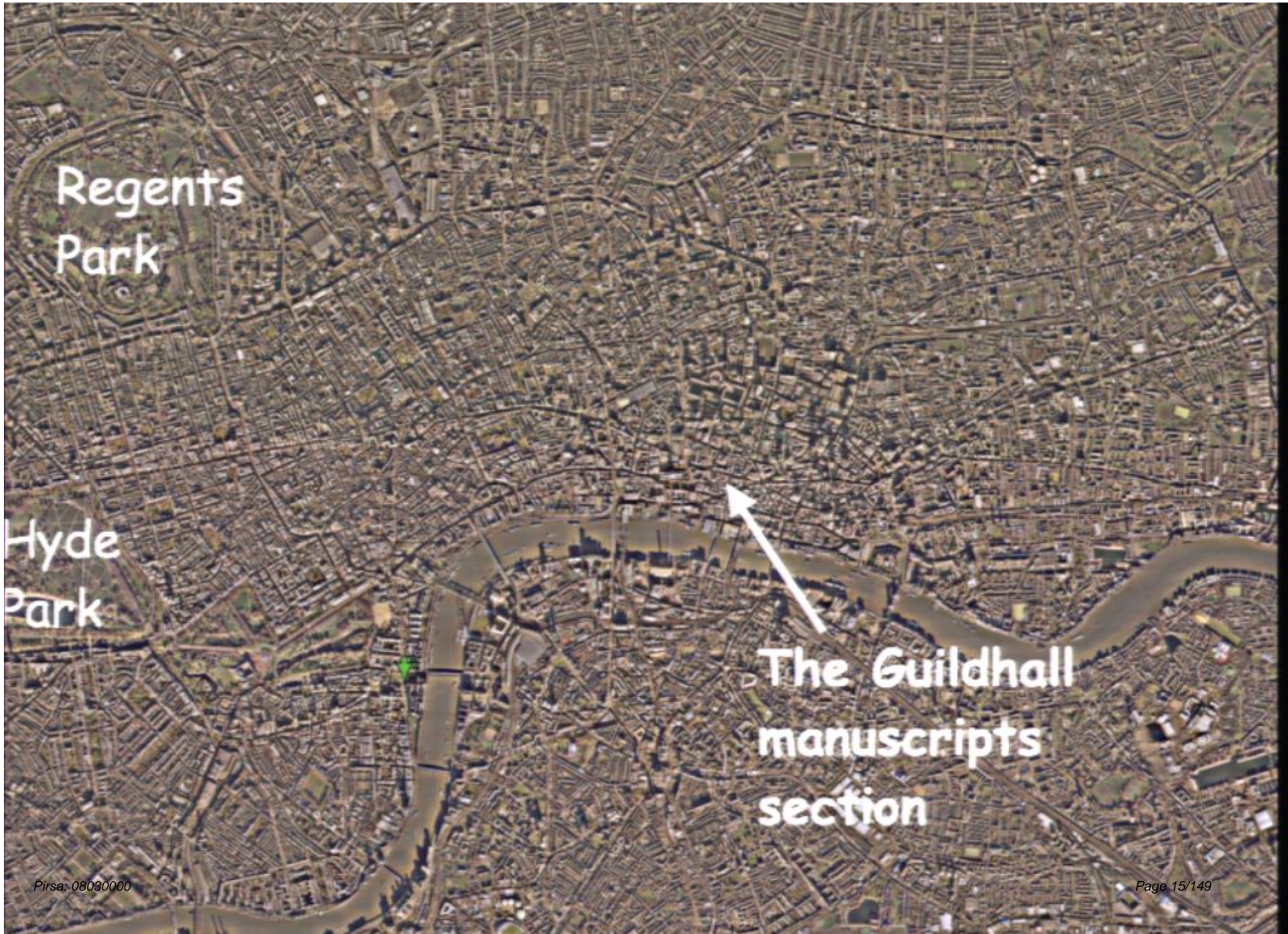


The Guildhall
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Regents
Park



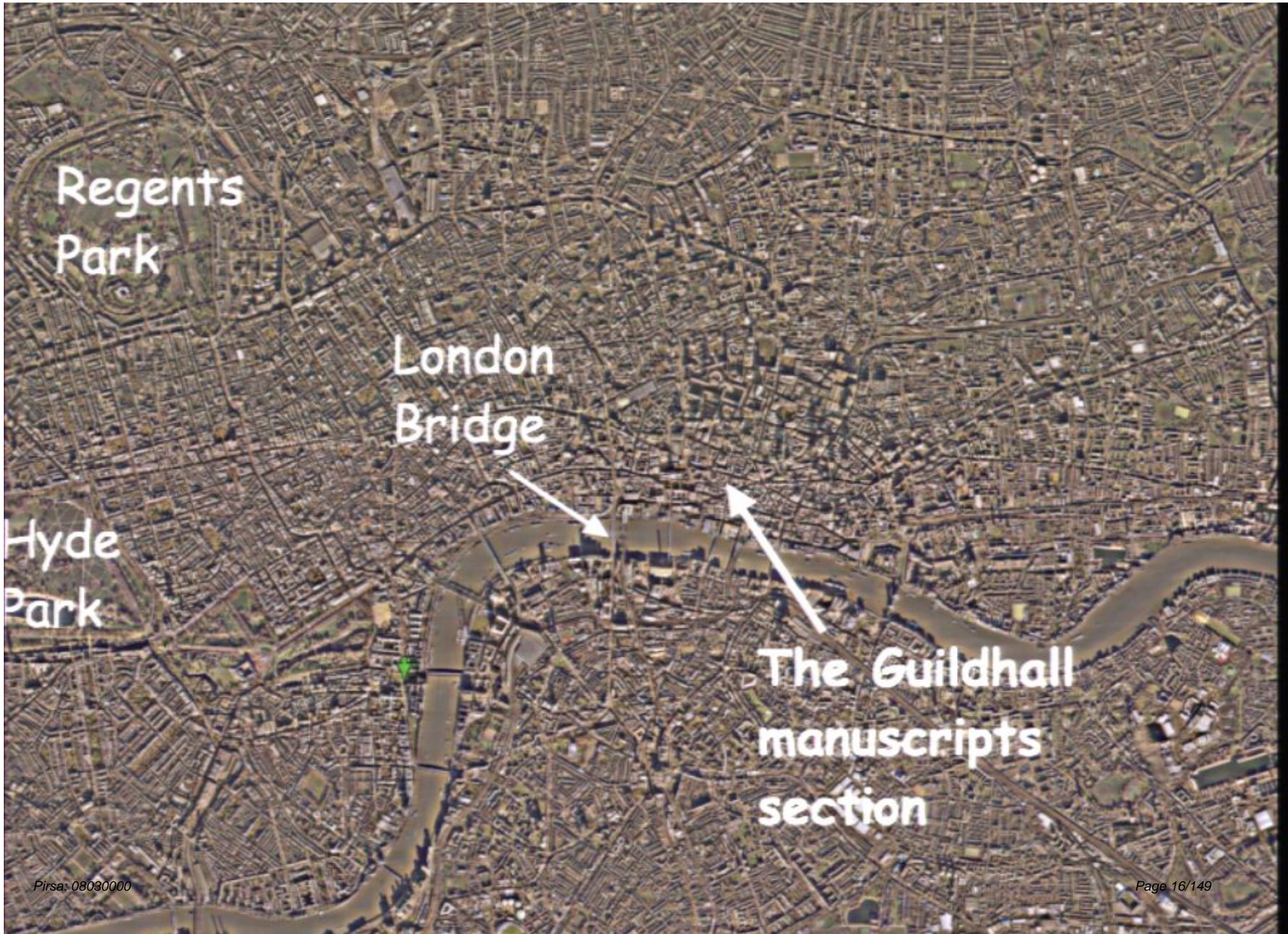
The Guildhall
manuscripts
section



Regent's
Park

Hyde
Park

The Guildhall
manuscripts
section

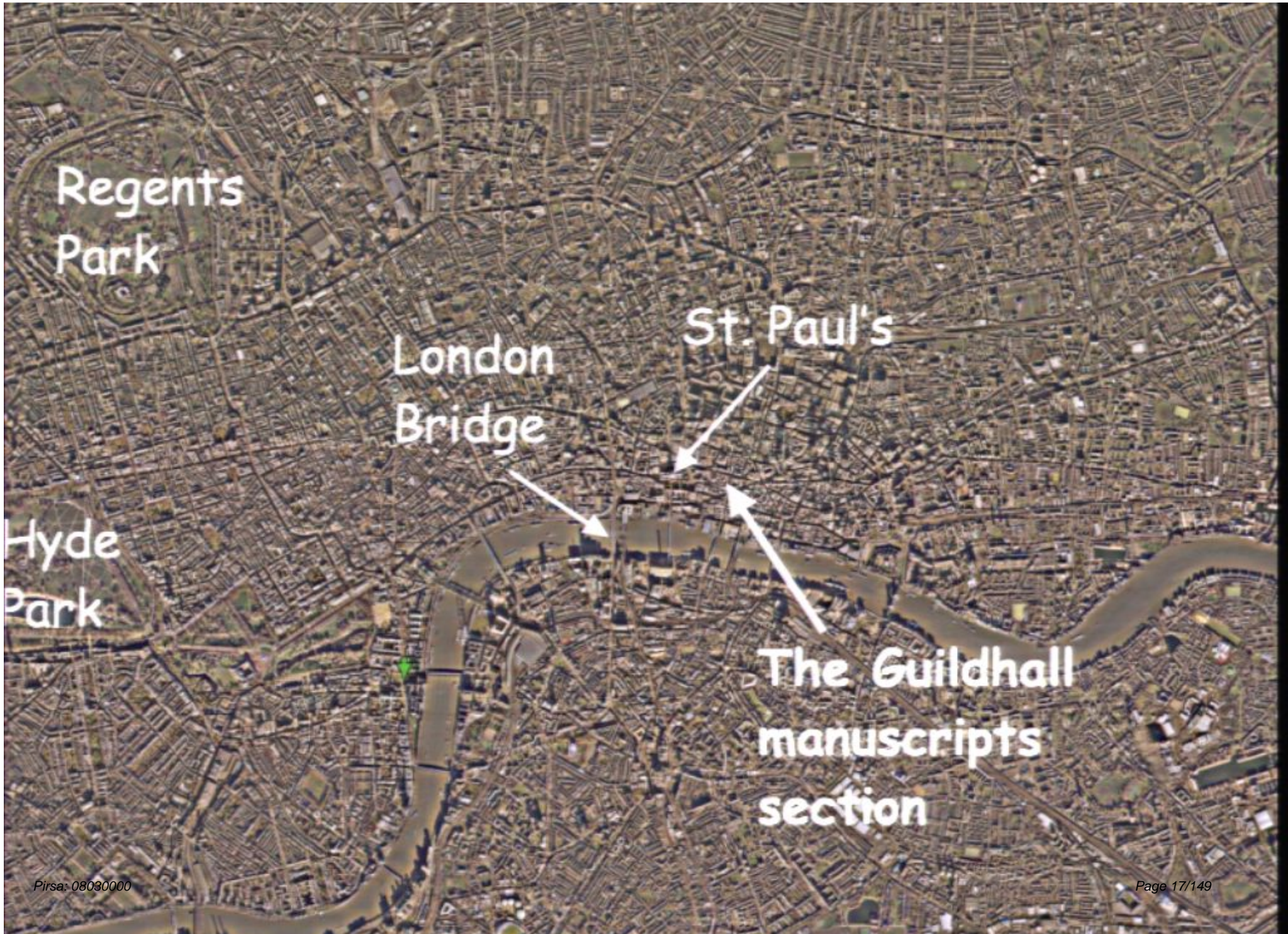


Regent's
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Bridge

Hyde
Park

The Guildhall
manuscripts
section



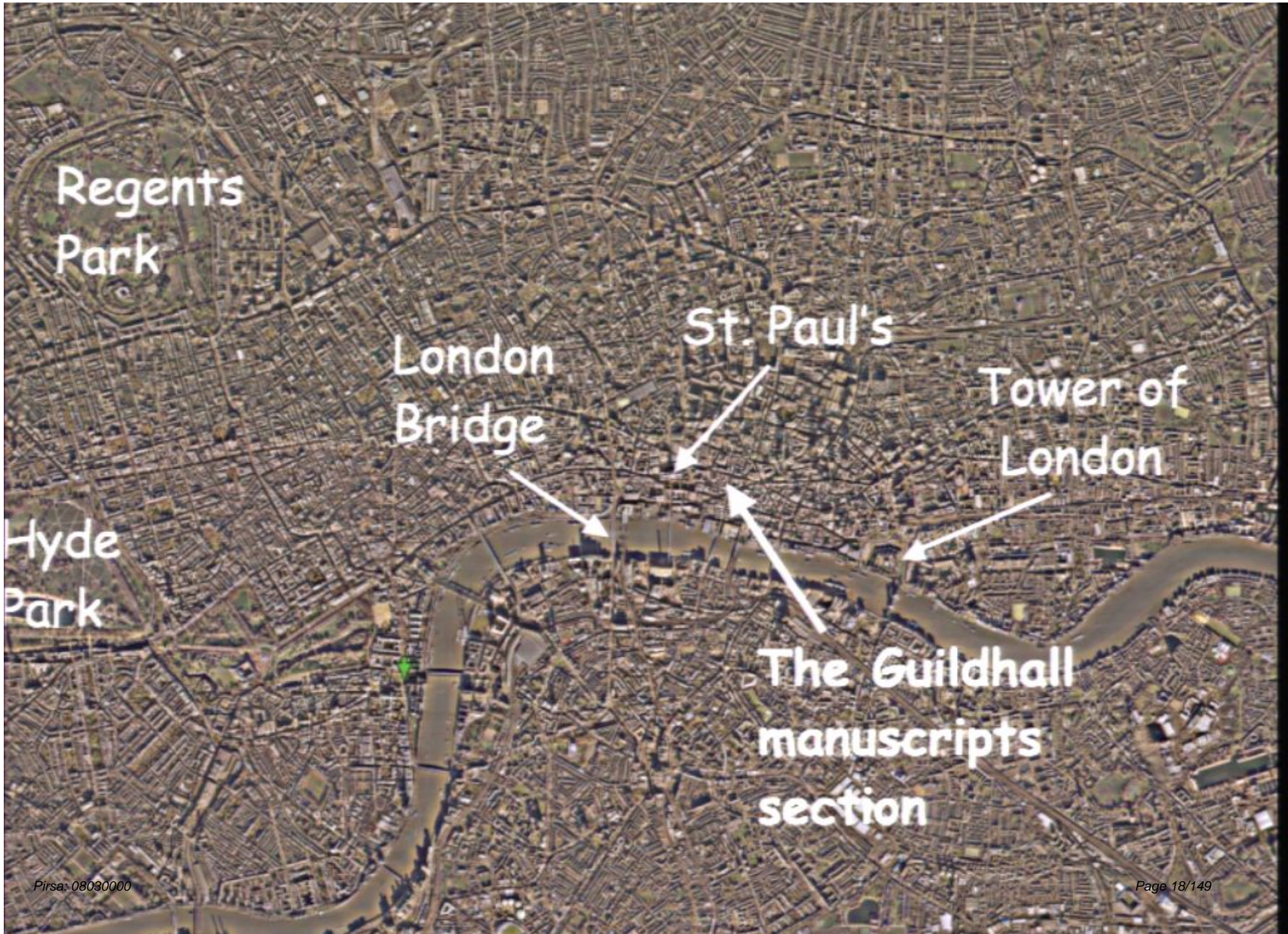
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St. Paul's

Hyde
Park

The Guildhall
manuscripts
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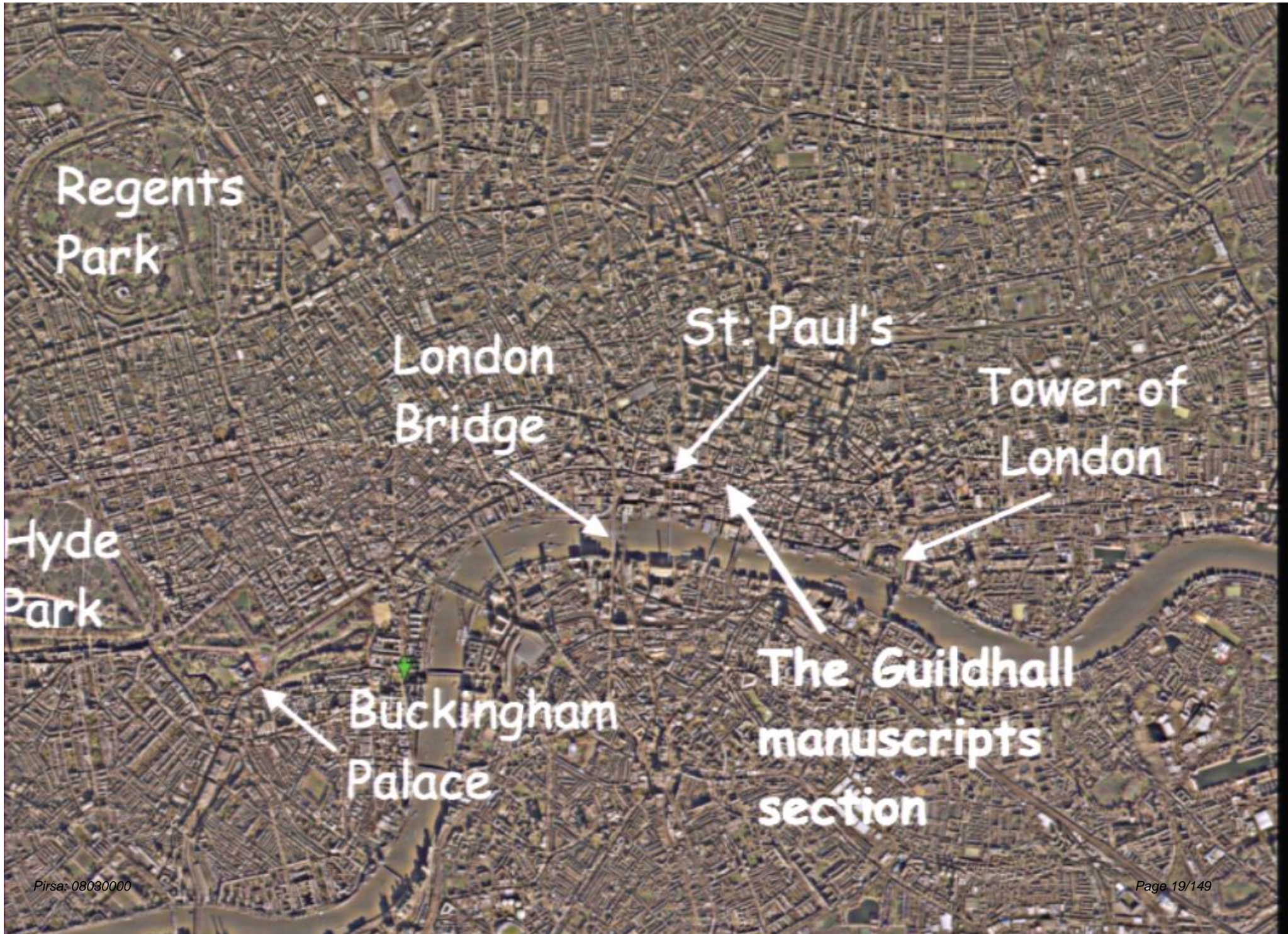
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St. Paul's

Tower of
London

Hyde
Park

The Guildhall
manuscripts
section



Regent's
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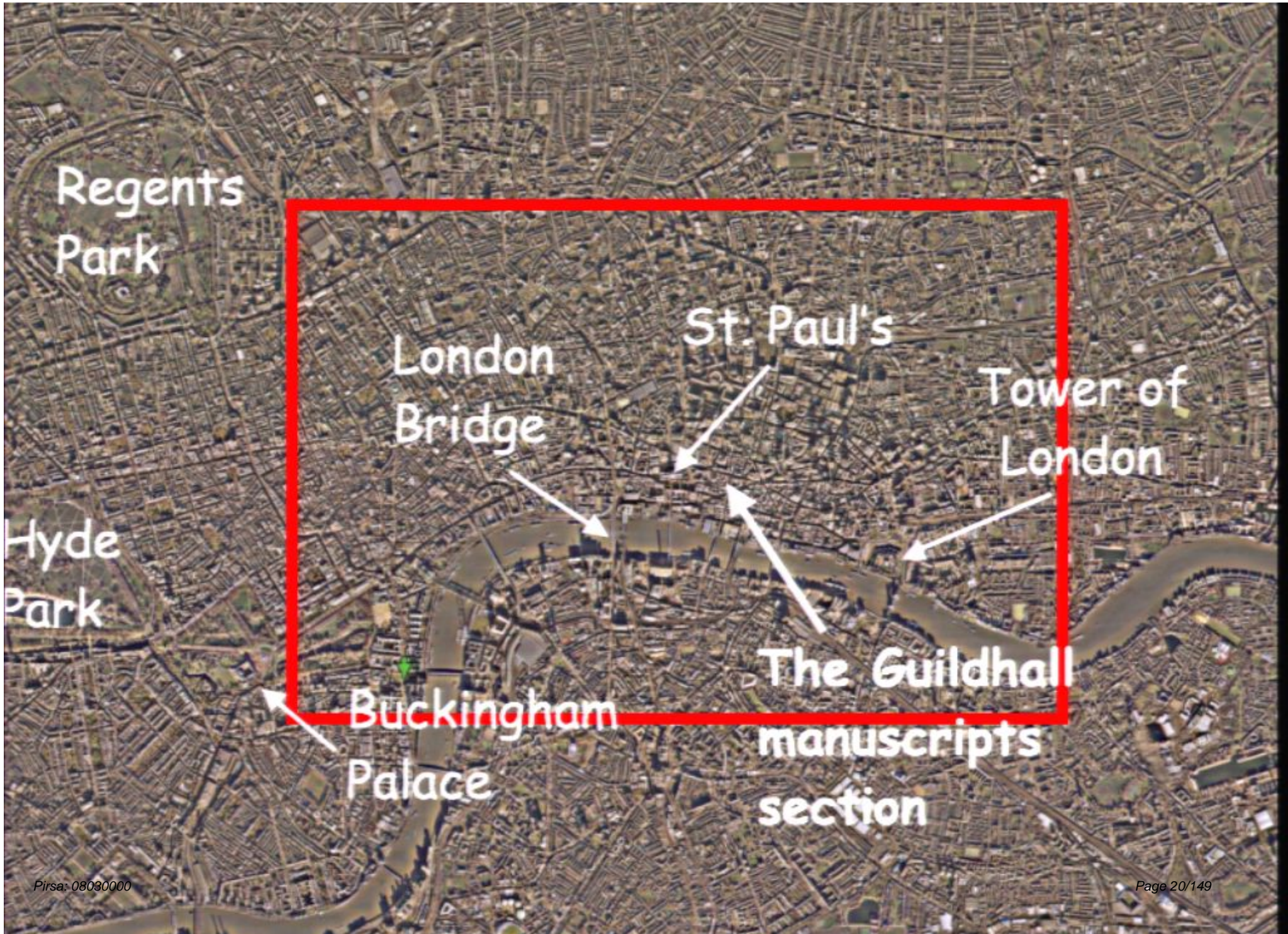
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St. Paul's

Tower of
London

Buckingham
Palace

The Guildhall
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Park

Hyde
Park

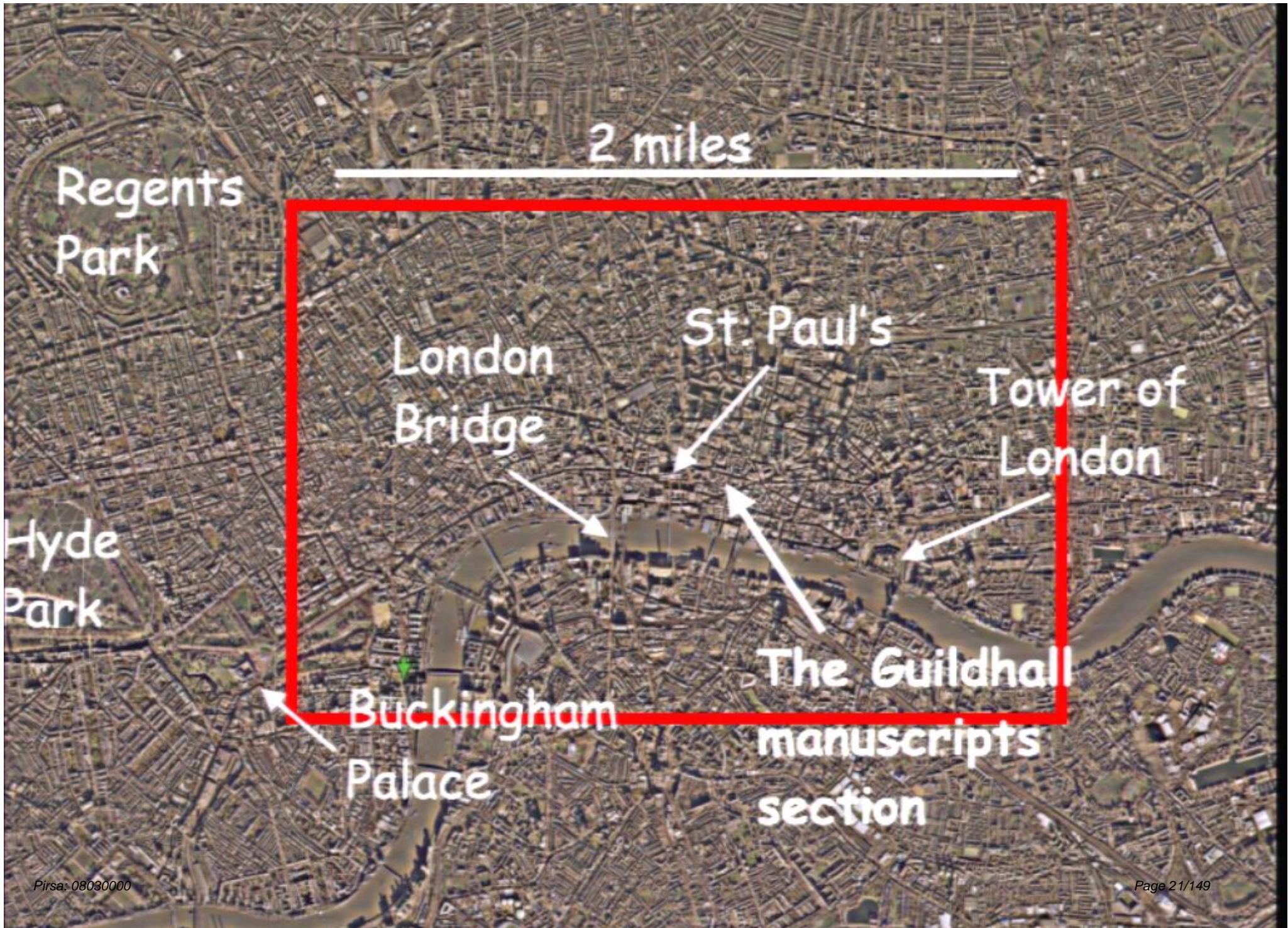
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St. Paul's

Tower of
London

Buckingham
Palace

The Guildhall
manuscripts
section



2 miles

Regent's
Park

London
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St. Paul's

Tower of
London

Hyde
Park

The Guildhall
manuscripts
section

Buckingham
Palace

London, as it appeared in 1665



London, as it appeared in 1665



St Paul's
Cathedral



London, as it appeared in 1665



St Paul's
Cathedral



London
Bridge



London, as it appeared in 1665



St Paul's
Cathedral

1890

London
Bridge



London, as it appeared in 1665



St Paul's
Cathedral



2007



London
Bridge



London, as it appeared in 1665



St Paul's
Cathedral



1665

London
Bridge



The Great Plague of London in 1665

- Location
- **Data sources**
- Temporal pattern
- Spatial pattern
- Transmissibility

The Diseases and Casualties this Week.



Frighted	1
Goat	1
Grief	1
Gripping in the Guts	3
Jaundies	35
Impoſthume	8
Infanes	9
Kingſevil	2
Micagrome	2
Plague	5533
Purples	2
Rickets	10
Riſing of the Lights	13
Rupture	1
Scurvy	5
Spotted Fever	65
Stilborn	10
Stone	3
Stopping of the ſtomach	6
Suddenly	1
Surfeit	36
Teeth	112
Thruſh	3
Tiſſick	5
Vomiting	4
Winde	1
Wormes	12
Bortive	6
Aged	50
Ague	1
Apoplexie	2
Childbed	42
Chriſtomes	11
Cold	1
Conſumption	99
Coarſion	63
Cough	1
Droptic	22
Drownd at St. Martin in the Fields	1
eaver	268
iftula	2
ox and Small-pox	4
ix	1
und dead in the Fields at St. Mary Iſlington	1

Chriſtined	Males	68	Buried	Males	3212	Plague	5533
	Females	78		Females	3248		
	In all	146		In all	6460		
Decreased in the Burials this Week				1837			
Parishes clear of the Plague				7 Parishes Infected 123			

ſſize of Bread ſet forth by Order of the Lord Mayor and Courts of Aldermen, A penny Wheaten Loaf to contain Nine Ounces and a half, and three half-penny White Loaves the like weight.

London 41 From the 26 of September to the 3 of October. 1665

Parish	Plag	Parish	Plag	Parish	Plag
S ^t Alban Woodſtrec	16	12	S ^t George Bloſſhane	1	1
Albhallows Barkin	40	34	S ^t Gergory by S ^t Pauls	25	25
Albhallows Breadſtrec	1	1	S ^t Healen	6	5
Albhallows Greca	42	41	S ^t James Dukes place	27	23
Albhallows Honeyman	5	5	S ^t James Garſickſtrec	10	12
Albhallows Leſſe	17	17	S ^t John Baptiſt	11	10
Albhallows Lumbardſtrec	5	5	S ^t John Exogelick	12	9
Albhallows Staining	24	18	S ^t John Zachary	12	9
Albhallows the Wall	33	28	S ^t Katharine Coleman	20	16
S ^t Wipinge	13	5	S ^t Kicharine Creechurch	34	29
S ^t Andrew Hubbard	4	4	S ^t Lawrence Jewry	6	5
S ^t Andrew Underſhaft	16	14	S ^t Lawrence Pountney	14	10
S ^t Andrew Wardrobe	30	24	S ^t Leonard Eaſtcheap	3	3
S ^t Ann Alderſgate	18	17	S ^t Leonard Fotherſtrec	16	13
S ^t Ann Blackeryes	57	50	S ^t Margus Parſh	5	4
S ^t Antholin Parſh	7	4	S ^t Margaret Ludbury	7	6
S ^t Audlin Parſh	4	3	S ^t Margaret Moles	13	13
S ^t Bartholomew Exchange	7	7	S ^t Margare Newſtrec	13	13
S ^t Bennet Fynck	4	2	S ^t Margare Piccone	4	3
S ^t Bennet Gracechurch	4	2	S ^t Mary Abchurch	7	5
S ^t Bennet Paulwharf	15	7	S ^t Mary Aldermanbury	14	14
S ^t Bennet Sherebrig	2	1	S ^t Mary Aldermay	4	4
S ^t Bonibillington	8	8	S ^t Mary le Bow	1	1
Chriſts Church	44	39	S ^t Mary Boleſay	6	4
S ^t Chriſtophers	4	4	S ^t Mary Colechurch	3	3
S ^t Clement Eaſtcheap	1	1	S ^t Mary Hill	11	8
S ^t Dionis Backchurch	9	2	S ^t Mary Mounthaw	4	3
S ^t Dunſon Eaſt	18	24	S ^t Mary Somerſet	44	38
S ^t Edmund Lumbardſtrec	3	1	S ^t Mary Spayning	3	2
S ^t Ethelborough	7	4	S ^t Mary Woolchurch	7	4
S ^t Faith	8	6	S ^t Mary Woolnoth	7	5
S ^t Filtre	8	6	S ^t Martin lemongerſtrec	2	2
S ^t Gabriel Fenchurch	3	3			
S ^t George Bloſſhane	1	1	S ^t Martin Ludgates	12	10
S ^t Gergory by S ^t Pauls	25	25	S ^t Martin Organs	8	5
S ^t Healen	6	5	S ^t Martin Oerwich	6	5
S ^t James Dukes place	27	23	S ^t Martin Vintory	44	44
S ^t James Garſickſtrec	10	12	S ^t Mathew Friſterſtrec	4	4
S ^t John Baptiſt	11	10	S ^t Mathew Milburn	4	4
S ^t John Exogelick	12	9	S ^t Mathew Oldſtrec	5	6
S ^t John Zachary	12	9	S ^t Michael Budgeſtrec	10	7
S ^t Katharine Coleman	20	16	S ^t Michael Cornhill	4	3
S ^t Kicharine Creechurch	34	29	S ^t Michael Cornewall	15	12
S ^t Lawrence Jewry	6	5	S ^t Michael Queneſtrec	25	23
S ^t Lawrence Pountney	14	10	S ^t Michael Queen	4	3
S ^t Leonard Eaſtcheap	3	3	S ^t Michael Royal	20	17
S ^t Leonard Fotherſtrec	16	13	S ^t Michael Woodſtrec	6	3
S ^t Margus Parſh	5	4	S ^t Mildred Breadſtrec	4	4
S ^t Margaret Ludbury	7	6	S ^t Mildred Parſh	4	2
S ^t Margaret Moles	13	13	S ^t Nicholas Acon	4	3
S ^t Margare Newſtrec	13	13	S ^t Nicholas Coleſtrec	8	8
S ^t Margare Piccone	4	3	S ^t Nicholas Olaves	8	8
S ^t Mary Abchurch	7	5	S ^t Olive Harthorn	13	12
S ^t Mary Aldermanbury	14	14	S ^t Olive Jewry	5	4
S ^t Mary Aldermay	4	4	S ^t Olive Silverſtrec	4	4
S ^t Mary le Bow	1	1	S ^t Pancras Superſtrec	1	1
S ^t Mary Boleſay	6	4	S ^t Peter Cheap	1	1
S ^t Mary Colechurch	3	3	S ^t Peter Cornhill	8	6
S ^t Mary Hill	11	8	S ^t Peter Paulwharf	10	10
S ^t Mary Mounthaw	4	3	S ^t Peter Poor	8	7
S ^t Mary Somerſet	44	38	S ^t Severn Colemanſtrec	43	38
S ^t Mary Spayning	3	2	S ^t Steven Wallſtrec	1	2
S ^t Mary Woolchurch	7	4	S ^t Swithin	6	5
S ^t Mary Woolnoth	7	5	S ^t Thomas Apyll	8	4
S ^t Martin lemongerſtrec	2	2	Trinity Parſh	10	9

Chriſtined in the 97 Parishes within the Walls	39	Baried	1149	Plague	948
S ^t Andrew Holborn	173	151	S ^t Bonolph Aldgate	374	338
S ^t Bartholomew Greca	17	15	S ^t Bonolph Biſhopſgate	253	221
S ^t Bartholomew Leſſe	7	7	S ^t Dunſon Weſt	63	59
S ^t Bridge	92	67	S ^t George Southwark	140	113
Midwel Precinct	23	23	S ^t Giles Cripplegate	196	151
S ^t Bonolph Alderſgate	71	64	S ^t Olive Southwark	378	281

Chriſtined in the 16 Parishes without the Walls	45	Baried	and at the Publiſhe	2258	Plague	1922		
S ^t Giles in the fields	95	78	Lambeth Parſh	49	39	S ^t Mary Abchurch	15	12
Stokeney Parſh	12	12	S ^t Leonard Shoreditch	95	91	S ^t Mary Whitmonſep	328	302
S ^t James Clerkenwe	48	42	S ^t Magdalen Benmonſley	128	106	Richmond Parſh	21	18
S ^t Kath near the Tower	55	49	S ^t Mary Newington	81	81	S ^t Swayney Parſh	674	631

Chriſtined in the 5 Parishes in the City and Liberties of Weſtminſter	18	Baried	600	Plague	590			
S ^t Clement Danes	12	10	S ^t Martin in the fields	209	143	S ^t Marguer Wetminſter	309	297
S ^t Paul Covent Garden	25	24	S ^t Mary Savoy	19	16	Baried at the Publiſhe	4	

The Diseases and Casualties this Week.



Frighted	1
Goose	1
Grief	1
Gripping in the Guts	3
Jaundies	35
Imposthume	8
Infanes	2
Kingfevil	2
Meagrome	2
<u>Plague</u>	<u>5533</u>
Purples	2
Rickets	10
Rising of the Lights	13
Rupture	1
Scurvy	5
Spotted Fever	65
Stilborn	10
Stone	3
Stopping of the stomach	6
Suddenly	1
Surfeit	36
Teeth	112
Thrush	3
Tiffick	5
Vomiting	4
Winde	1
Wormes	12

Christened	Males	68	Buried	Males	3212	Plague	5533
	Females	8		Females	3248		
	In all	146		In all	6460		
Decreased in the Burials this Week				1837			
Parishes clear of the Plague		7		Parishes Infected	123		

Price of Bread set forth by Order of the Lord Mayor and Courts of Aldermen, A penny Wheaten Loaf to contain Nine Ounces and a half, and three half-penny White Loaves the like weight.

London 41 From the 26 of September to the 3 of October. 1665

Parish	Christened	Buried	Parish	Christened	Buried
S ^t Alban Woodstreet	16	12	S ^t George Blopphane	1	1
Albion Barings	10	34	S ^t Gregory by S ^t Pauls	15	25
Albion Breadstreet	1	1	S ^t Helen	6	5
Albion Geca	42	41	S ^t James Dukes place	17	23
Albion Honeyman			S ^t James Garlickhithe	10	12
Albion Lefe	17	17	S ^t John Baptish	11	10
Albion Lumbardree	5	5	S ^t John Eskinghithe		
Albion Seining	22	18	S ^t John Zachary	12	9
Albion the Wall	33	28	S ^t Katharine Coleman	20	16
S ^t Wipinge	13	5	S ^t Katharine Creechurch	34	29
S ^t Andrew Hubbard	4		S ^t Lawrence Jewry	6	5
S ^t Andrew Undershaft	16	14	S ^t Lawrence Pountney	14	10
S ^t Andrew Wardrobe	30	24	S ^t Leonard Eastcheap	3	3
S ^t Ann Alderigate	18	27	S ^t Leonard Fothering	16	13
S ^t Ann Blackeryes	57	50	S ^t Margus Parish	5	4
S ^t Anthonis Parish	7	4	S ^t Margaret Ludbury	7	6
S ^t Austins Parish	4	3	S ^t Margret Mole		
S ^t Bartholomew Exchange	7	7	S ^t Margret Newfishstreet	18	13
S ^t Bennet Fynck	4	2	S ^t Margret Piccone	4	3
S ^t Bennet Gracechurch	4	2	S ^t Mary Abchurch	7	5
S ^t Bennet Paulwharf	15	7	S ^t Mary Aldermanbury	14	14
S ^t Bennet Sherehithe	2		S ^t Mary Aldermay	4	4
S ^t Boniah Billingsgate	8	8	S ^t Mary le Bow	1	1
Christ Church	44	39	S ^t Mary Bishaw	6	4
S ^t Christophers	4	4	S ^t Mary Colechurch	3	1
S ^t Clement Eastcheap	1	1	S ^t Mary Hill	11	8
S ^t Dionis Backchurch	9	2	S ^t Mary Mounthaw	4	3
S ^t Dunstan East	18	24	S ^t Mary Sommerset	44	38
S ^t Edmund Lambardree	3	1	S ^t Mary Spayning	3	1
S ^t Ethelborough	7	4	S ^t Mary Woolchurch	7	4
S ^t Faith	8	6	S ^t Mary Woolnoth	7	5
S ^t Filz	8	6	S ^t Martin lemongerlane	2	2
S ^t Gabriel Fenchurch	3	3			

Christened in the 97 Parishes within the Walls		39	Buried		1149	Plague		948
S ^t Andrew Holborn	173	151	S ^t Boniph Aldigate	374	338	Savoyers Southwark	364	352
S ^t Bartholomew Geca	17	15	S ^t Boniph Bishopsgate	853	121	S. Sepulchres Parish	137	95
S ^t Bartholomew Lefe	7	7	S ^t Dunstan West	63	59	S ^t Thomas Southwark	20	36
S ^t Bridge	92	67	S ^t George Southwark	140	113	Trinity Minories	24	21
Midwell Precinct	23	23	S ^t Giles Cripplegate	196	151	At the Pettiboule	8	8
S ^t Boniph Alderigate	71	64	S ^t Olive Southwark	378	281			

Christened in the 16 Parishes without the Walls		45	Buried		1623	Plague		1922
S ^t Giles in the fields	95	78	Lambeth Parish	49	39	S ^t Mary Abchurch	15	31
Stokeney Parish	12	12	S ^t Leonard Shoreditch	95	91	S ^t Mary Wharfedale	328	301
S ^t James Clerkenwell	48	42	S ^t Magdalen Beconsfield	128	106	Botham Parish	21	18
S ^t Kath near the Towers	55	39	S ^t Mary Newington	81	81	Savoy Parish	674	631

Christened in the 5 Parishes in the City and Liberties of Westminster		18	Buried		600	Plague		590
S ^t Clement Danes	11	10	S ^t Martin in the fields	109	141	S ^t Margret Westminster	309	297
S ^t Paul Covent Garden	25	24	S ^t Mary Savoy	19	16	Warren at the Pettiboule	4	

Mortality Bills are typically handwritten...

LONDON 29 th From the 4 th of July to the 11 th of the same 1665											
		Buried.	Plag.			Buried.	Plag.			Buried.	Plag.
St Alban Woodstreet	2	1	St Clement Eastcheap	1		St Margaret Newfishst			St Michael Crookedla.	4	3
Alhallows Bark-	2		St Dionis Backchurch	1		St Margaret Pattons			St Michael Queenhith	3	
Alhallows Breadstreet	1		St Dunstons East	2		St Mary Abchurch	1		St Michael Quern	1	
Alhallows Great	1		St Edmund Lumbardst.			St Mary Aldermanbury			St Michael Royal		
Alhallows Honilant	1		St Ethelborough	2		St Mary Aldemary			St Michael Woodstreet		
Alhallows Lef	1		St Faiths	1		St Mary le Bow			St Mildred Breadstreet		
Alhallows Lumbardst.	1		St Gabriel Fenchurch			St Mary Bothaw			St Mildred Poultre		
Alhallows Staining	1		St George Botolphlane			St Mary Colechurch			St Nicholas Acons		
Alhallows the Wall	4	3	St Gregories by St. Paul			St Mary Hill			St Nicholas Coleabby-		
St Alphage	1		St Hellen	2	1	St Mary Mag. Milkstr.			St Nicholas Olaves		
St Andrew Hubbard			St James Dukes place	1		St Mary Mag. Oldfishst			St Olave Hartstreet		
St Andrew Undershaft	3		St James Garlickhithe	1		St Mary Mounthaw			St Olave Jewry		
St Andrew Wardrobe	1		St John Baptist			St Mary Summersec	2	1	St Olave Silverstreet	4	1
St Anne Aldersgate	1		St John Evangelist			St Mary Stainings			St Pancras Soperlane		
St Anne Blackfryers	7	6	St John Zachary			St Mary Woolchurch			St Peter Cheap		
St Antholins Parith.	1		St Katharine Coleman	1		St Mary Woolnoth			St Peter Cornhil		
St Austins Parish			St Katharine Creechur.			St Martins Iremongerl.			St Peter Paulswharf		
St Barthol. Exchange	1		St Lawrence Jewry			St Martins Ludgate	2	1	St Peter Poor	1	
St Bennet Fynck			St Lawrence Pountney			St Martins Orgars			St Steven Colemanstr.	2	1
St Bennet Gracechurch	2		St Leonard Eastcheap			St Martins Outwich	1		St Steven Walbrook		
St Bennet Paulswharf	7		St Leonard Fosterlane			St Martins Vintrey	1		St Swithin	2	1
St Bennet Sherehog			St Magnus Parish	1		St Matthew Frydaystr.			St Thomas Apostle	1	1
St Botolph Billingsgate			St Margaret Lothbury			St Michael Bassishaw	5	4	Trinity Parish	1	
St Christ Church	5	3	St Margaret Moser			St Michael Cornhil			St Vedast alias Fosters		
St Christophers											
Christned in 27 the Parishes within the Walls				Buried				Plague			
				86				28			
St Andrew Holborn	06	40	St Botolph Aldergate	11	9	St George Southwark	13	4	St Sepulchres Parish	117	51
St Bartholomew Great	7	7	St Botolph Aldgate	24	7	St Giles Cripplegate	105	47	St Thomas Southwark	7	5
St Bartholomew Lef			St Botolph Bishopgate	37	20	St Olave Southwark	20	8	Trinity Minories		
St Bridget	24	17	St Dunstan West	19	9	St Saviour Southwark	21	1	At the Pesthouse	9	6
St Jewel Precinct											

But handwriting is typically clear...

The image shows two sections of a handwritten table. The top section is titled 'LONNDN 29' and lists four parishes with columns for 'Buried.' and 'Plag.'. The bottom section is titled 'Christned in 97 the Parishes' and lists five parishes with columns for 'Buried.' and 'Plag.'. The handwriting is clear and legible.

LONNDN 29		
	Buried.	Plag.
St Alban Woodstreet	2	1
Alhallows Bark.	2	
Alhallows Breadstreet		
Alhallows Great	1	

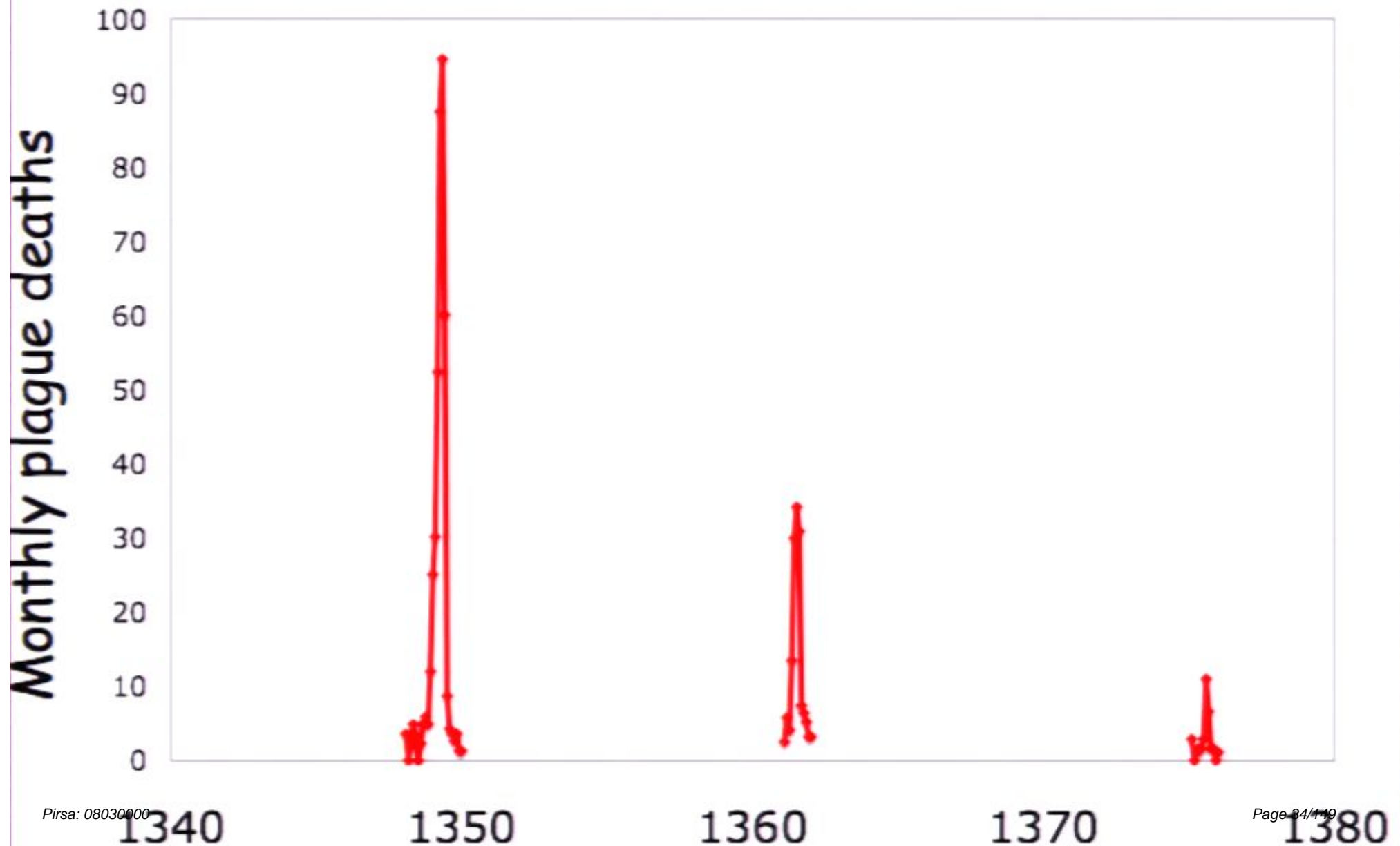
Christned in 97 the Parishes		
	Buried.	Plag.
St Andrew Holborn	66	40
St Bartholomew Great	7	4
St Bartholomew Less		
St Bridget	24	17
Bridewel Precinct	1	1

Christned in the 16 Parishes

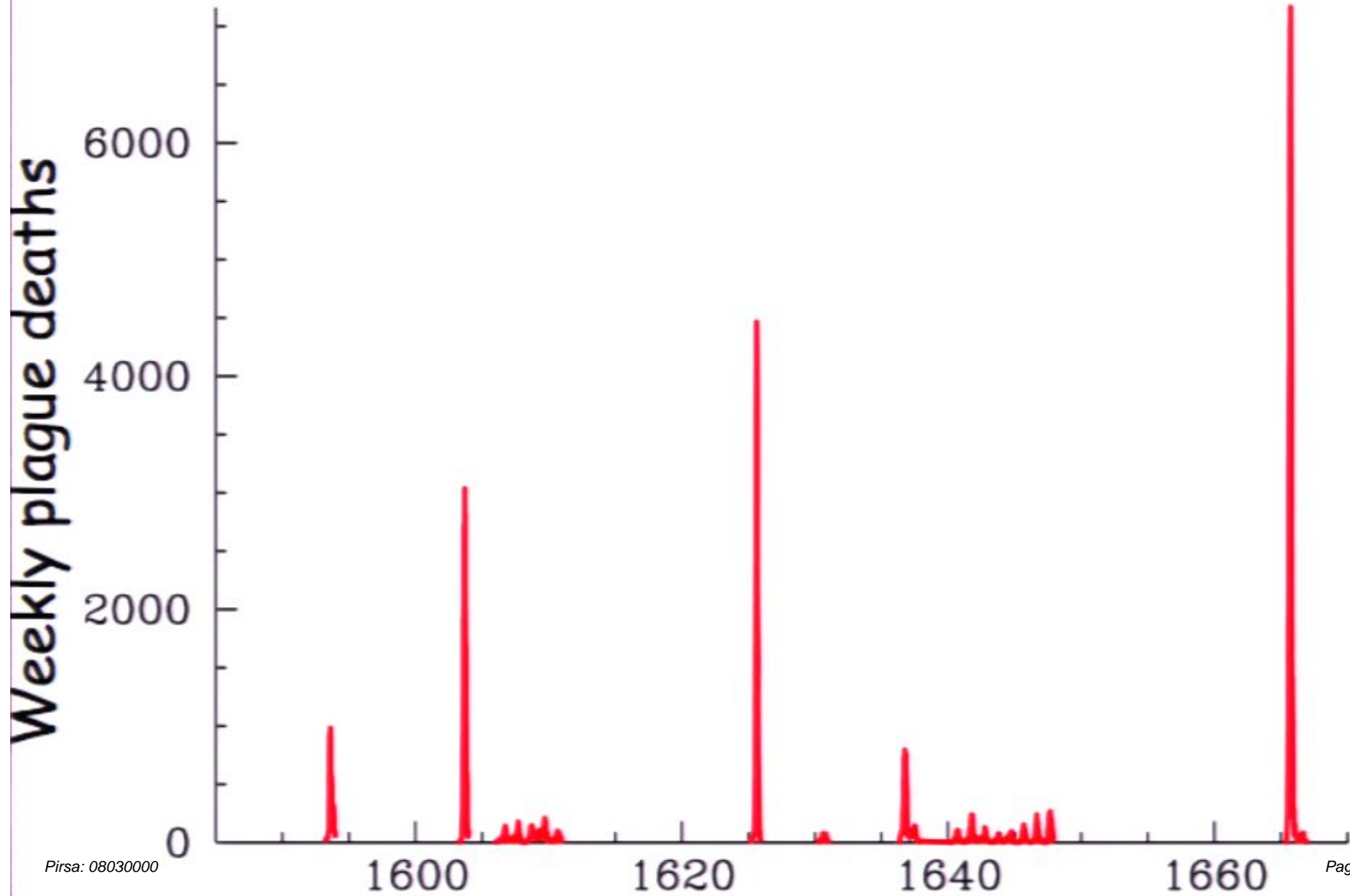
The Great Plague of London in 1665

- Location
- Data sources
- **Temporal pattern**
- Spatial pattern
- Transmissibility

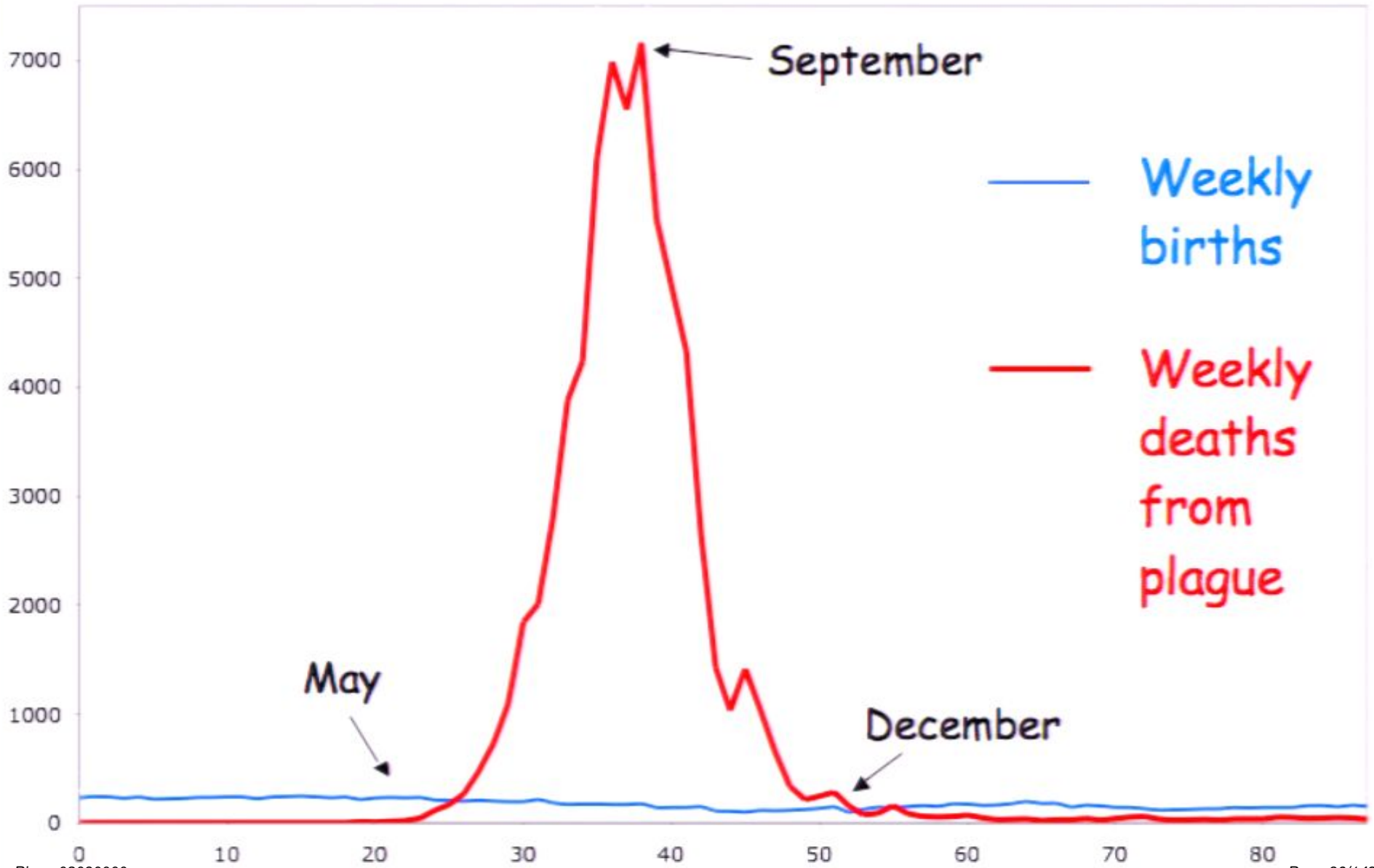
Plague in London, England, 1348-1376



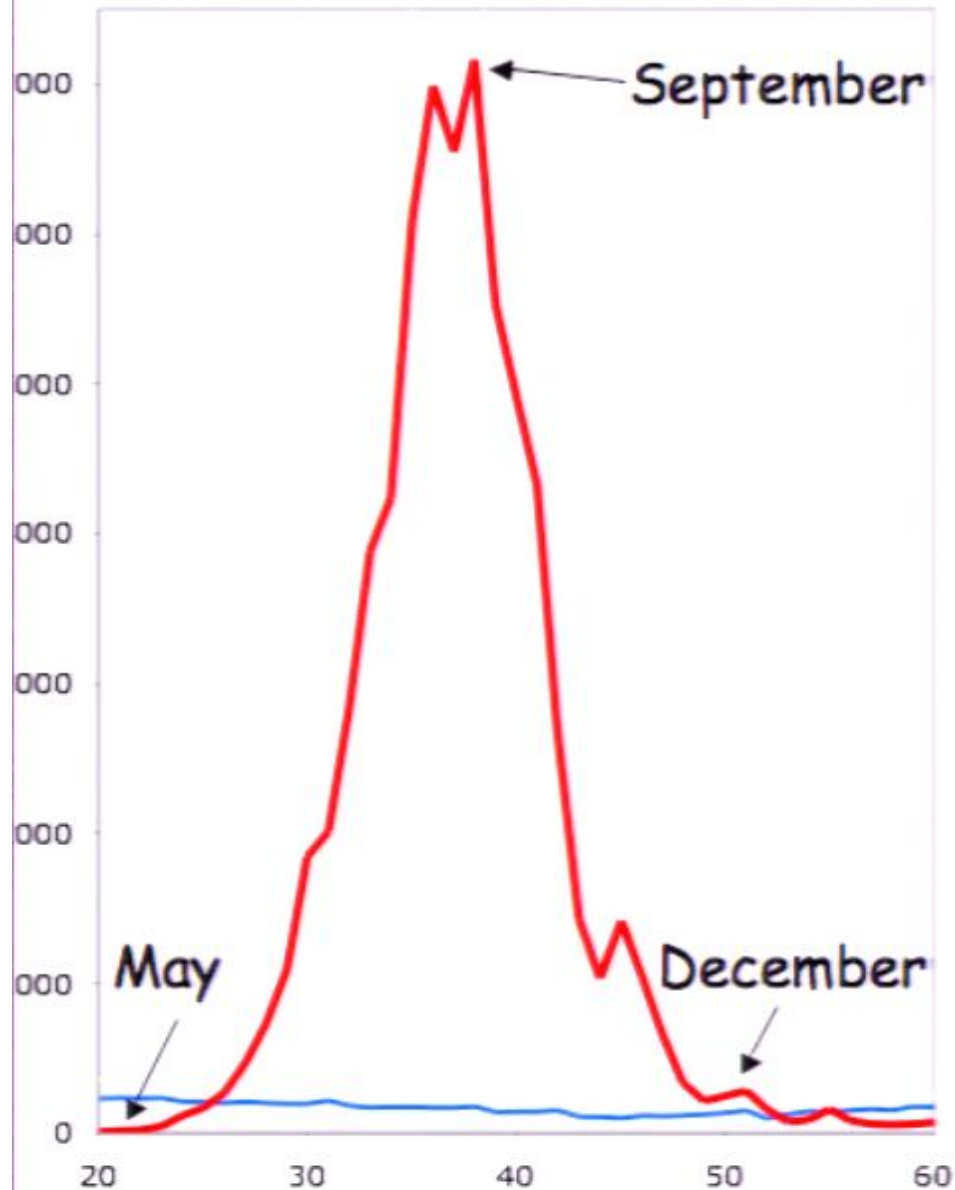
Plague in London, England, 1592-1666



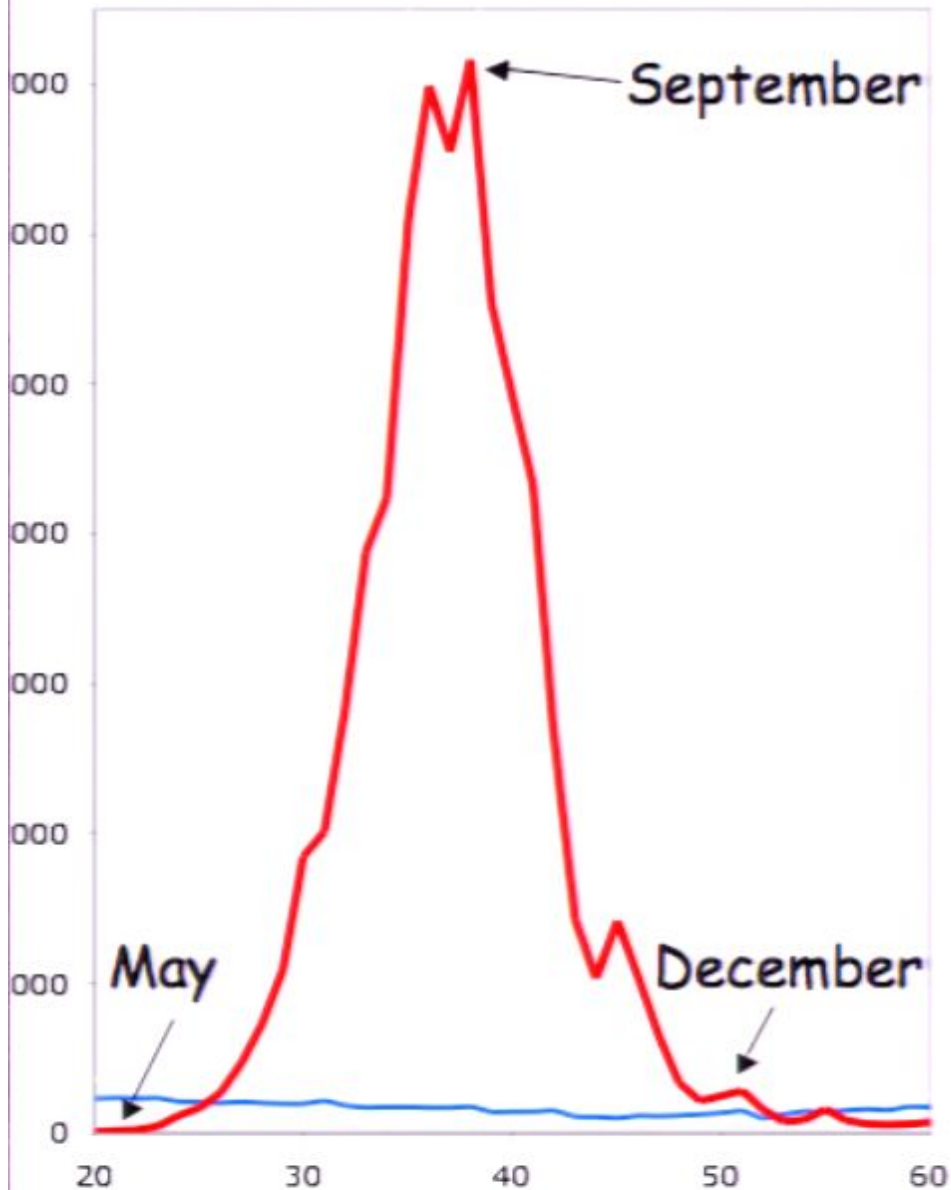
The Great Plague of London, 1665



The Great Plague of London, 1665

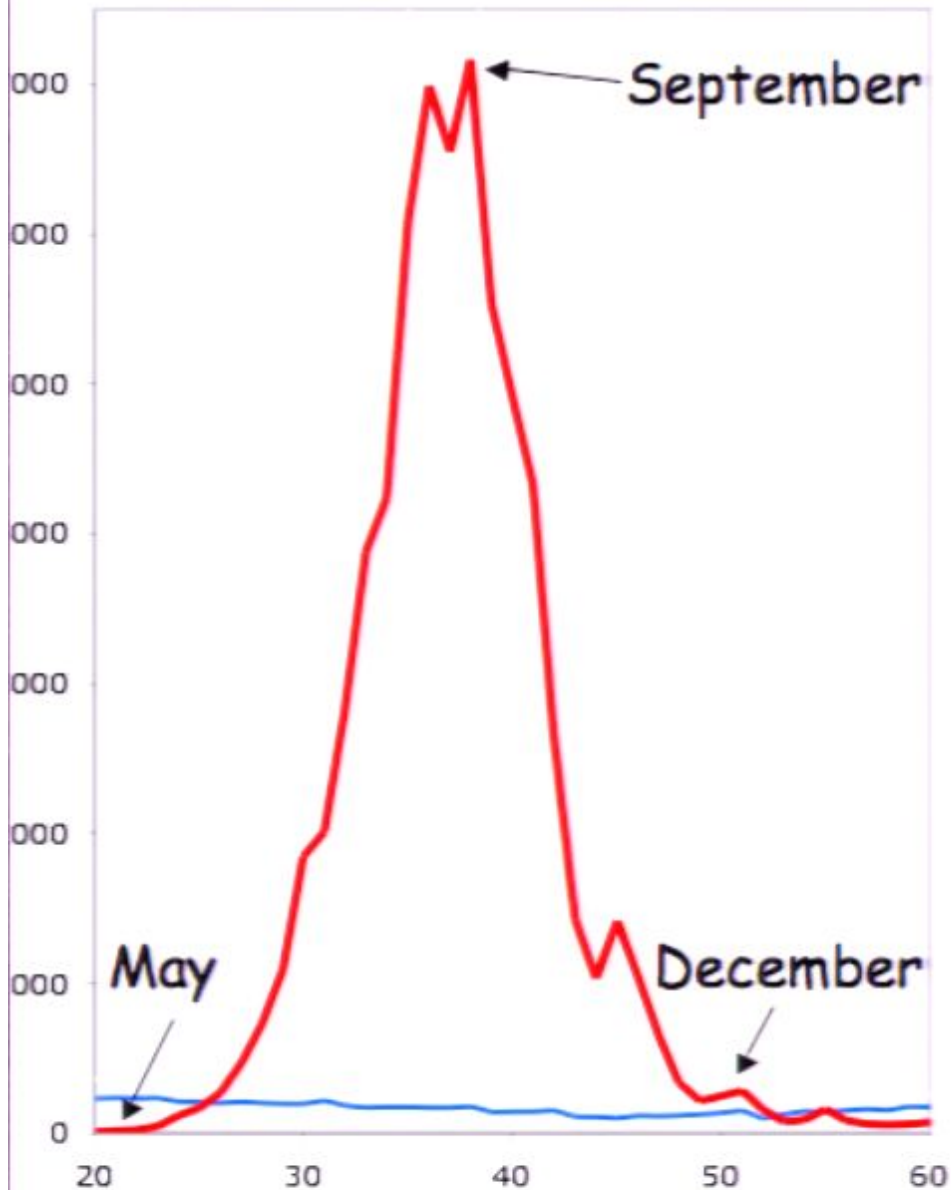


The Great Plague of London, 1665



Can we reliably estimate transmissibility from this epidemic curve?

The Great Plague of London, 1665



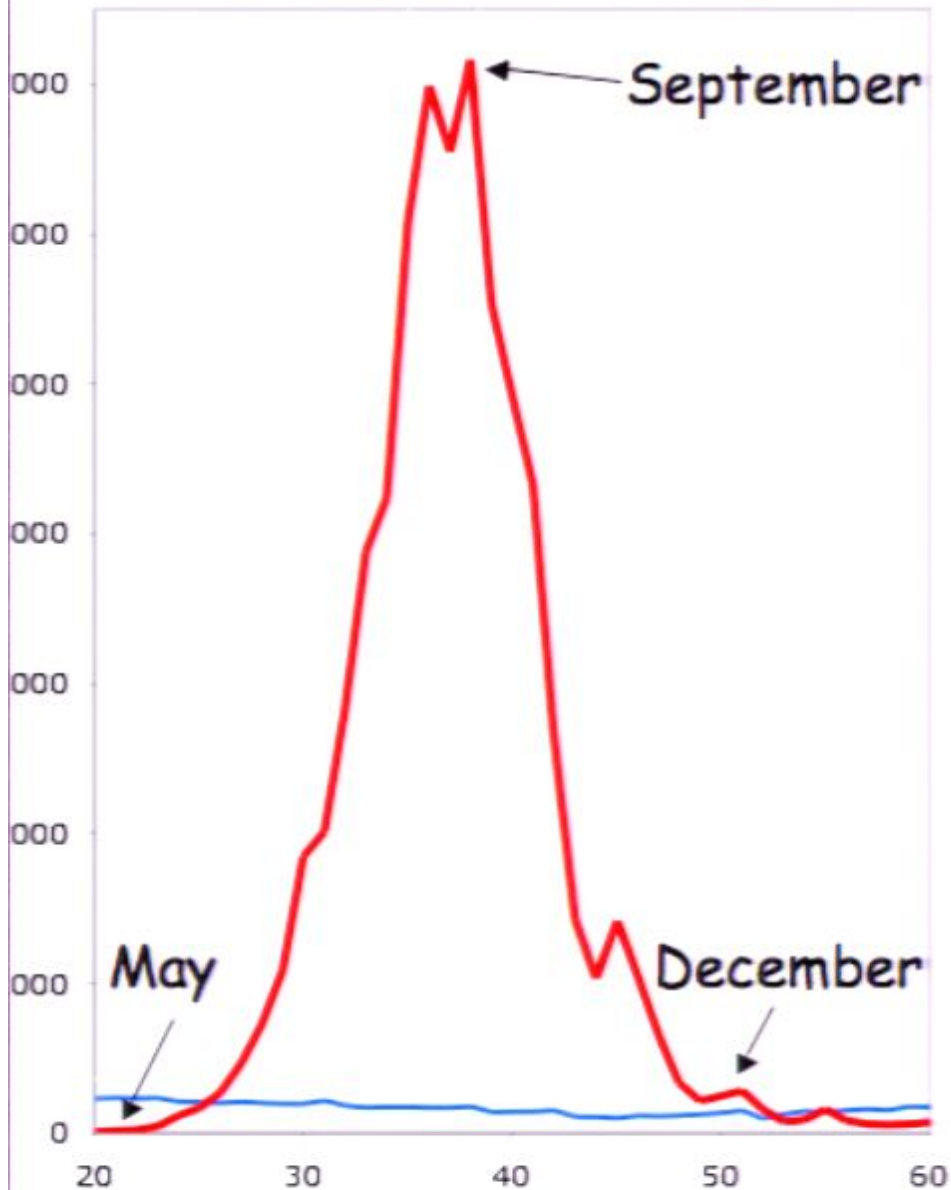
Pirsa: 08030000

Can we reliably estimate transmissibility from this epidemic curve?

Was the population homogeneously mixed on the scale of the whole city (~2 miles in diameter)?

Weeks since 27 December 1664

The Great Plague of London, 1665



Pirsa: 08030000

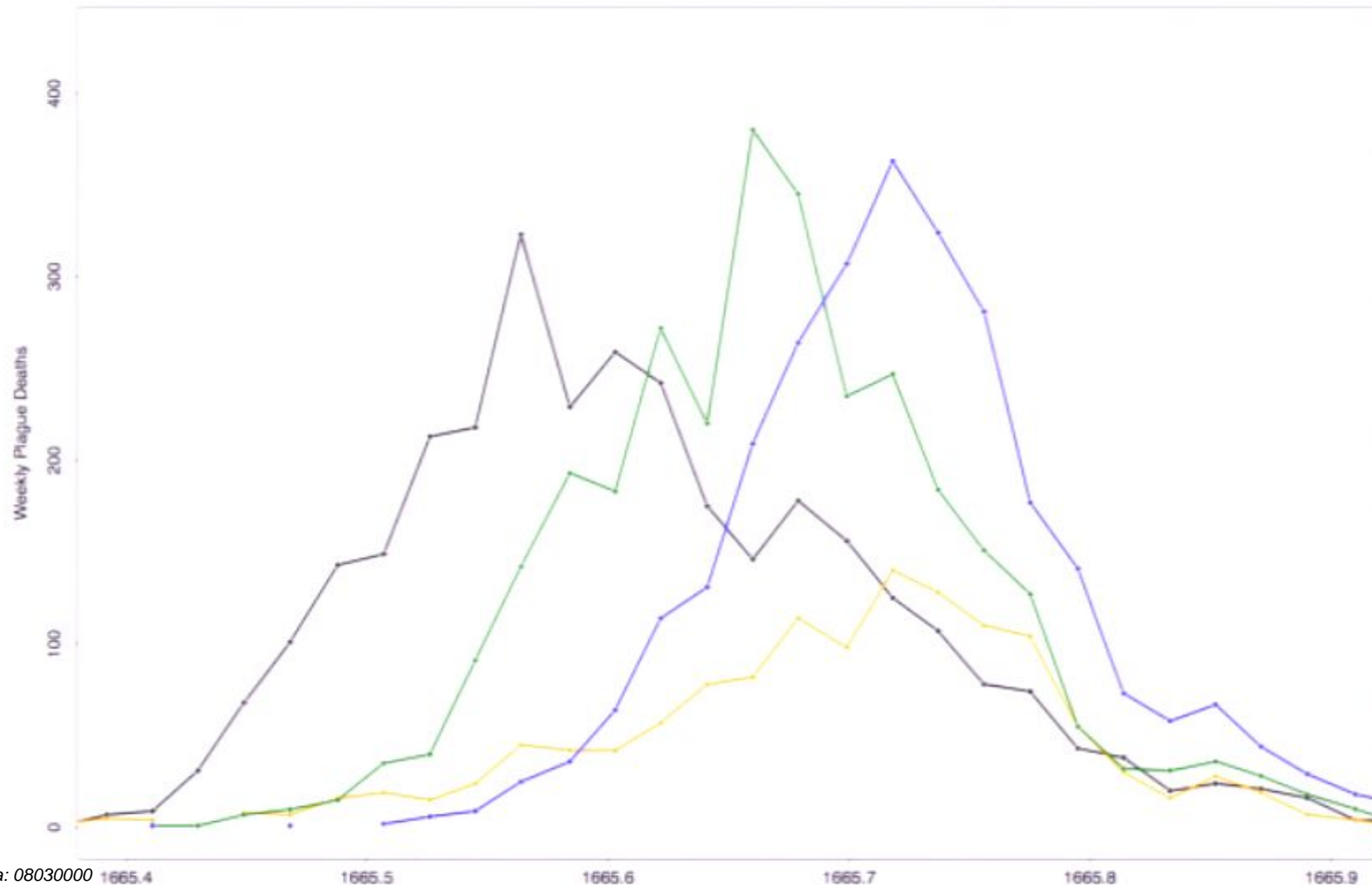
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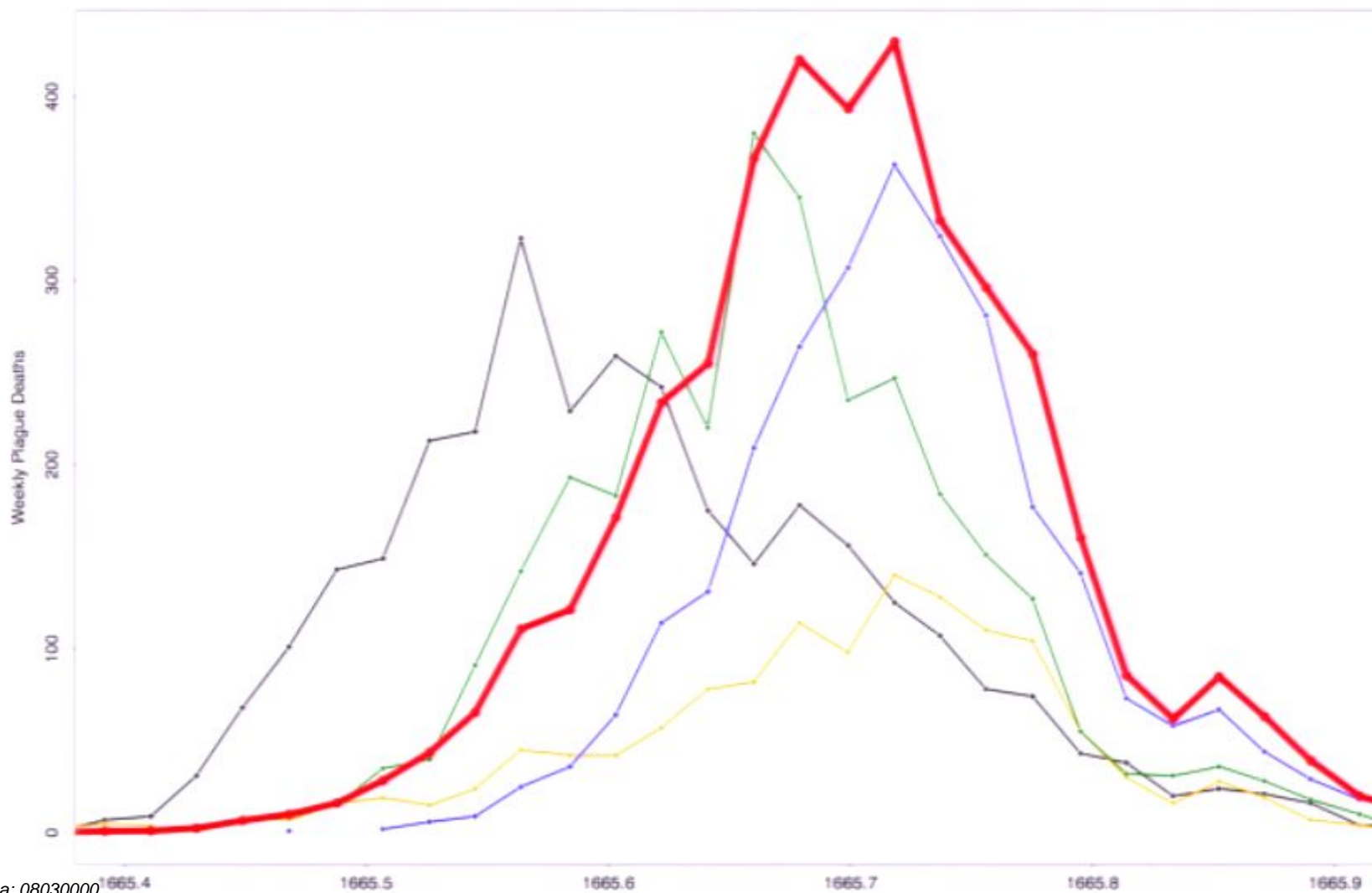
Did the disease become evident in all parts of the city simultaneously? Or is there evidence for spatial spread?

Weeks since 27 December 1664

First few parishes infected during the Great Plague...



First few parishes infected... together with scaled aggregate time series

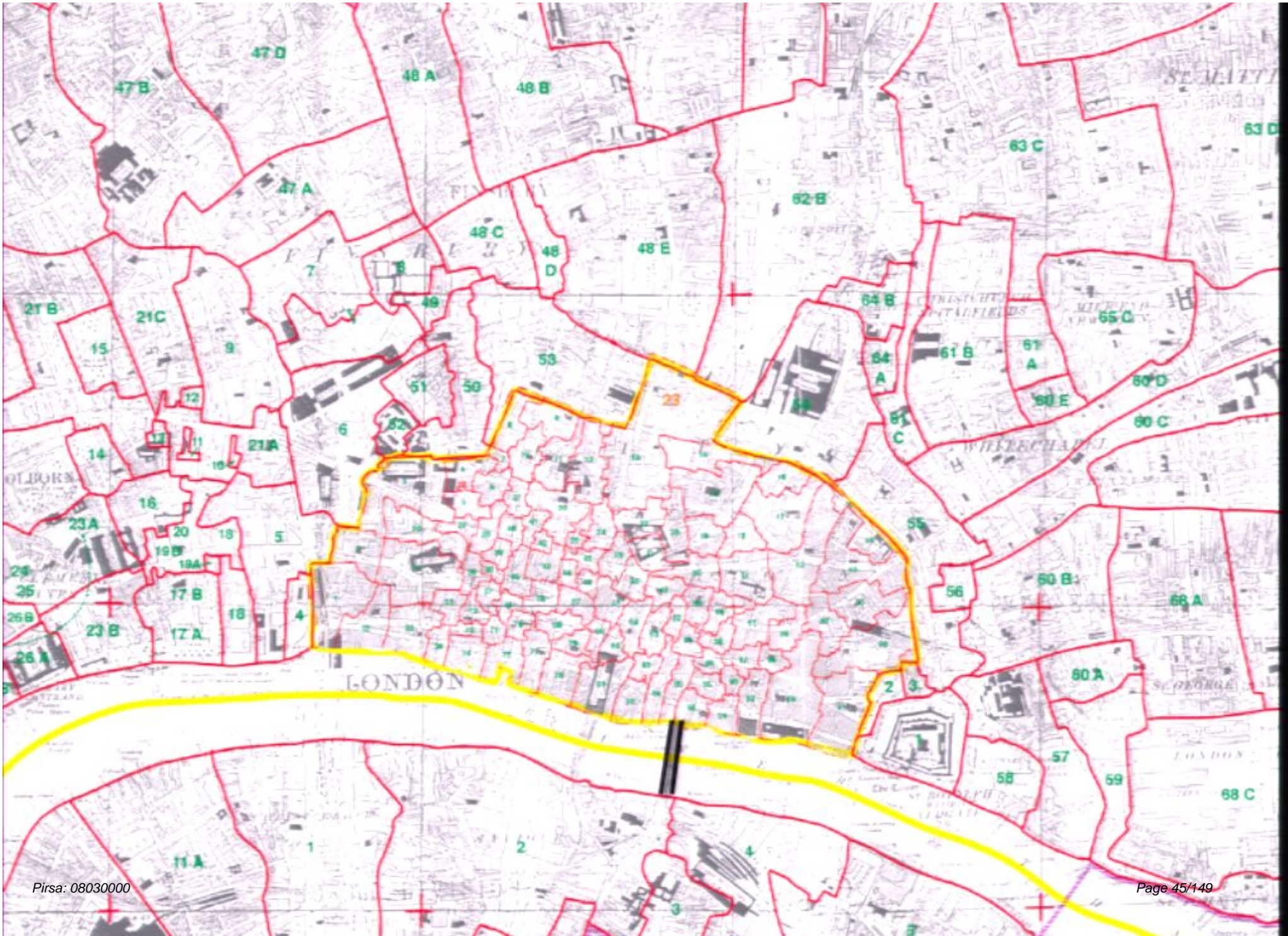


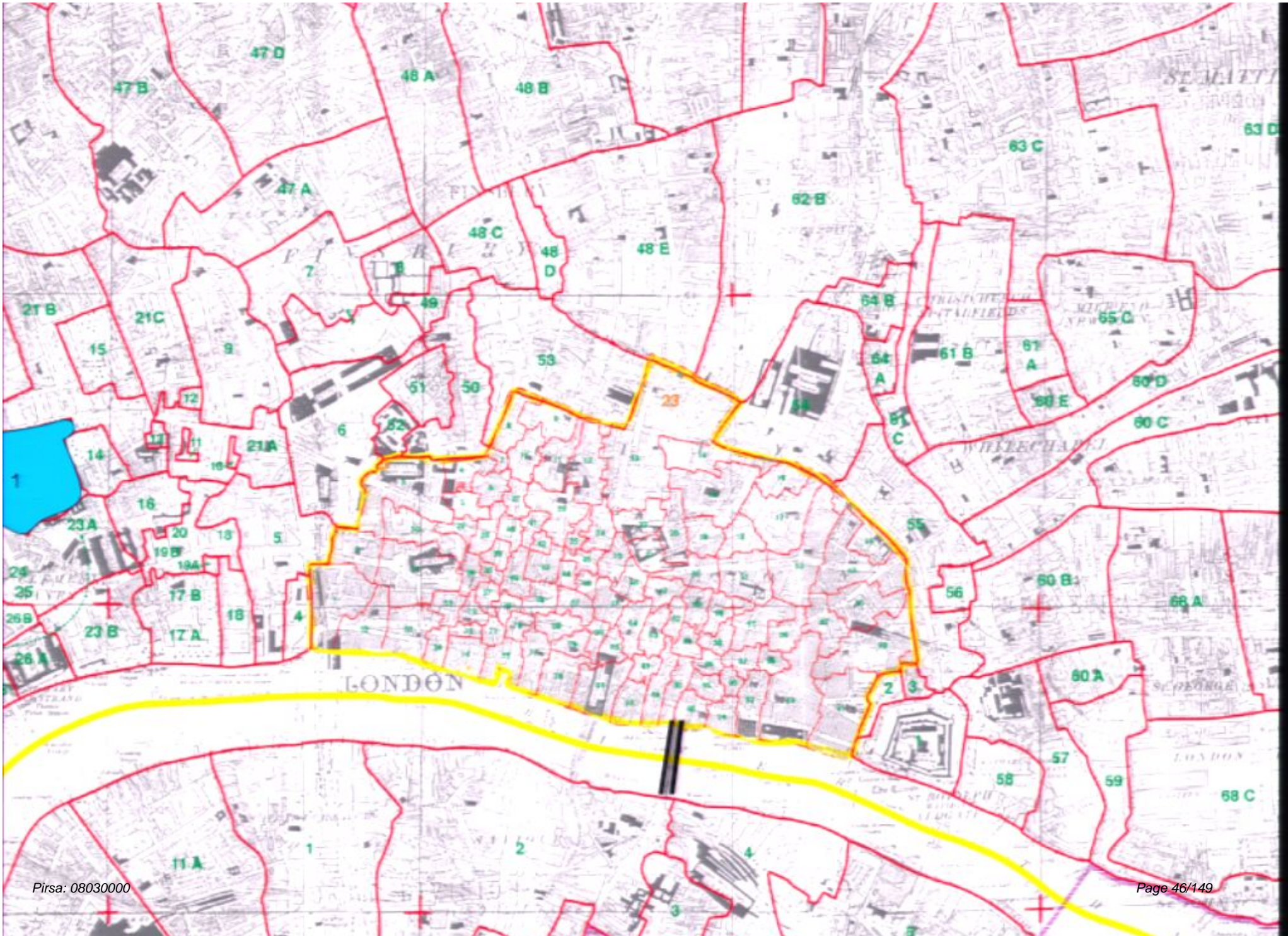
The Great Plague of London in 1665

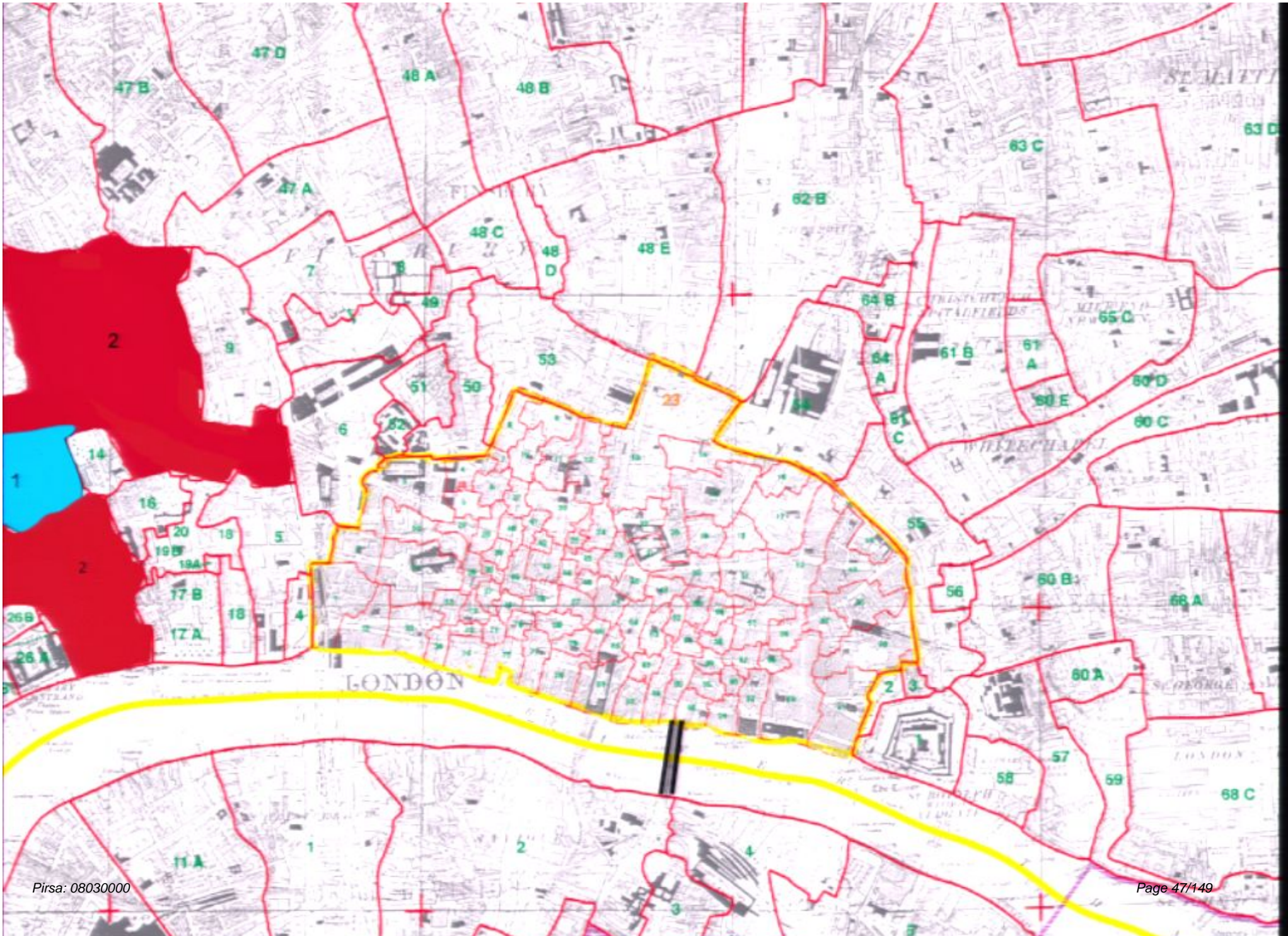
- Location
- Data sources
- Temporal pattern
- **Spatial pattern**
- Transmissibility

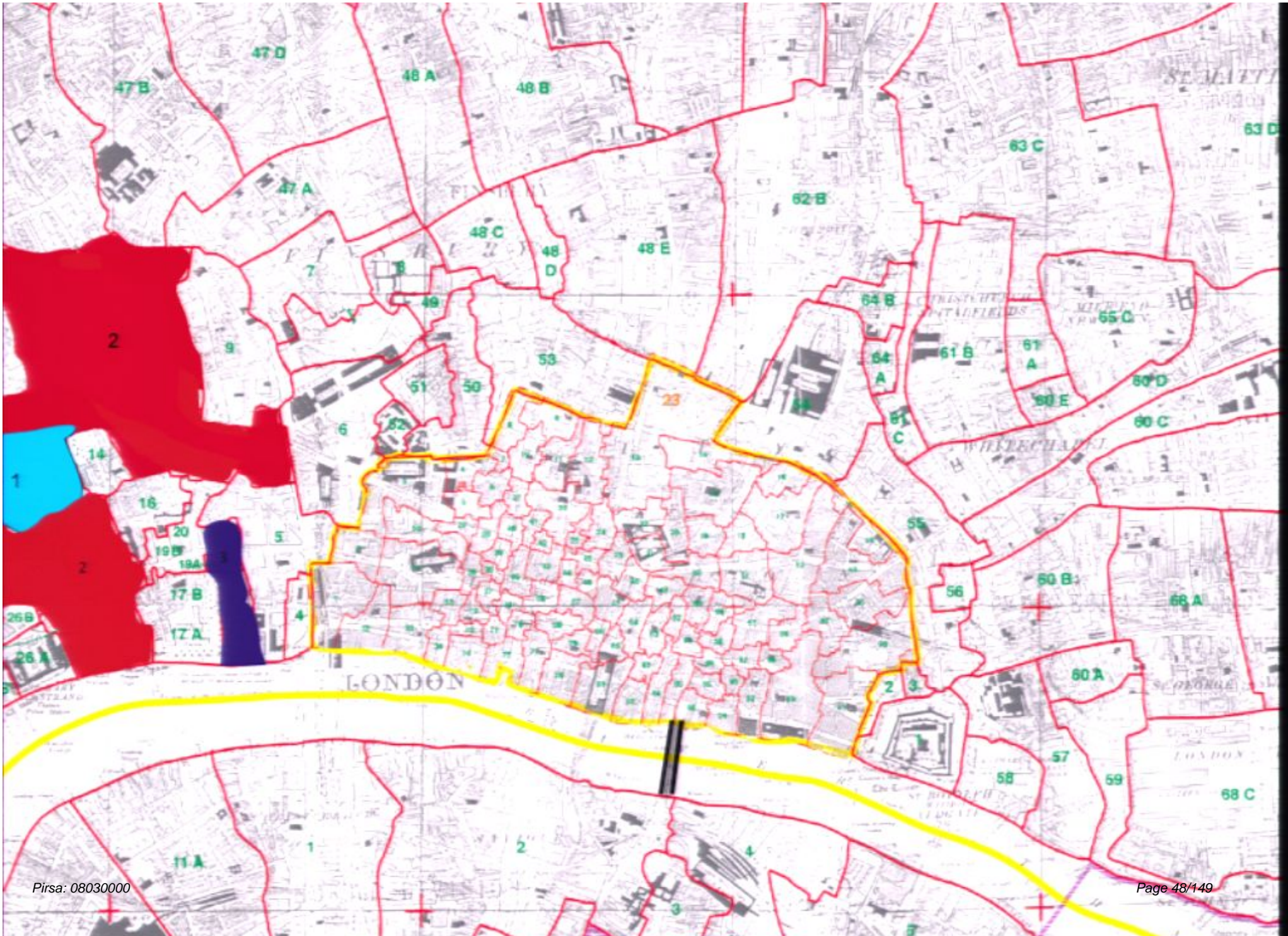
Visualization of the spatial structure of mortality in London

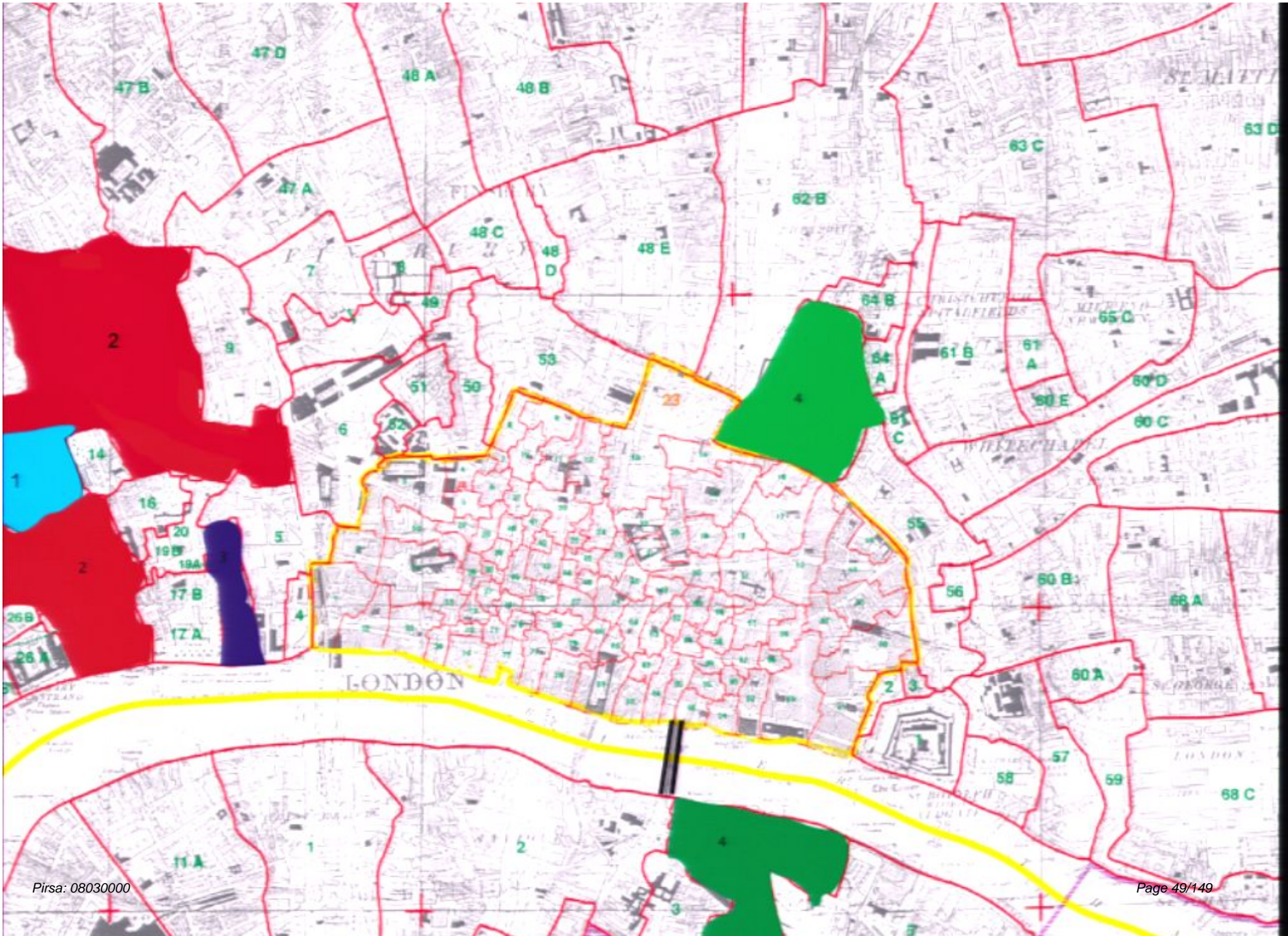
- GIS encoding of parish boundaries
- Visualization of epidemic
 - Overlay parish boundaries on more modern map for reference
 - Colour parishes as they become infected
 - *Is there evidence for spatial spread or was the spatial pattern random?*

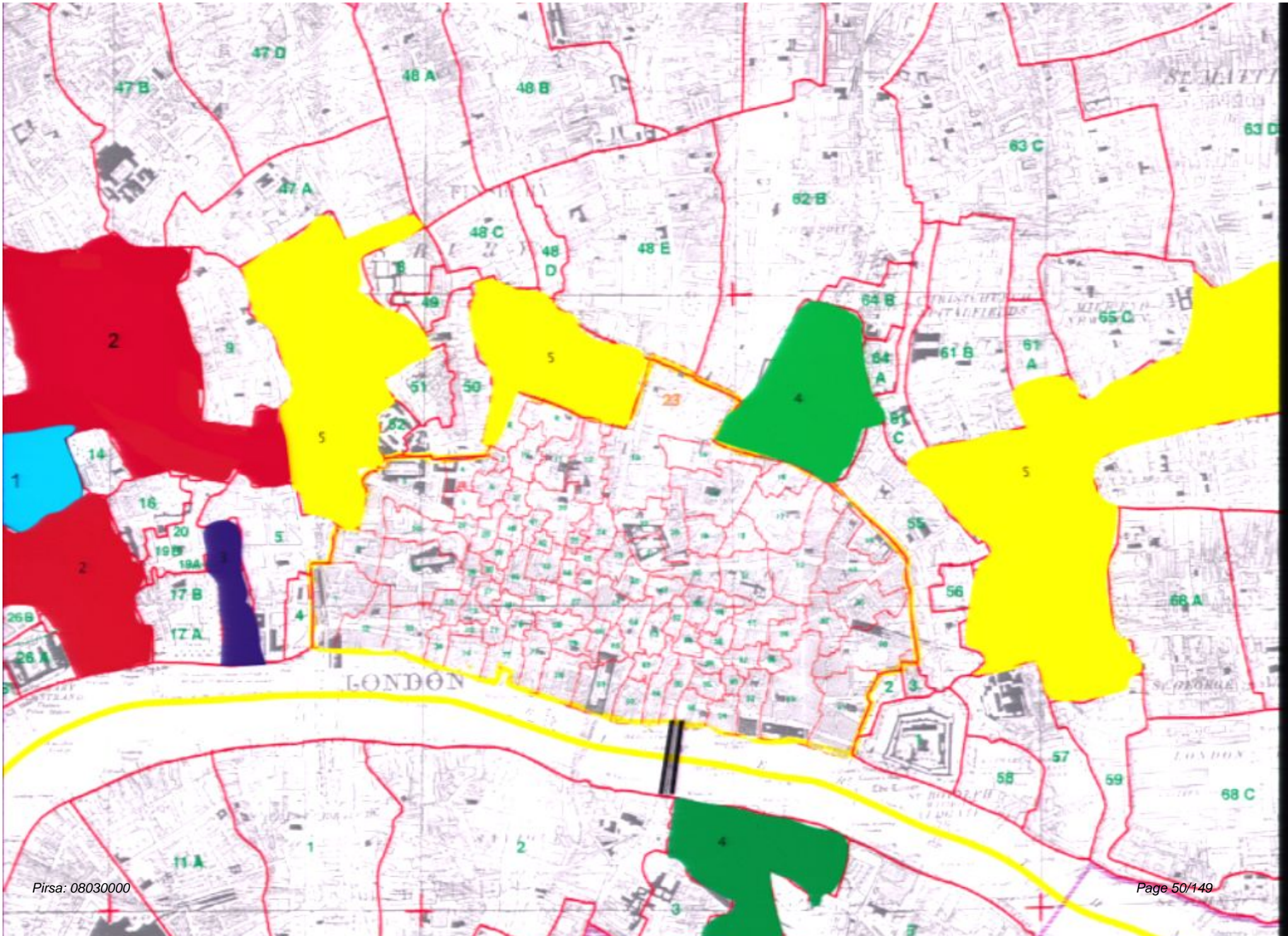


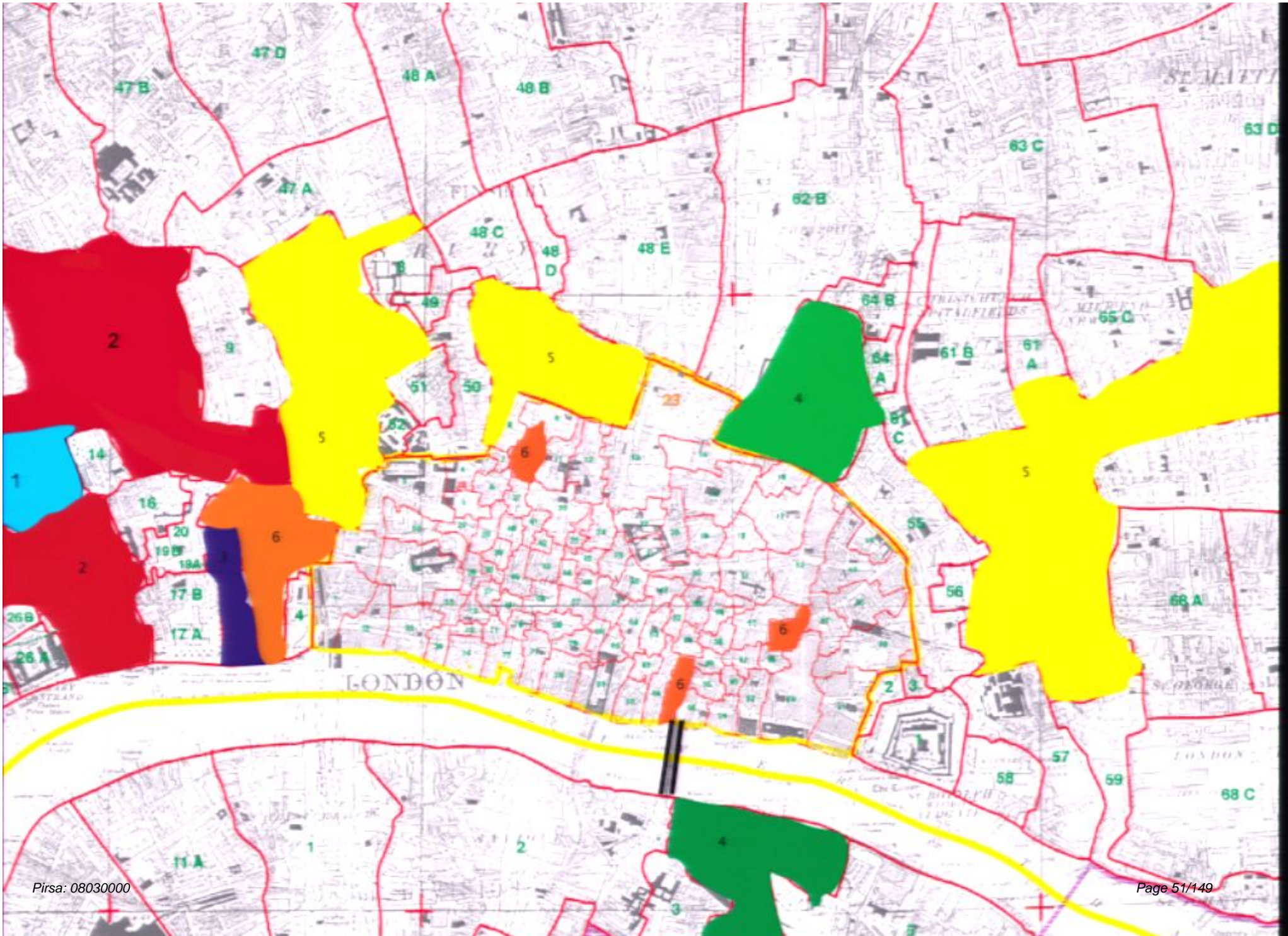


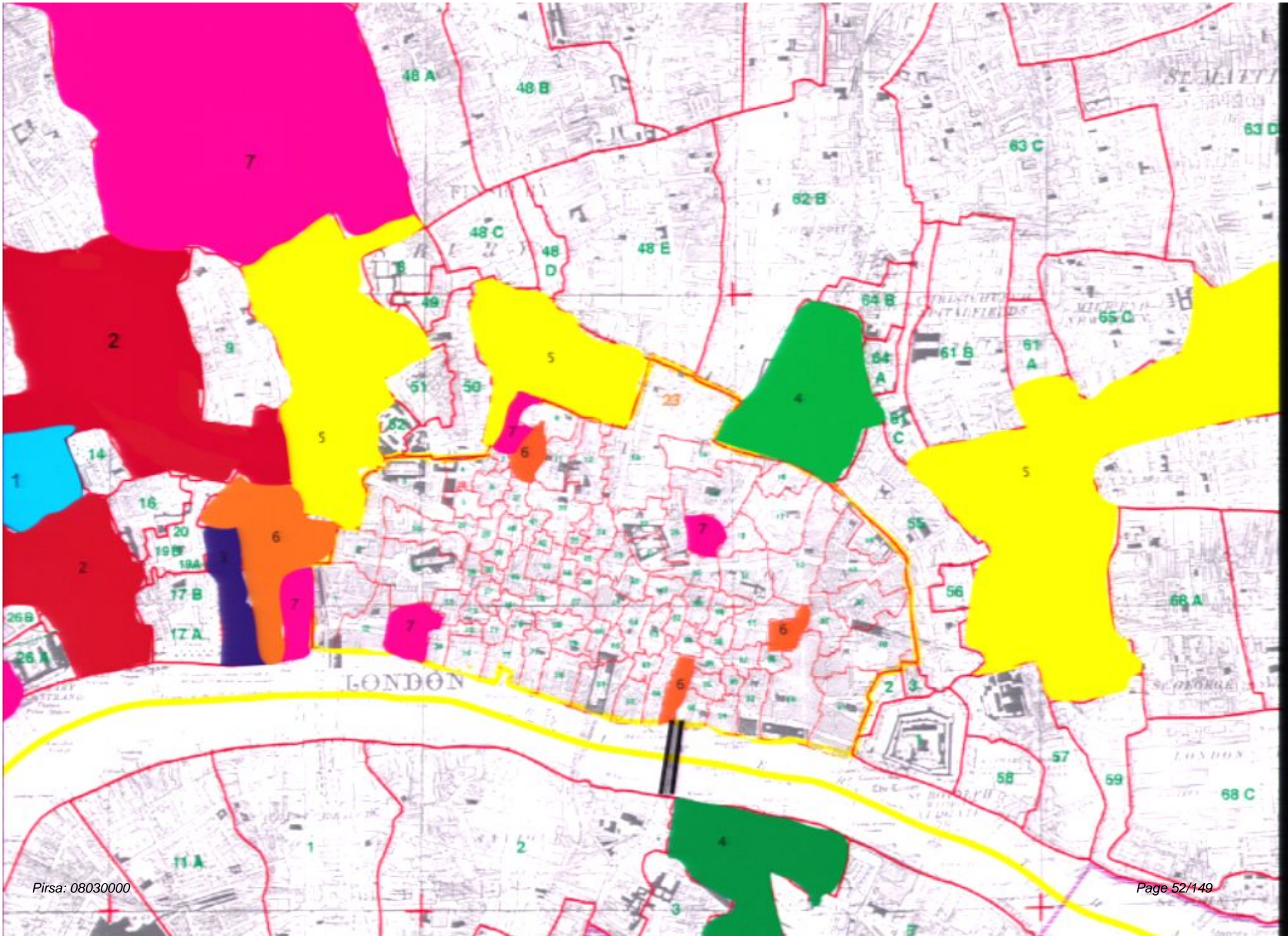


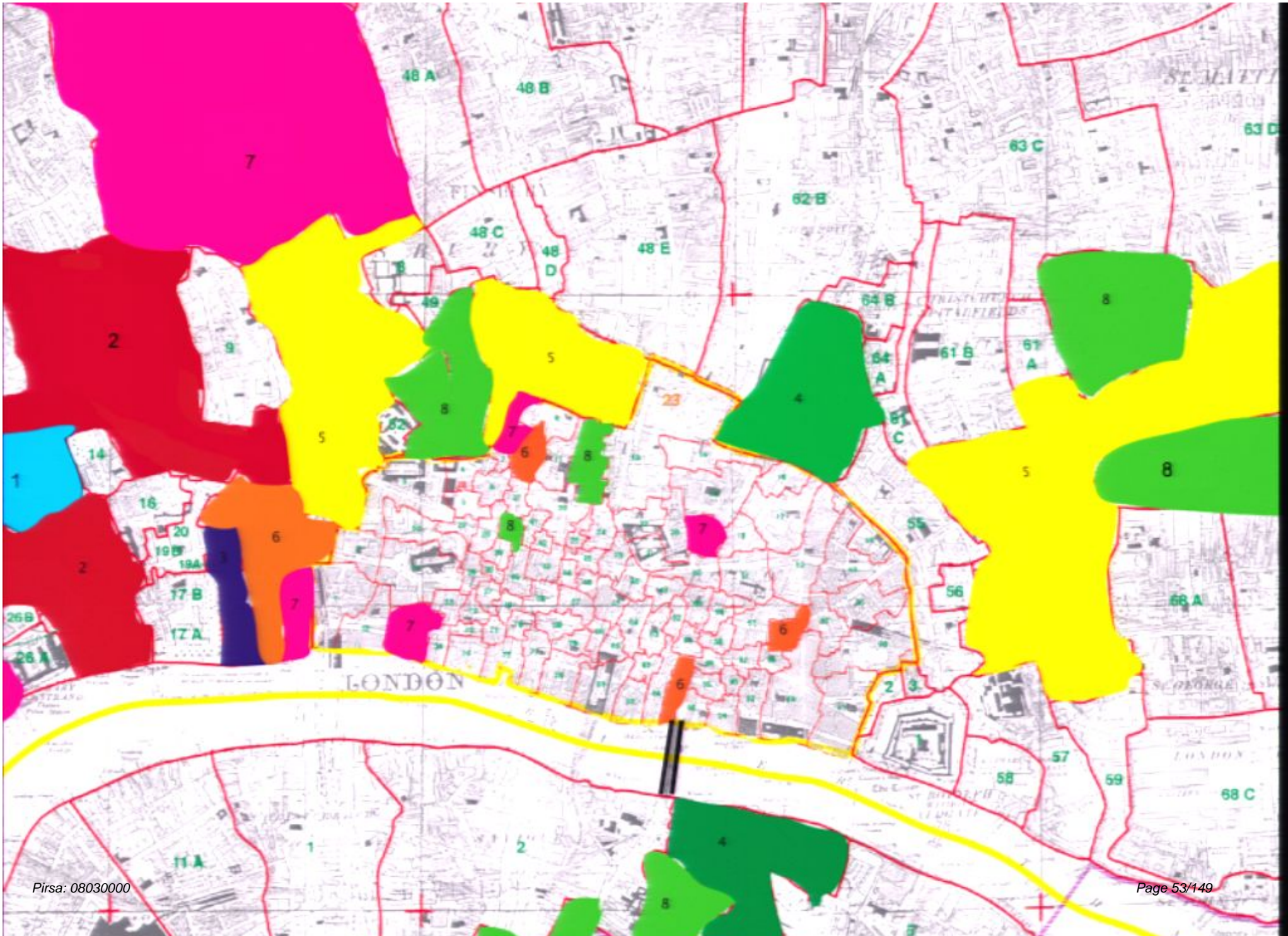


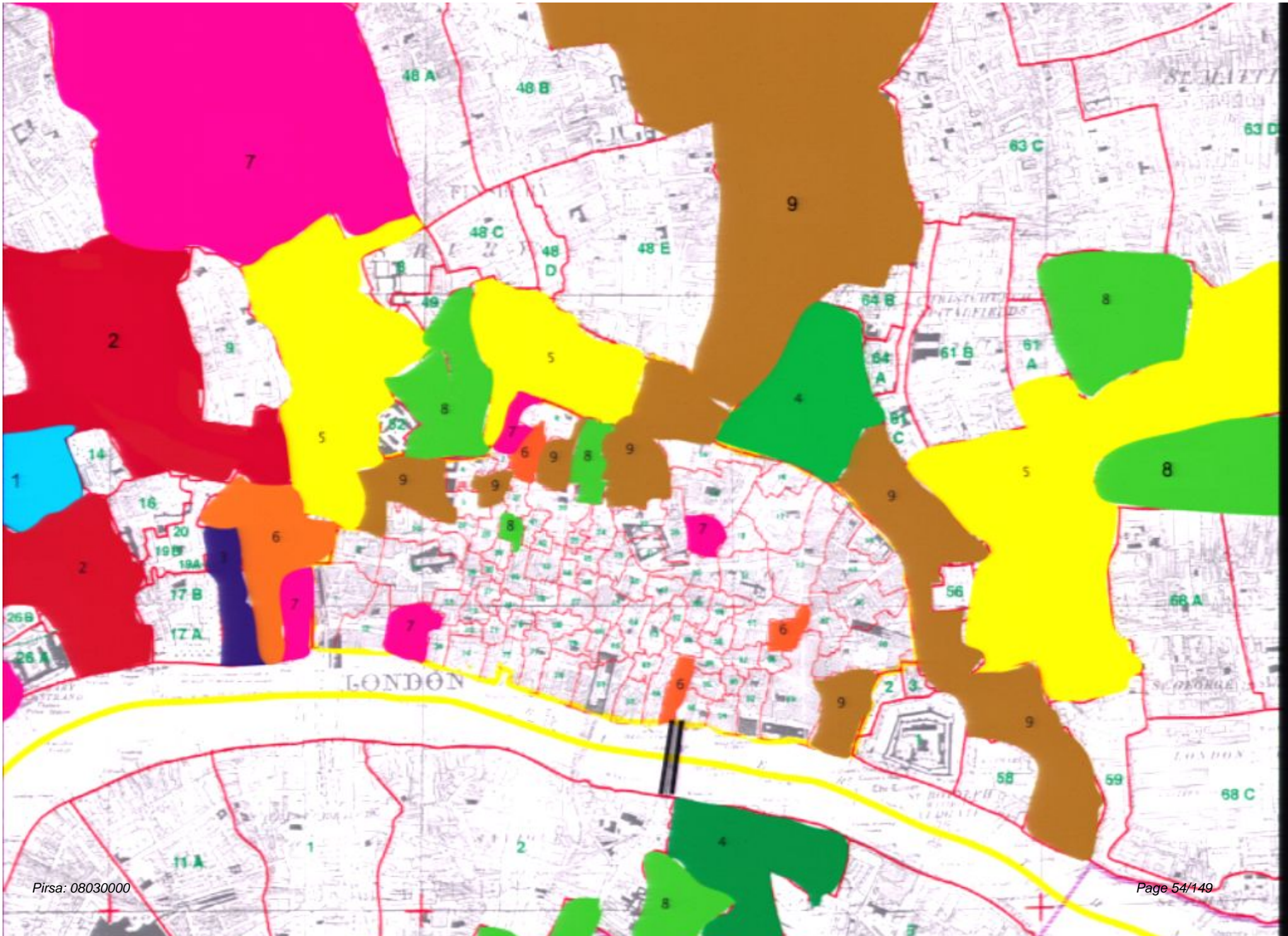


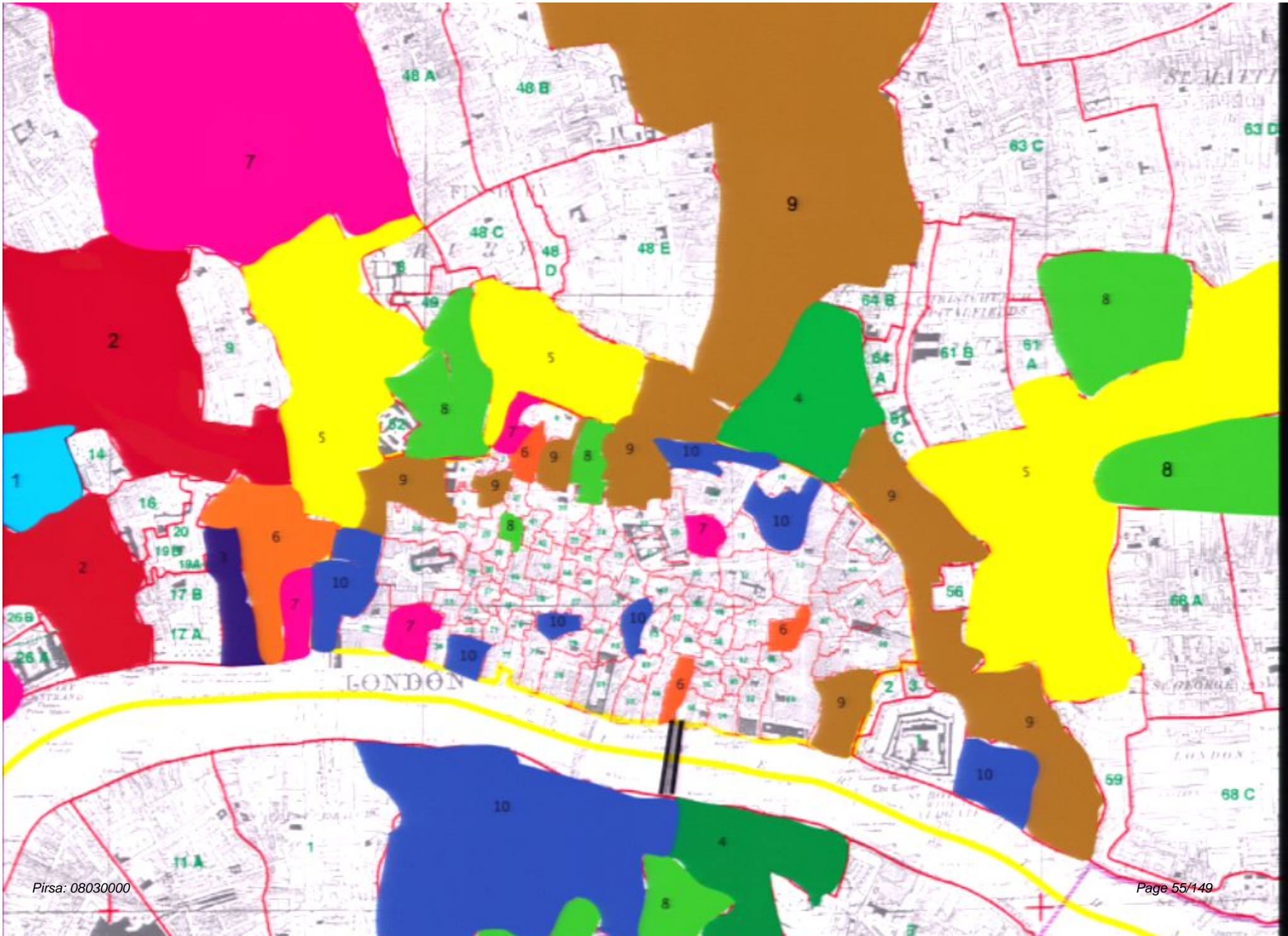


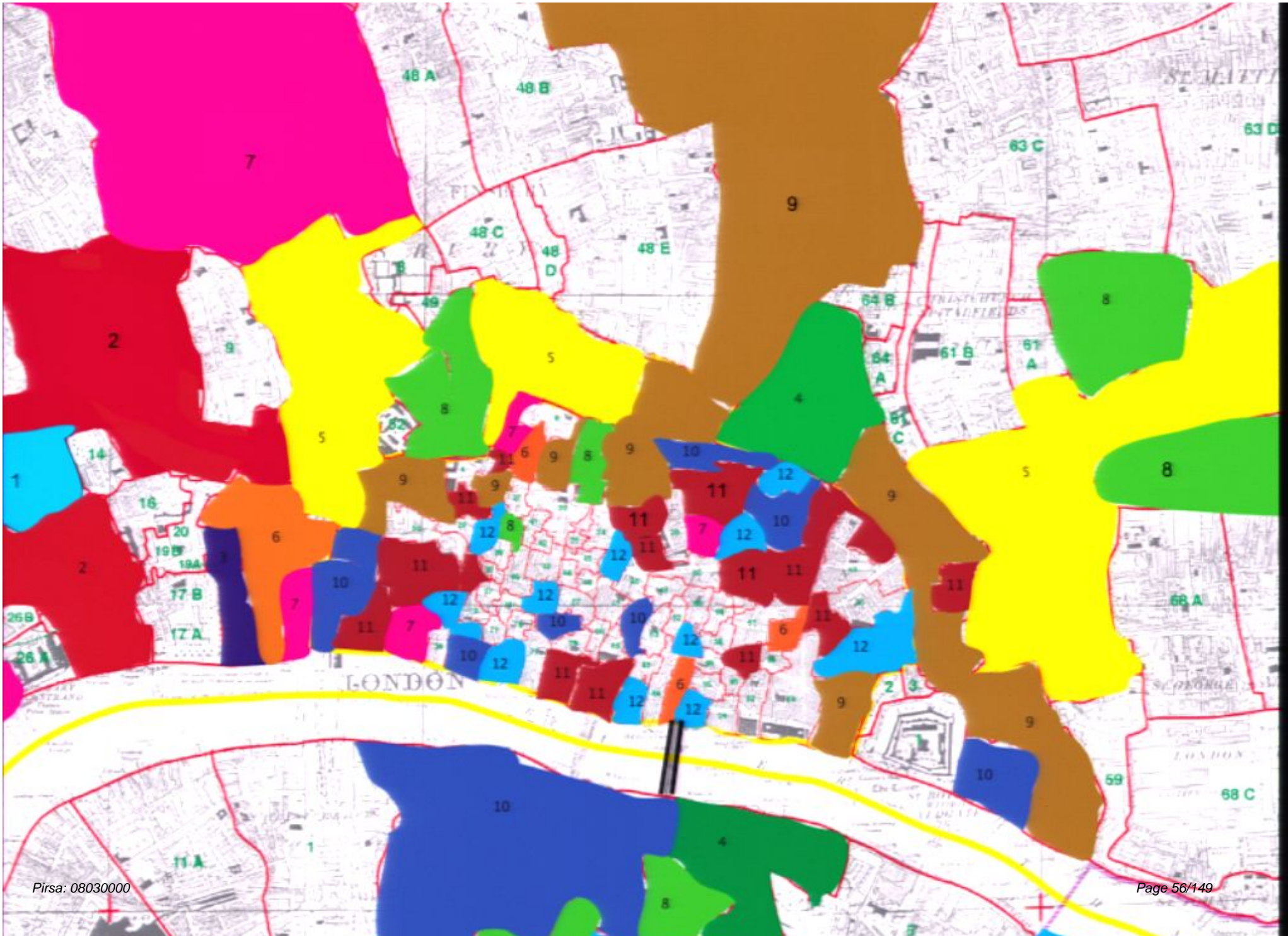


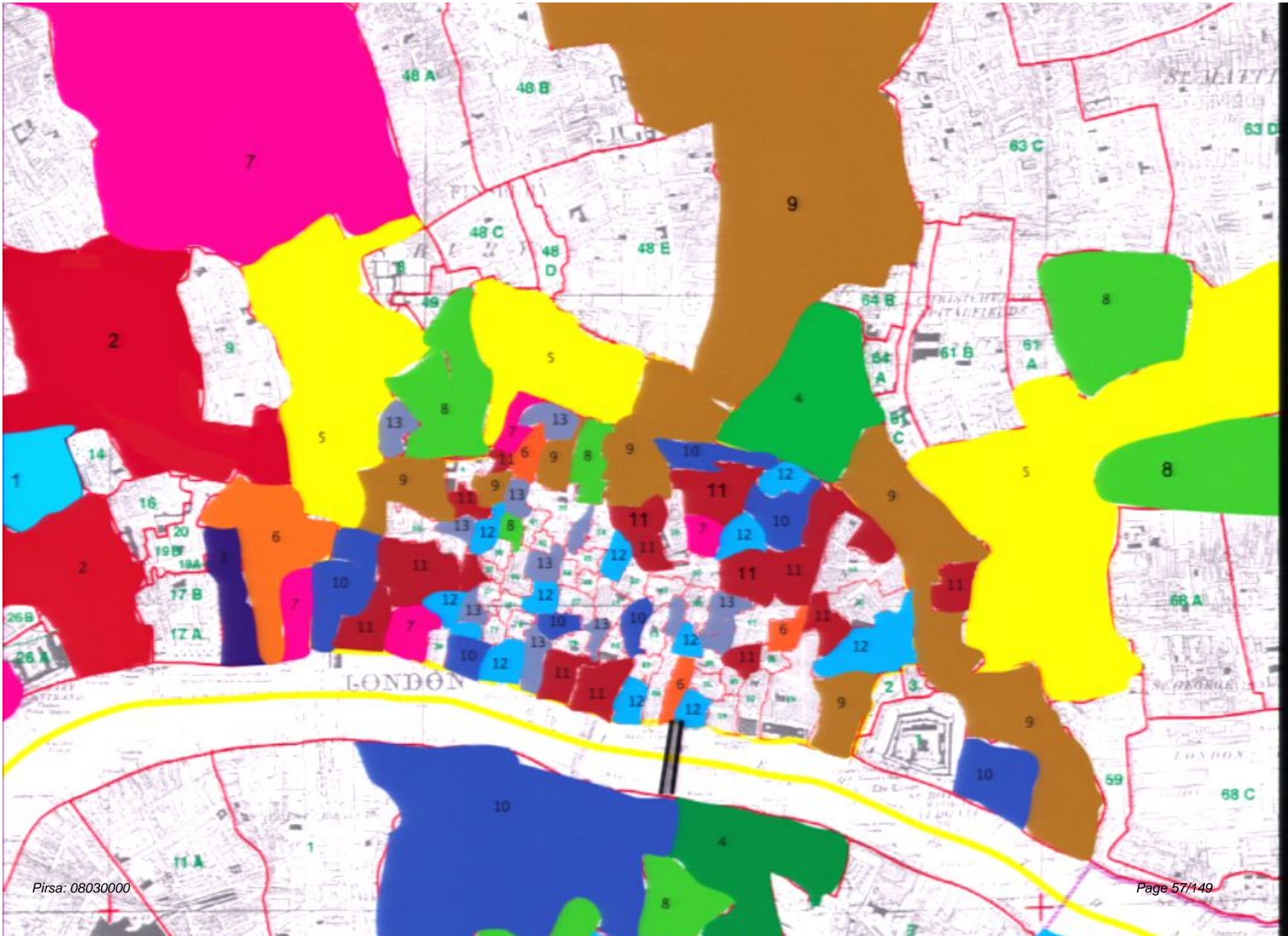


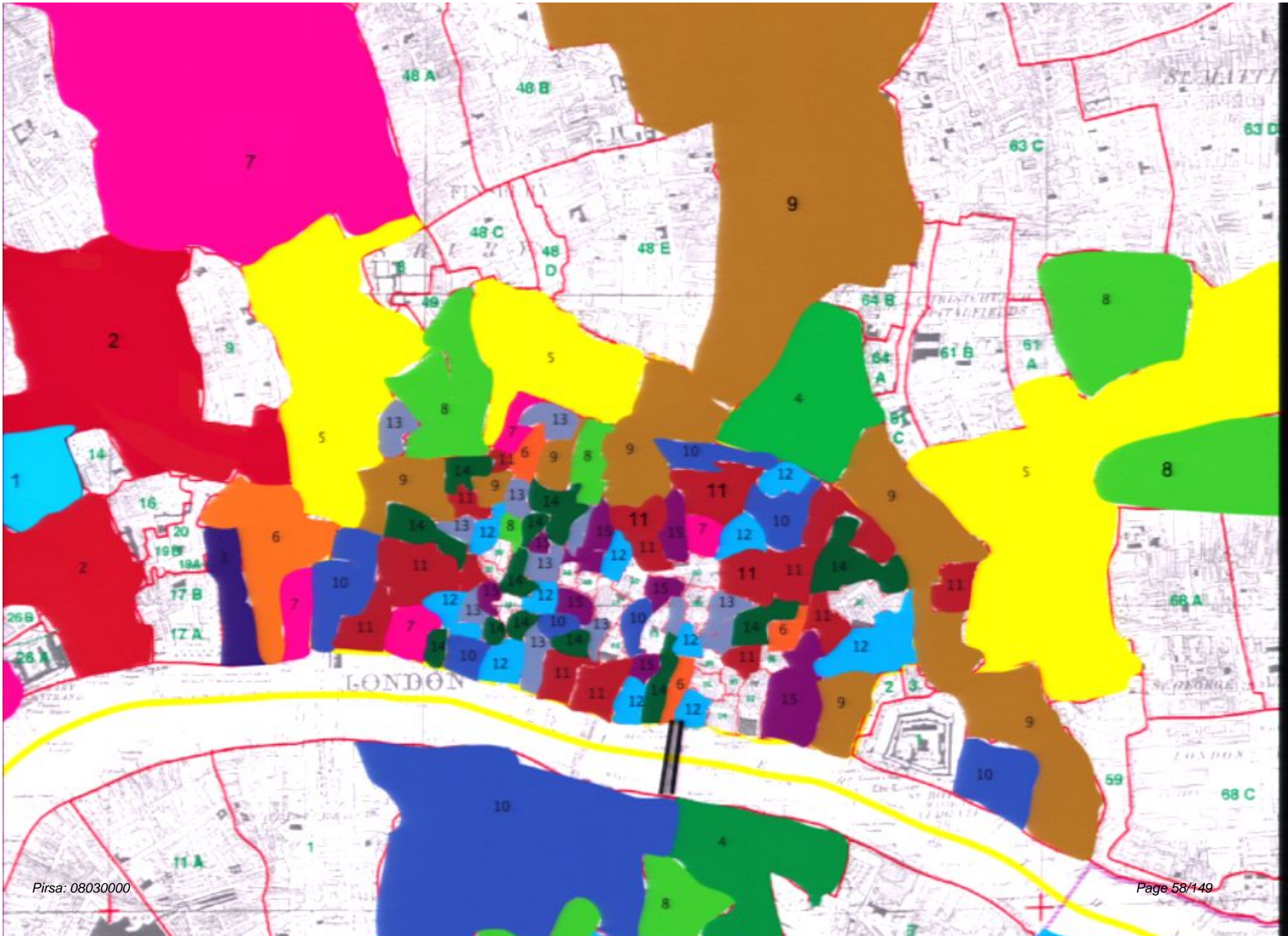


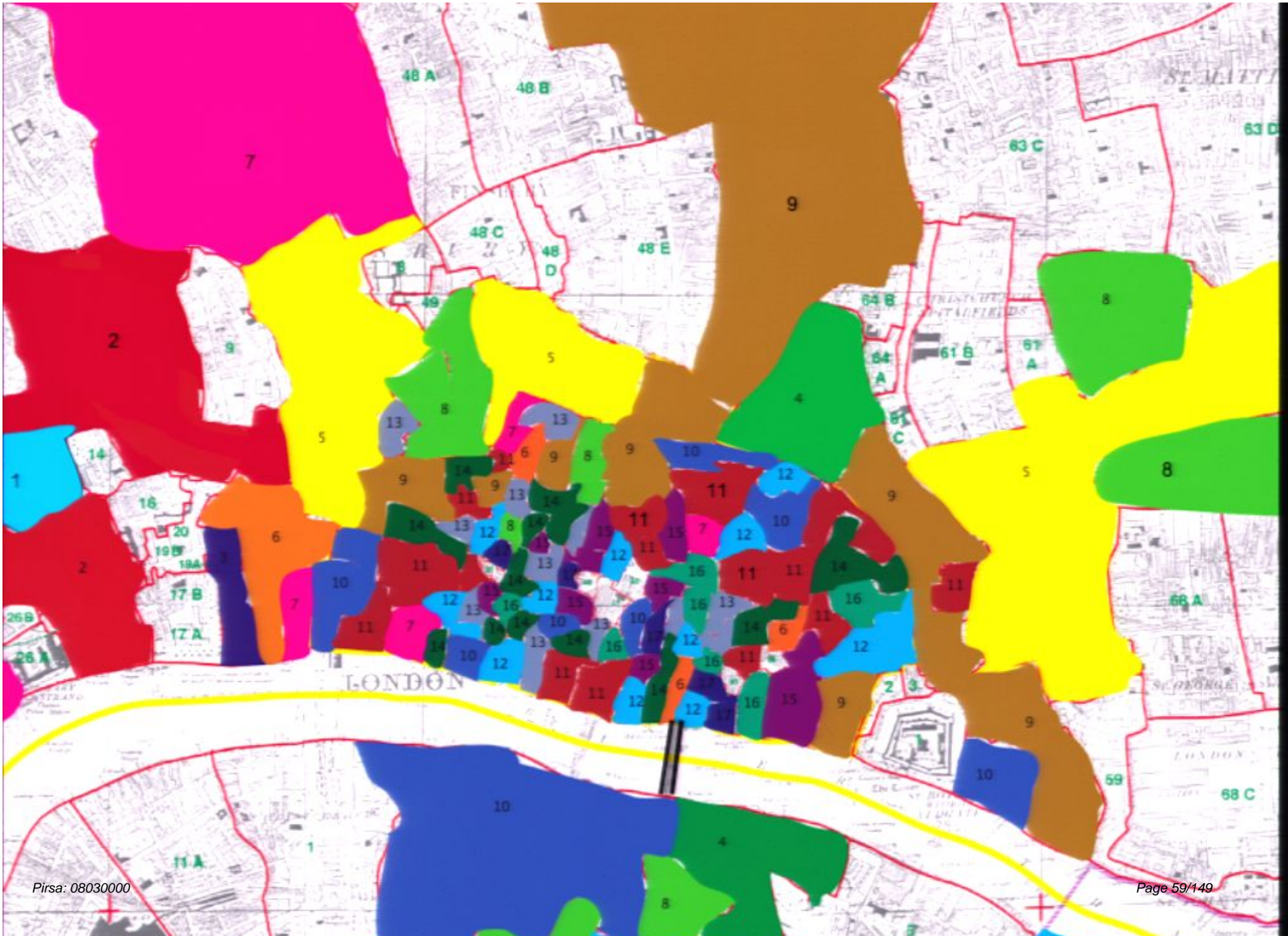


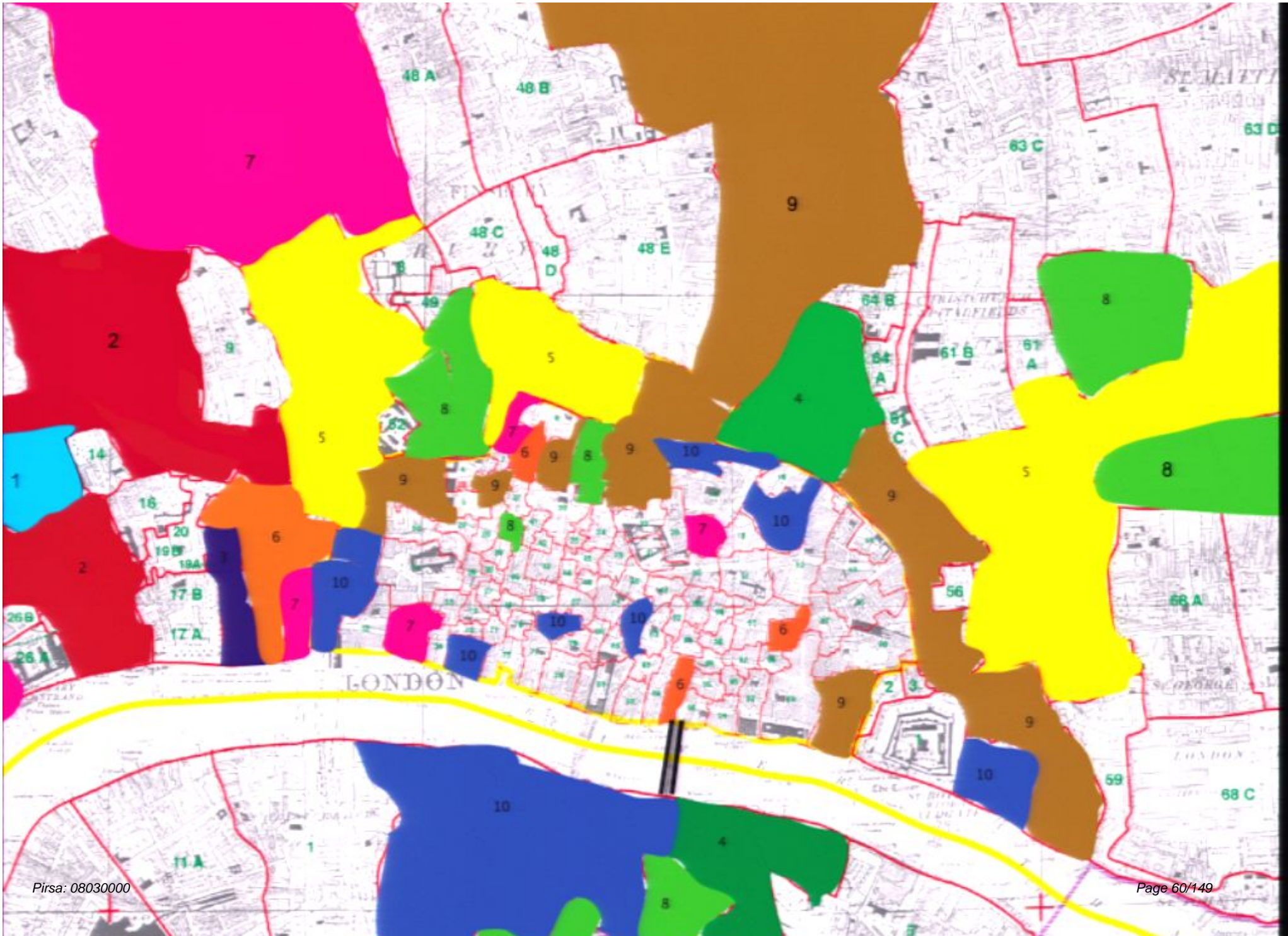


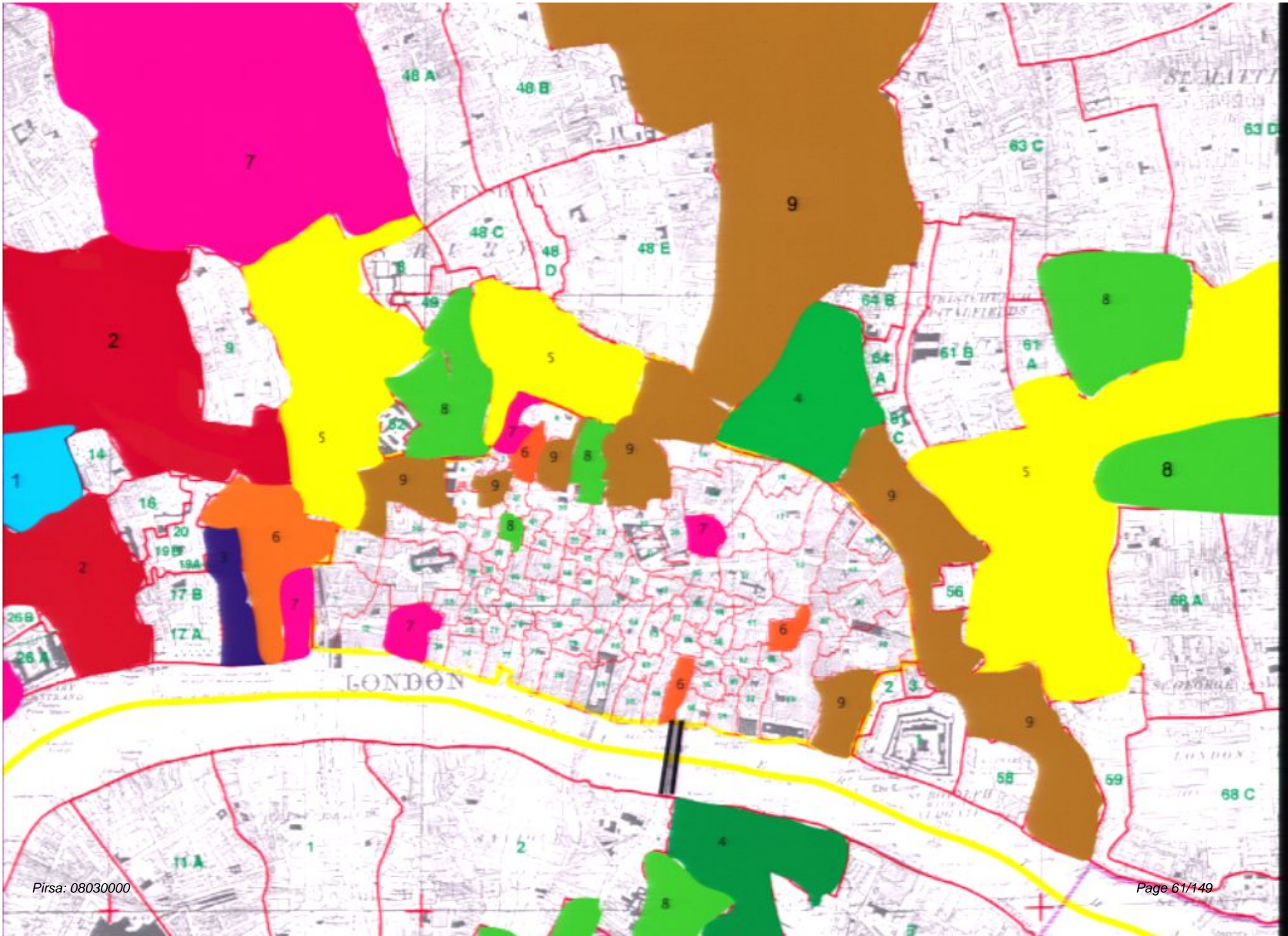


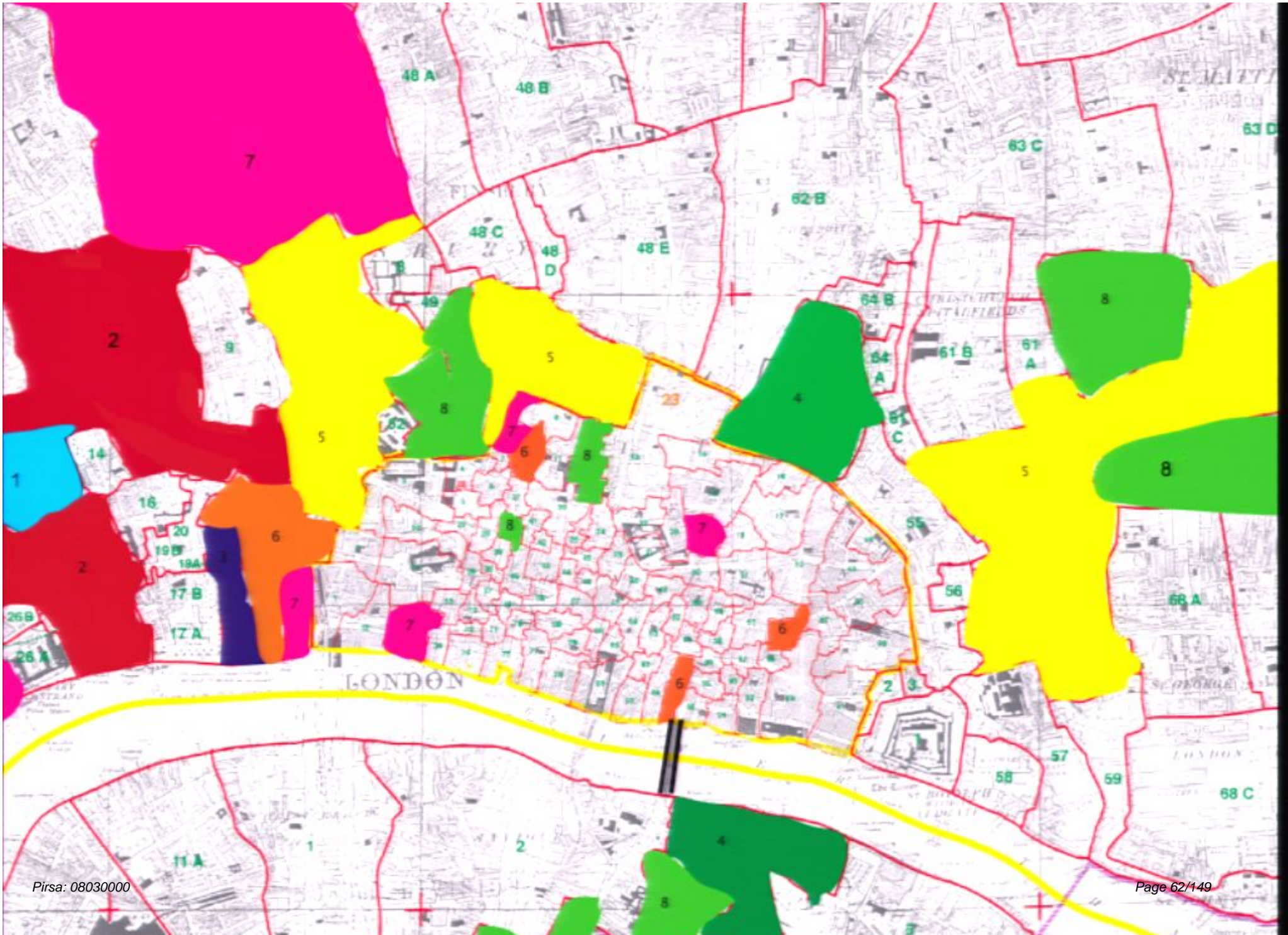


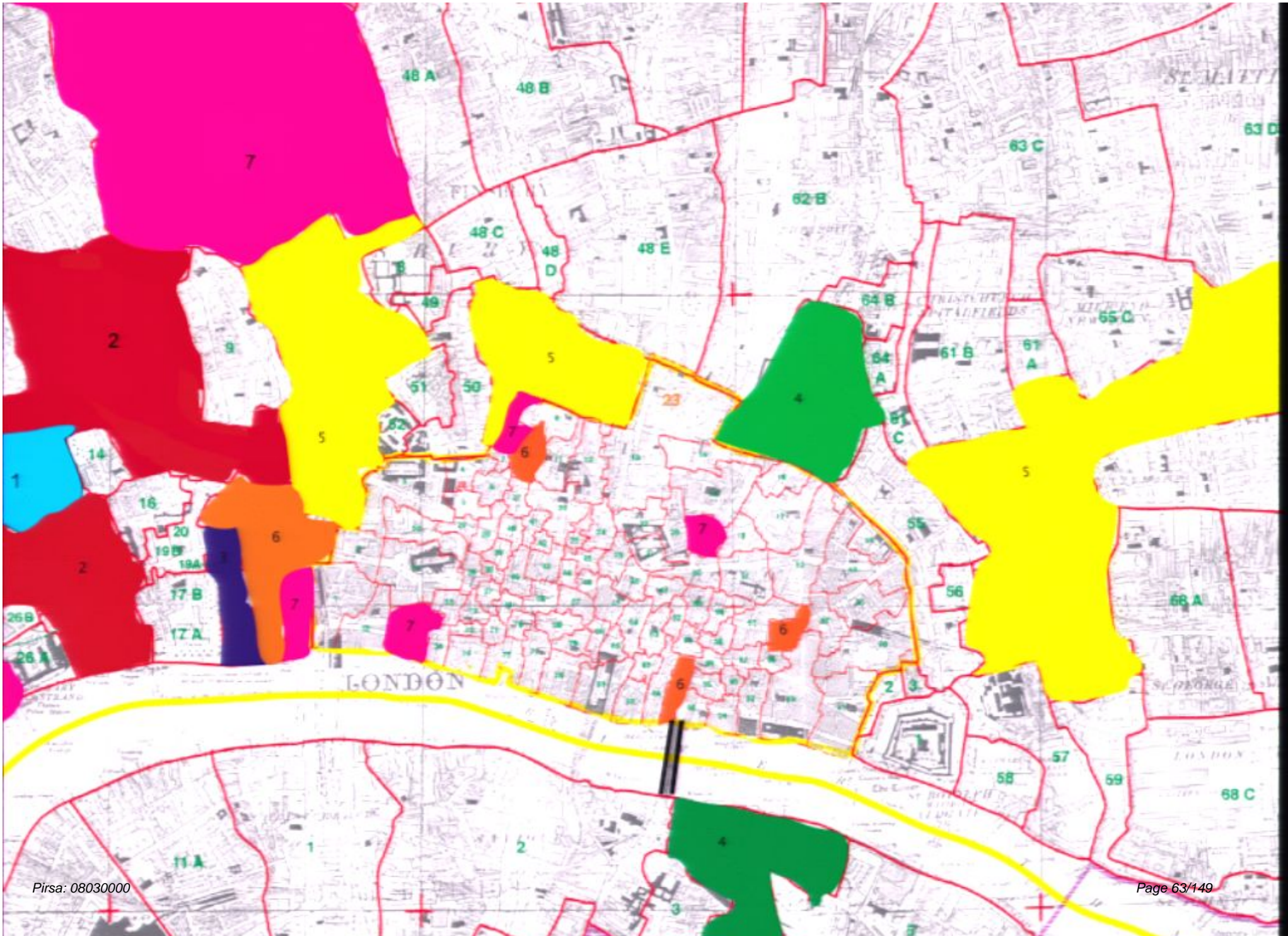


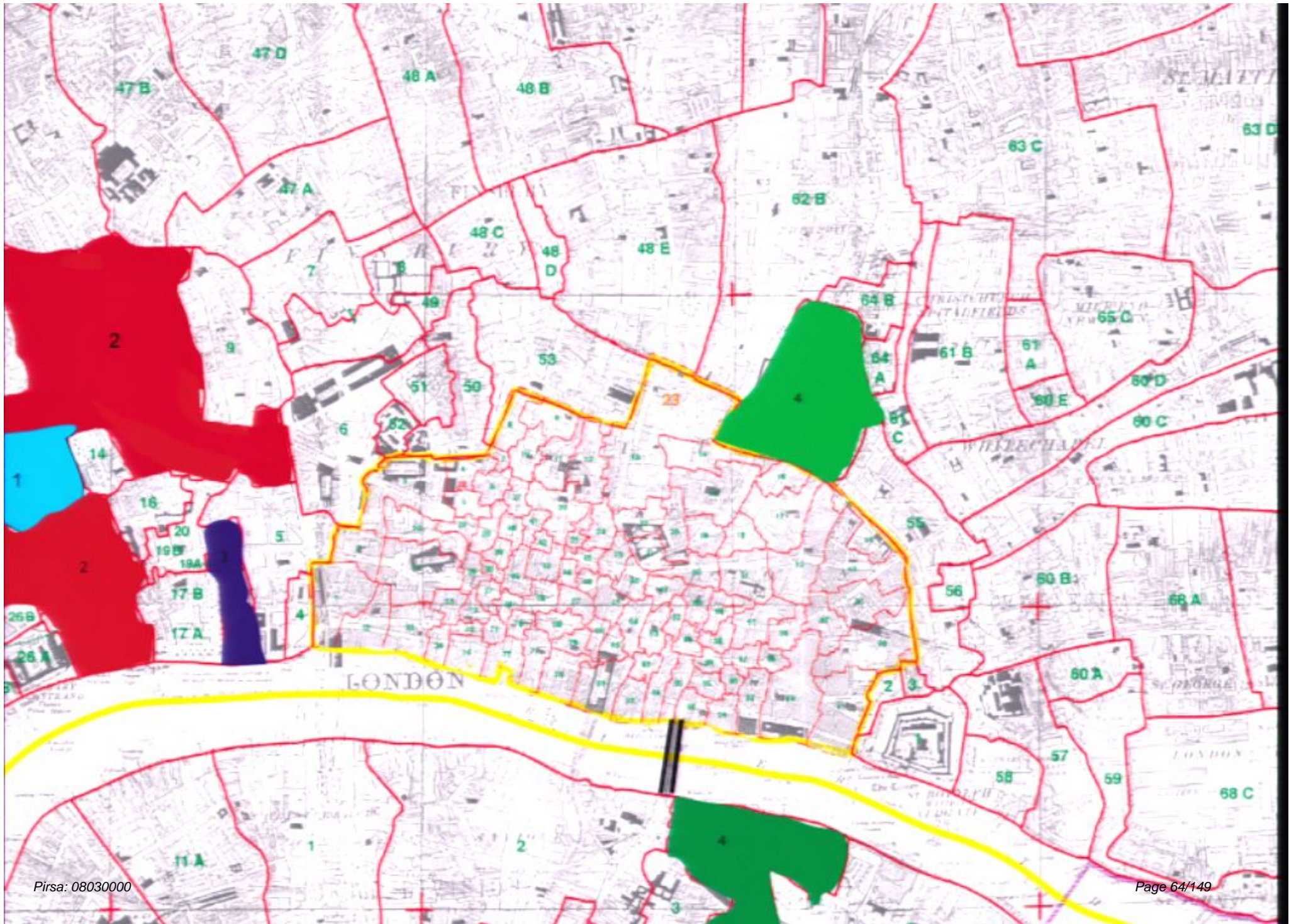


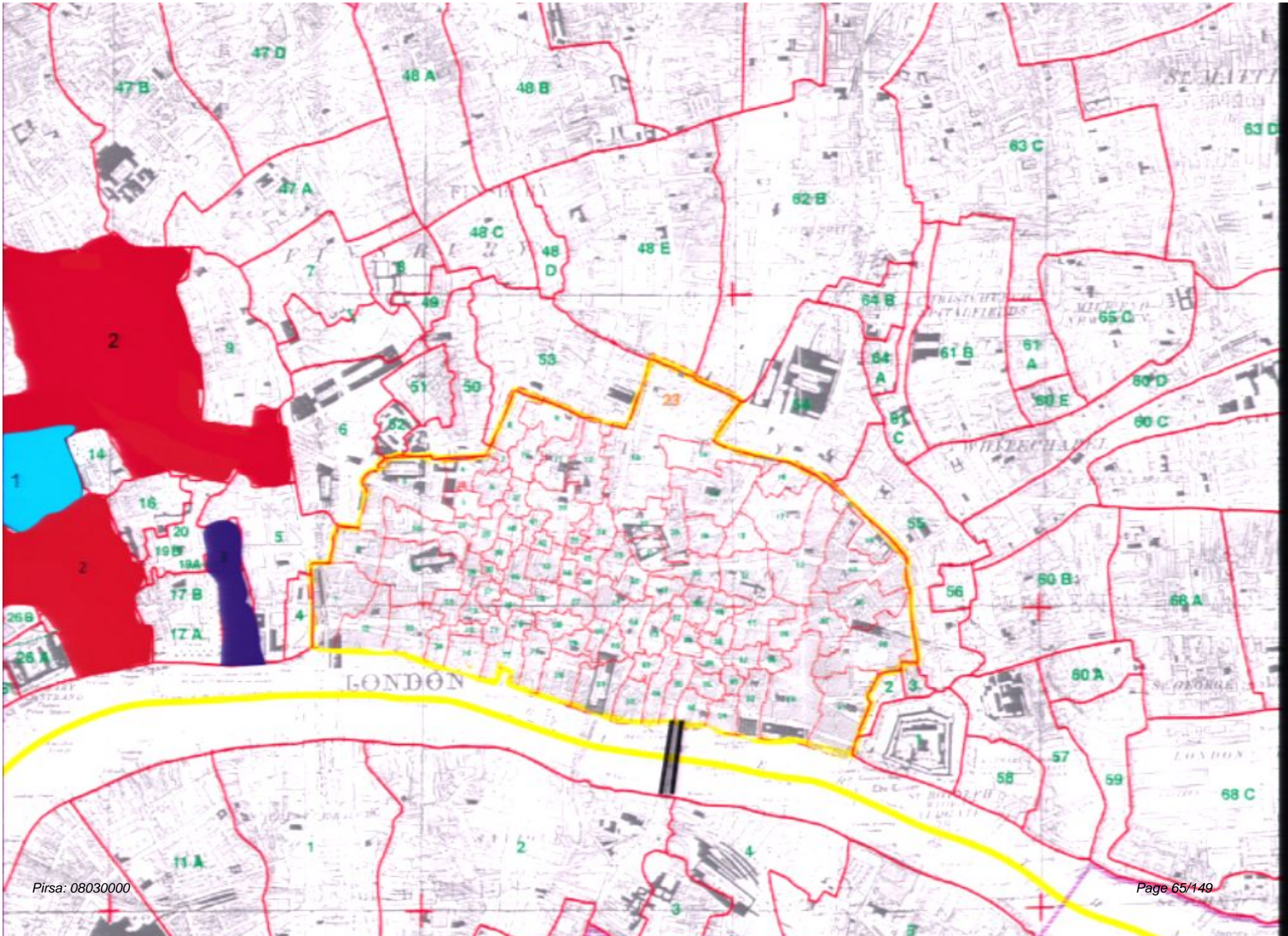


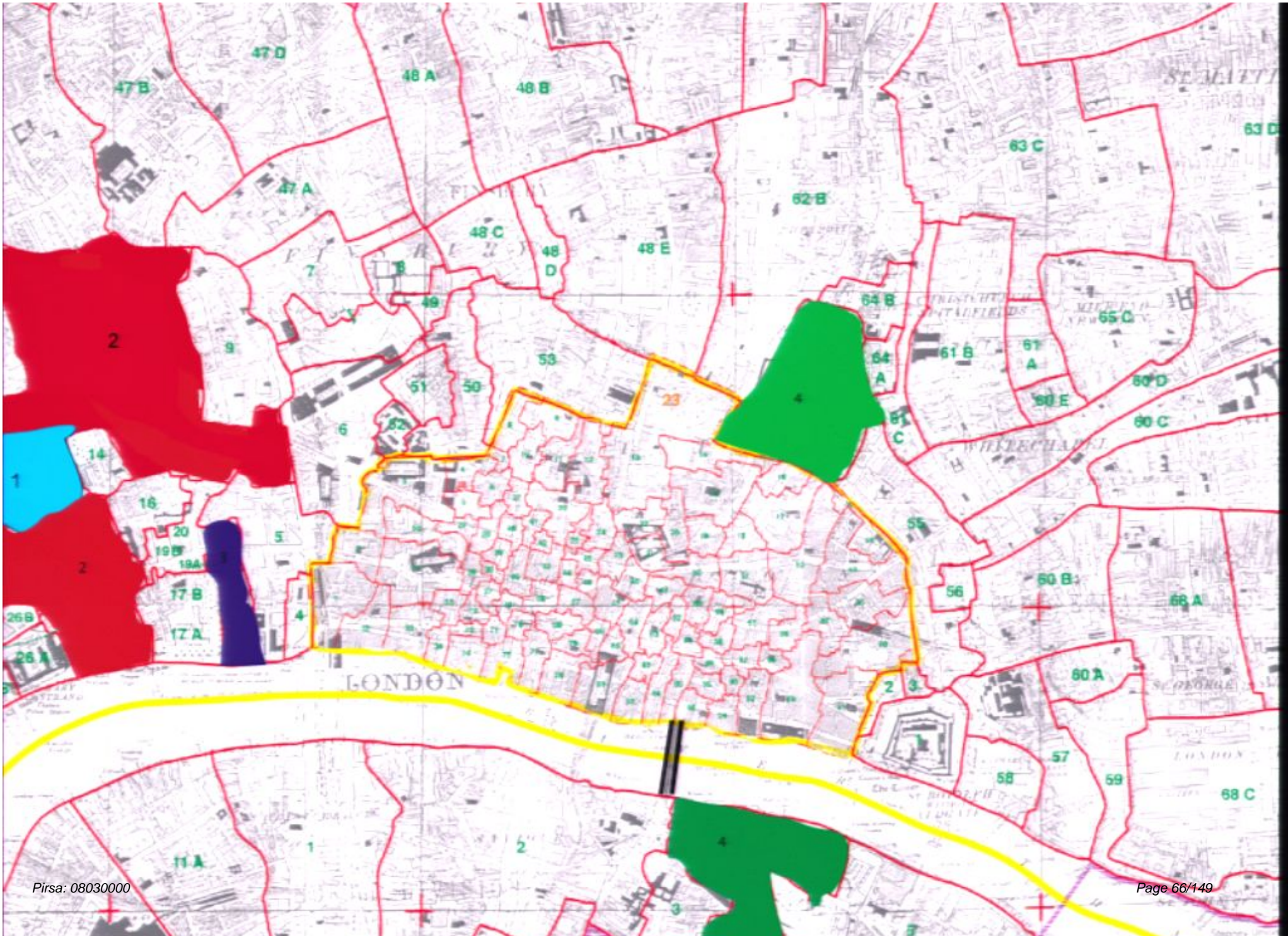


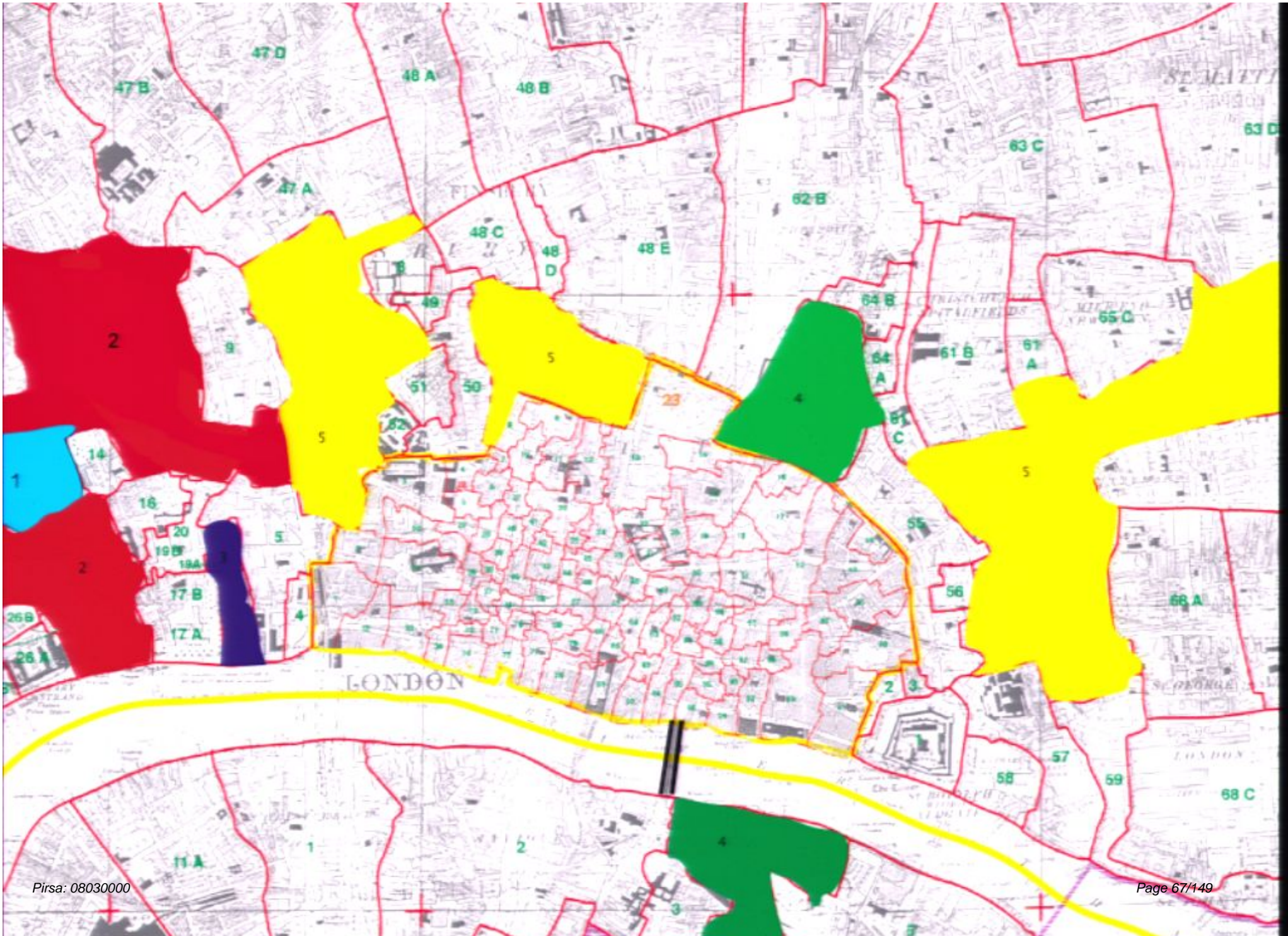


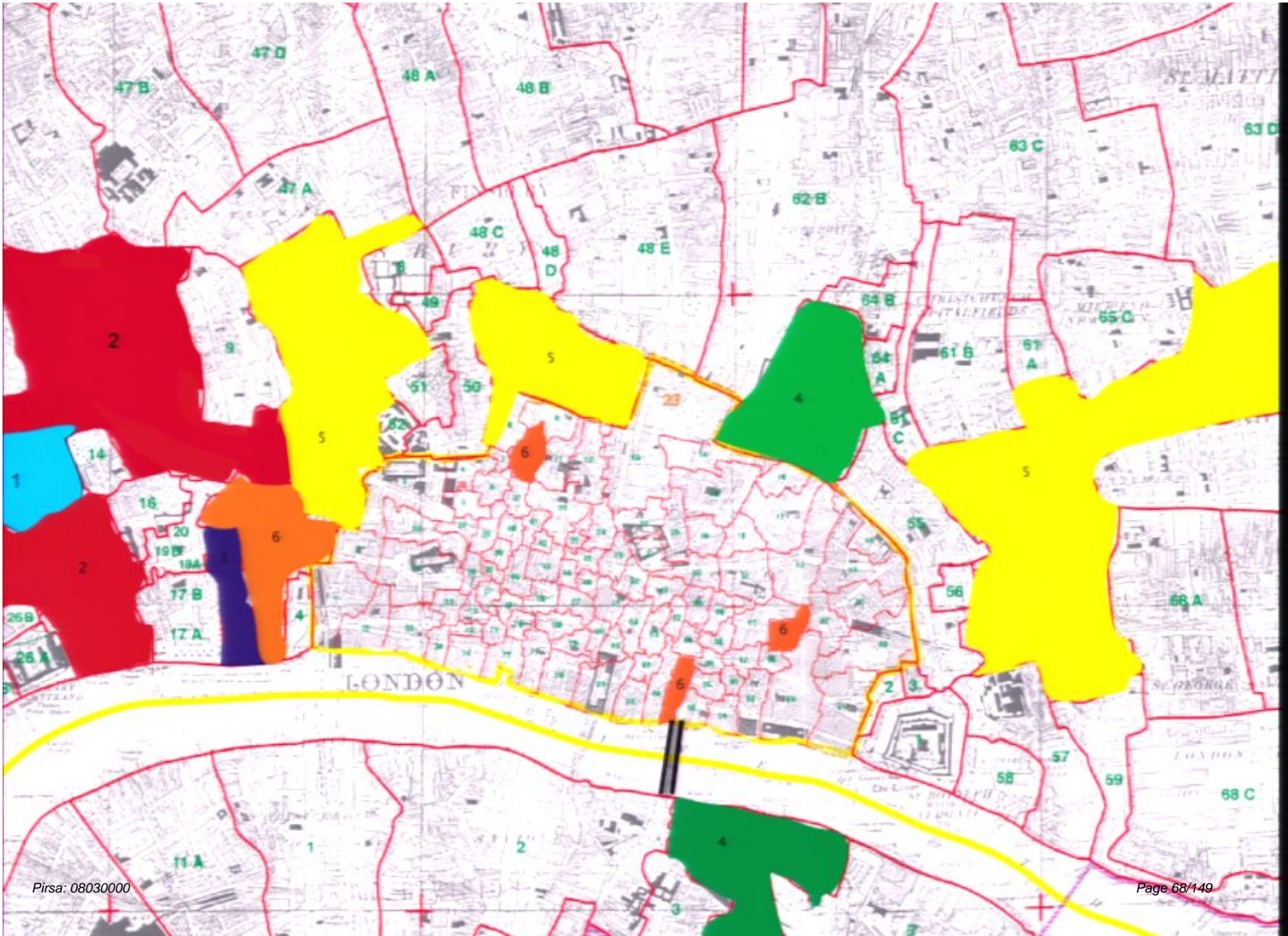


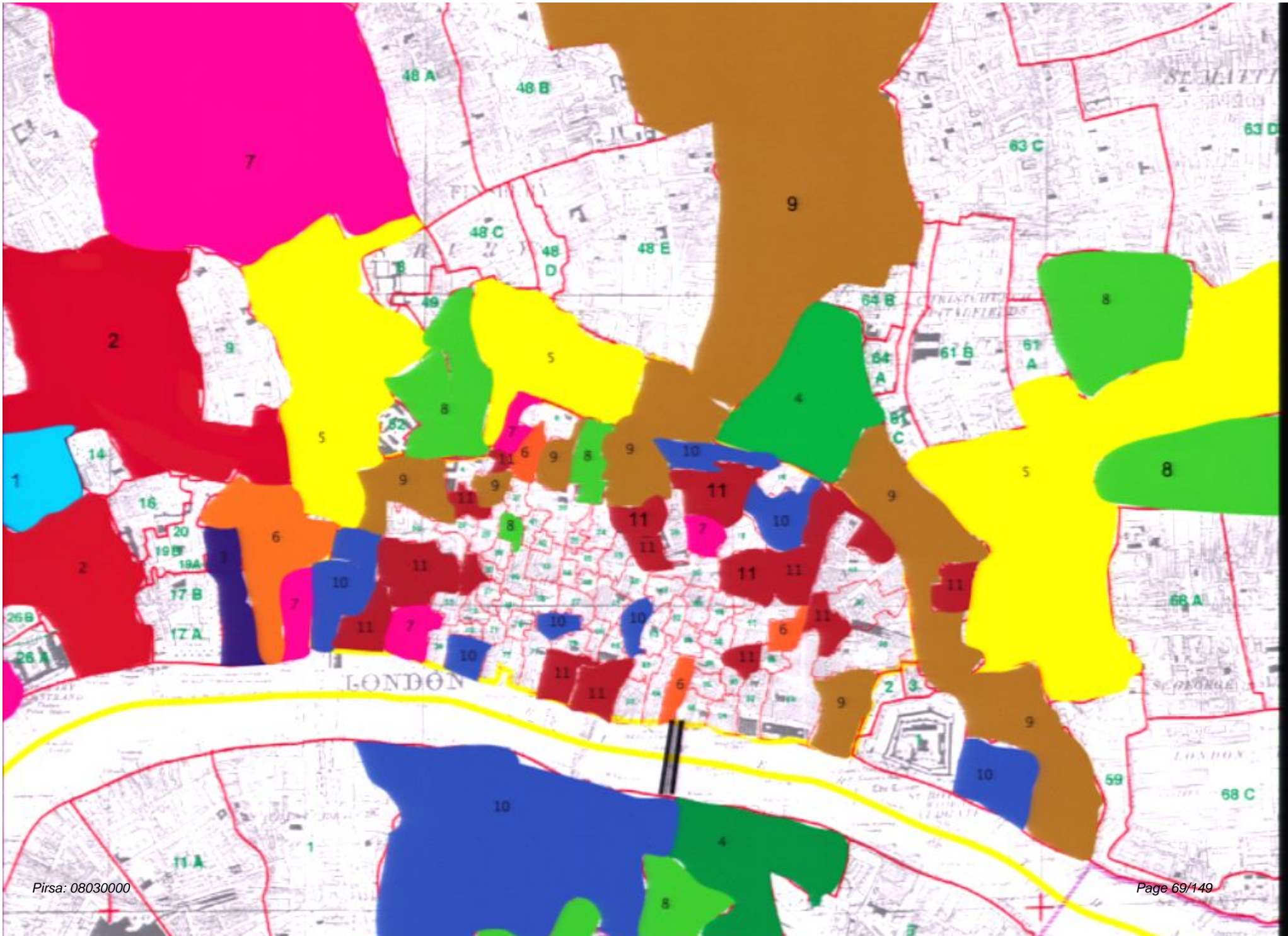


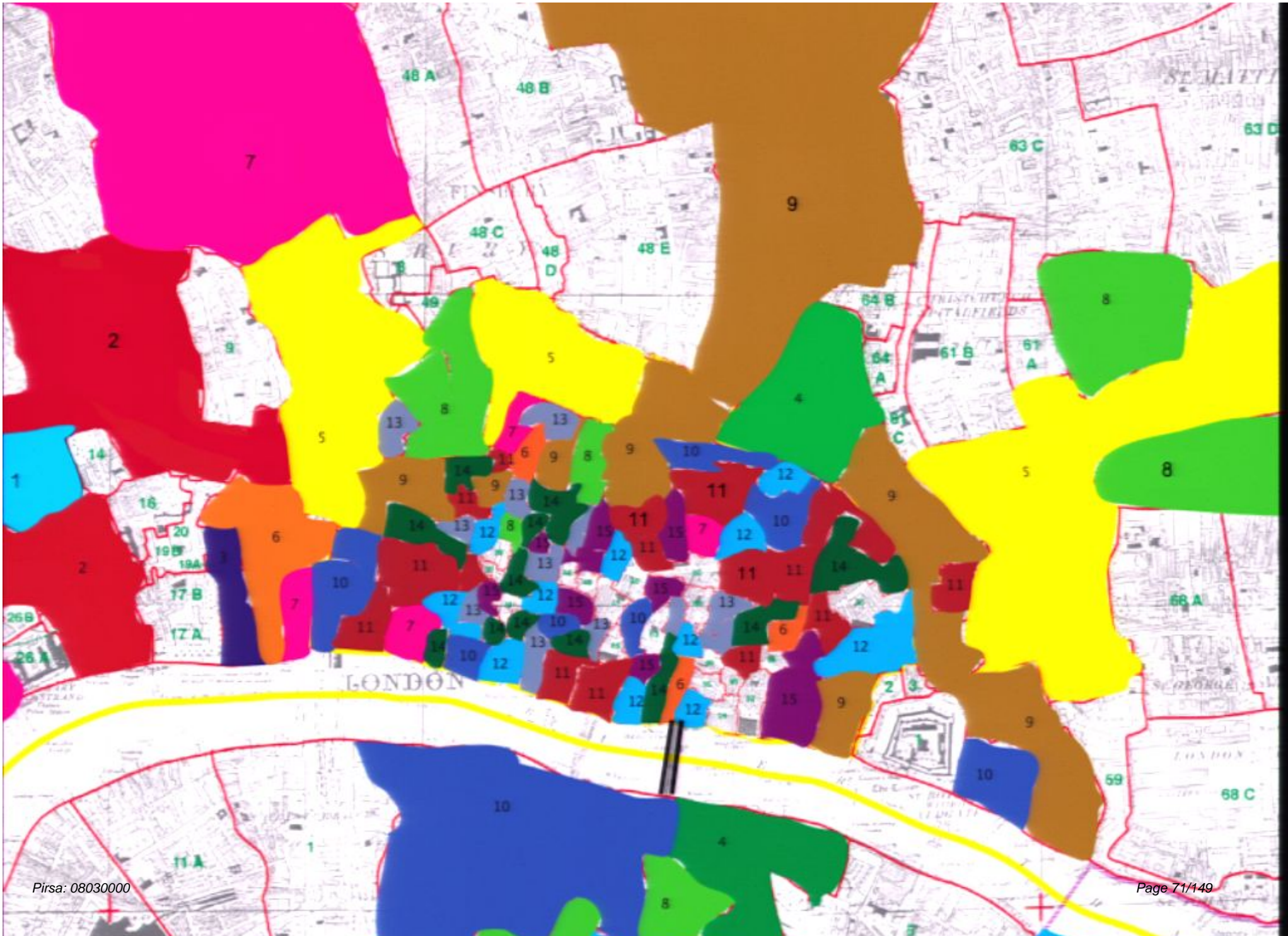












More detailed visualization

- Go beyond pattern of spatial spread
- Magnitude of epidemic in each parish
- Visualize full spatial epidemic structure

More detailed visualization

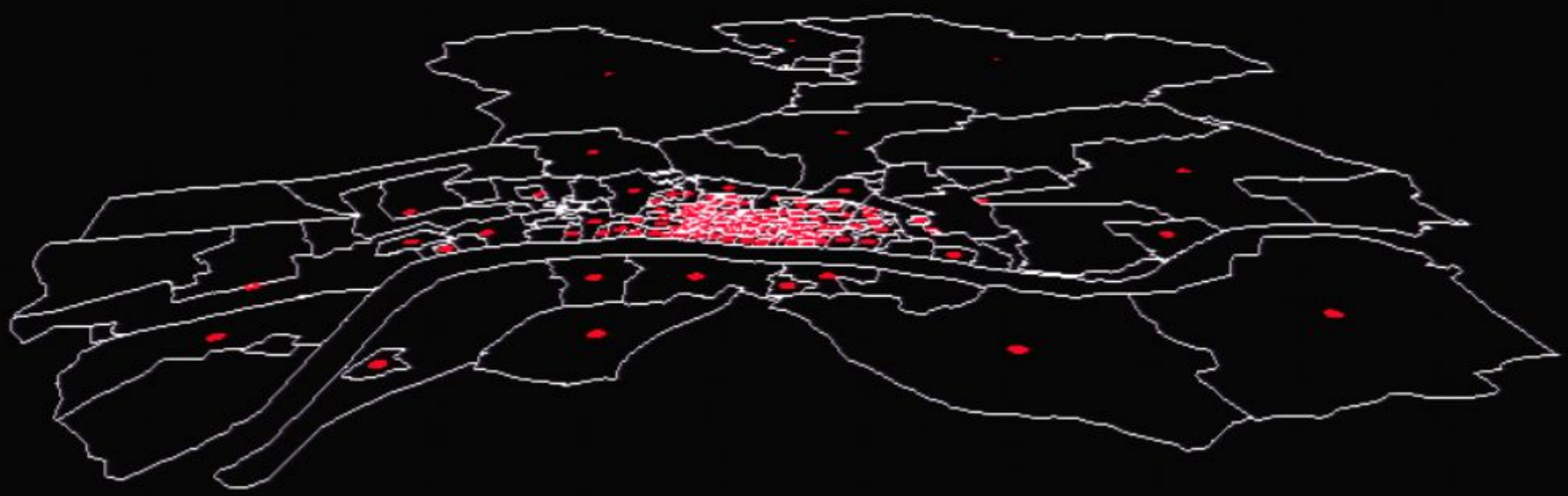
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- Magnitude of epidemic in each parish
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- For this, we have built a generic visualization tool for spatio-temporal ecological data...



Frame rate: 10

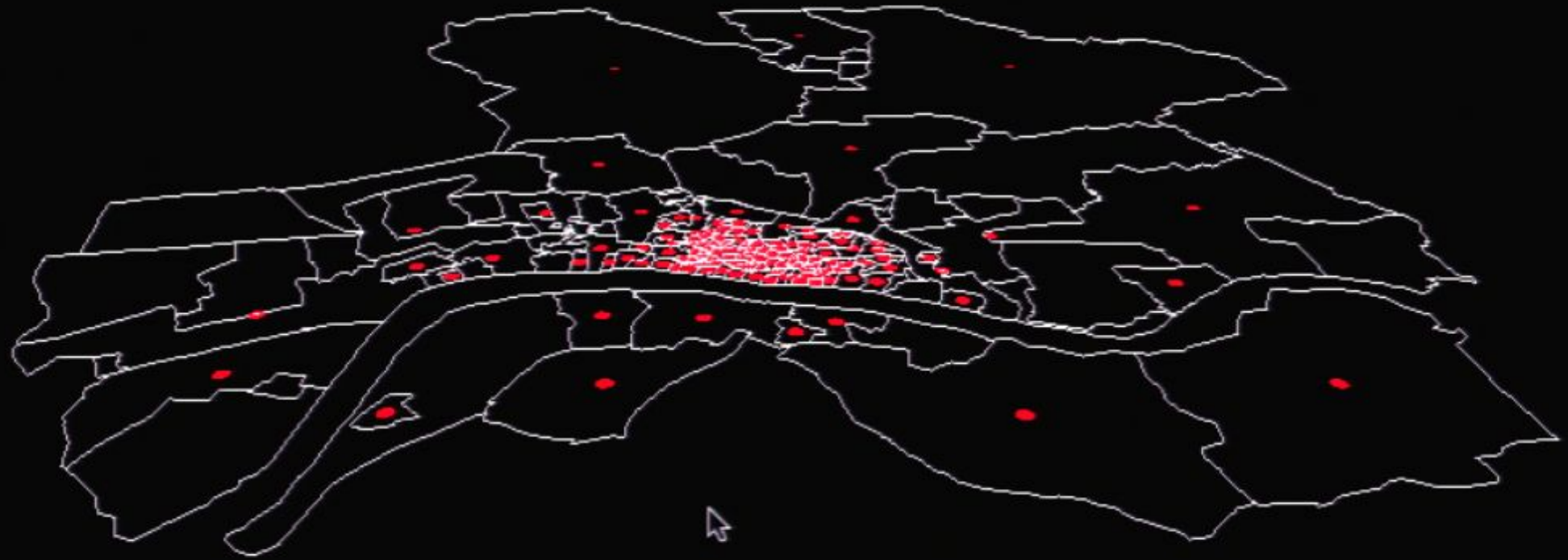
Dec 21, 1664





Frame rate: 10

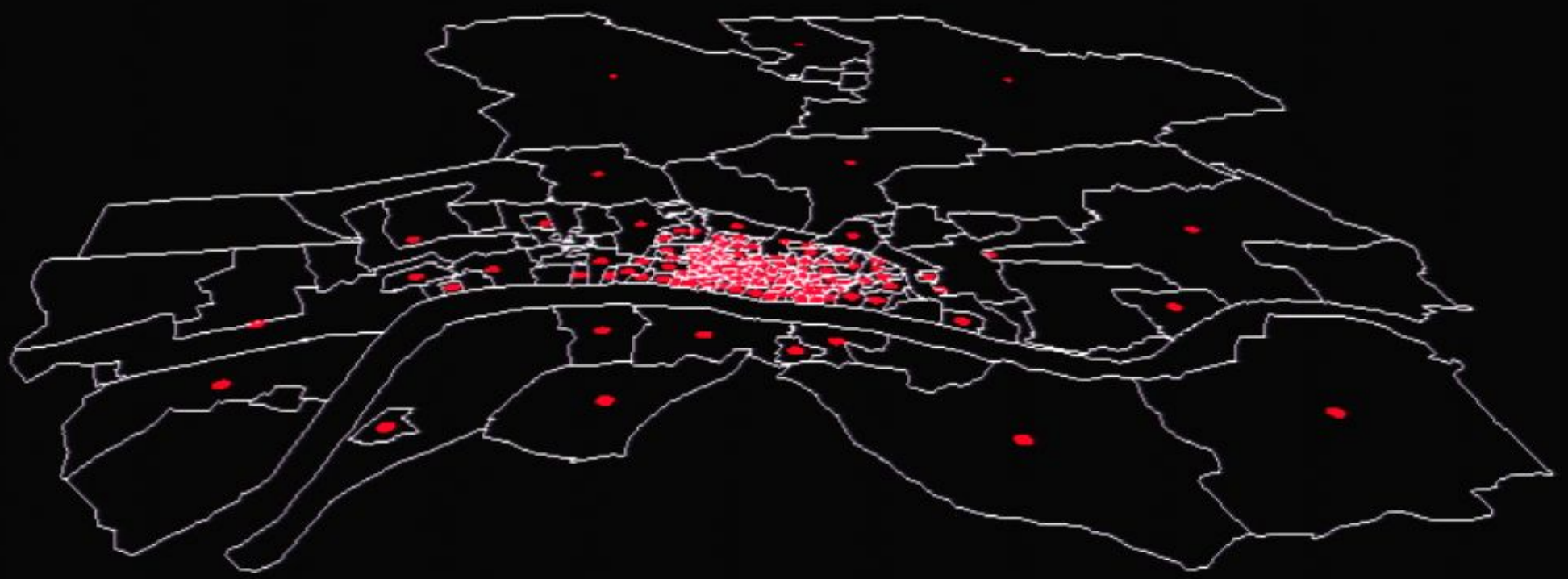
Dec 21, 1664





frame rate: 10

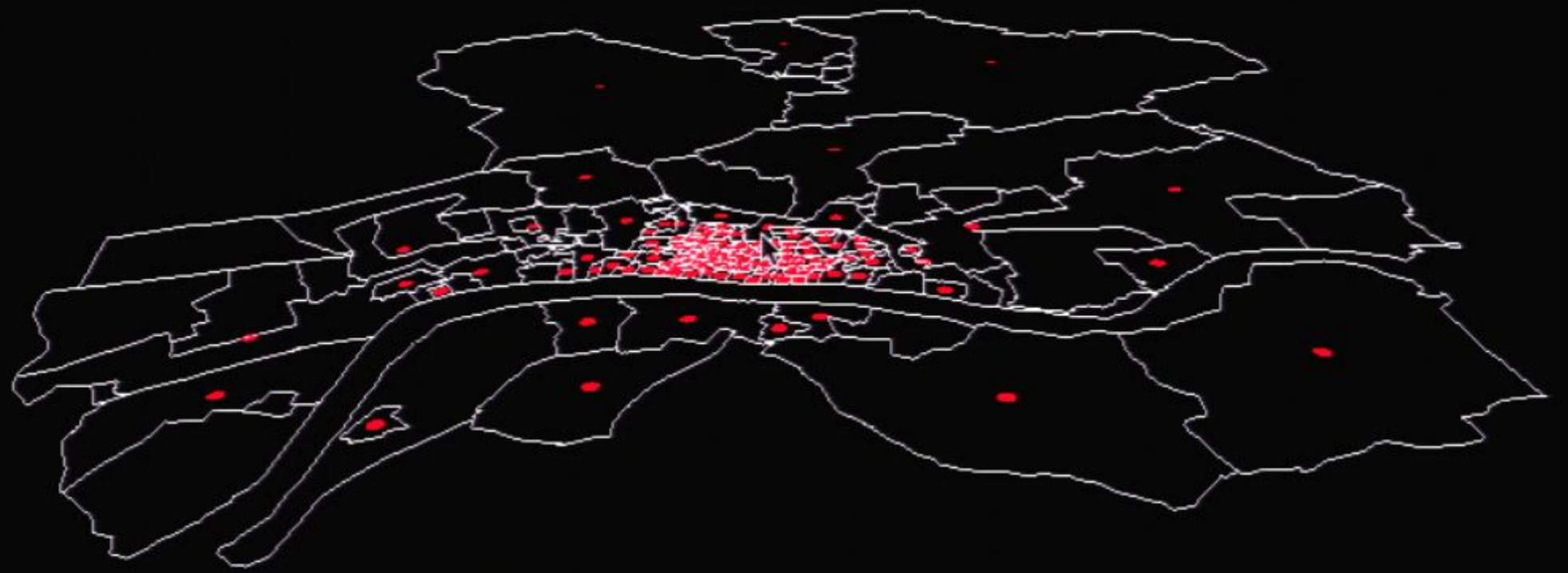
Dec 21, 1664





Frame rate: 10

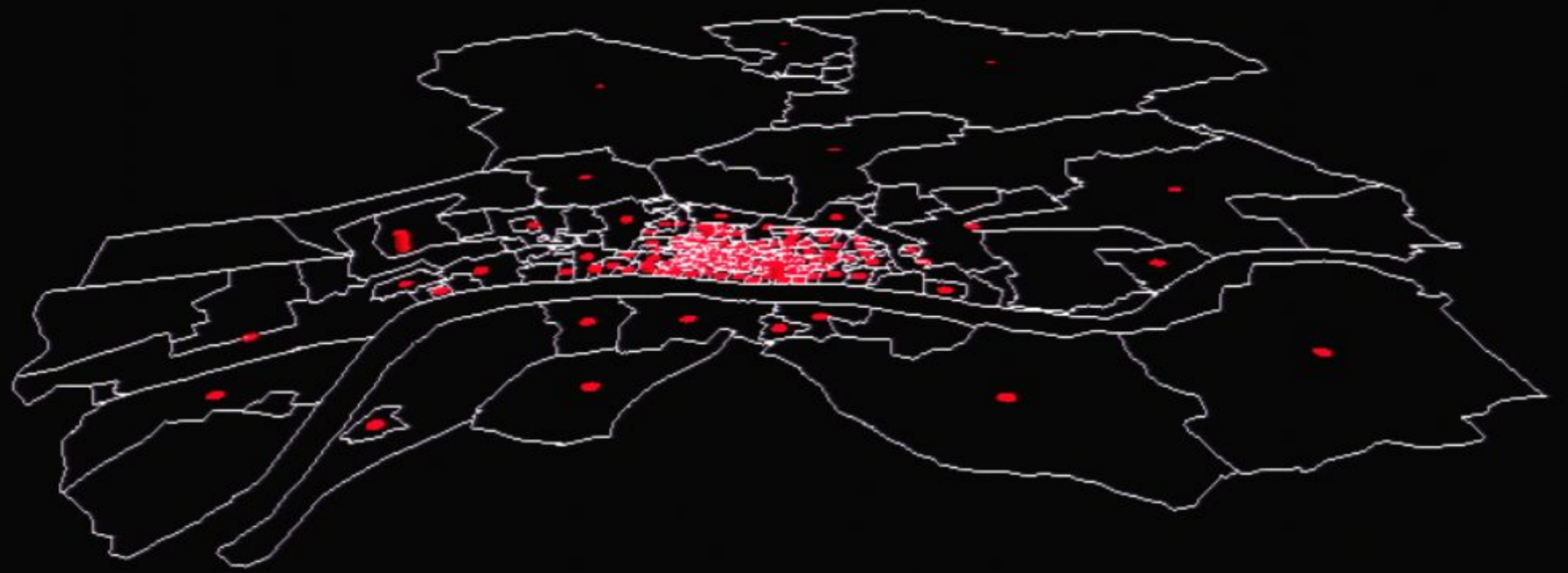
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Frame rate: 10 |

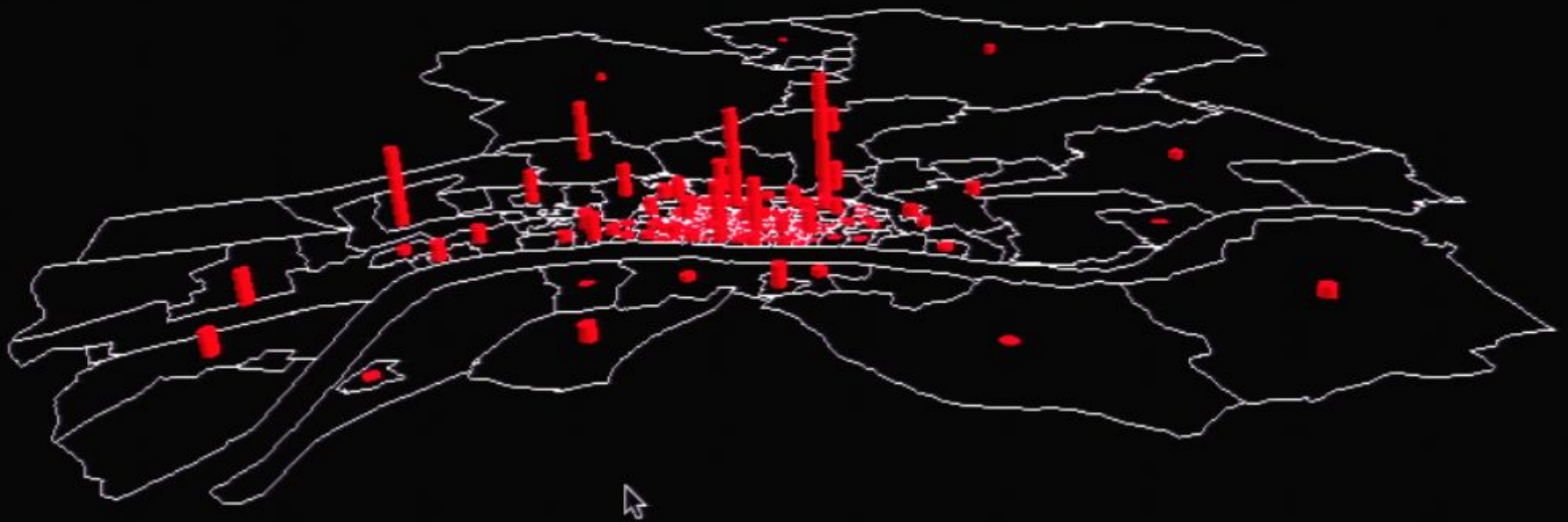
Jun 12, 1665



Game rate: 10 | [Slider]

Navigation icons: Home, Print, Settings, Camera, Mobile, Previous, Stop, Next, Full Screen, Volume, Zoom, Search

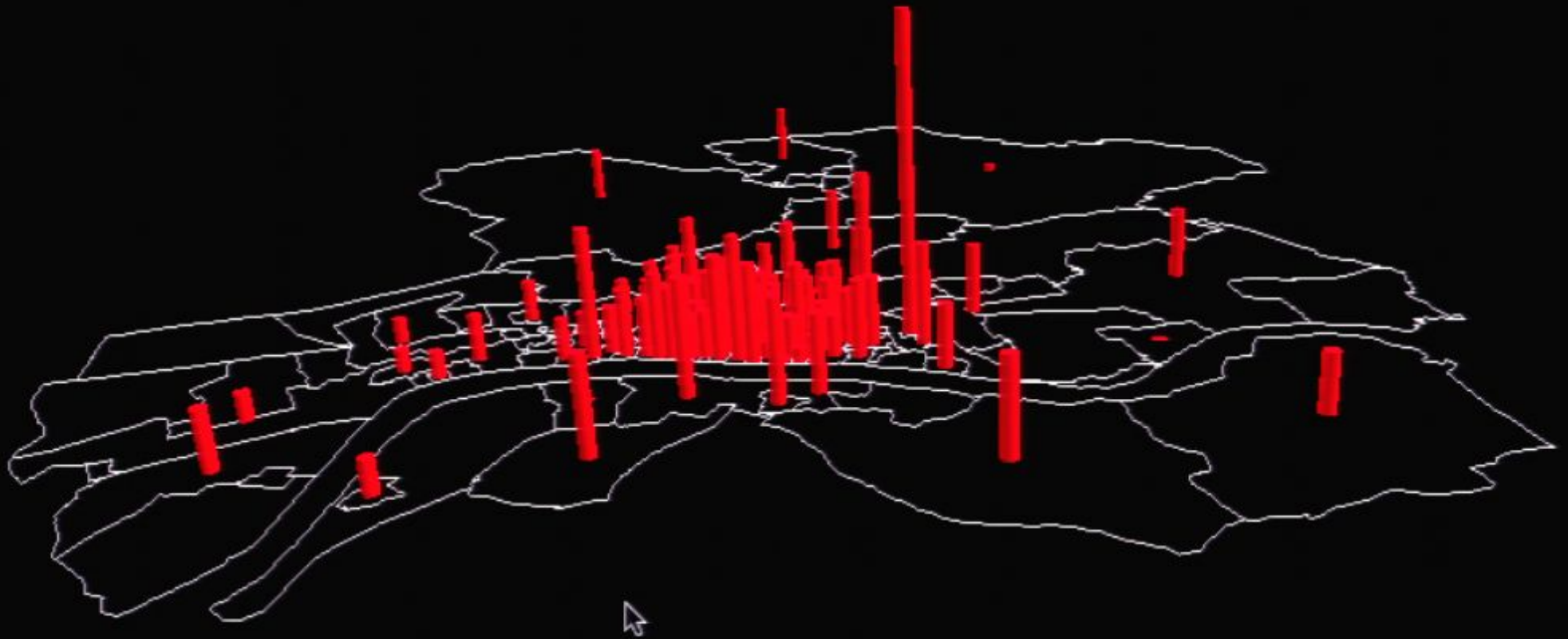
Jul 22, 1665



Game rate: 10 | [Slider]



Sep 24, 1665



Game rate: 10 | [Slider]



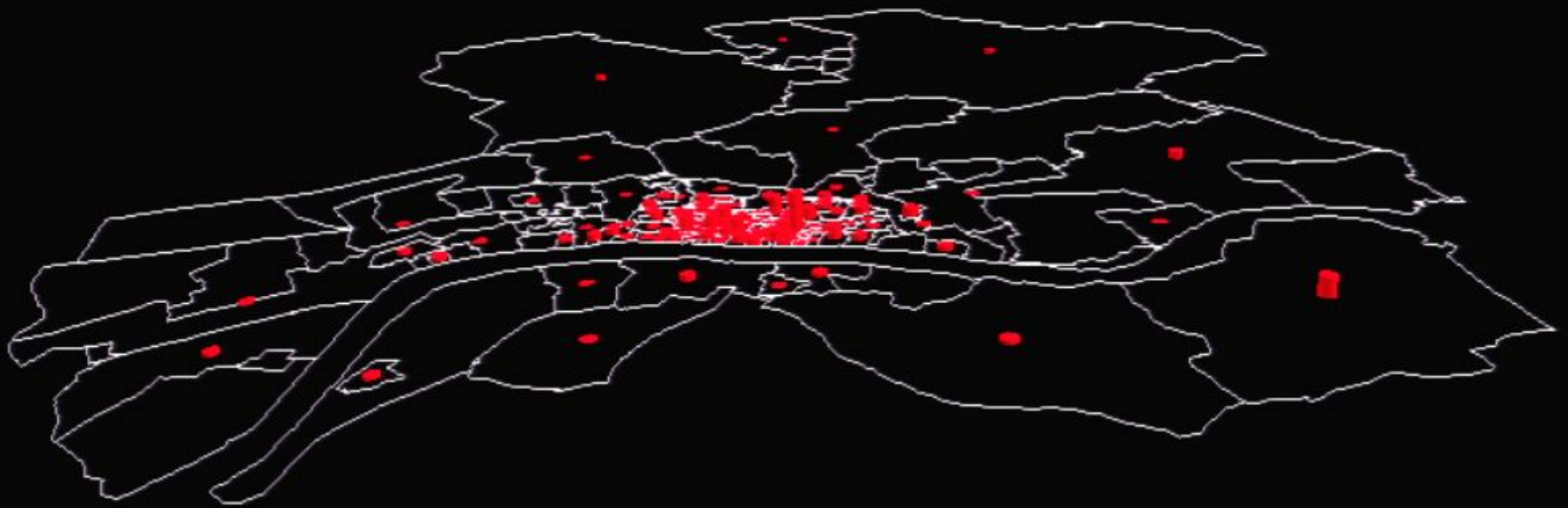
Oct 25, 1665



Game rate: 10

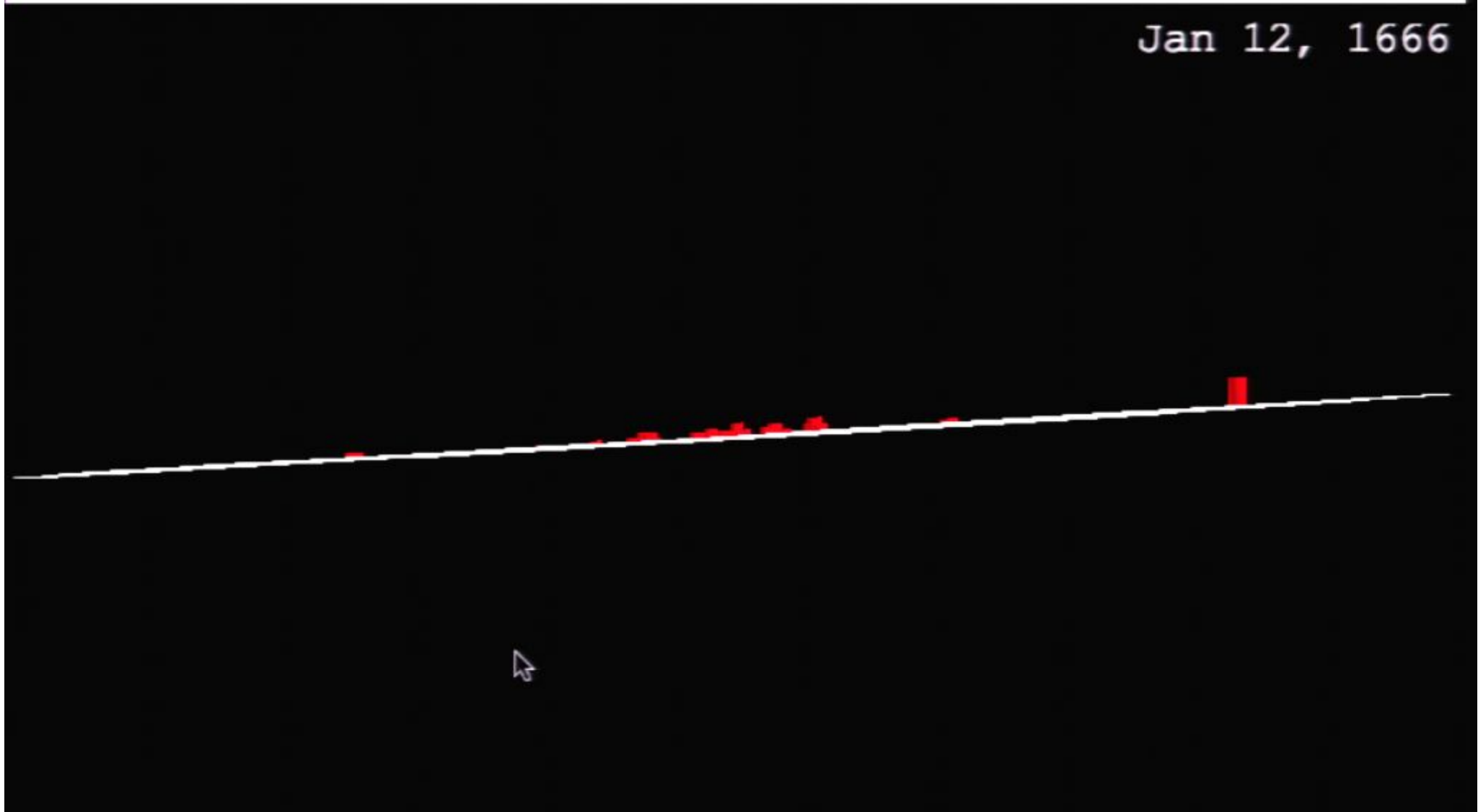


Nov 27, 1665



Navigation toolbar with icons for home, print, settings, camera, video, back, forward, play, stop, volume, zoom, and search. Below the icons is a 'frame rate' control with a text box containing '10' and a slider.

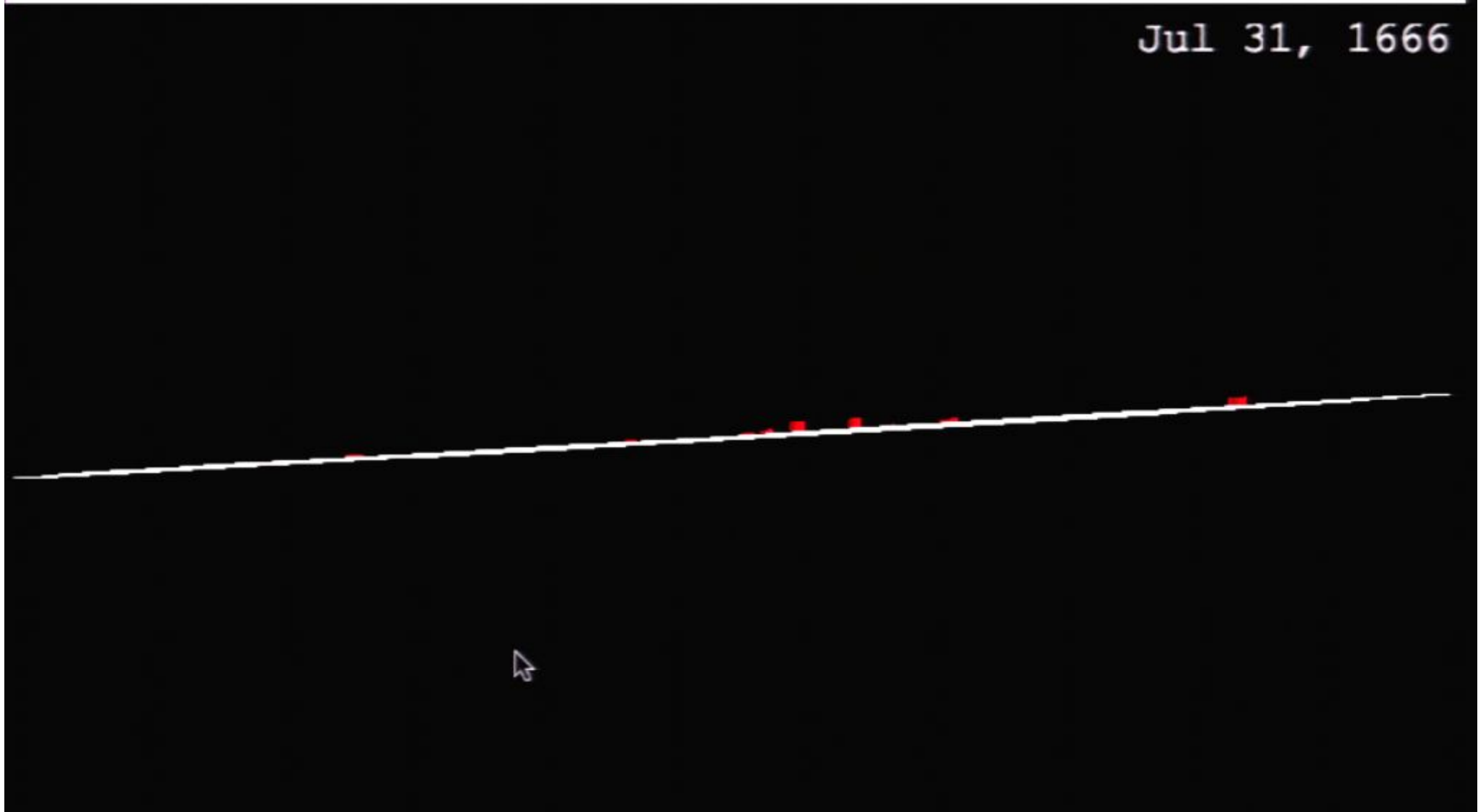
Jan 12, 1666



Game rate: 10



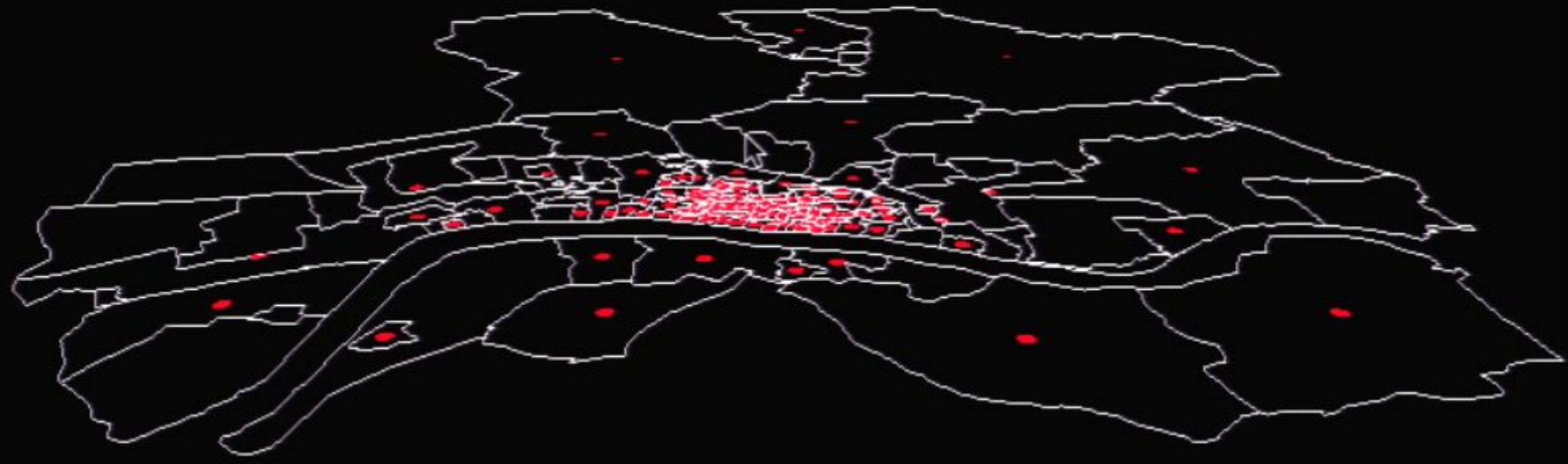
Jul 31, 1666



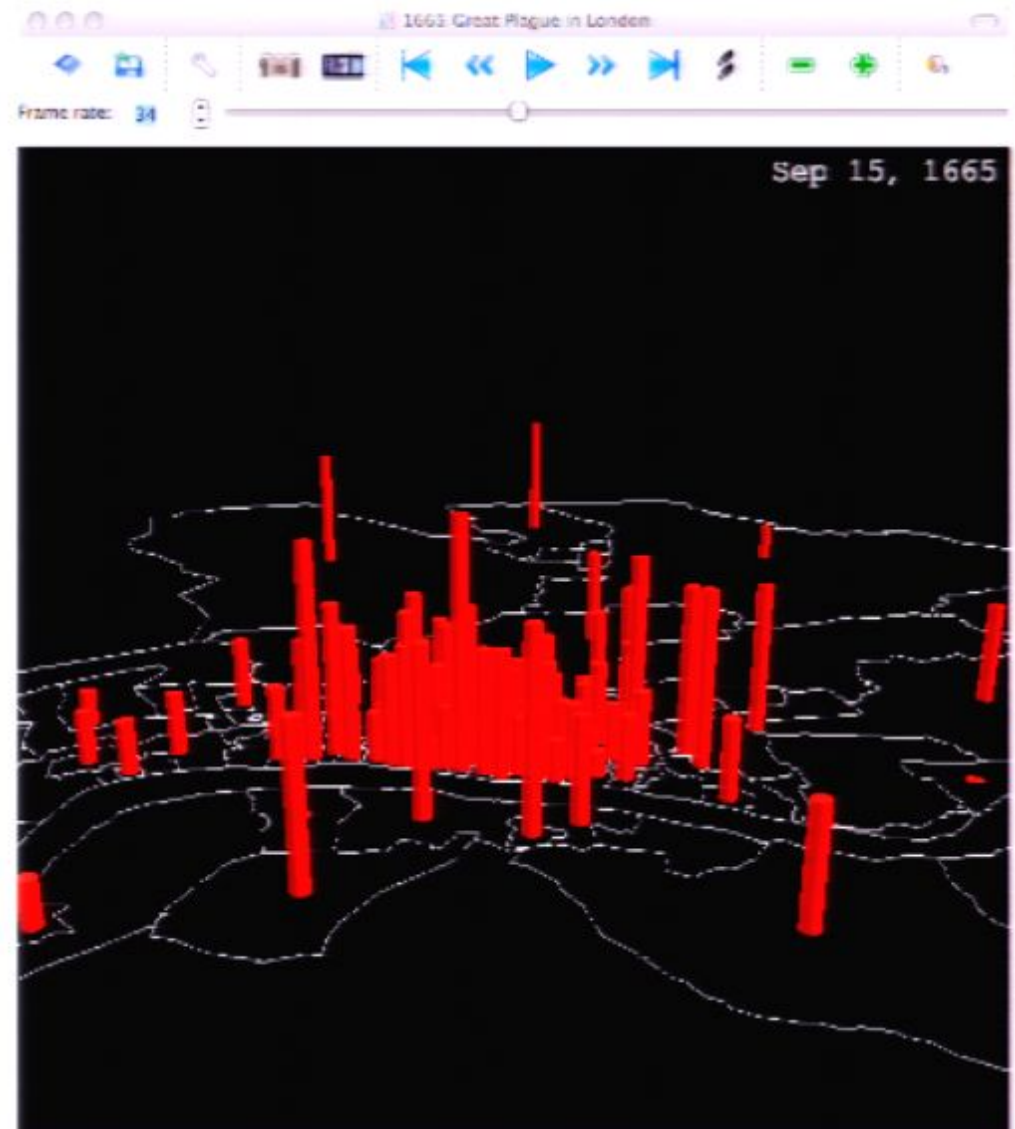
Game rate: 10 | [Slider]



Dec 18, 1666



Epidemic visualization



Work in progress...

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- What is the structure (and speed) of the wave that encroaches on the city centre?
 - Is it consistent with bubonic plague? rat transmission?

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- What is the structure (and speed) of the wave that encroaches on the city centre?
 - Is it consistent with bubonic plague? rat transmission?
- Can we successfully reproduce the spatial dynamics by simulating a transmission model?
 - Does this yield constraints on disease properties? mixing patterns?

The Great Plague of London in 1665

- Location
- Data sources
- Temporal pattern
- Spatial pattern
- **Transmissibility**

Transmissibility of the Great Plague of London

- The quantity of interest is the basic reproductive ratio R_0
 - Average number of secondary cases from a given primary case, early in the epidemic
- No case pedigrees, so must estimate indirectly
 - Final size
 - Growth rate

Before we go on...

- What is your guess for the value of R_0 for the Great Plague of London?

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- What is your guess for the value of R_0 for the Great Plague of London?
- A few standard estimates
 - Malaria: $R_0 \sim 20 - 100$
 - Measles: $R_0 \sim 17$
 - Whooping Cough: $R_0 \sim 15$
 - Smallpox: $R_0 \sim 4$
 - Influenza: $R_0 \sim 2 - 8$
 - SARS: $R_0 \sim 2$

Estimating R_0 from final size

- Simplest method is to exploit relationship between basic reproductive ratio (R_0) and final size (Z) of epidemic:

$$Z = 1 - e^{-R_0 Z}$$

[Kermack & McKendrick 1927]

- 20% of population died, so:

$$Z \geq 0.2 \quad \Rightarrow \quad R_0 \geq 1.12$$

- This at least gives a lower bound (assuming the pathogen was human-to-human transmissible)

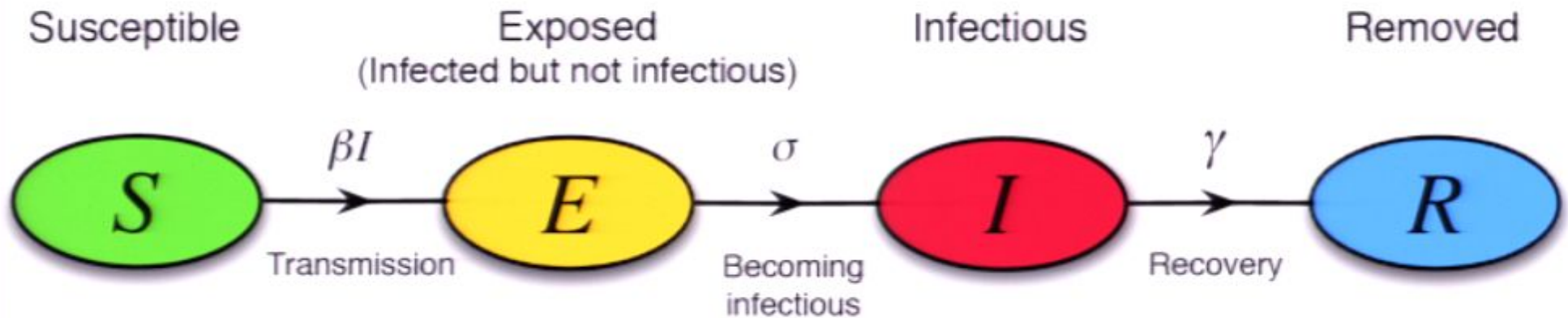
Estimating R_0 from growth rate

- We first estimate the epidemic's exponential growth rate λ
 - Get λ by fitting straight line to $\log(\text{deaths})$
 - Do this separately for each parish
 - Use distribution of fitted growth rates to get confidence interval on "true λ "
 - Find $\lambda = 20 \pm 6$ / year
 - What about confidence intervals on λ in each parish?
 - Bootstrap method? Other ideas?

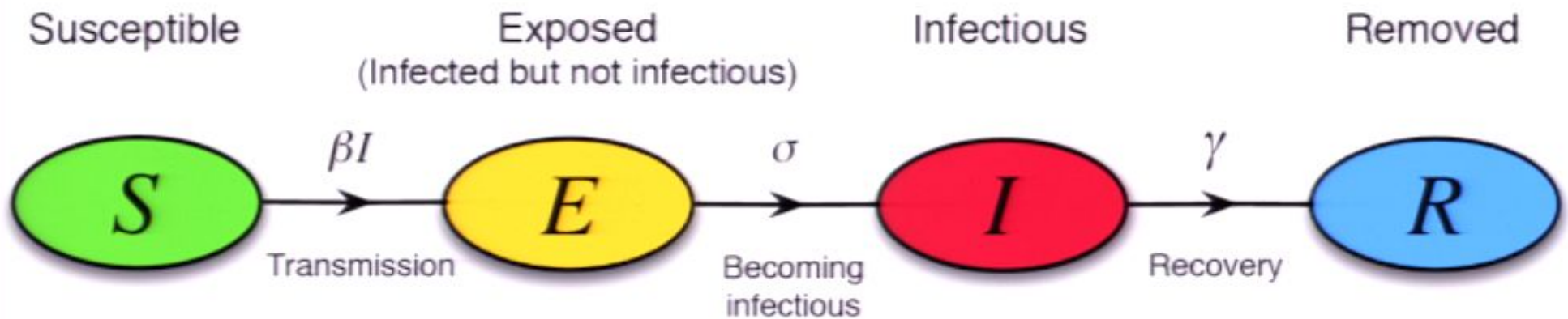
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- We then use a transmission model to express R_0 in terms of λ and various disease parameters

SEIR Model of Infectious Disease Transmission



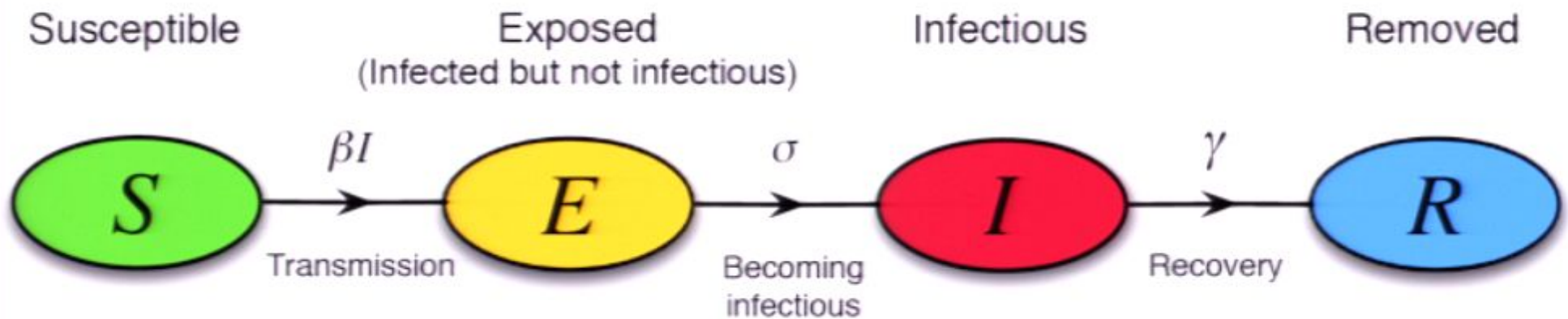
SEIR Model of Infectious Disease Transmission



Can express R_0 in terms of:

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- Mean latent period T_{lat}
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SEIR Model of Infectious Disease Transmission



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Unfortunately unknown!

From growth rate λ to reproductive number R_0

- In fact, the relationship depends only on the serial interval distribution, regardless of the detailed structure of model
 - If M is the moment-generating function for the serial interval distribution then:

$$R_0 = \frac{1}{M(-\lambda)}$$

[Wallinga & Lipsitch, 2007]

- Note that M is also the Laplace transform of the serial interval distribution

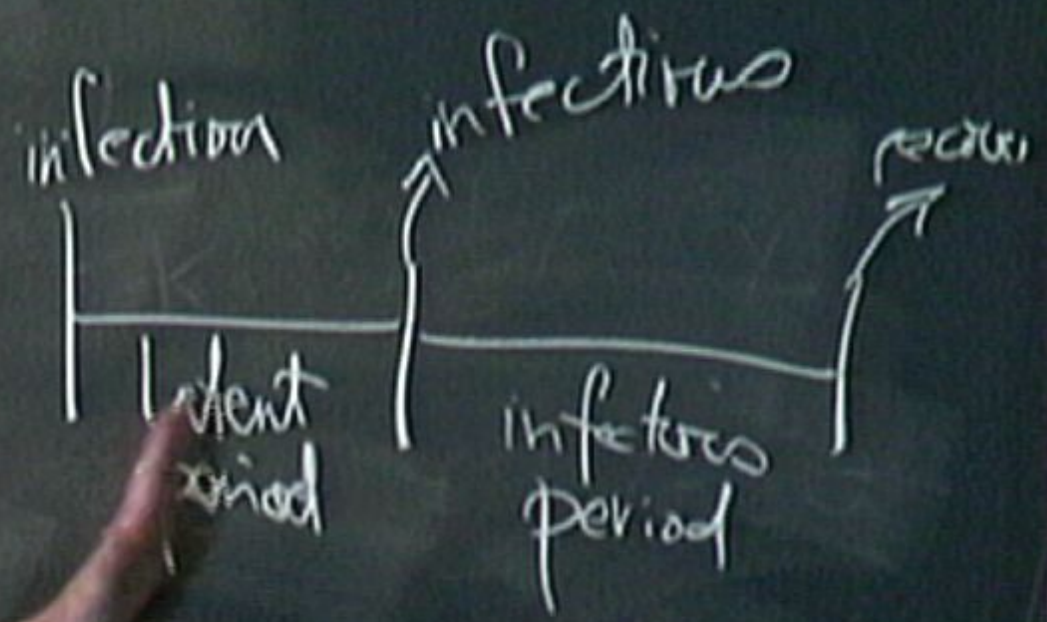
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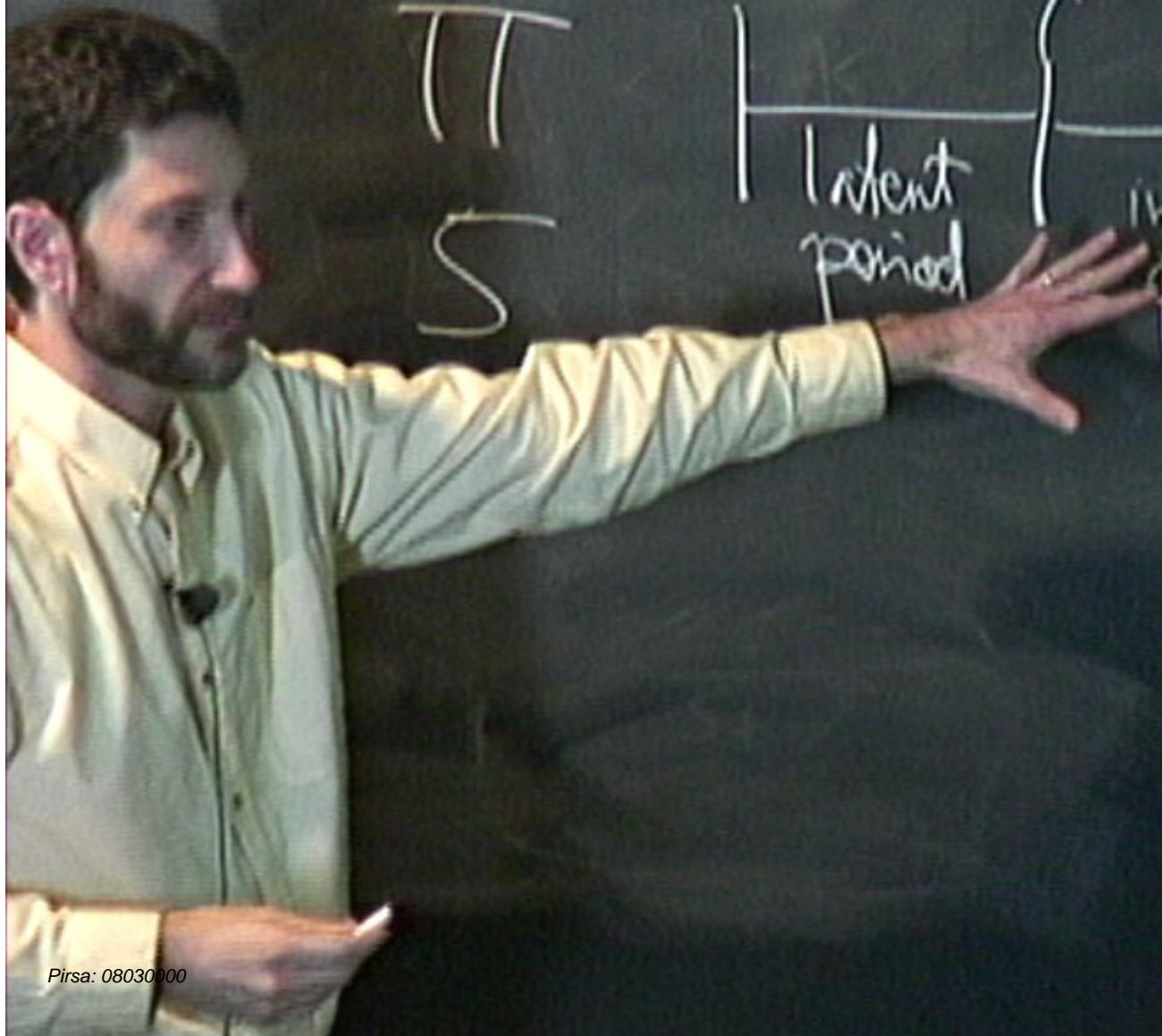
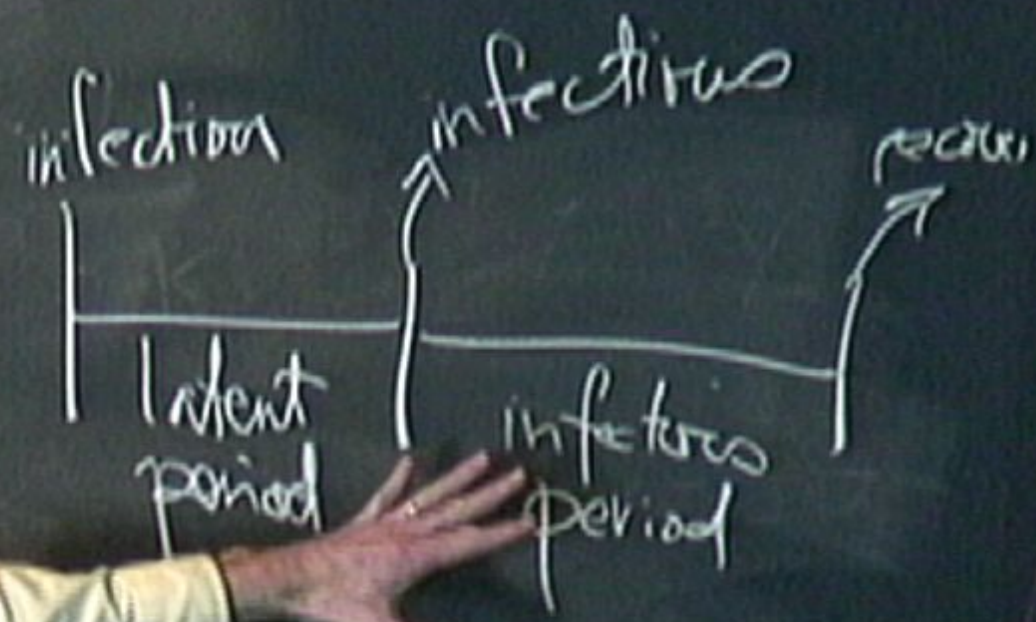
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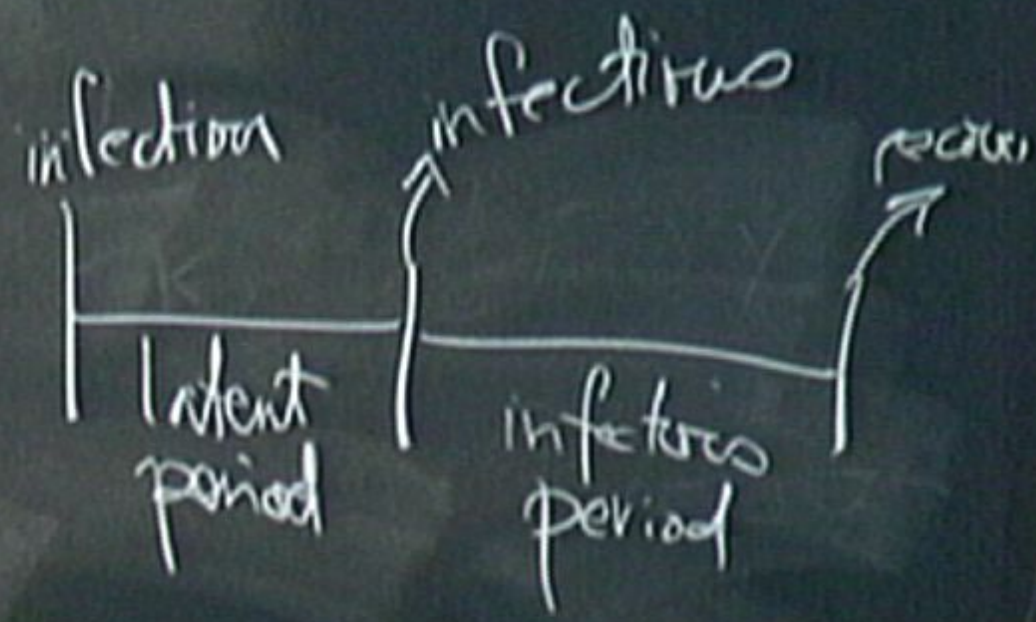
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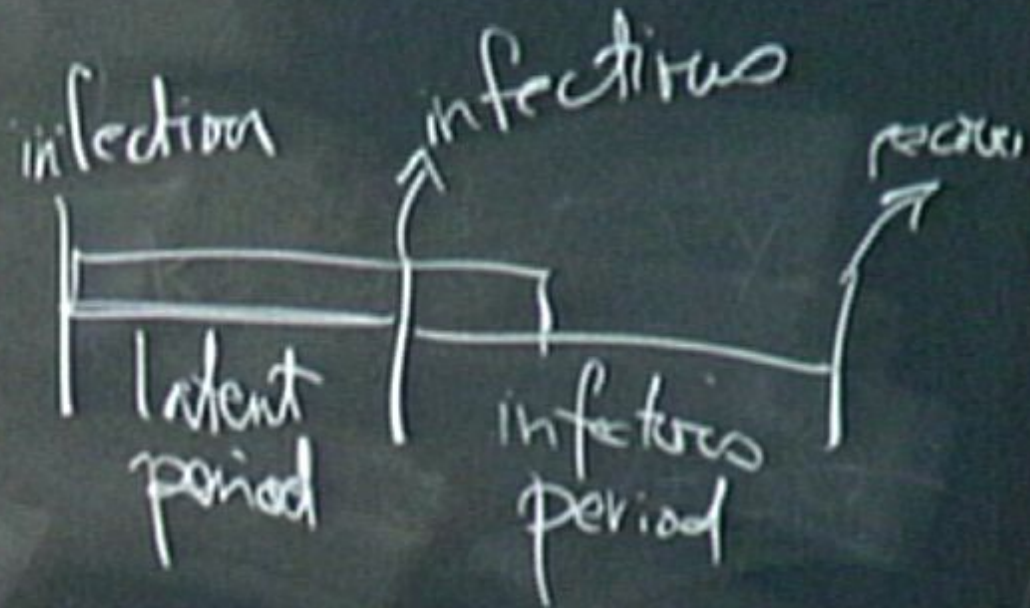
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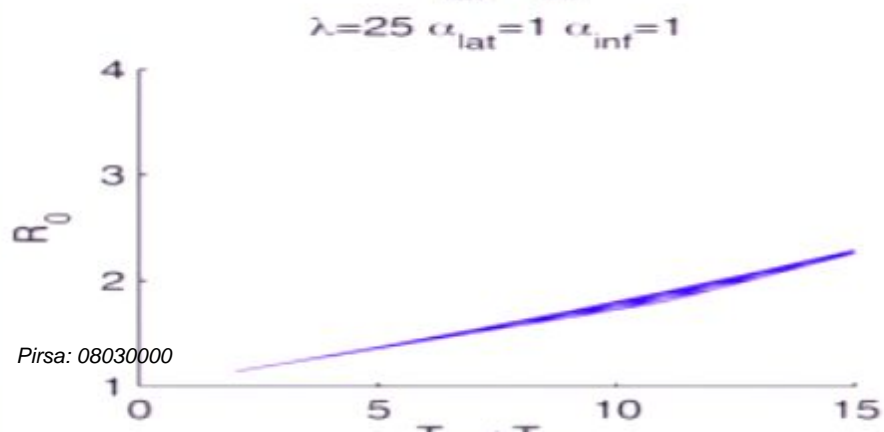
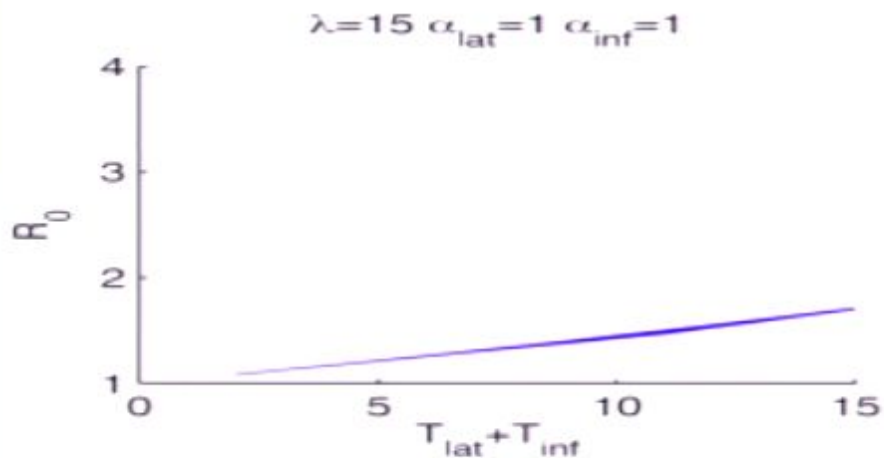
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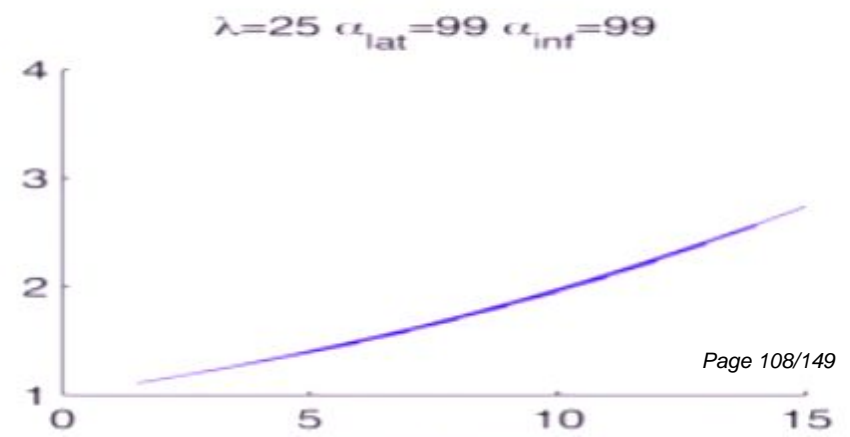
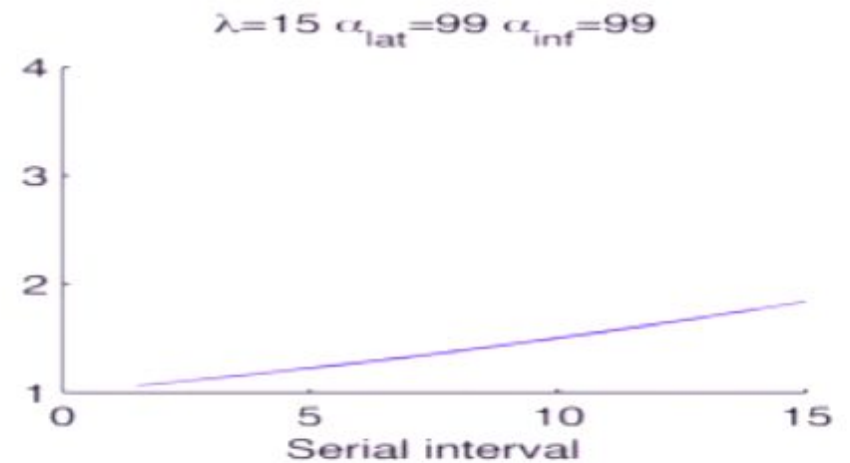
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From growth rate λ to reproductive number R_0

Exponentially distributed latent and infectious periods



Fixed stage durations



Results: R_0 for Great Plague

- For plausible serial interval distributions (mean < 2 weeks):

$$R_0 < 2$$

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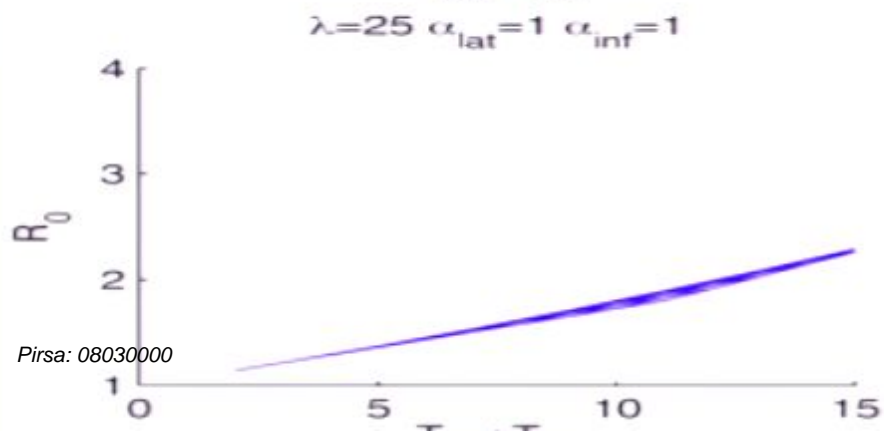
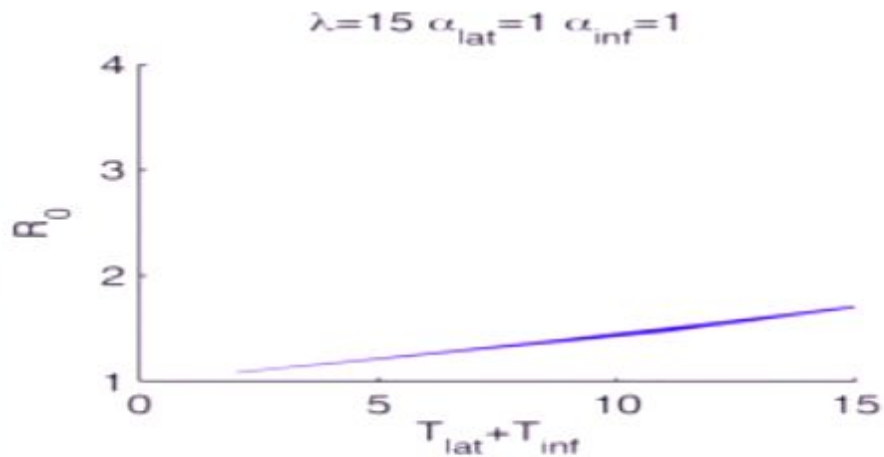
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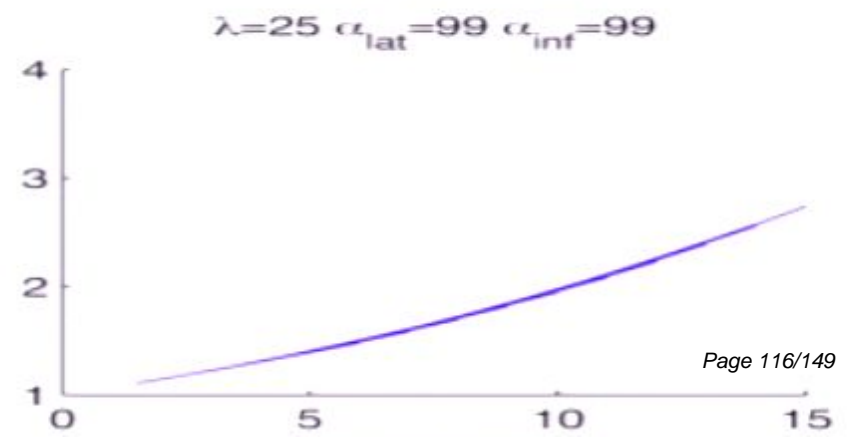
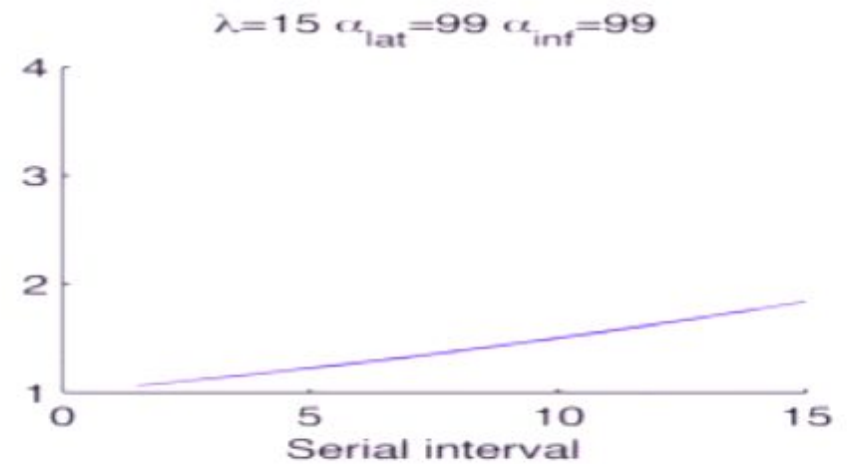
Results: R_0 for Great Plague

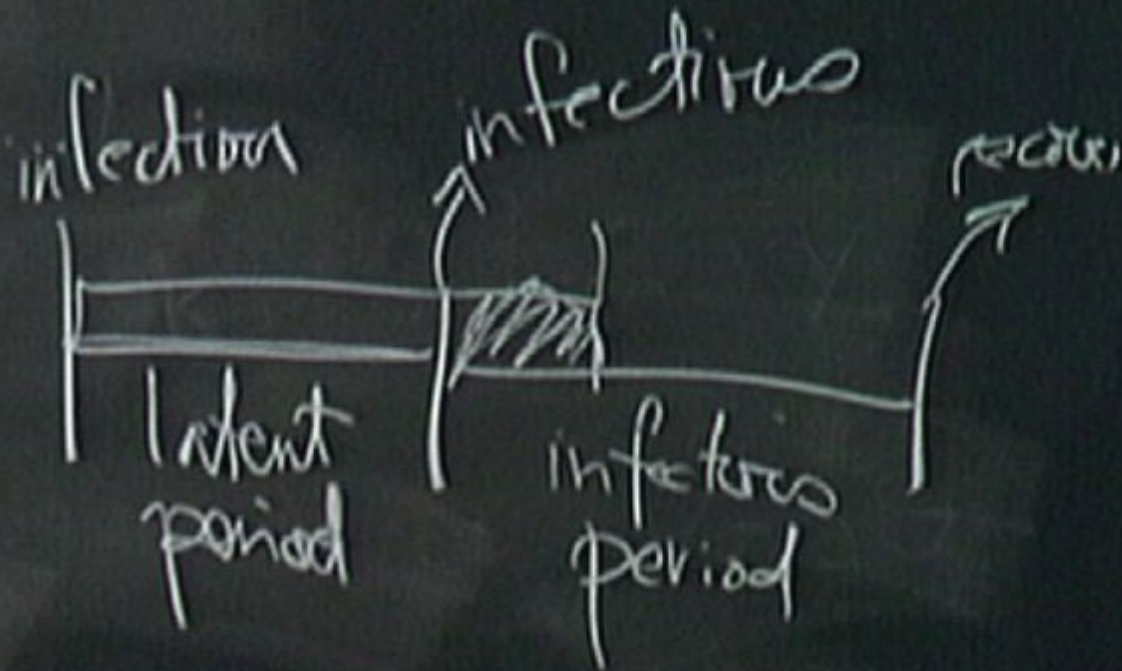
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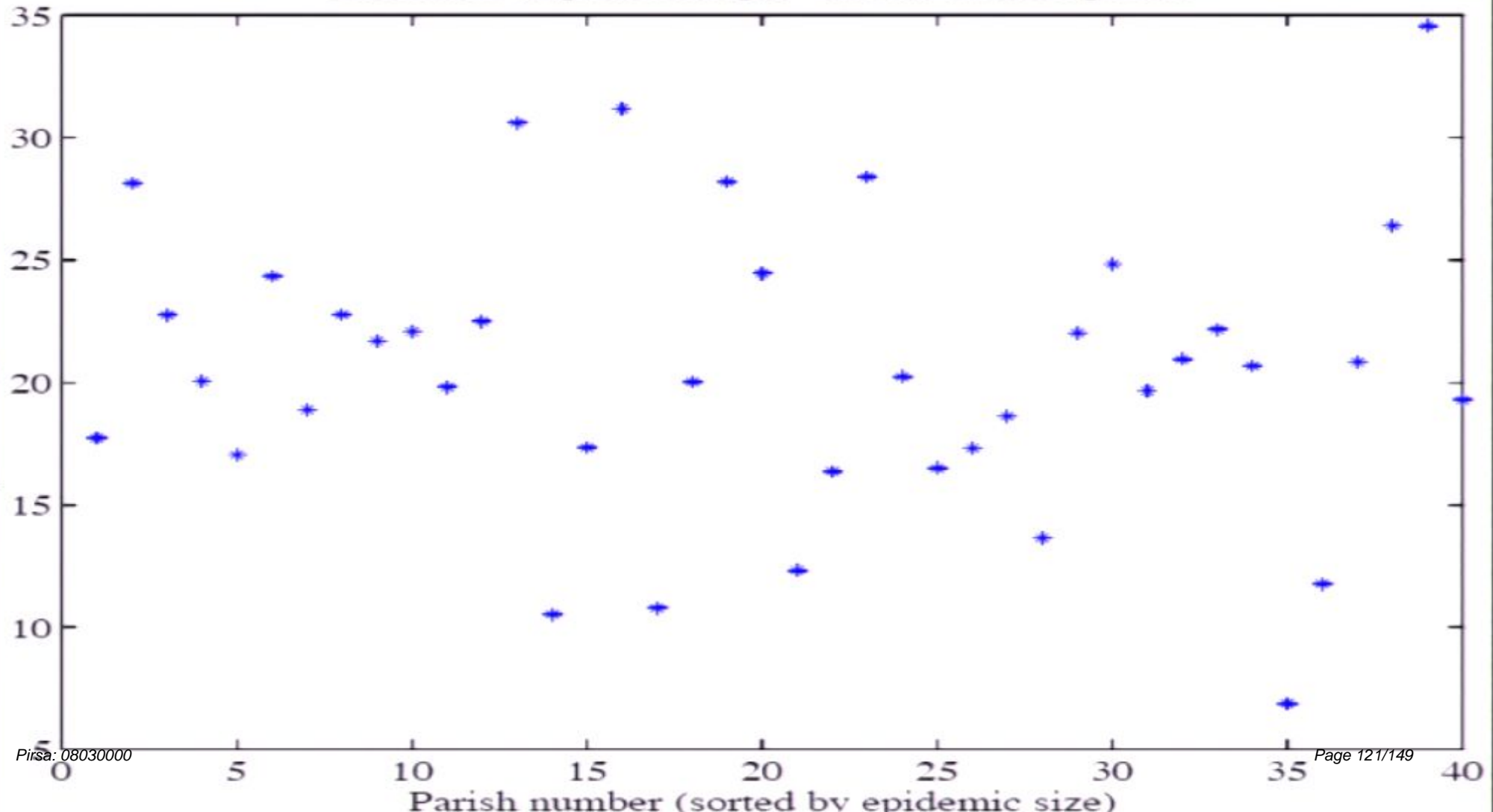
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Results: Variation in λ (or R_0)

λ versus parish epidemic size

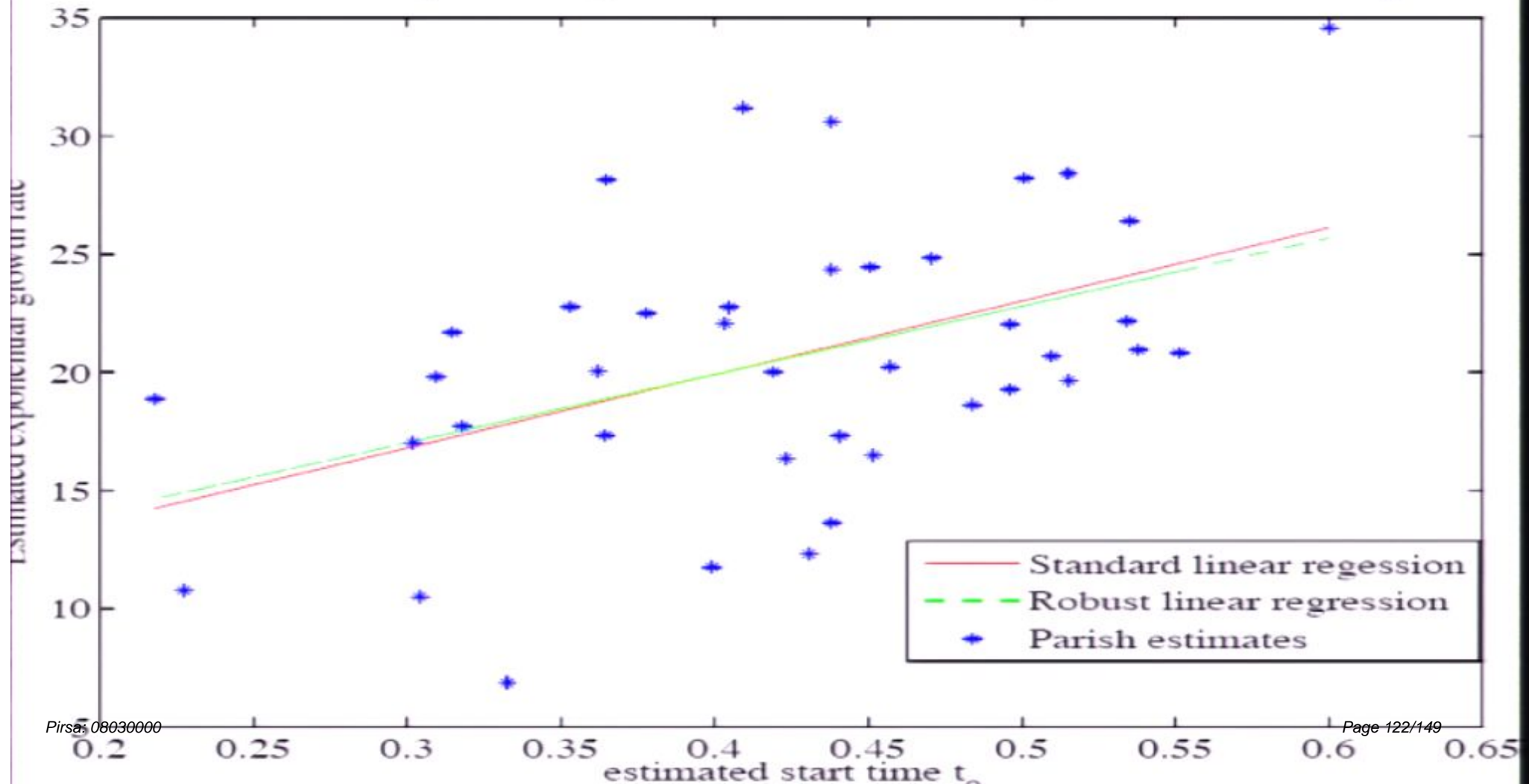
Estimated exponential growth rate in each parish



Results: Variation in λ (or R_0)

λ versus parish start time t_0

Estimated exponential growth rate vs estimated epidemic start time t_0



Results: Variation in λ (or R_0)

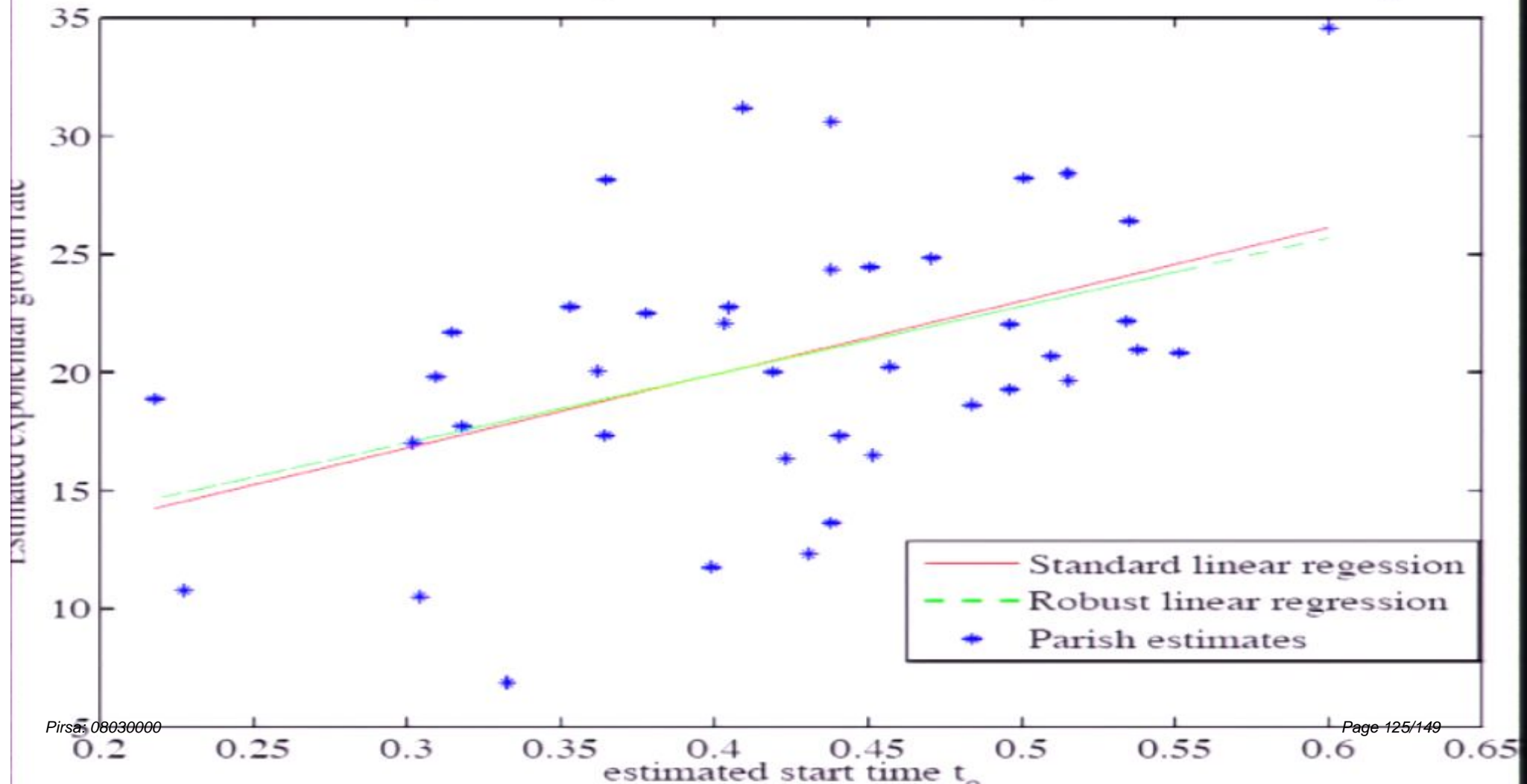
- Single linear regression: λ versus *parish start time* t_0
 - $R^2 = 0.22$, $p = 0.0022$

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Results: Variation in λ (or R_0)

λ versus parish start time t_0

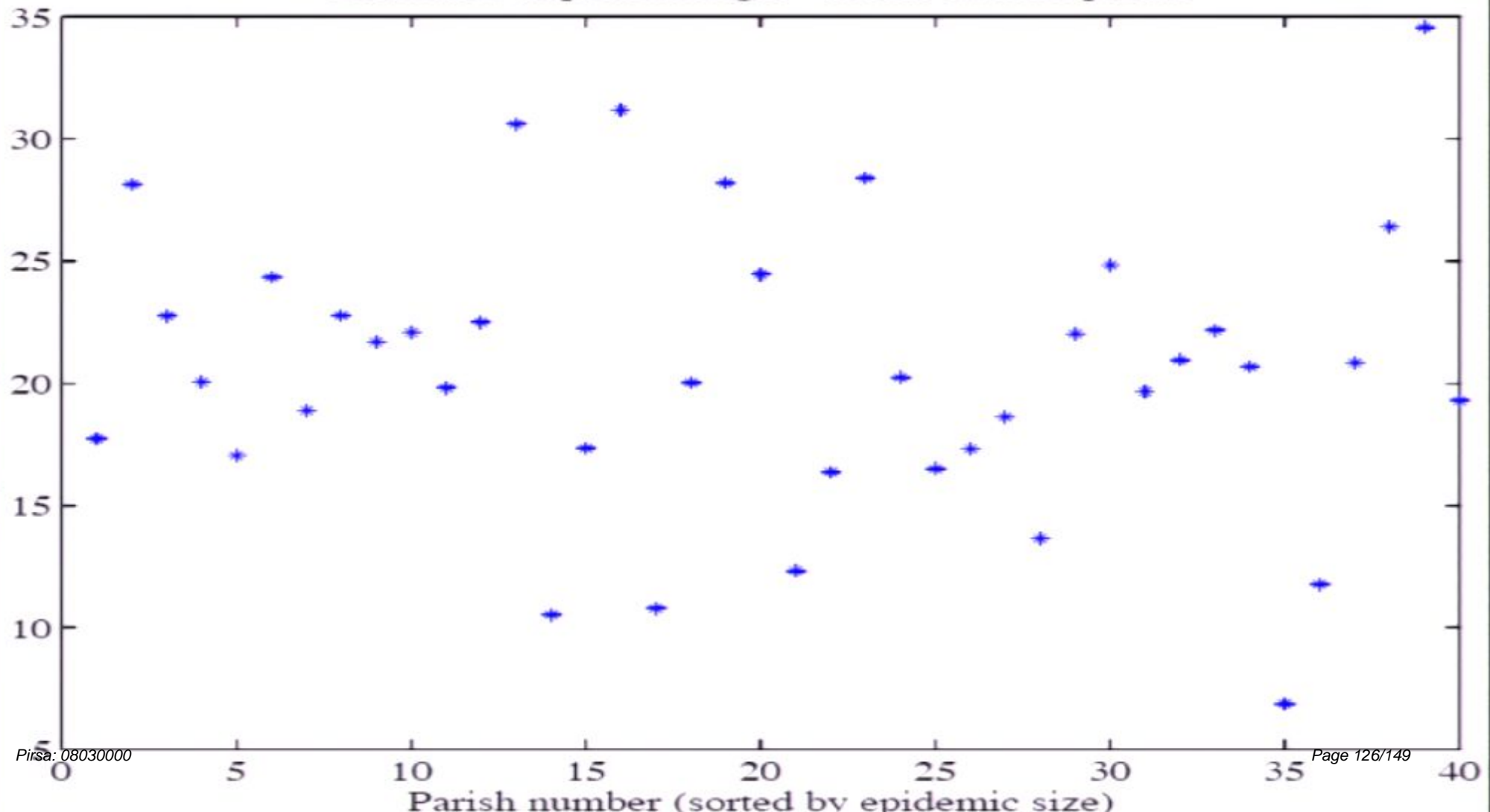
Estimated exponential growth rate vs estimated epidemic start time t_0



Results: Variation in λ (or R_0)

λ versus parish epidemic size

Estimated exponential growth rate in each parish



Results: R_0 for Great Plague

- For plausible serial interval distributions (mean < 2 weeks):

$$R_0 < 2$$

- If latent and infectious periods are distributed exactly like modern pneumonic plague:

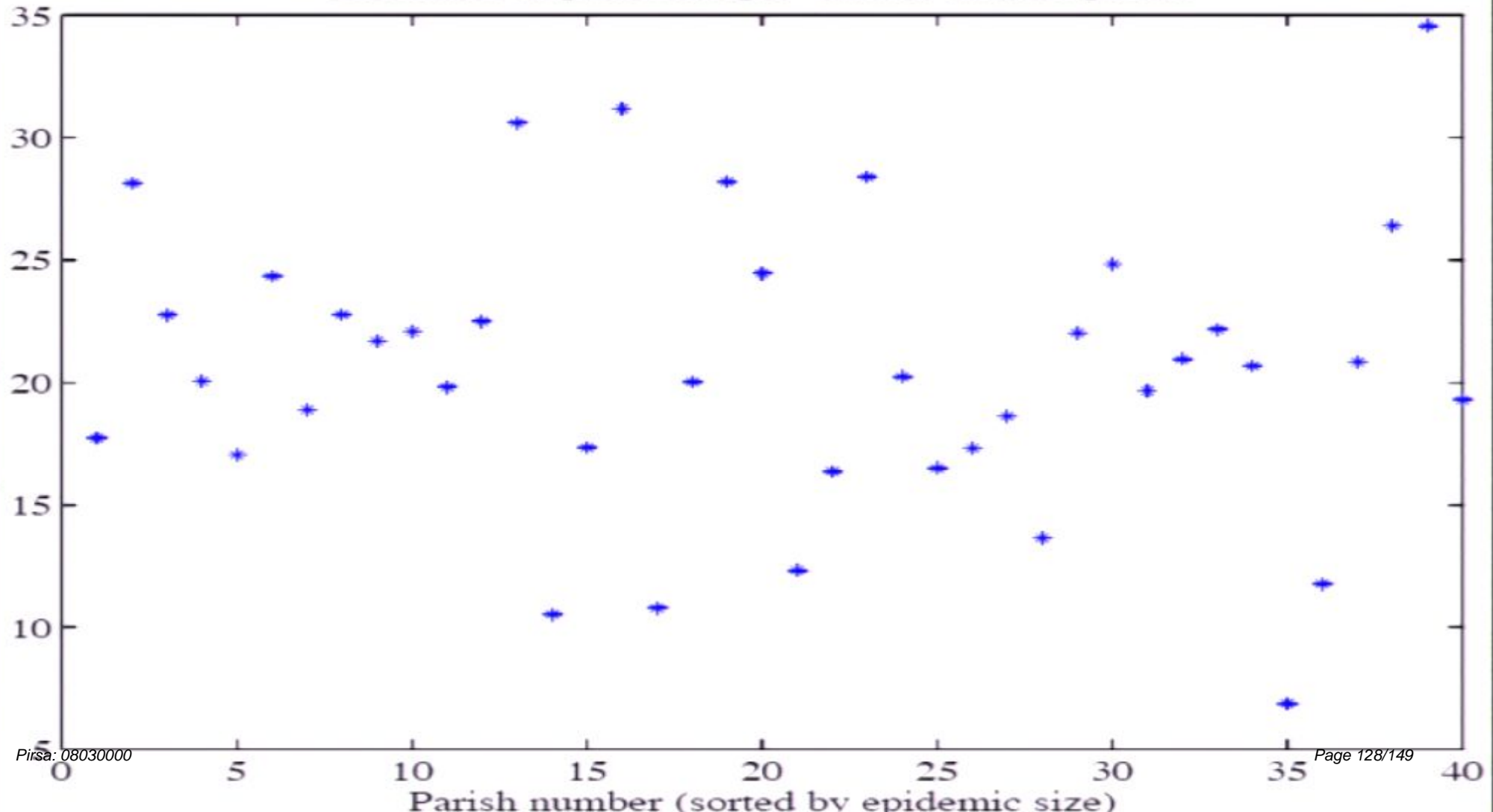
$$R_0 \sim 1.3$$

- **Upshot:** The Great Plague was devastating, yet it was caused by pathogen that was only weakly transmissible
 - Transmissibility similar to SARS or 1918 influenza
- **Recurrent lesson:** Don't be fooled by low transmissibility pathogens... they are often the worst...
BUT they are also the easiest to control...

Results: Variation in λ (or R_0)

λ versus parish epidemic size

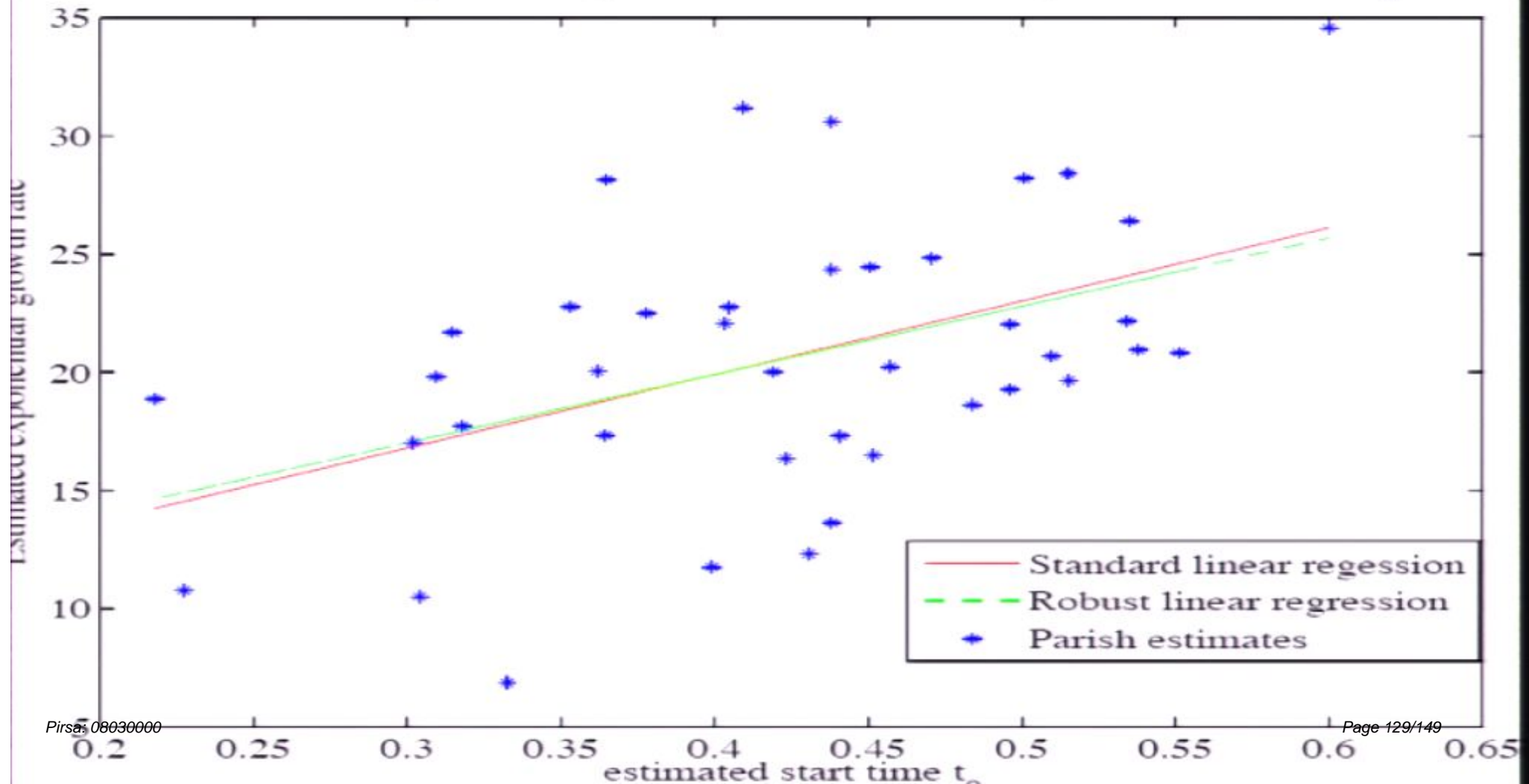
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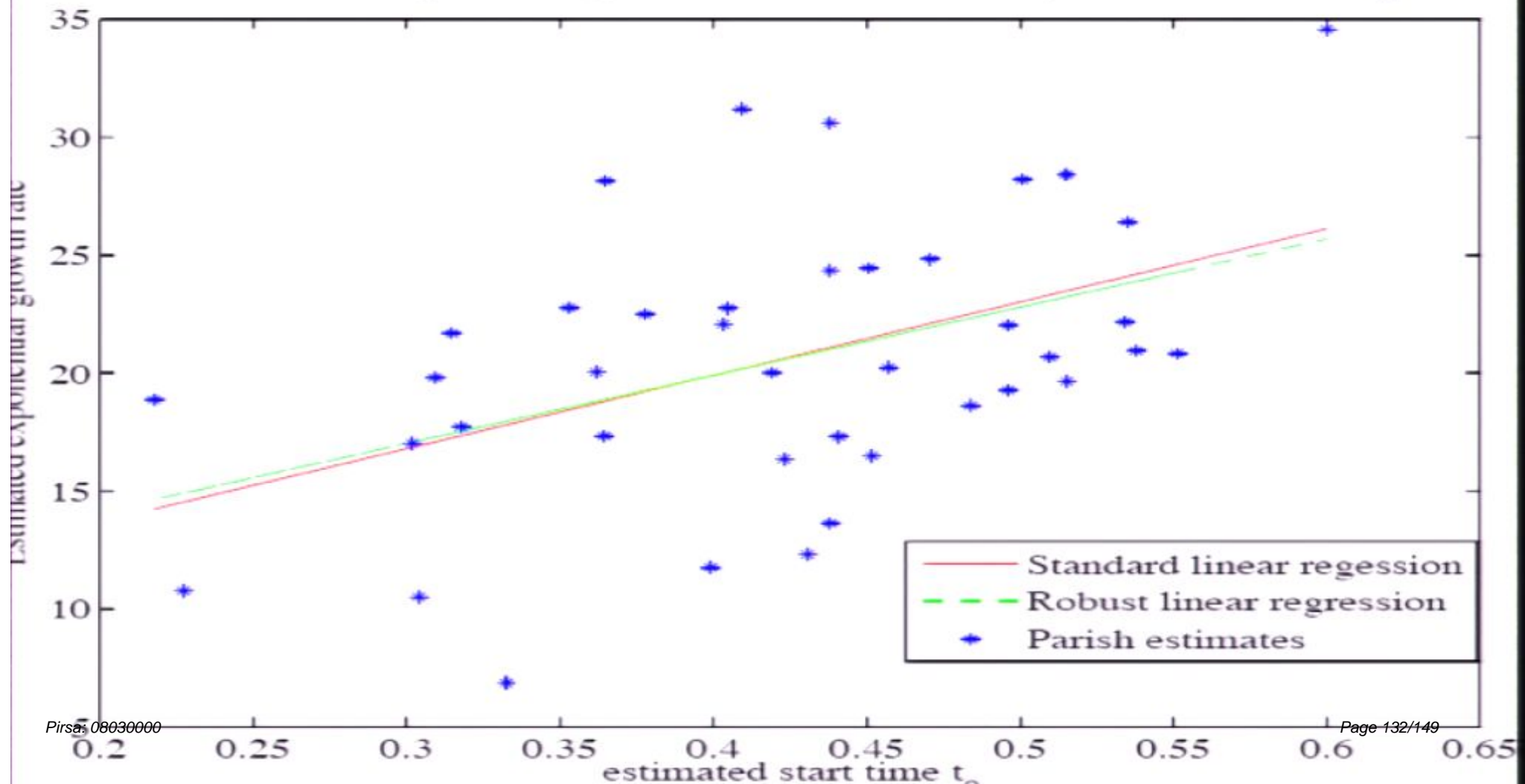
- Single linear regression: λ versus *parish start time* t_0
 - $R^2 = 0.22$, $p = 0.0022$

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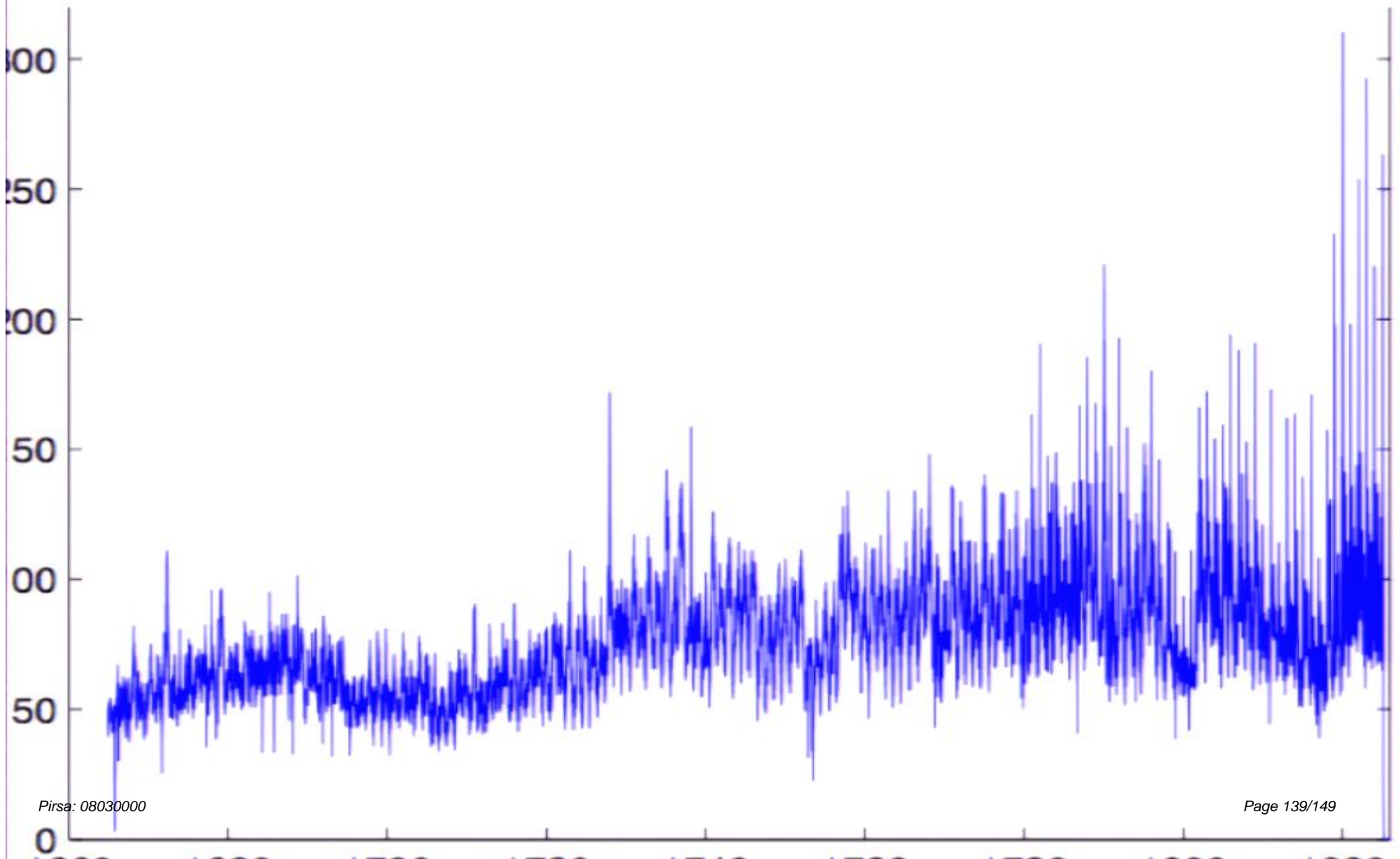
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- Interpretation?
 - Suspect R_0 increases with population density...

Other Open Questions about Plague

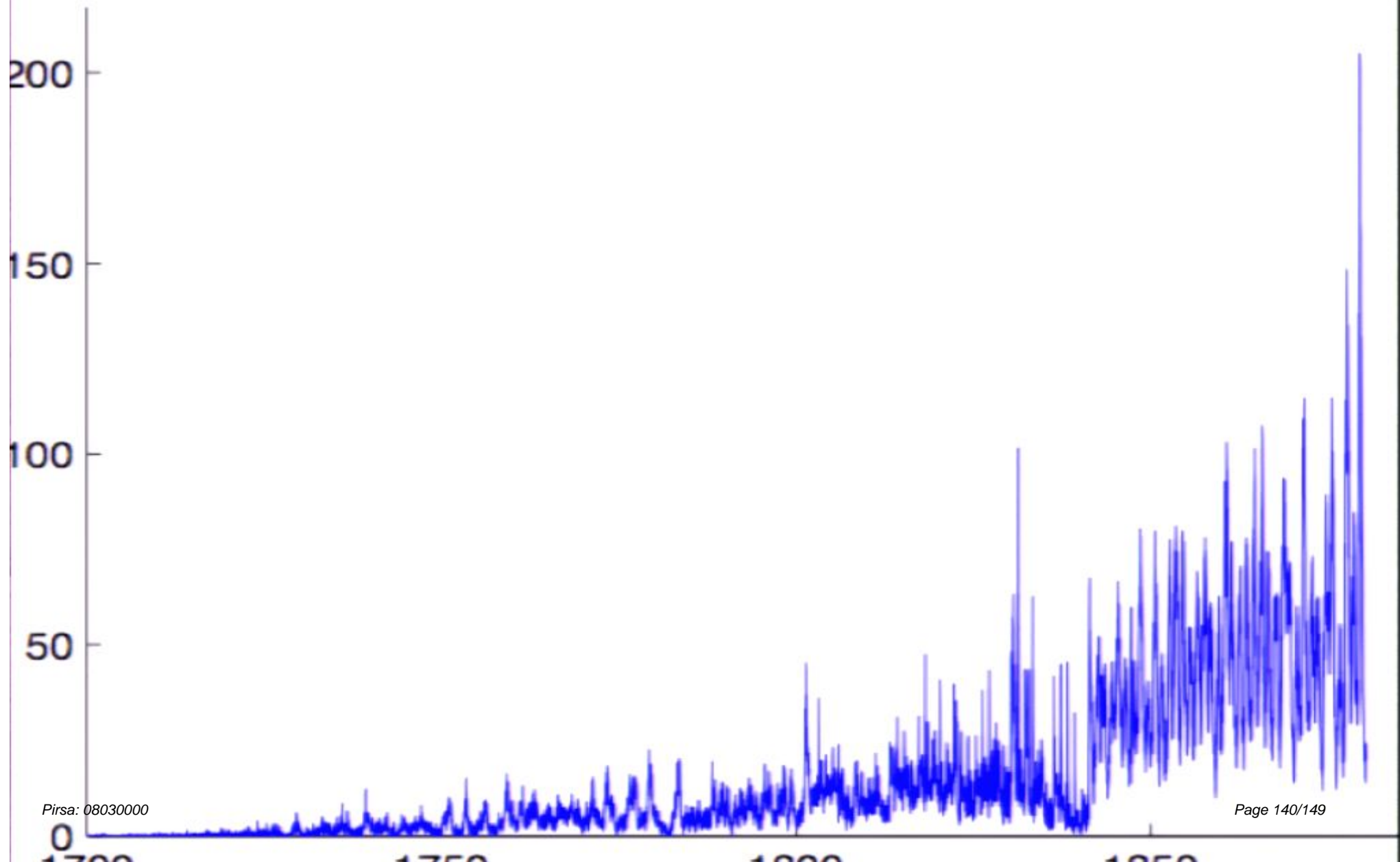
- What was the pathogen?
 - Field and lab work with Hendrik Poinar
 - The mortality data tell us where to dig
- What caused the observed temporal pattern of plague incidence from 1592 to 1666?
- Why did plague go extinct in England after 1665?

Other Diseases? ...

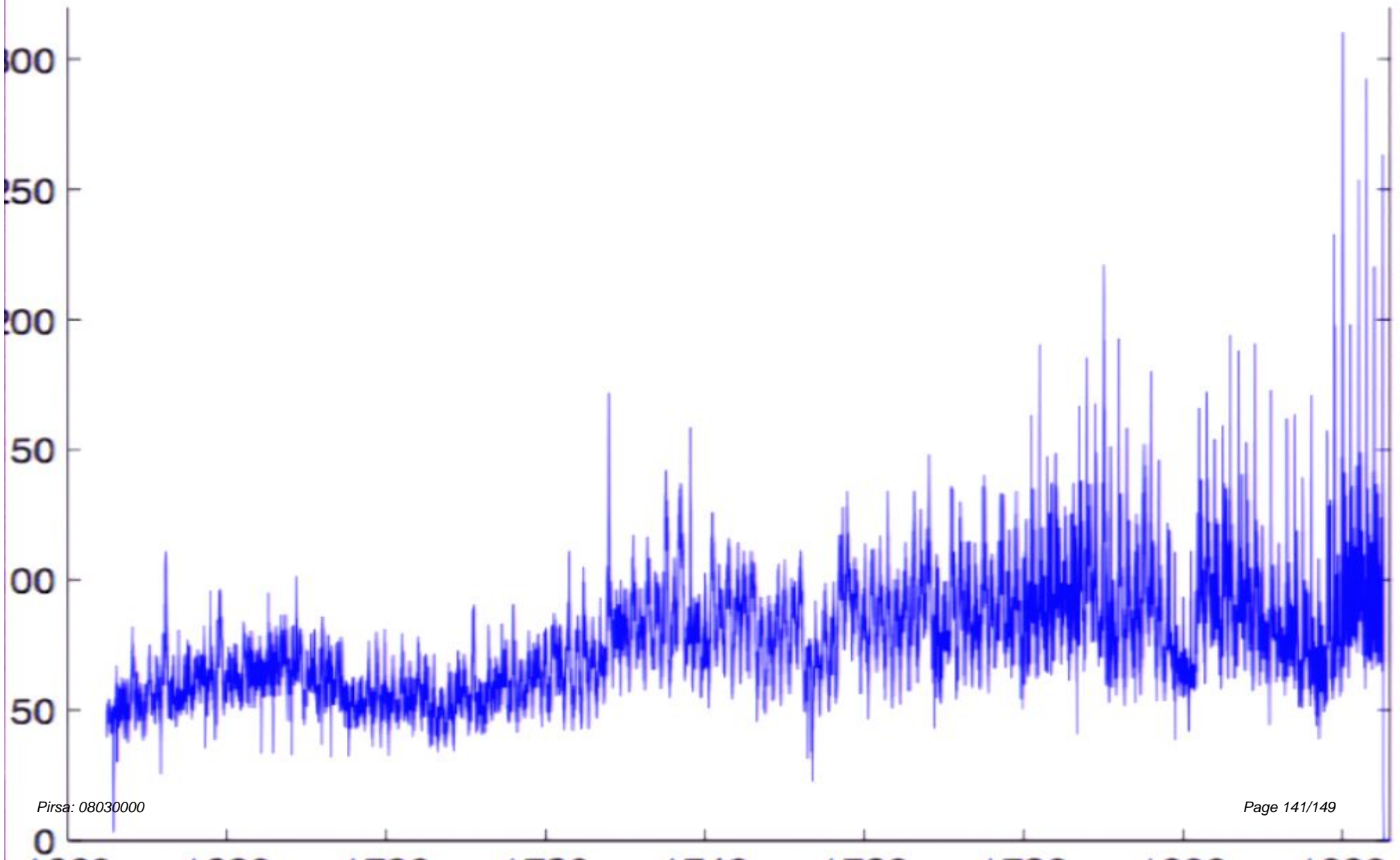
Tuberculosis in London, 1665-1830



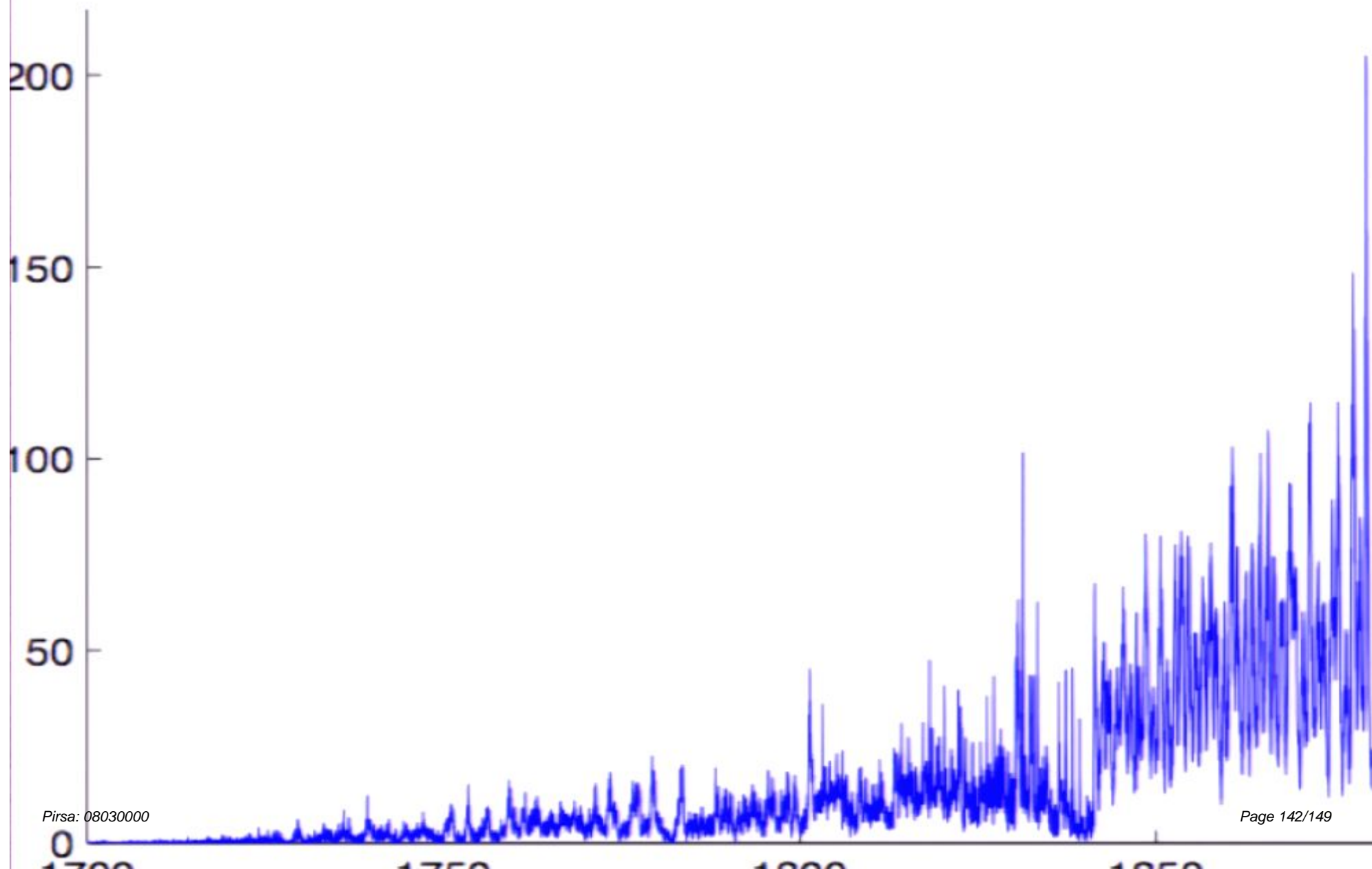
Whooping Cough in London, 1700-1880



Tuberculosis in London, 1665-1830



Whooping Cough in London, 1700-1880



Smallpox in London, 1664-1880

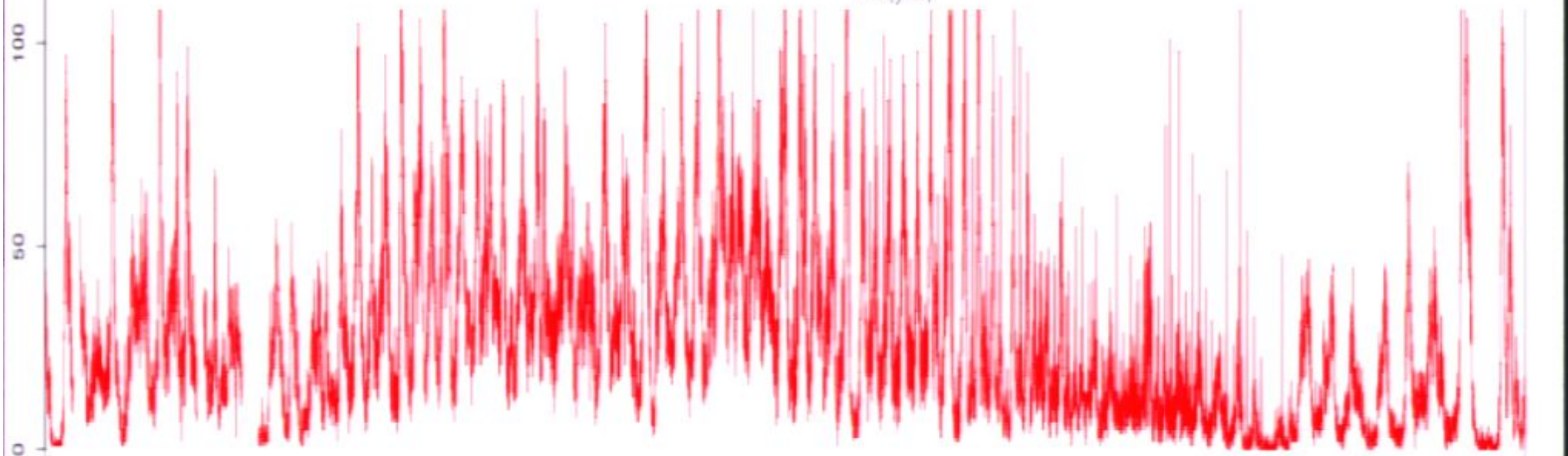
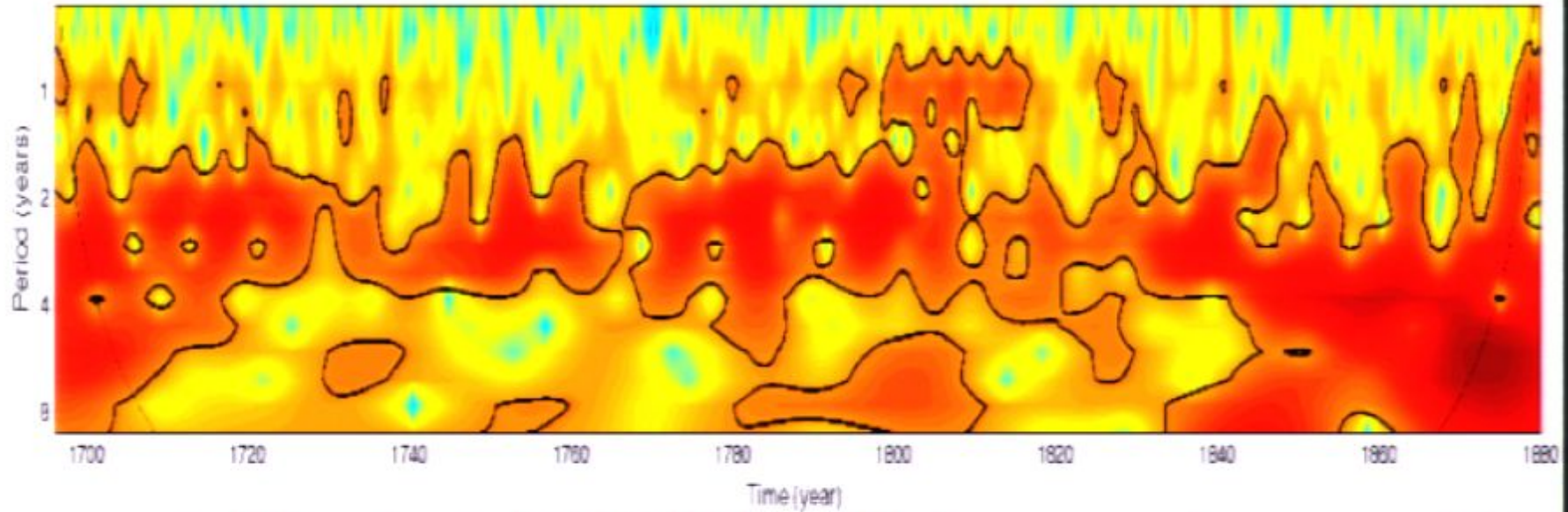


Olga Krylova



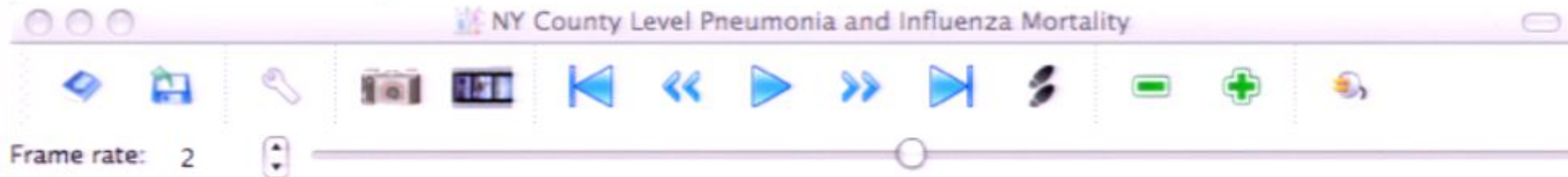
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Wavelet Power Spectrum of the Smallpox Mortality Data (1695-1880)

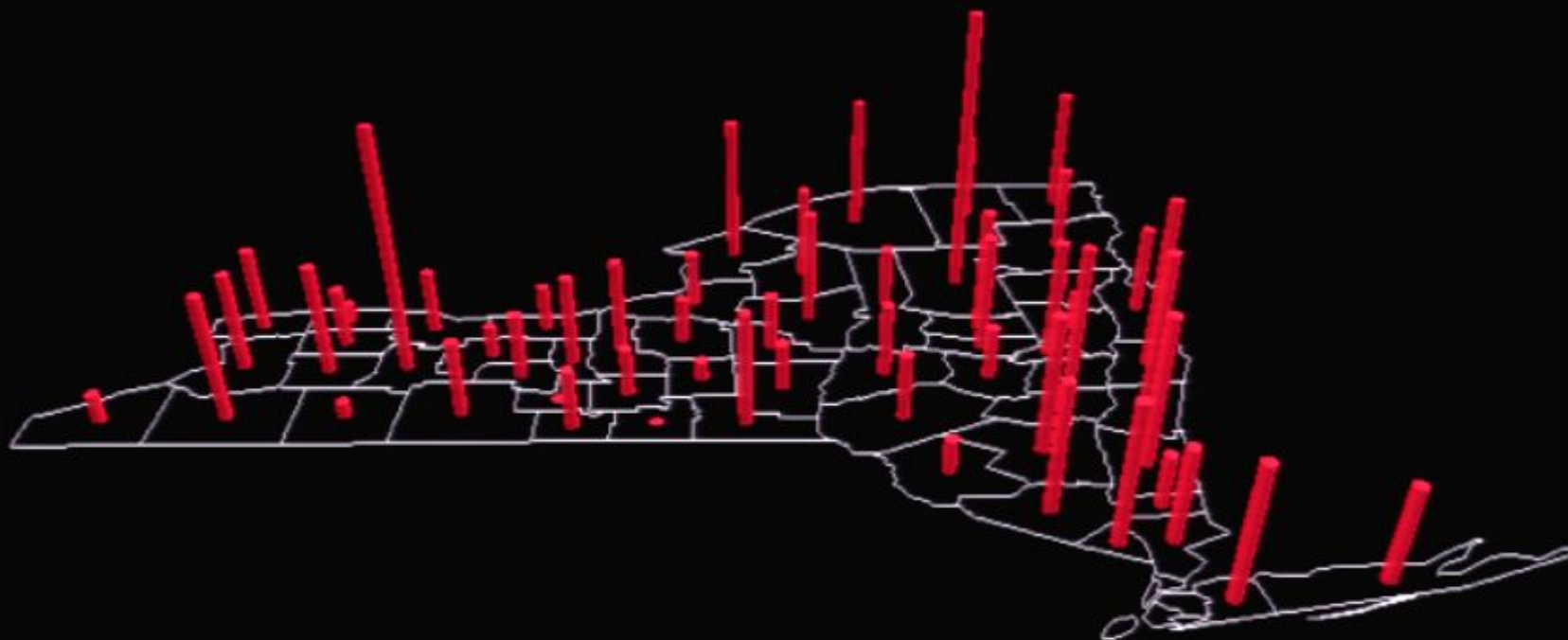


Daily NY flu deaths, 1918

NY County Level Pneumonia and Influenza Mortality



Oct 22, 1918



Take-home messages

- Historical infectious disease data are wonderful resources for understanding epidemic dynamics

International Infectious Disease Data Archive



<http://iidda.mcmaster.ca>

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