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# Using polygons to model maritime movement in antiquity

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*DOI:*
10.1016/j.jas.2019.104997

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*Document Version*
Peer reviewed version

*Citation for published version (Harvard):*
Harpster, M & Chapman, H 2019, 'Using polygons to model maritime movement in antiquity', *Journal of Archaeological Science*, vol. 111, 104997. https://doi.org/10.1016/j.jas.2019.104997

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Download date: 26. Apr. 2024

Elsevier Editorial System(tm) for Journal of Archaeological Science
Manuscript Draft

Manuscript Number:

Title: Using Polygons to Model Maritime Activity in Antiquity

Article Type: Research Paper

Keywords: Maritime Activity; Maritime Landscapes; GIS; Maritime Archaeology; Mobility

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Abstract: Conducted between 2013 and 2015, the MISAMS (Modeling Inhabited Spaces of the Ancient Mediterranean Sea) Project developed a new GIS-based interpretive methodology that collates and superimposes a series of polygons to model densities of maritime activity in the antique Mediterranean Sea. This technique uses the large corpus of maritime archaeological data on the Mediterranean seafloor like previous approaches, but rather than portraying activity as a series of schematic vectors or links, the polygons are able to illustrate varying densities of activity while accommodating the ambiguity inherent in modeling past movement. In turn, the results can propose the presence of places within past maritime space. This paper summarizes this new methodology's methodological and theoretical foundation, describes its application with real-world archaeological datasets, and tests results against randomized data to demonstrate the viability of the models.

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# Using Polygons to Model Maritime Mobility in Antiquity

**Keywords**: Mobility, Maritime Landscapes, GIS, Maritime Archaeology, Maritime Activity

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## Abstract

Conducted between 2013 and 2015, the MISAMS (Modeling Inhabited Spaces of the Ancient Mediterranean Sea) Project developed a new GIS-based interpretive methodology that collates and superimposes a series of polygons to model densities of maritime activity in the antique Mediterranean Sea. This technique uses the large corpus of maritime archaeological data on the Mediterranean seafloor like previous approaches, but rather than portraying activity as a series of schematic vectors or links, the polygons are able to illustrate varying densities of activity while accommodating the ambiguity inherent in modeling past movement. In turn, the results can propose the presence of *places* within past maritime space. This paper summarizes this new methodology's methodological and theoretical foundation, describes its application with real-world archaeological datasets, and tests results against randomized data to demonstrate the viability of the models.

# Using Polygons to Model Maritime Mobility in Antiquity

## Introduction

The MISAMS (Modeling Inhabited Spaces of the Ancient Mediterranean Sea) project based at the University of Birmingham from 2013 to 2015, developed a GIS-based interpretive methodology that uses maritime archaeological data within the Mediterranean Sea to model changing concentrations of maritime activity on a centennial basis.[1] Rather than using vectors or links between terrestrial locations like past studies, however, this novel approach collates a series of polygons to model maritime areas with higher densities of activity – areas that may be considered *places* within the inhabited landscape of the sea in antiquity. This paper will discuss the method's theoretical foundation, demonstrate and evaluate its application to an archaeological dataset, then discuss the method's potential.[2]

## Modeling Mobility at Sea

Crucial to using maritime archaeological data to model past maritime activity is balancing a need to portray where a ship was moving whilst accommodating the ambiguity inherent to an archaeological dataset. This is particularly pertinent as conventional portrayals of activity utilize points and vectors to represent past movement. Possibly derived from the ability to use recent textual sources to recreate a ship's last route, such as the work by Marsden or Price and

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[1] Supported by a FP7 Marie Curie Action IEF Grant #331707.

[2] See Harpster (in press) for a recent application, and Harpster (2017) for an early iteration of this method.

Muckelroy, scholars use these elements to create a variety of portrayals.[3] For example, using the point of the assemblage's location on the seafloor and its contents to generate a vector, Benoit, Kapitän, and Nieto each generated discrete routes for the ancient ships they examined.[4] Alternatively, Bonifay and Tchernia created a more schematic model of activity between Roman-era North Africa and Rome by synthesizing a dataset of 37 assemblages.[5] Network models of maritime activity, with their links and nodes, use the same rubric in a more abstracted fashion.[6]

As Leidwanger has argued, the routes or, more accurately, vectors produced by this approach are understandably generalized as much activity may leave no evidence in the archaeological record.[7] Scholars may illustrate a ship's movement as predictable and orderly, for example, yet the craft may have repeated or reversed parts of its journey many times prior to loss.[8] Additionally, if the proposed route is based only upon the material in the cargo, how might the non-cargo items fit into the model?

The alternative posed in this study accommodates some of this ambiguity and generalization by modeling and collating areas of movement rather than schematic linkages. It does so by fashioning polygons to represent the area in which a ship's activity was most likely taking place. Rather than prioritizing the

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[3] Marsden 1972, 1976; Price and Muckelroy 1974. See also Owen (1970, 29) who wrote that a preserved cargo is as good as the ship's written itinerary.

[4] Benoit 1961; Kapitän 1970; Nieto 1988, 1997.

[5] Bonifay and Tchernia 2012.

[6] Leidwanger 2017; Gustas and Supernant 2017.

[7] Leidwanger 2017.

[8] See Nieto (1988, 1997) and Boetto (2012) who each use points and vectors, yet also propose more haphazard models of activity.

location of the assemblage on the seafloor, an attribute of the archaeological material, a polygon priorities mobility, a key characteristic of the ancient ship. Moreover, the polygon represents the vessel's mobility without favoring a particular route or vector while it embodies the human interests and needs that generated that activity. In turn, superimposing of a corpus of polygons may illustrate similarities in activity and people's habits.

## Polygon Theorization and Generation

Creating and interpreting these polygons relies upon the adoption and adaptation of two elements often applied in other types of archaeology. The first is the catchment basin from Site Catchment Analysis (SCA), and the second is a variation of an interpretive component in Social Network Analysis (SNA). Established and tested by Vita-Finzi and Higgs in their 1970 study of different Epipaleolithic-era settlements in the Levant, SCA is partially built upon an understanding and modeling of the catchment basin, the space commonly demarcated by the sources of items in an assemblage. In 1970, Vita-Finzi and Higgs defined this basin as a parcel of land 10 kilometers in radius, an area that likely represented the limits of activity within an intensive subsistence agricultural economy.[9]

In its inaugural use, therefore, the catchment basin was a fixed area determined by an estimation of the prehistoric economic structure of the Levant. It could assess the relationship between people, their settlement, and the surrounding

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[9] Vita-Finzi and Higgs 1970.

environment, and contribute to a new style of archaeological investigation focusing on a region in which human activities take place. By artificially fixing the boundary, however, the approach was also open to critique; some felt that this limit was deterministic.[10] Nevertheless, and important to this study, variations of the approach arose and are still being applied today. In 1976, for example, Flannery published his use of SCA in Oaxaca and Tehuacán, South America, consciously avoiding any pre-determined boundary and demonstrating the different scales at which a settlement's activities need to be understood.[11] Rather than assessing what resources were available within a fixed area, Flannery demonstrated that a site's catchment basin varied in relation to the type of resources collected.[12] Whereas some items' sources were within the bounds of the settlement itself, others were found over five kilometers away. The magnetite found on site had origins 6, 27, or 33 kilometers away, but the shells and shark teeth likely traveled from the coast, over 200 kilometers distant.[13] With the advent of spatial modeling in Geographic Information Systems (GIS) in the early 1990s and its archaeological applications, additional adaptations of Vita-Finzi and Higgs' circular catchment basin were proposed, based upon a variety of spatial and non-spatial data. Boundaries could be based upon elevation above sea level and follow a contour, or more accurately account for varying travel times over different surfaces or slopes.[14] As a result, although some

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[10] Roper 1979, 124; Doorn 1985, 280; Hunt 1992, 295; Wilkinson 2000, 252; Pauknerova *et al*, 2013, 134.

[11] Flannery 1976, 103.

[12] Flannery 1976, 109.

[13] Flannery 1976, 107-9.

[14] Hunt 1992, 288; Kvamme 1999, 175-6; Howey 2007, 1835-6; Barton *et al*. 2010, 5281.

scholars continue to use a fixed circular space to represent a settlement's catchment area, others such as Barton and his co-authors have established much more complex polygonal basins.[15]

This spatial variability of a catchment basin is important because this flexibility is one element key to its application to a corpus of submerged archaeological data. The second key element is how the concept of the catchment basin can represent more than the area within which natural resources were collected, and instead reflect many types of activities. In 1998, for example, Halpern proposed how genetic fingerprinting of faunal data from the Early Bronze Age levels at Megiddo could aid in defining a cultic or politico-economic catchment of the animals slaughtered for a ritual deposition.[16] Hodder proposed a more radical reinterpretation in 1974, as he turned the notion of the catchment basin on its head by developing distribution models of Romano-British coarse-ware pottery in southern England. Rather than determining a settlement's catchment based upon the sources of the collected natural resources, Hodder determined the area within which a settlement's products were distributed – a space he called the market area. Notable were the irregular shapes of his areas as well as their ability to propose the social or environmental constraints impacting movement of the wares.[17]

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[15] For relatively recent circular applications, see Hunt (1992), Hill (2004), and Hanks and Doonan (2009). Alternatively, the traditional geological and hydrological uses of 'catchment basin' are invariably irregular and governed by environmental factors.

[16] Halpern 1998, 59.

[17] Hodder 1974a, 1974b.

Despite these variations, however, a characteristic common to these approaches is the stationary nature of the settlement or assemblage represented by the archaeological data. Some settlements, such as those investigated by Vita-Finzi and Higgs, may be transitory chronologically, but they are all spatially fixed when in use. The collection, movement, and possible re-distribution of goods or natural resources within the catchment basin or market area, therefore, demonstrates movement between these settlements fixed in space. The people and goods are moving, not the settlements and assemblages around which the catchment areas emerge.

Although this study's methodological approach can still investigate a human / environment relationship like other regional studies using catchment basins, the stationary characteristic emblematic of other investigations was inverted for this study. This is because – unlike the assemblages on land – all of the submerged assemblages in this study's dataset represent the location where movement stopped, not a stationary feature of a landscape or a node in a network. Some assemblages, like the Middle to Late Bronze Age ceramics off the coast of Maroni, Cyprus, may be indicative of a very abbreviated journey from their manufacture on the island to their immediate loss off shore.[18] Other sites like the 1st-century BC site Grand Bassin B off the coast of France, with material from Spain, Italy, and France, may be an example of Rougé's 'grand commerce' between major entrepots.[19] Nevertheless, because these submerged

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[18] Manning 1998, 53-4; Hadjisavvas 2003, 63.

[19] Rougé 1966, 419; Parker 1992, #469.

assemblages are not representative of stationary settlements but the very things that moved and carried items, generating their catchment basins is a means of modeling where this movement was most likely taking place prior to deposition on the seabed.  The catchment area of each submerged assemblage, then, may be more properly called a *mobility area*.

Modeling this mobility area proceeds much like Flannery's work in southern England.  Key is determining the source(s) of the items in the assemblage then using those sources as the vertices or nodes of the resulting mobility polygon. The final node of the polygon is the location of the assemblage on the seafloor. The polygon contains no chronological component to propose what items were collected first or last, or how long the ship may have been in use, nor does it contain any vectors.  The polygon only poses the *most likely* area in which the activity was taking place before the material was deposited on the seafloor.

Importantly, this polygon contains a human component.  As ships and their activities do not progress independently of people's interests and needs, a polygon not only represents the mobility of the people operating the ship, but is also human expression.  A single polygon can represent how much of the sea was in use, how people were interacting with the sea, and be a discrete portion of a sea's cultural topography.  Nevertheless, a single polygon reveals little. Instead, like previous studies by Kingsley or Boetto, much more information emerges with the compilation of a large dataset.

If these mobility areas, derived from concepts within Site Catchment Analysis, can model the possible activities of one ship within a large corpus, then concepts emerging from Social Network Analysis, or SNA, are tools that can reveal patterns within the entire corpus. As one manifestation of graph theory, SNA uses nodes and links (or edges) as a means of modeling social networks. When applied in contemporary studies, the nodes may be a single person or a group of people, and the links joining nodes can represent a tangible or intangible unit that is shared between them. A shared unit could be a religious affiliation, a familial tie, educational status, or a lamp or cuisine. By plotting links between nodes, relationships and a hierarchy within the set of nodes may be illustrated. Equally, the constitutive nature of SNA is evident, for it is through the collection and compilation of a large body of nodes and links that patterns within the corpus emerge. In general, a dense cluster of links and their associated nodes may be interpreted as a social unit within the broader network, a unit that could be defined by similarities in cuisine, religion, or educational background. When SNA is applied archaeologically, however, the relationship between nodes more commonly relies upon the distribution of material data.[20] Thus, a relationship is often assumed through the presence of similar material culture, or similar material characteristics, but social communities among this set of nodes may still be assessed through the varying density of links and their strengths.

These projected polygons can also be used to pose the presence of communities forming around shared social expressions. Necessary, however, is the use of a

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[20] Knappett 2013, 8; Terrell 2013, 20.

different relational space. Rather than gauging a relationship between polygons based upon the sharing of units among nodes, requiring a relational space of distribution, relationships among these polygons are based upon the movement each represents. This requires a relational space that gauges mobility. As polygons are superimposed, the similarity or dissimilarity of the movements represented can gauge the strength of the relationship between the polygons (figure 1). A greater overlap equates to a greater similarity in activity, whereas the density of the projected polygons can represent the commonality of the activities and human experiences within the entire corpus.

As these polygons are projected in geo-referenced space, these loci of mobility may also represent the generation of a *place* at sea. As Lee and Ingold argued, and as reiterated by Ur, Leary, and Lucas, place is an origin, a destination, and the area of movement as well – through the entanglement of journeys, a place can be made.[21] This is an approach that draws upon the use of a ship as a shared experience. Seafaring, after all, is a journey across an environment that is often portrayed as antagonistic both physically and spiritually, and the ship is the most common vehicle for these experiences.[22] As a ship is a tool for structuring the surrounding space, this is an approach that also draws upon perceptions of the human creation of a landscape.[23] In this case, how these repeated activities and experiences transform a space into a meaningful place within people's social constructions of the sea.

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[21] Lee and Ingold 2006; Ur 2009; Leary 2014; Lucas 2014.

[22] Goldziher 1971; Robertson 1984, 378-80; Ramsey 1989, 89-91; Wyatt 1996, 127; Connery 2006, 499.

[23] Darvill 2010.

## Data Collection

### Sources of Data

The data within the AMD dataset, and the portion of that corpus used for this smaller study, were collected from two large sources. Perhaps predictably, the first source was the 1992 catalogue by A.J. Parker, *Ancient Shipwrecks of the Mediterranean and the Roman Provinces*, and the second was the collection of professional articles published since 1990 – sources that update and expand Parker's collection. Not all of the data available within these sources was used, however.

Within Parker's catalogue of 1100 sites within the Mediterranean region, only 754 were applicable to AMD because they were within the bounds of the Mediterranean Sea, and the entries provided the data necessary for analysis: dates, approximate amounts of items, and the typological style or specific source of the material on board.[24] The same qualifications were applied to sources published after 1990, so although material from 57 peer-reviewed journals, collections, and monographs was examined, data from only 25 sources within that corpus have been used. Within this study focusing on the western Mediterranean basin, approximately 80 percent of the data comes from Parker's dataset, whereas the remaining information has been collated from sources published after 1990.

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[24] Within AMD, the 'Mediterranean' presently excludes the Black Sea. This is because a long-term goal of this project is to test this methodology within other bodies of water, assessing its transferability and scalability. Thus, the Black Sea will be tested in the future.

A variety of on-line datasets of sites, such as DARMC (Harvard University), OXREP (Oxford University), and Benthos (University of North Carolina), are available, but they were not utilized for two reasons. First, as these resources seek comprehensiveness within particular chronological limits, they compile and summarize data from within and beyond professional journals. Using these on-line sources, then, would have necessitated a search methodology that segregated site reports with the necessary information, and within peer-reviewed media. Second, although these on-line sources are each portraying the same collection of archaeological data, the data are not reported in the same way. DARMC and Benthos each mention a Roman-era site off Chlef, Algeria, yet it is 'Cape Magroua' in the former and 'Cap Kagroua' in the latter; OXREP contains no reference to the site. This site's bibliographic information varies between the two on-line resources as well. Similar differences arise for the Roman-era sites Cherchel 1 and 2 (or Cherchel A and B), Pantelleria, or Cala Levante. Creating and applying a search methodology to generate a corpus of data independent of these on-line sources, even if the final result resembled the information available on-line, was more appropriate to the needs of this project.

### Reliability of Data

Questions of reliability can plague a study using a large set of archaeological data compiled from a variety of projects, and these questions can become more pertinent as the publications become older. New analytical approaches can revise previous conclusions, new excavations can refine chronologies, information is not evenly disseminated, and the repeated compilation of data can coalesce into new patterns that counter previous perceptions.  All of these dynamics are applicable to this study, and they were accommodated within AMD's rubric in two different ways.  The older set of data from Parker's catalogue was taken as a fixed set of information.  This was done for three reasons.  First, although the catalogue's extensive bibliography promotes the possibility of a lengthy updating or amending of the entries for all 754 assemblages in AMD's dataset, this is not the overall purpose of the AMD project.  Instead, AMD is driven to demonstrate new ways of interpreting and modeling maritime activity in antiquity based predominantly on the maritime archaeological record.  The second reason the data from Parker's catalogue was taken as a fixed set of information is because it enables a comparison gauging the usefulness of the corpus itself.  By segregating and projecting the 754 assemblages, then comparing the results to a similar projection of post-1990 data, it is possible to gauge how reliable the older interpretations are.  Radical differences in the two projections suggest the former is no longer reliable, whereas minor discrepancies suggest otherwise.  The third reason is a corollary to the second – keeping Parker's corpus as a fixed set of data enables qualitative and historical comparisons.  His catalogue is emblematic of the state of knowledge in the early 1990s; widespread discrepancies between the two corpora thus suggest distinct changes within the discipline as well.

In comparison to Parker's corpus, however, the post-1990 information is in a constant state of expansion.  In 2015, the AMD dataset contained 201 assemblages from post-1990 sources, and by 2016 that number had risen to

242. It is now almost 400. Equally, it is being adjusted and refined. The database entry on the assemblage Tantura F off the coast of Israel, for example, has been gradually updated through the studies by Royal, Kahanov, Barkai, and Avissar published between 2000 and 2010.[25]

## Model Building

A fundamental element of this study's theory is that a series of superimposed mobility polygons can model the coalescence and change of a *place* in maritime space. This place may arise through a higher density of polygons within a particular region or through similarities in activity and, thus, people's needs and interests. Geographic Information Systems (GIS) with its scalability and ability to project spatial and non-spatial data in geo-referenced space, is understandably the best tool for the effort, and in this study ArcGIS 10.4 was used. All of the following instructions relate to that version.

In comparison to other GIS studies utilizing polygons to model movement or illustrate spatial change over time, the methods discussed in this essay may be familiar but considerably coarser. Chronologically, the finest unit of measurement is a century, a segregation undeniably longer than the weeks or days that may be modeled in the STAMP approach created by Robertson, Nelson, Boots and Wulder.[26] Equally, an event-based approach, like that by Sadahiro and Umemura, is untenable in this archaeological perspective; the only events we have reliable evidence for are the creation of the ship and its

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[25] Royal and Kahanov 2000; Barkai and Kahanov 2007; Barkai et al. 2010.

[26] Robertson et al. 2007.

deposition on the seafloor.[27] As will be evident, AMD's method of determining the density of the polygons is different than the pattern association tests proposed by Maruca and Jacquez, whereas illustrating change through the superimposition of data – with 'snapshots' or 'chess maps' as described by Peuquet – is not uncommon, but it is relatively basic.[28] Nevertheless, with a limited set of information about the ship's date of loss and, at times, only general information about the sources of items on board, these limitations were created by the dataset itself.

### Raw Superimposition with No Interpolation

Unlike the interpolative processes that follow, this is the only approach that projects no data beyond the boundaries of the polygons themselves. This happens because once the polygons are generated, each is assigned a color and it is the gradual superimposition of the colors that demonstrates the varying spatial density of the polygons. Figures 2 and 3 display a superimposition and shading of a generic set of polygons, each with 60 percent transparency. The robust color emerging in the left half of figure 3 results from a greater concentration of polygons and, presumably, clarifies the area with the highest similarities in movement, activity, and human interests. Theoretically, this blue nexus is a more coherent place within this space of activity.

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[27] Sadahiro 2001; Sadahiro and Umemura 2001.

[28] Peuquet 1994, 445; Maruca and Jacquez 2002. See also Peuquet (2001, 18), Sadahiro and Umemura (2001, 139), McIntosh and Yuan (2005) for more nuanced used of this snapshot approach to modeling change over time.

Key to interpreting the polygons with this approach is assigning each polygon to a separate shapefile within GIS.  Thus, all of the polygons may have been initially created within the same shapefile, but the necessary gradients in color cannot be achieved if the polygons are all part of the same layer because they do not act independently.  Once each polygon is a separate shapefile, a color and its level of transparency may be assigned.  It is also important to note that the color and transparency assigned to the polygon is not a permanent characteristic of the shapefile.  If the shapefile is removed from the Table of Contents (TOC) and re-inserted later, ArcGIS will assign a default color to the polygon with no transparency.  As a result, all of the polygon shapefiles need to be generated, color-coded, and held in the TOC for this analysis to proceed.

Generating a separate shapefile for each polygon is a clear drawback for this approach.  Although the example in figures 2 and 3 is only using a set of 20 schematic polygons, AMD is presently operating with a corpus of c.1100, requiring the manipulation and management of them all to produce certain models.  An advantage of this approach, however, is that it produces results with a minimal amount of extrapolation from the raw data.  Other than the creation of the polygon, there is no additional step creating greater interpretive distance from the assemblage.  Equally, the polygons' color-coding may be coordinated with particular characteristics.  Assemblages with items from only two sources may be represented by a particular color (figure 4), and others may be categorized by their date of investigation or, if possible, the type of ship on the seabed.  In figure 5, the colors are based upon the contents of the assemblages: sources from the western side of this hypothetical space add red to the mobility polygon and sources from the eastern side add blue. As these colors may be mixed in a proportion that matches the proportion of western / eastern material in the assemblage, color concentrations propose areas of activity characteristic of one side or the other, whereas areas with purple polygons – mixtures of blue and red – may represent areas of inter-regional or heterogeneous activity.[29]

## Interpolation with Inverse Distance Weighting (IDW)

If the superimposition of mobility polygons creates a place in space, then the texture of that place is likely related to the similarity of the superimposed polygons and their density. A low density of polygons with a variety of shapes and sizes should create a diffuse region at sea, whereas a high density of identical polygons should create a concise and well-defined location. The IDW tool is useful because the rasters it produces help assess these characteristics. To produce the rasters, however, it is first necessary to generate a join count of the overlapping polygons – a value representing how many polygons are superimposed within a particular area. Within AMD, two methods have been used in the past to quantify the join count within a set of these mobility polygons. One method, discussed first, uses the Fishnet and Spatial Join tools to generate the join count, whereas the second uses a Count Overlapping Polygons tool from Sadeck Geotechnologies.

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[29] To determine the color proportions of a polygon, divide 256 (the maximum value in the RGB color scale) by the number of sources in the assemblage. Next, multiply that result by the number of sources that share the same characteristic. The resulting number is the value applied to that characteristic's color in the RGB color scale. The formula for an assemblage with two sources from the west (red) and one from the east (blue), for example, is $256 \div 3 = 85.34$, so Red $\approx 171$ and Blue $\approx 85$.

The Fishnet tool will generate a polygonal shapefile composed of a series of uniform squares or rectangles. The entire Fishnet shapefile must be large enough to cover all of the mobility polygons to be assessed, and the nature of the Fishnet's units determines the resolution – more and smaller units generates a finer level of detail. Using the Spatial Join tool to unite the fishnet and the polygon shapefile generates the necessary join count, but it is important to make the Target layer the Fishnet shapefile and the Join layer the mobility polygon shapefile. By doing so, the Spatial Join tool will generate a join count of the number of polygons represented within each unit of the fishnet. Thus, in figure 6 with three overlapping polygons, most units in the Fishnet have a join count value of zero, some are one, and others are two or three. Using the mobility polygon shapefile as the Target layer will generate a join count as well, but the results only reflect the number of units of the fishnet that each polygon has joined with, not the density of overlap among the polygons themselves. Within the AMD methodology that requires a quantified density of polygons, it is important to make the Target Layer the Fishnet shapefile when using the Spatial Join tool to generate a join count.

The shapefile created by the Spatial Join tool may be interpolated through IDW by using the join count in the shapefile as the Z value to be measured and projected in the resulting raster image. This raster may be similar to figure 7, illustrating where the polygons have the greatest density – theoretically representing a place built from repeated activity – but equally important is the maximum density of the raster. This value may be compared to other sets of superimposed polygons to gauge the relative coherence of the place itself.

Using a Fishnet joined to a shapefile of mobility polygons will generate values and an image representative of the density of the polygons, but because IDW has join count values for all of the units in the Fishnet, all of those values are part of the interpolative process. With a relatively high number of polygons distributed over much of the area encompassed by the fishnet, this is not necessarily a problem. With a low number of polygons – such as in figure 6 – many of the units in the Fishnet have a join count of zero. In turn, these evenly spaced values generate the repetitive bullseye pattern evident in figure 7. The values are correct and the area of highest density is evident, but the result can be confusing visually unless modifications are made to the relative impact of distance on the IDW process.

Generating a join count with the Count Overlapping Polygons tool eliminates this bullseye effect because no Fishnet shapefile is necessary. Rather than using the Fishnet to divide the polygon shapefile into a series of equal units, each containing a join count, the Count Overlapping Polygons tool instead identifies all the polygons represented within the polygon shapefile, then generates a join count for each polygon it identifies. In figure 8, some polygons have a join count of one, two, or three, whereas the space around the polygons is not calculated and, in turn, has no value. The resulting raster image is in figure 9, and the differences between it and figure 7 are a result of how the join count values are calculated, represented spatially, and interpolated. One has a series of uniform squares or rectangles, each with a particular join count value, whereas the other applies a single join count value to the entirety of the identified polygon.

AMD has used these two methods of interpolating the polygons in the past although, simply for reasons of efficiency, the approach using the Count Overlapping Polygons tool will continue to be used in the future.

### Results with Real-World Archaeological Data

Using a combination of these methods applied to archaeological data, AMD has been able to generate a variety of preliminary results.  In figures 10, 11, and 12, with a superimposition and shading of 140 polygons, concentrations of 'localized' activity within the western Mediterranean basin in the 1st century BC are illustrated.  Similarly, figure 13 displays the same data analyzed with the Count Overlapping Polygons tool and interpolated through IDW, clarifying a region of dense activity between central Italy, southern France, and central Spain.  Lastly, by superimposing Strabo's maritime topography of the western basin (figure 14), it is possible to compare these contemporaneous geographies of the sea. Whereas the raster may be modeling how the activities of the muted maritime community in antiquity structured their maritime landscape, Strabo's work may be portraying how a literate and more elite community viewed the sea.  Do the similarities in the regions of the Tyrrhenian and Sardinian Seas demonstrate that these two ends of the societal spectrum shared a common maritime topography? Alternatively, do differences manifest divergent perceptions of the same region, or are they revealing lacunae in Strabo's data or the archaeological record?  Is this a means of gauging the accuracy of Strabo's work for our interpretation of past maritime activity?

### Testing Real-World Results

The results generated by the 1st-century BC assemblages and the subsequent questions rely upon the presumption that the patterns generated by the archaeological dataset are portraying more than random variations in a dispersed collection of information. After all, the archaeological assemblages in the AMD dataset have been subjected to forces that scramble and eliminate their contents, their places of deposition on the seabed are not purposeful, and they may or may not represent accurately the scale and scope of past maritime activity. Despite its size, the AMD dataset may be particularly haphazard. Are the real-world results portraying more than a random collection of compiled and interpolated data?

To answer this question, a set of 140 randomized assemblages were projected within the same western-Mediterranean space, acting as a baseline set of data to compare to the material from the 1st century BC. These test assemblages were randomized in two ways. The same 140 terrestrial sources surrounding the western Mediterranean coastline, and which supplied the contents of the archaeological dataset, were each assigned a number. These numbers were then applied to each test assemblage to generate their contents, but the dispersal of those contents among the assemblages was controlled by the randomizing function in Microsoft Excel (*fx*=RANDBETWEEN (1,140)). This ensured that there was no pattern to the dispersal of the contents, and there was very little repetition.[30] The dispersal of the 140 assemblages in the western Mediterranean basin was also randomized by using the Create Random Points tool within ArcGIS; their distribution was bounded by the coastline, and they could not be less than 10 meters apart. A set of mobility polygons was generated from these randomized assemblages, and projected across the western-Mediterranean region (Figure 15).

As mentioned previously, the key comparable characteristic is the density of the overlapping polygons. If the maximum density of the archaeological mobility polygons is greater than that generated by comparable random data, this suggests that there is a pattern or structure to the activity represented, and the coalescence of a place at sea. If the random data generates a higher maximum density, however, then the results emerging from the archaeological data cannot be distinguished from coincidence.

Visually, the results generated by the randomized data (Figure 16) are similar to that emerging from the archaeological dataset. Quantitatively, however, they are clearly different. The maximum density of the archaeological polygons is 33. After four different dispersals of the randomized assemblages in the western basin, however, the maximum density of the associated polygons is 27.7 (Graph 1). Moreover, decreasing the randomness of the test assemblages' locations by

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[30] Among the values assigned to the assemblages, none were repeated more than four times, and only six (39, 56, 75, 84, 94, and 119) were repeated four times. For assemblages with material from more than one source, no combination of values was repeated. The percentages of randomized assemblages with one or more sources closely approximated the percentages in the archaeological dataset.

concentrating their distribution in 250km$^2$ and 100km$^2$ areas, a pattern that adds repetition and predictability, still generates similar values (Figures 17 and 18 and Graph 1).

The limited range of the density values generated by the randomized data is not an anomaly. Projecting, interpolating, and quantifying a set of 100 generic assemblages eight times in an abstract working space with 56 sources (Figures 19 and 20) generated density values within a similarly limited range (Graph 2). In addition, similar results emerge when the same comparative test is applied to archaeological datasets from other centuries. The 55 mobility polygons generated by the 3rd-century AD archaeological assemblages in the western Mediterranean are illustrated in figures 21, 22 and 23. Creating a set of 55 randomized test assemblages and projecting and interpolating their polygons within the western-Mediterranean basin generated the values in Graph 3. Whereas the 55 archaeological mobility polygons had a maximum density of 33.9, the randomized test polygons' density varied between 6.5 and 8.9.[31]

Presently, the comparison between the archaeological and the randomized datasets appear valid, and the results reinforce the underlying theory of this approach. Using concepts from SCA and SNA, the projection and superimposition of mobility polygons generated from the contents of a set of submerged assemblages manifest areas of higher activity, or *places*, within the ancient Mediterranean Sea.

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[31] Among the content values assigned to these randomized polygons, no value was repeated more than twice, and only 12 values were repeated twice (18, 27, 42, 46, 52, 60, 87, 89, 102, 115, 118, 137).

## Problems and Advantages

As a new method of portraying and modeling maritime activity in antiquity, this approach still has elements that need to be refined. One drawback is the need to store and to manipulate a large number of individual shapefiles when superimposing and projecting multiple mobility polygons. A second, yet more ubiquitous issue, is the reliability of the data itself; further modeling may require additional evaluation of data published prior to 1990. As Leidwanger has demonstrated, such efforts can produce considerably more refined understandings of submerged archaeological assemblages.[32] The depth of a re-evaluation may be balanced by the nature of the investigation, however, because differences in sources or type may produce important conclusions at a local level that are otherwise invisible at the regional or pan-Mediterranean scale.

This scalability of the modeling, however, may be a clear benefit of this approach. With enough data, high-resolution results can be generated that illustrate change across an ocean, a sea, a lake, or a river. Equally valuable, as the underlying dataset continues to grow, is the nature of the results. As evident though a comparison to Strabo's maritime topography of the western Mediterranean basin, this approach can generate models that are independent of, and equivalent in scale to, narratives of the sea from other media. Moreover, a chronological sequence of models generates a narrative of maritime activity equivalent in scope as well – it is theoretically possible to compare changes in

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[32] Leidwanger 2017.

this archaeological narrative of maritime activity to changes in port cities, socio-economic trends, or environmental disasters.  For example, did activity change with the eruption of Mount Vesuvius in AD 79?

Future efforts and testing of this methodology in AMD include the ongoing expansion of the dataset, particularly in the Adriatic, as well as exploring its limitations.  While a comparison between the maximum densities of the archaeological models and a randomized dataset can establish the reliability of results, what is the minimum number of assemblages necessary to generate reliable results?  Does this number change depending upon the geographic scale of the model?  Similarly, what is the smallest geographic area that can presently be modeled?  Lastly, once this modeling has produced an extensive narrative of maritime activity in the antique Mediterranean, demonstrating its viability, what may be done with data from the Atlantic or the Pacific?

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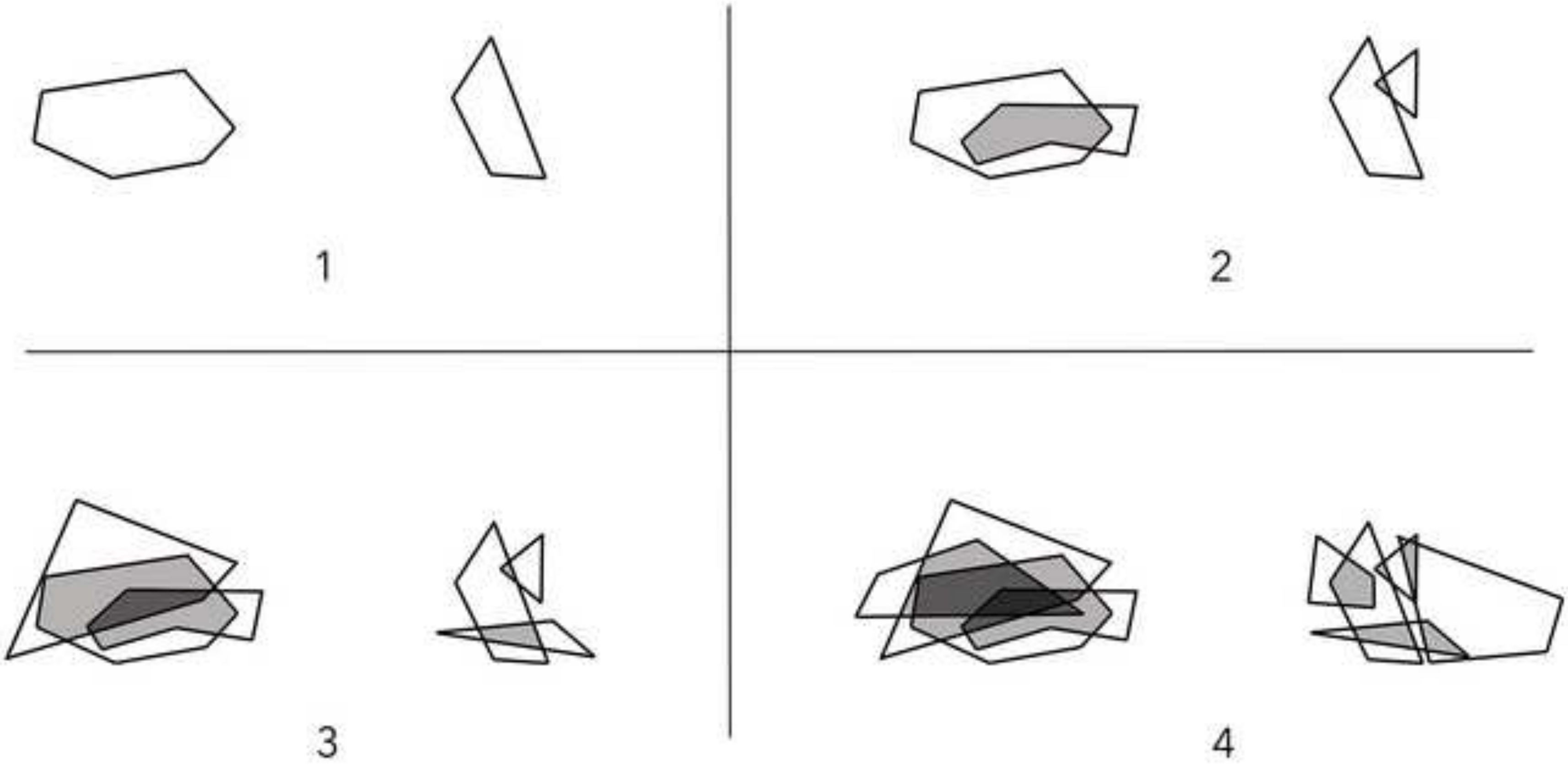
Figure 1



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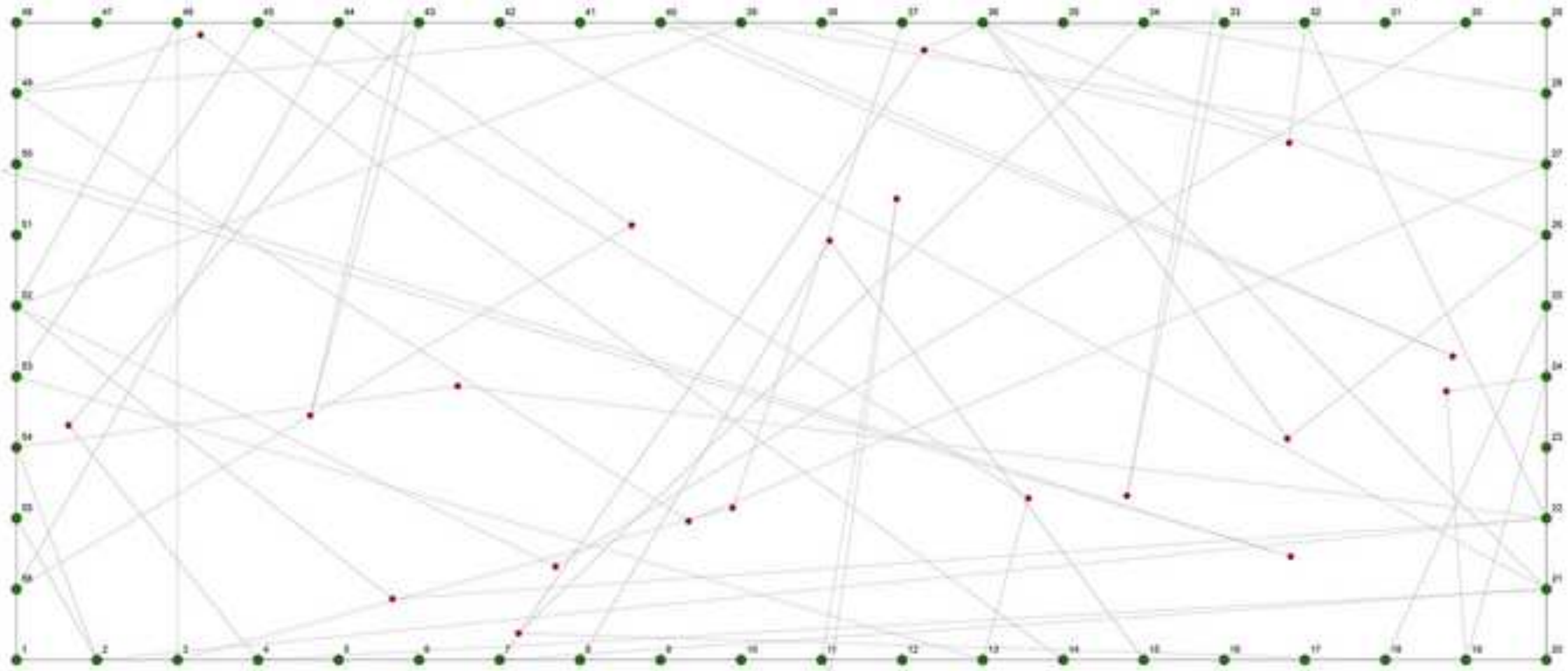
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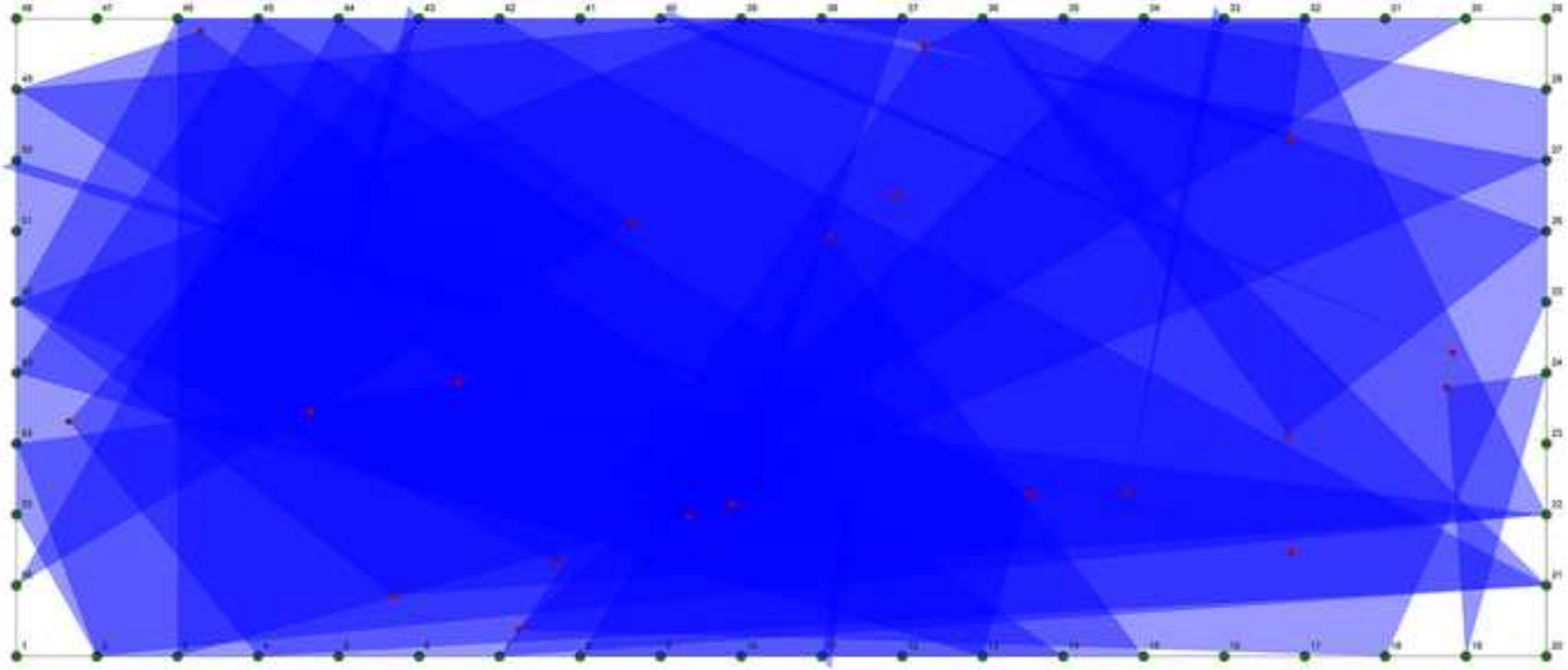

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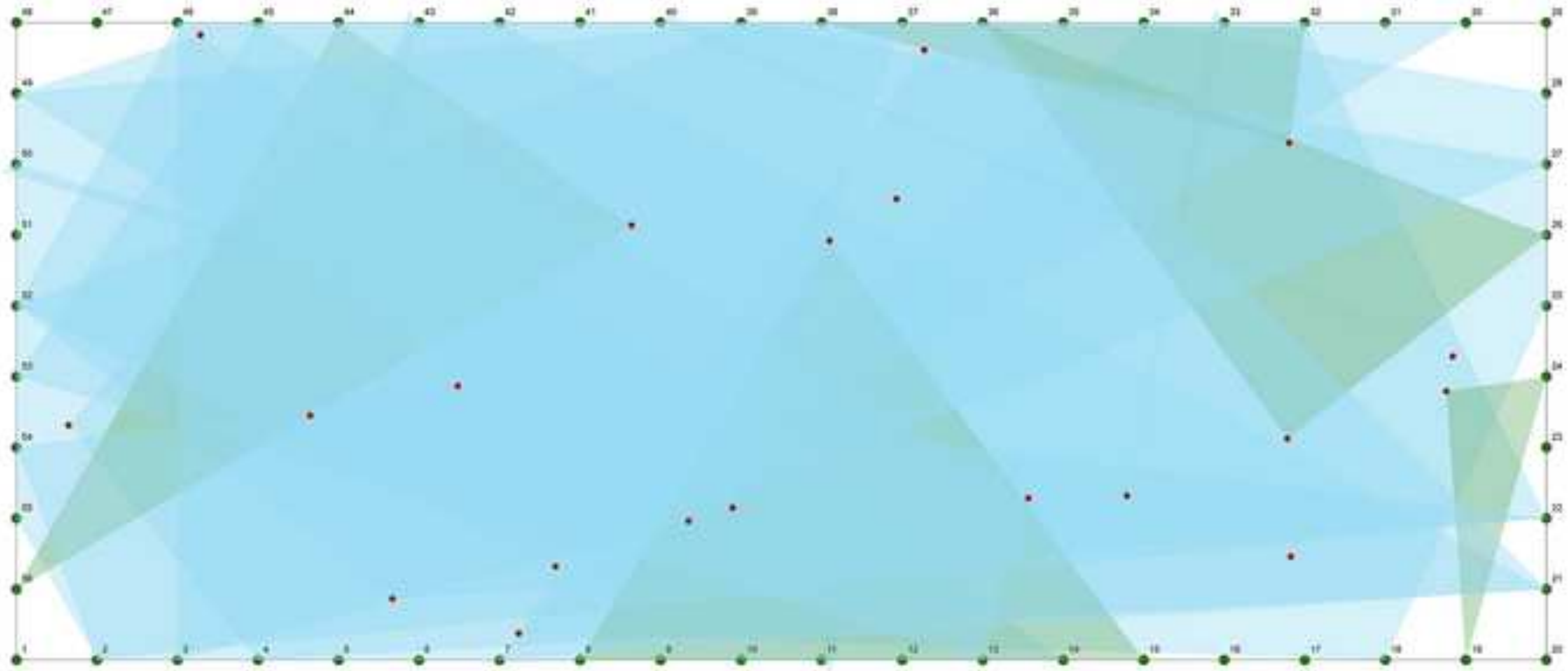

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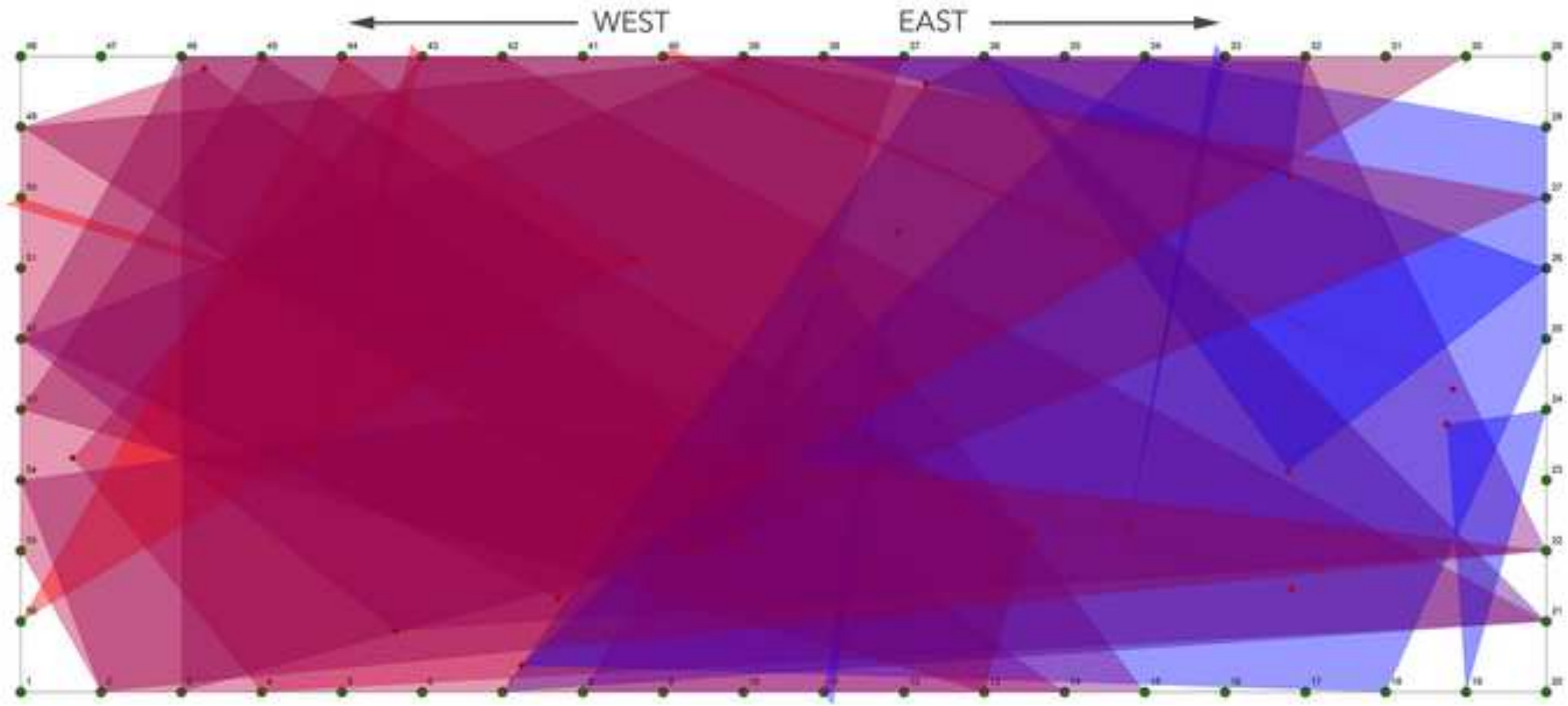

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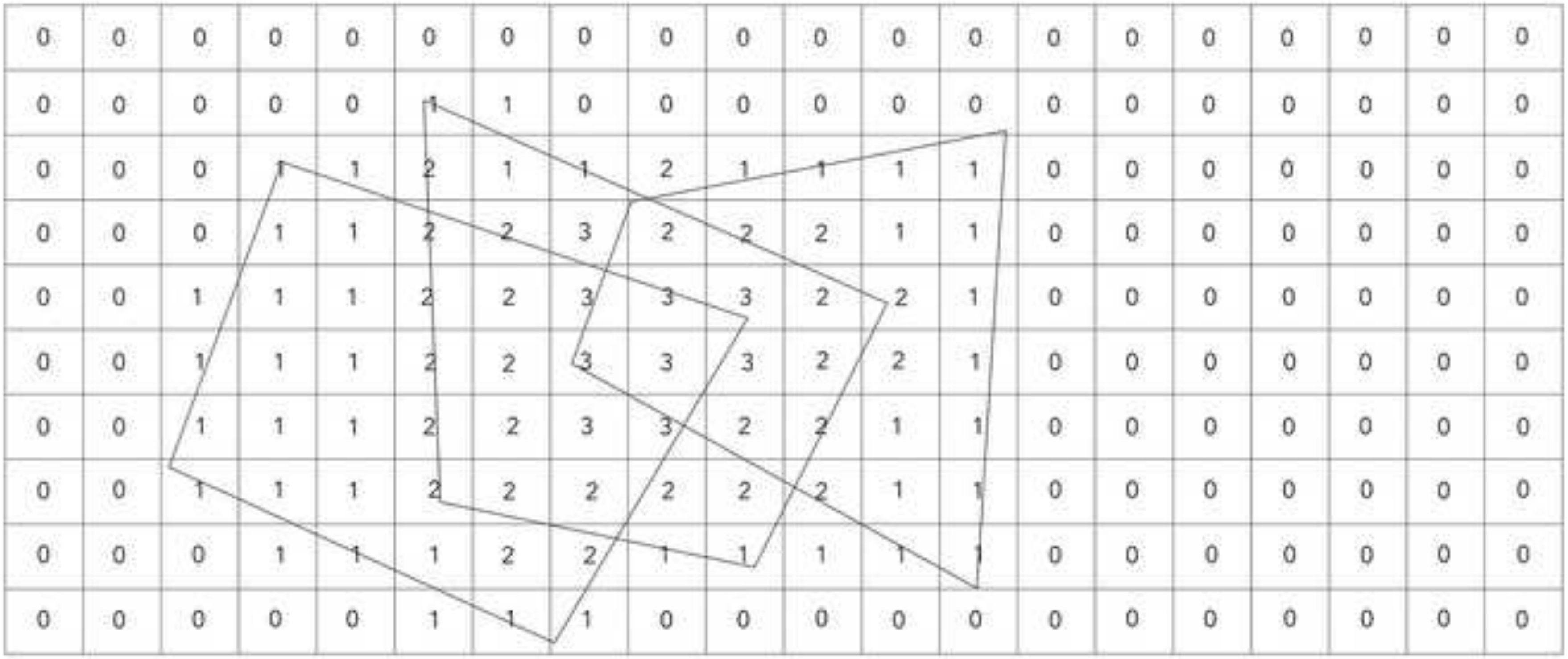

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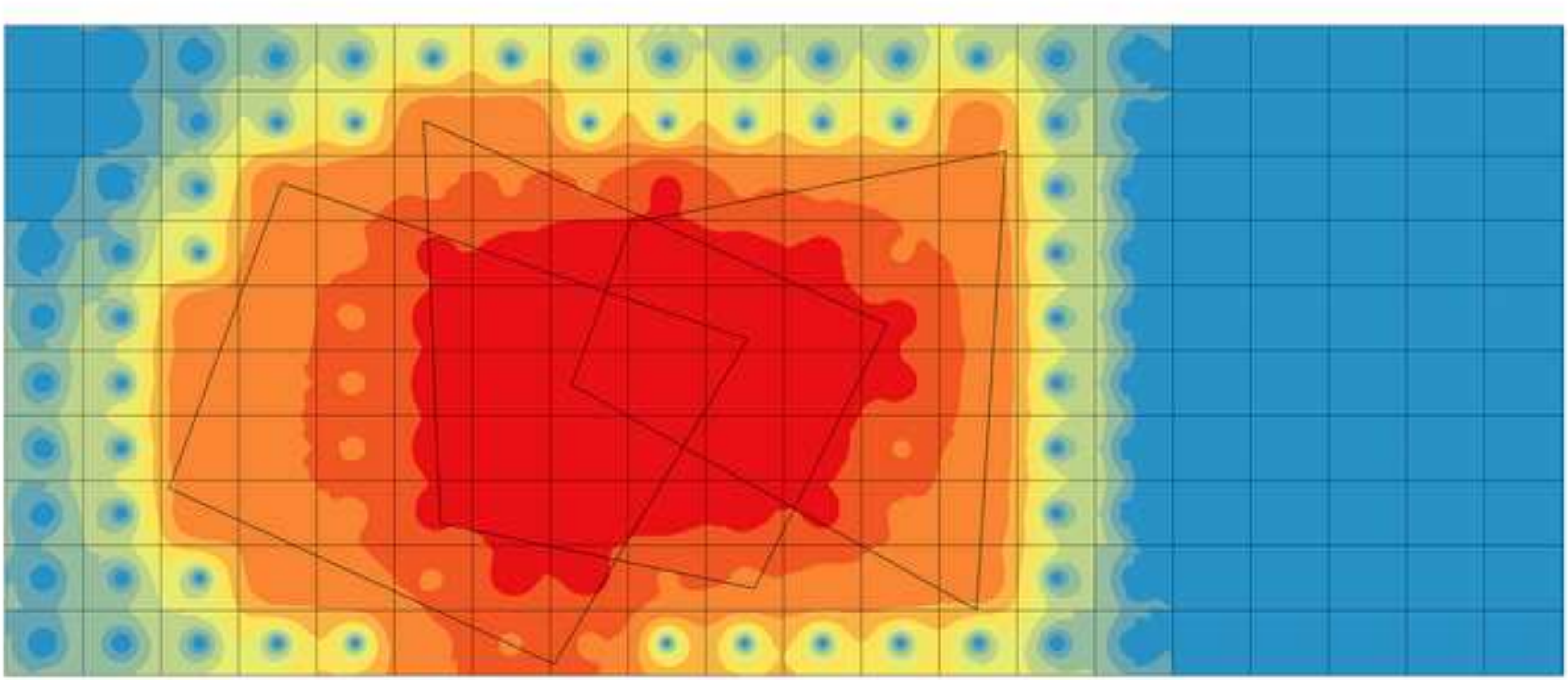

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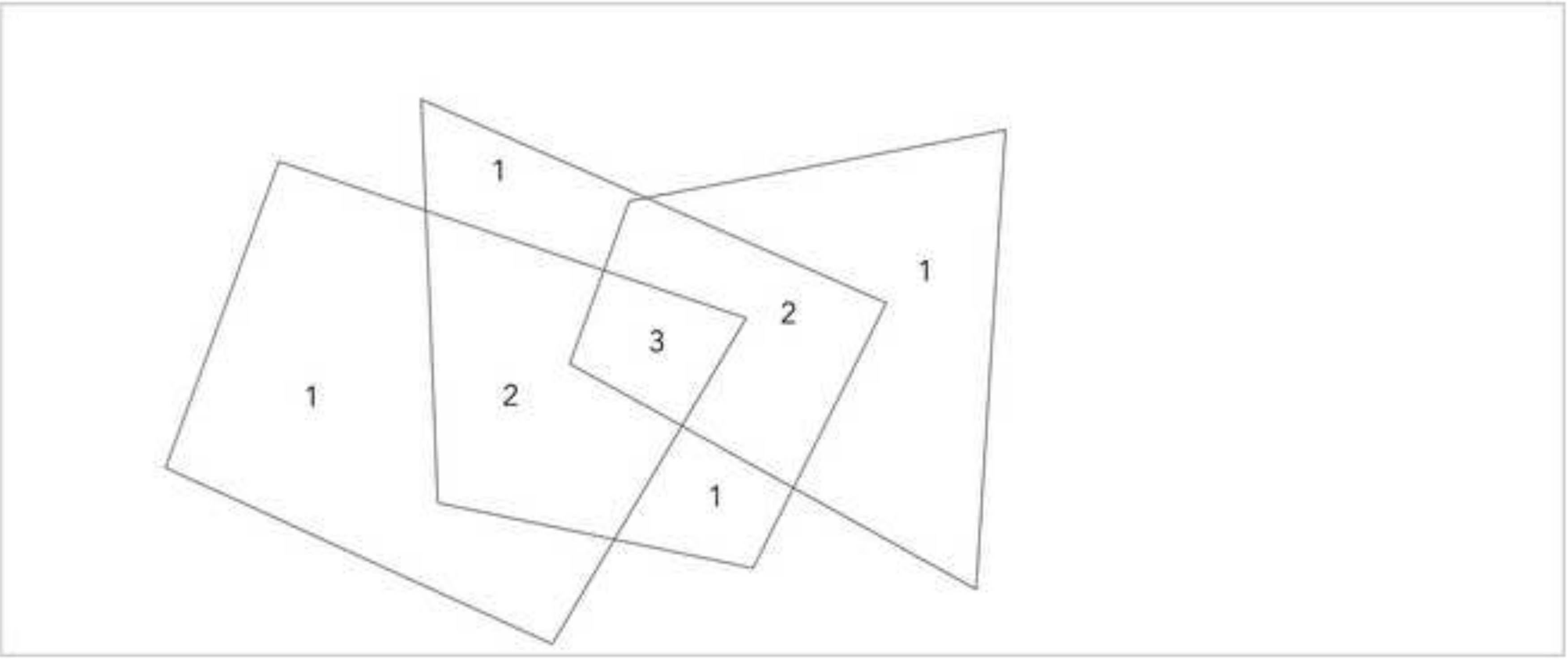

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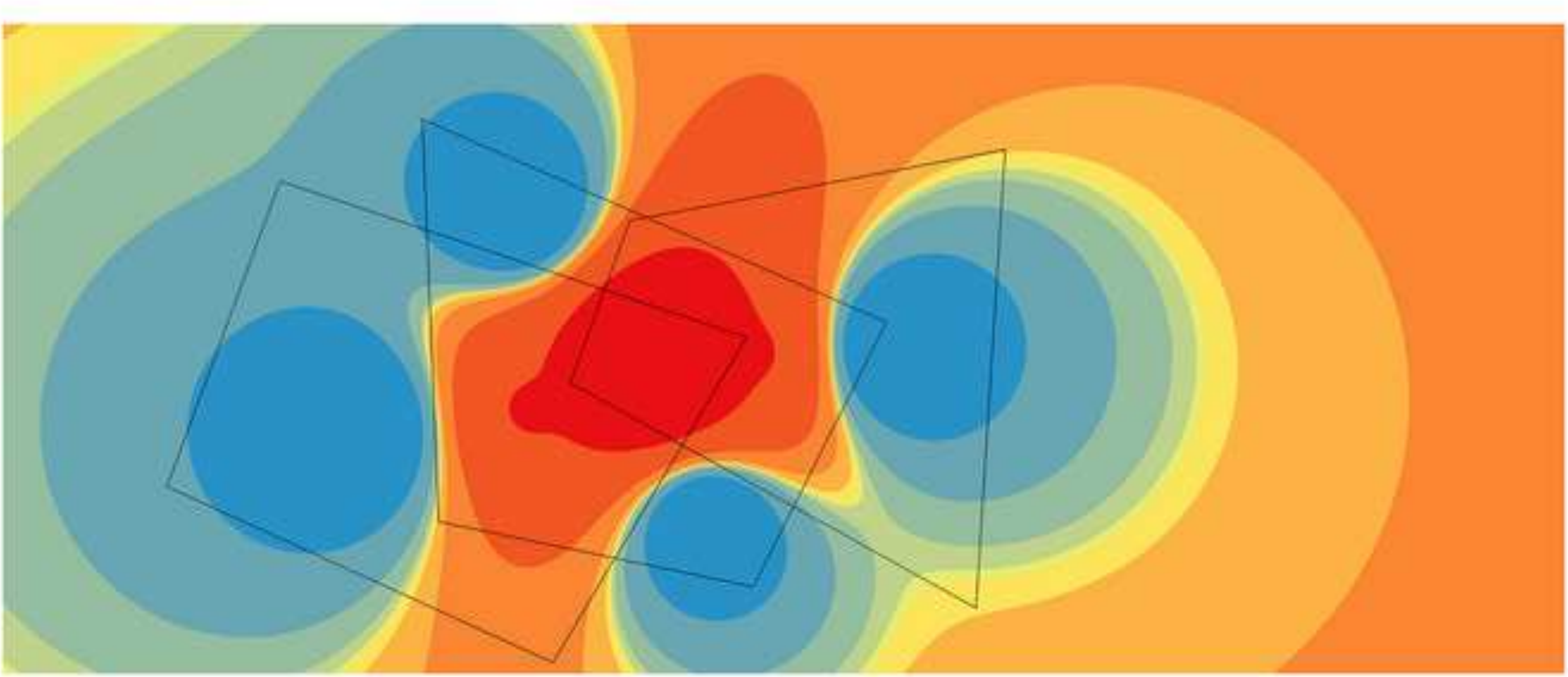

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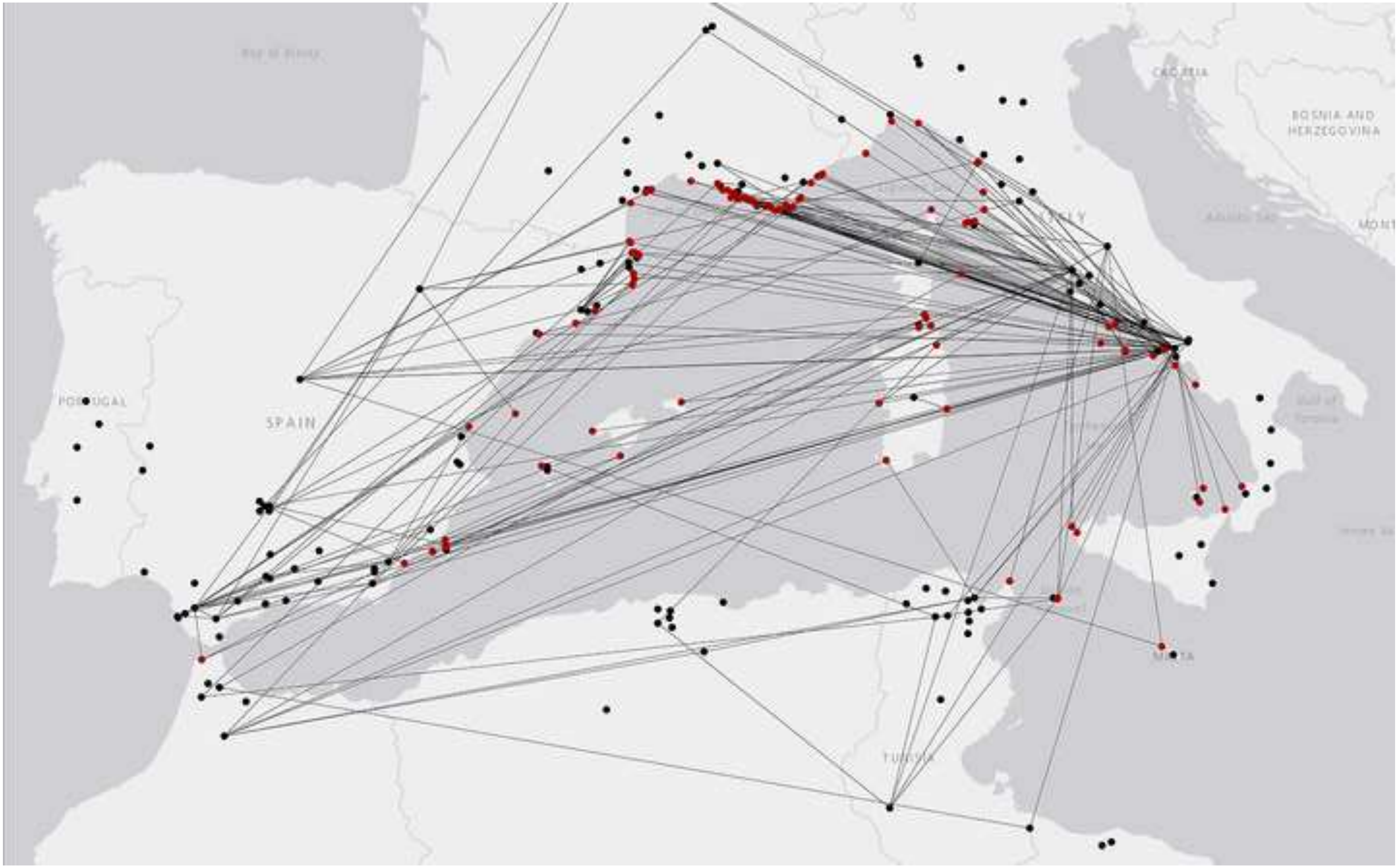
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**Figure 11**

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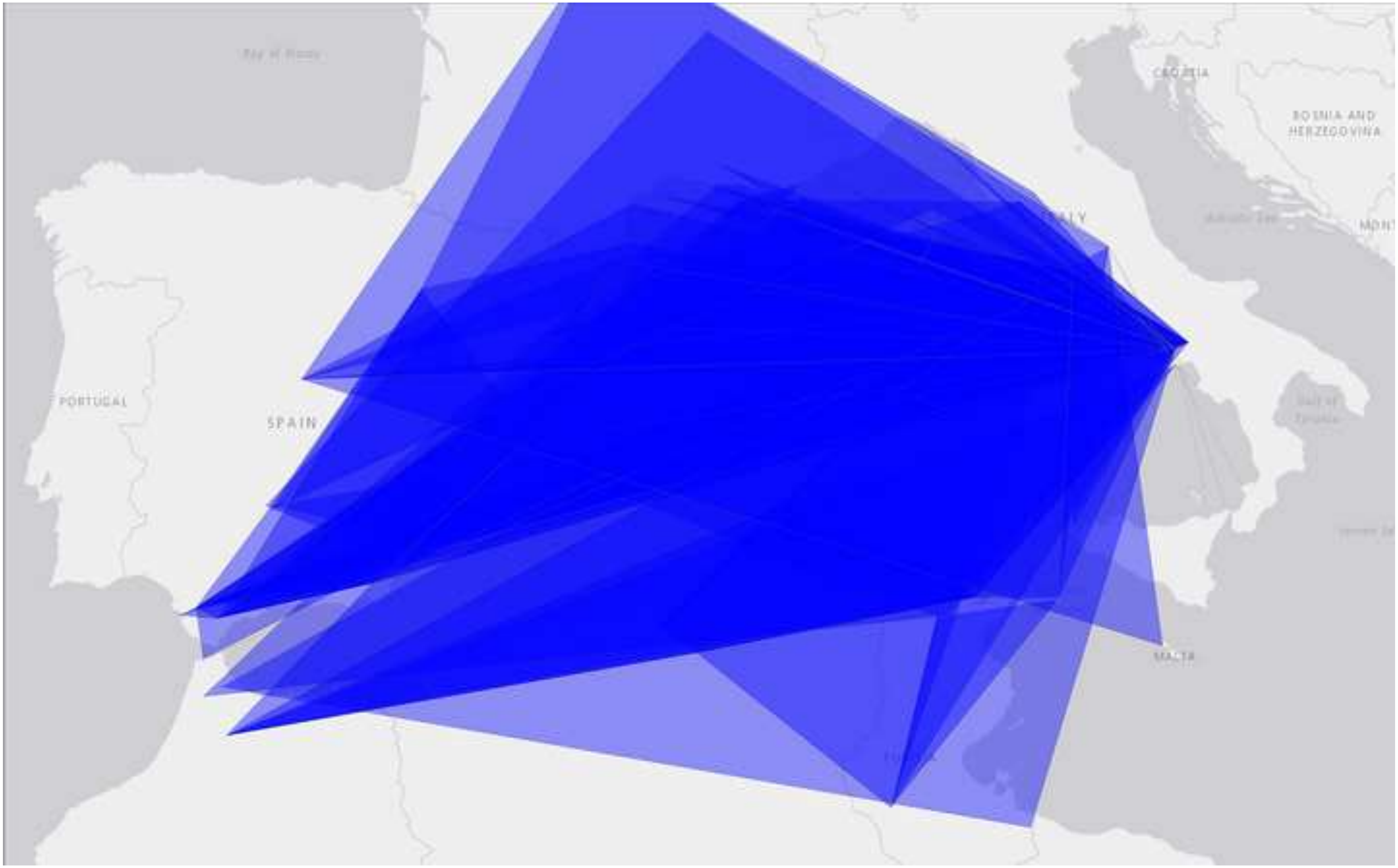

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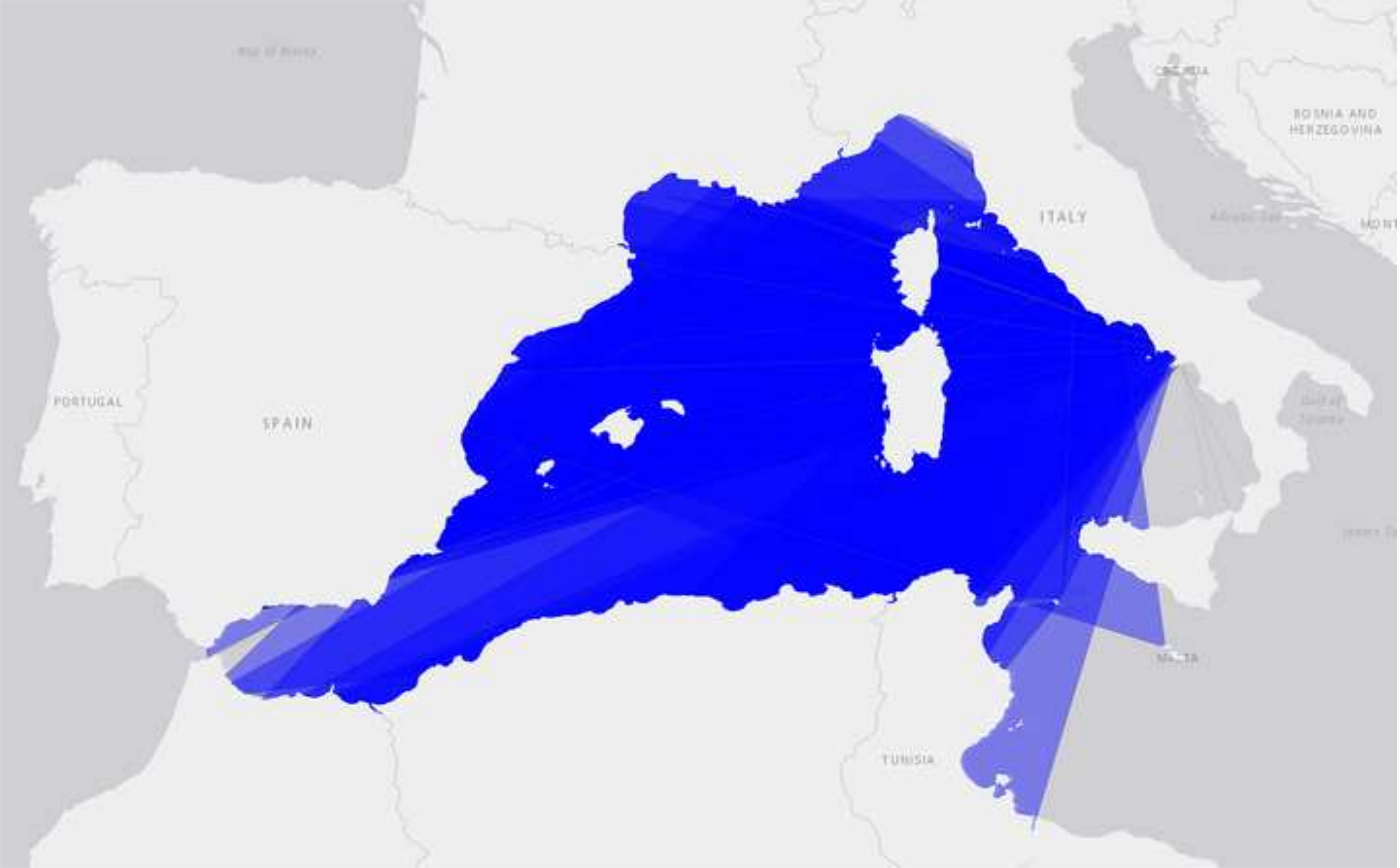
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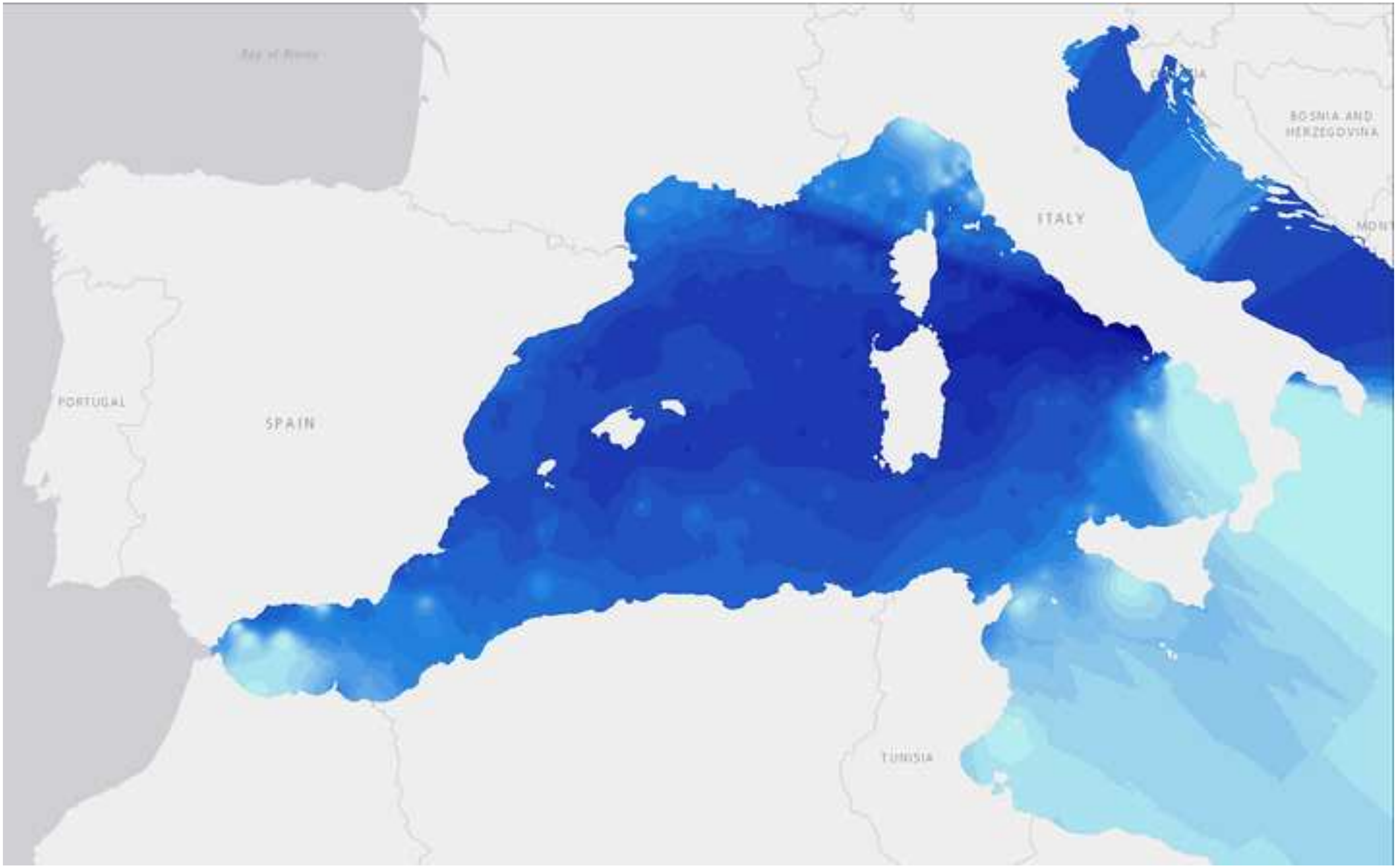
Figure 13



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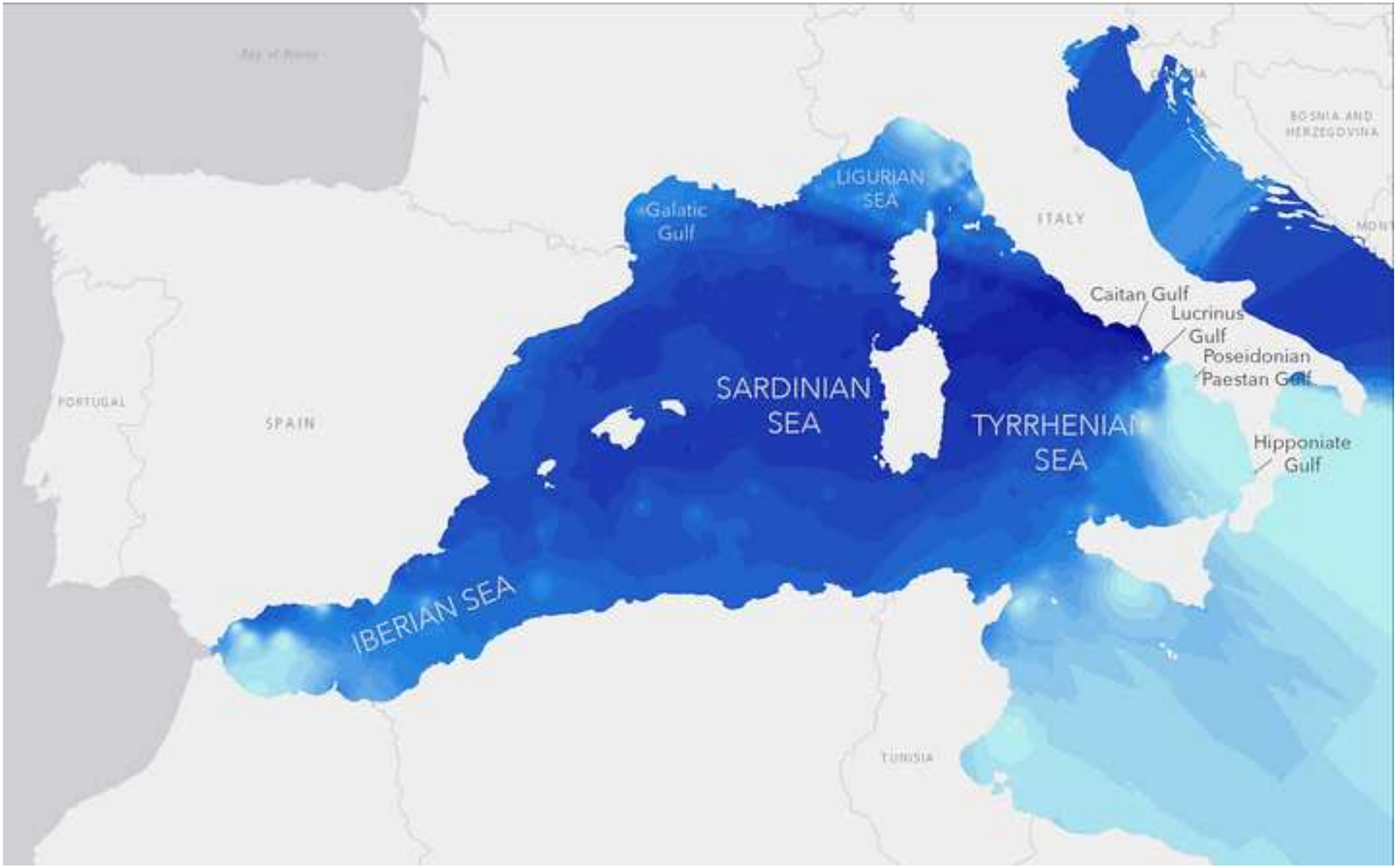
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Figure 15

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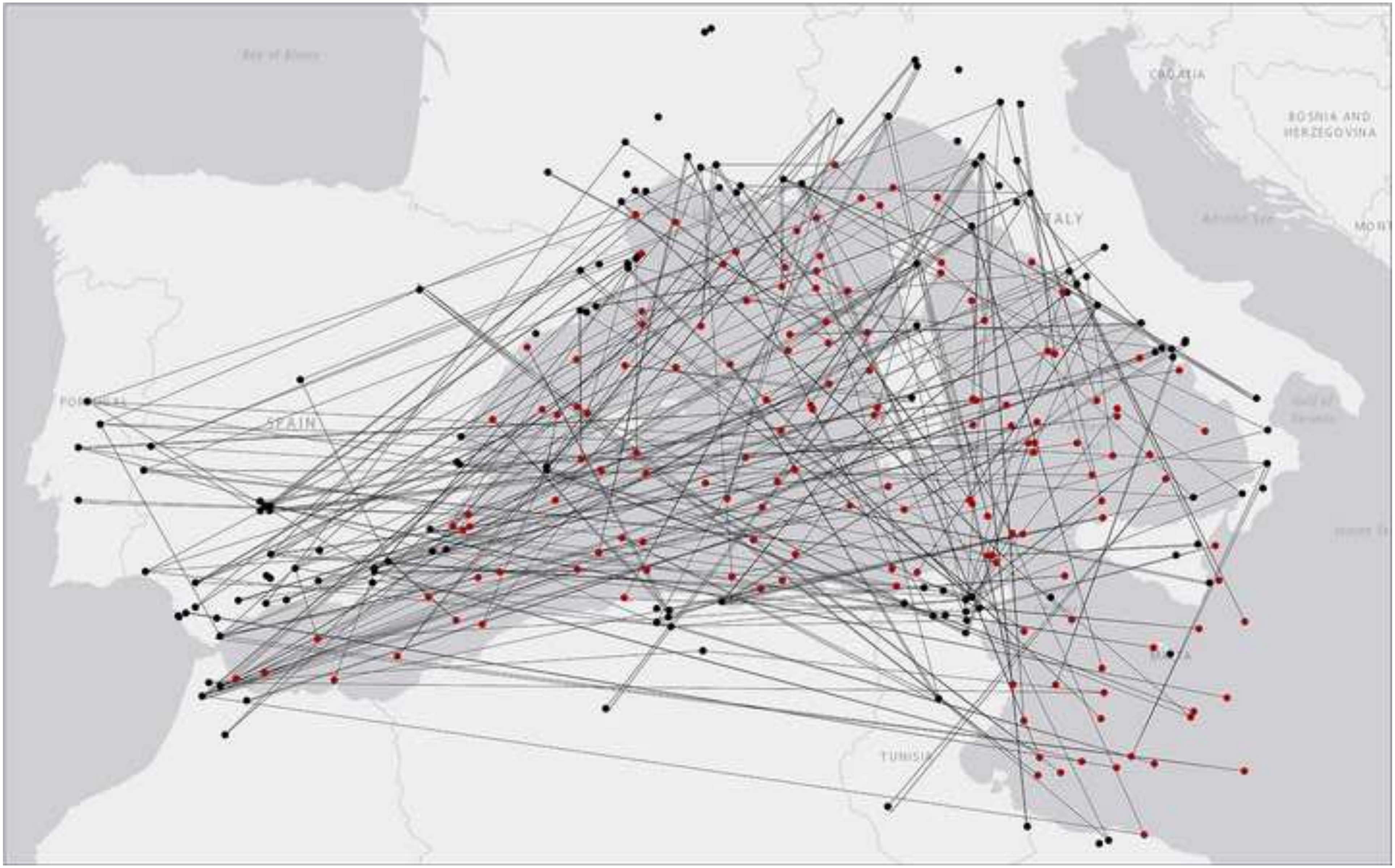

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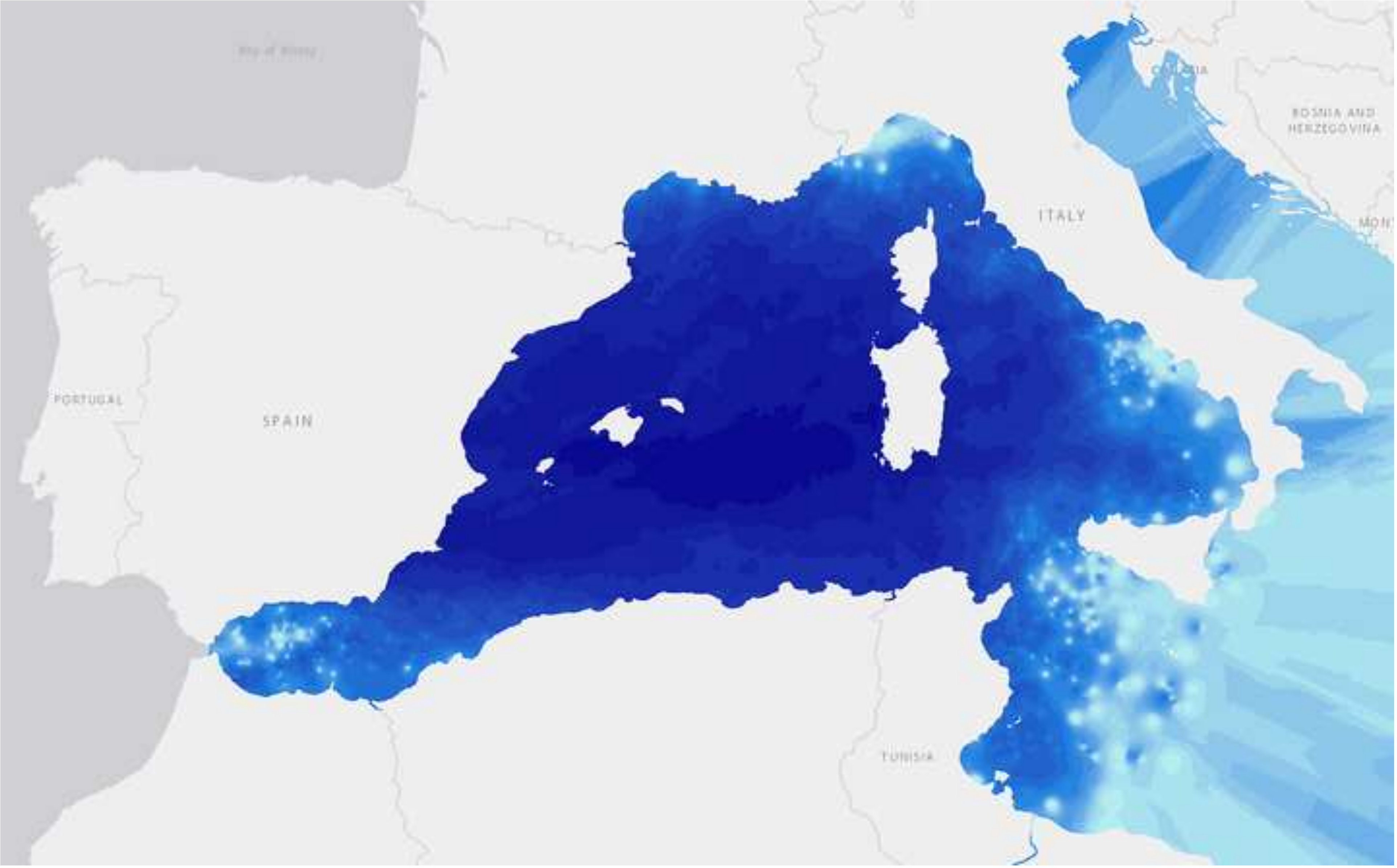
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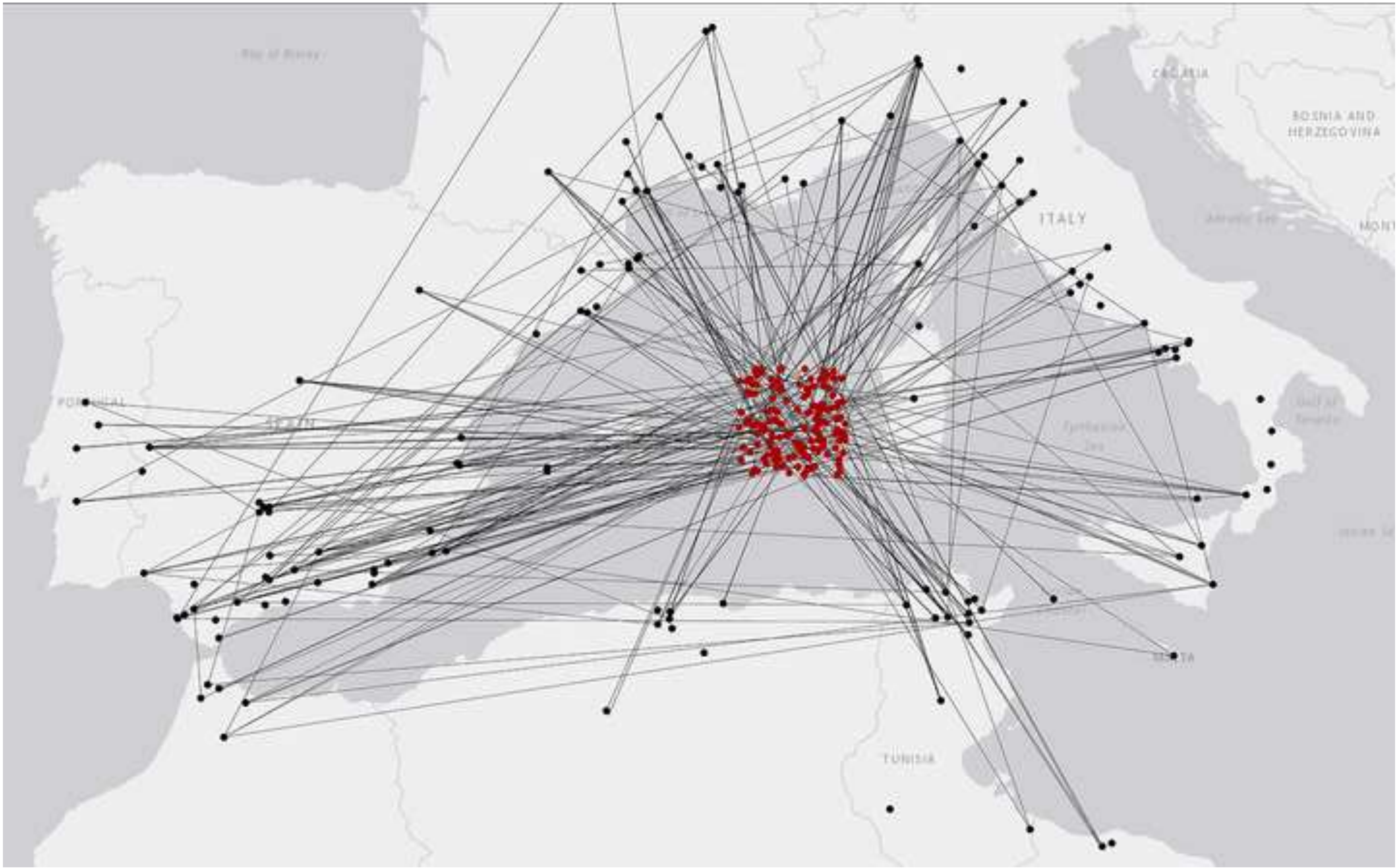
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**Figure 18**

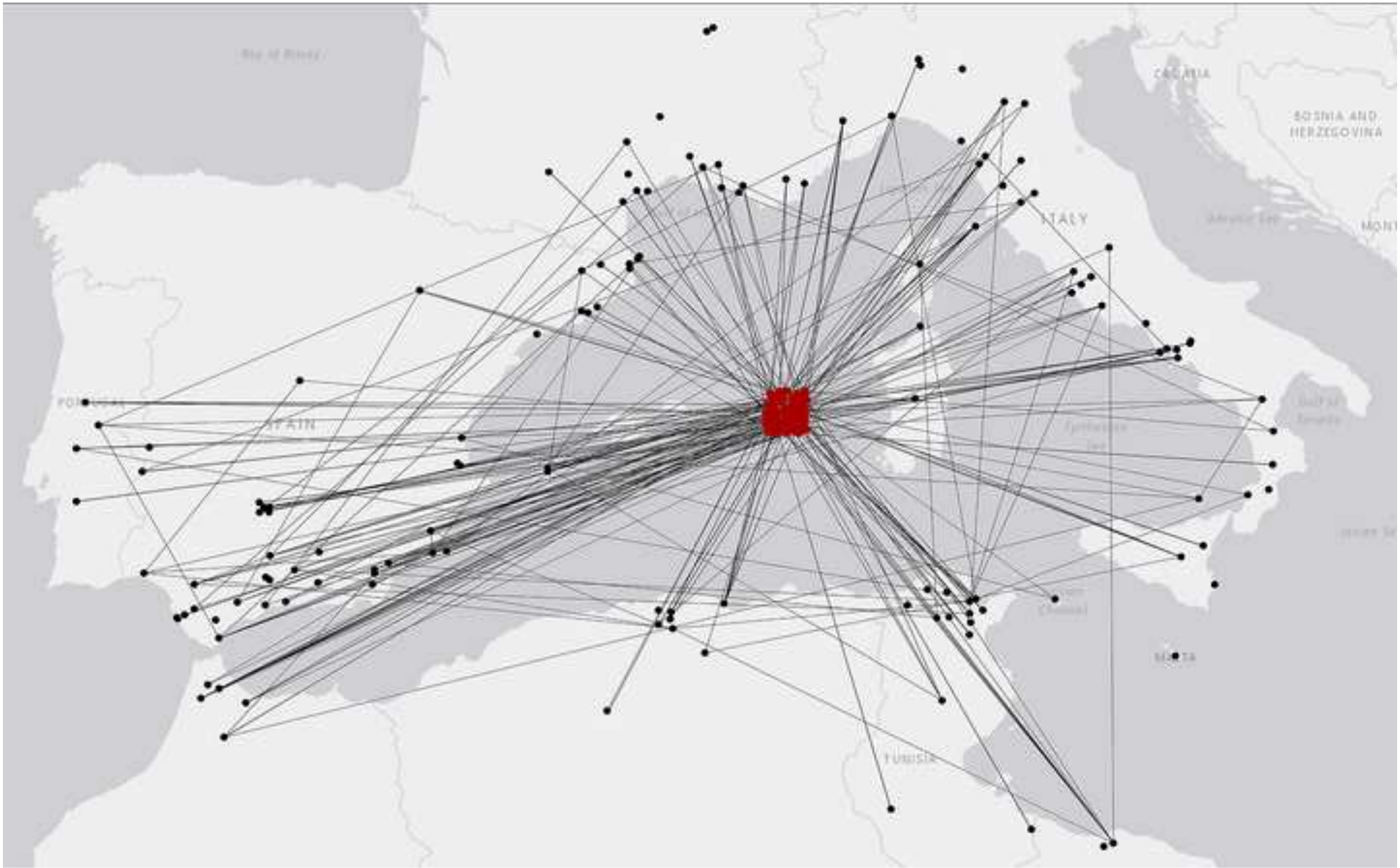
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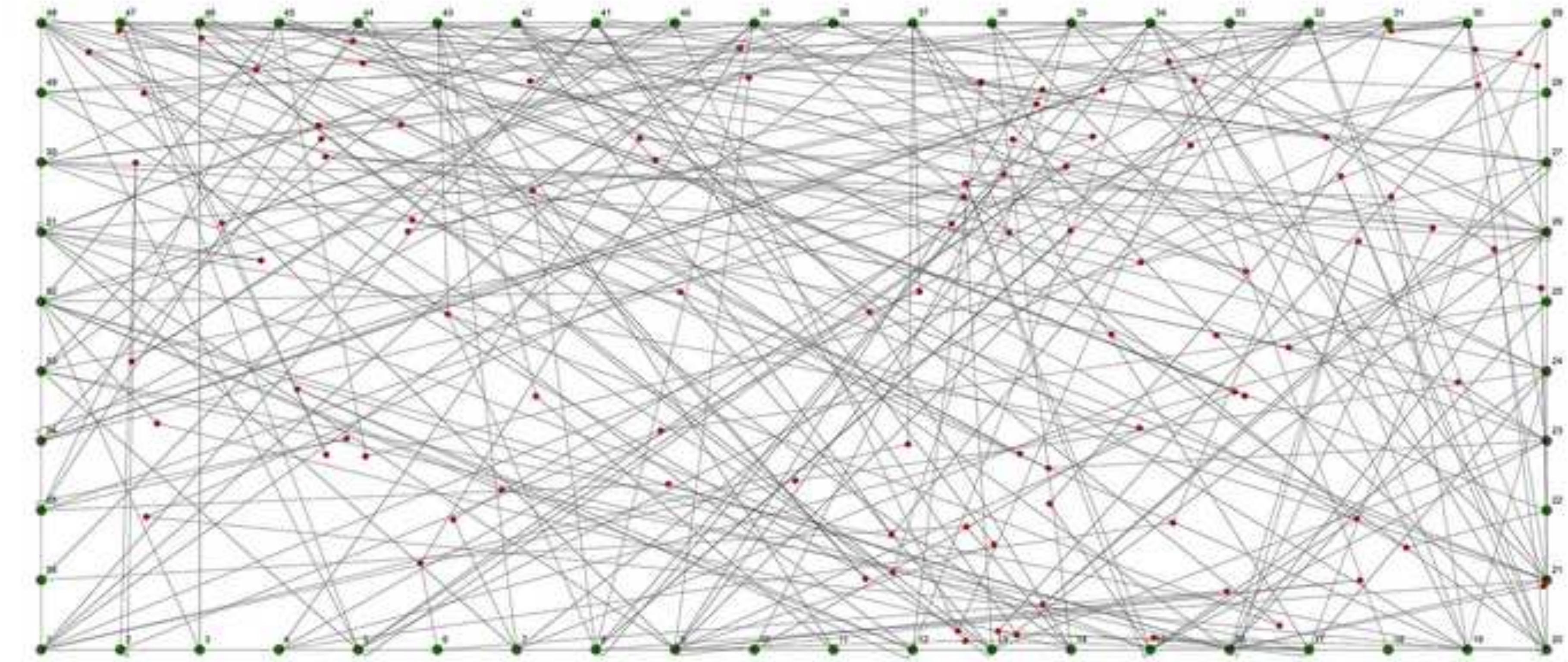
Figure 19



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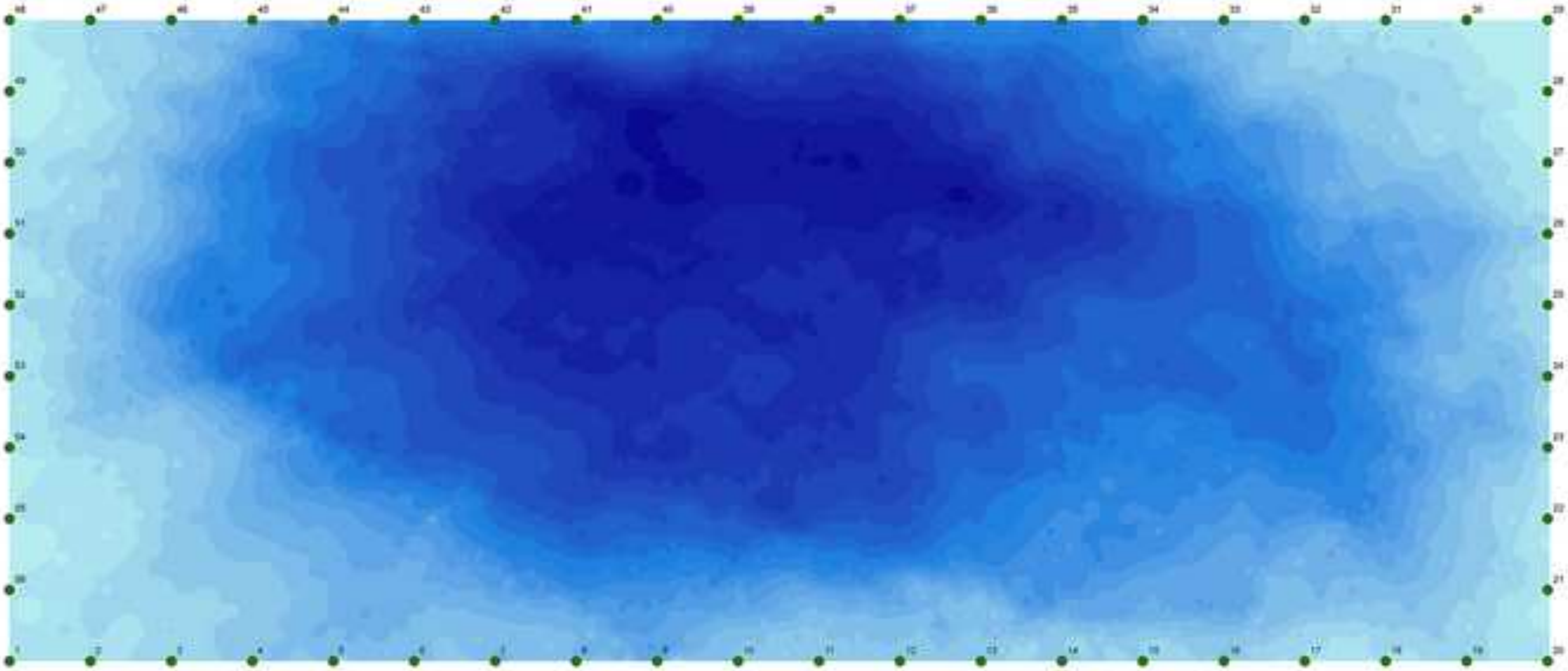

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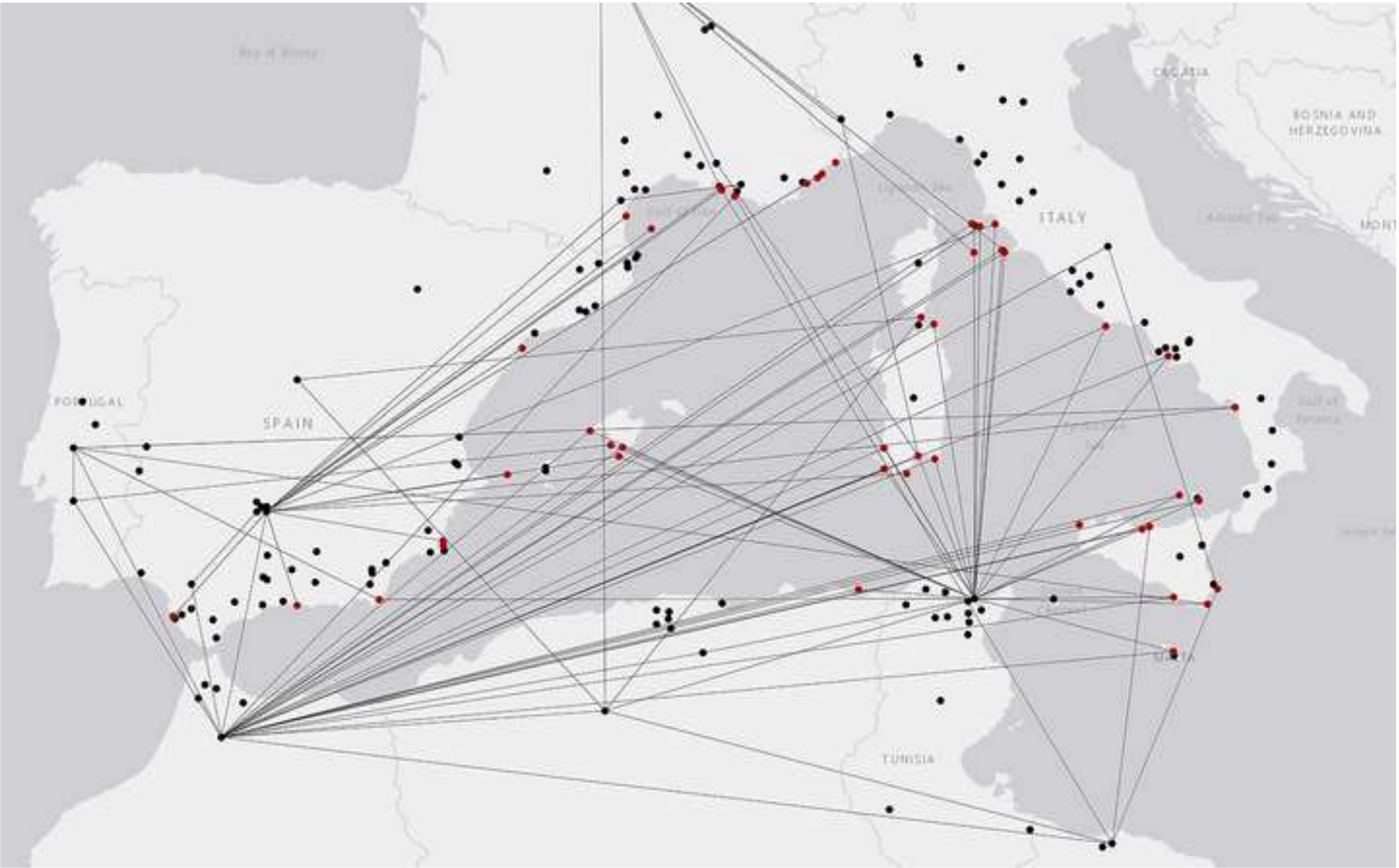
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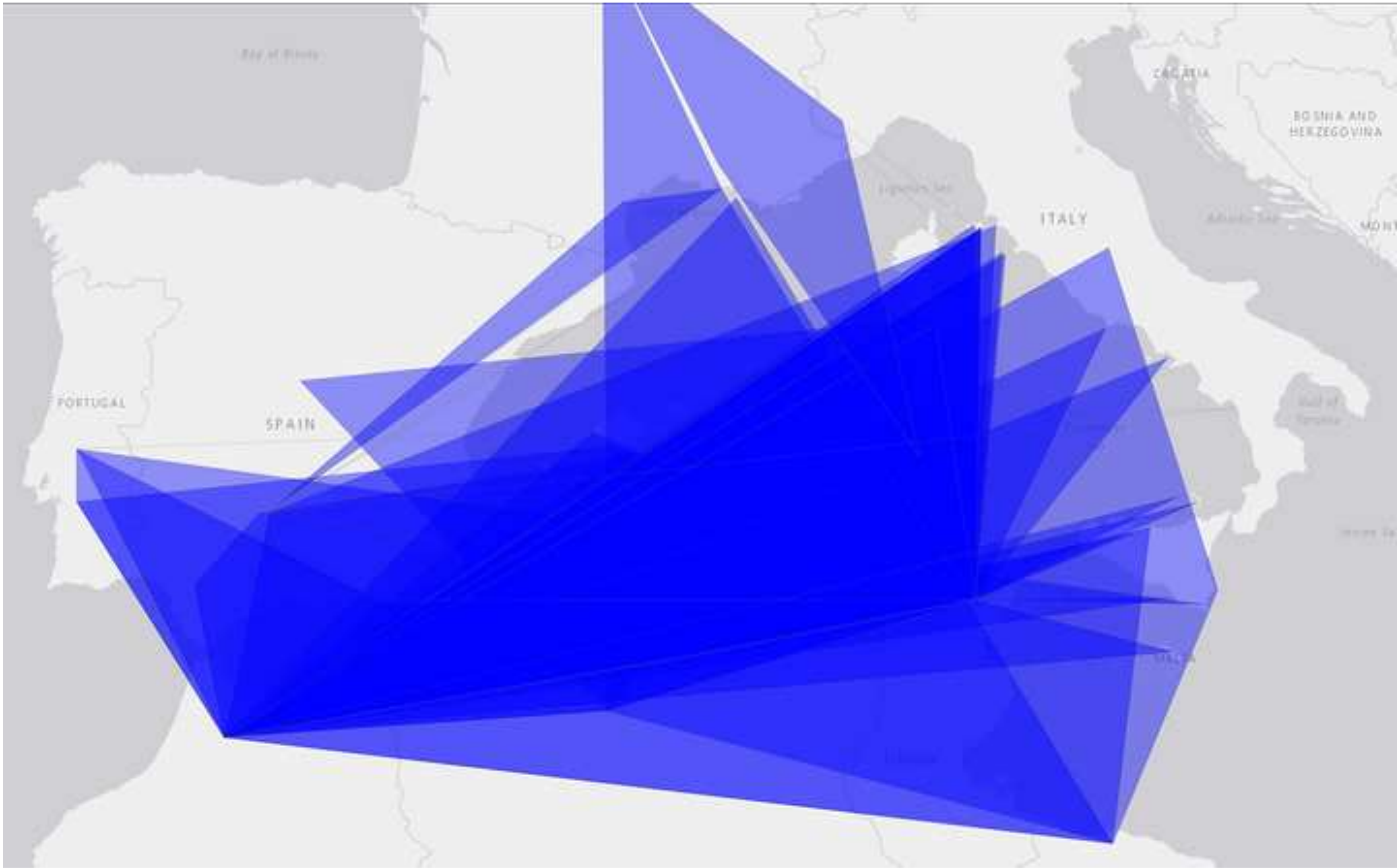
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BOSNIA AND HERZEGOVINA
ITALY
PORTUGAL
SPAIN
Ligurian Sea
Adriatic Sea
MONT
Gulf of Taranto
Ionian Sea
MALTA

Figure 23

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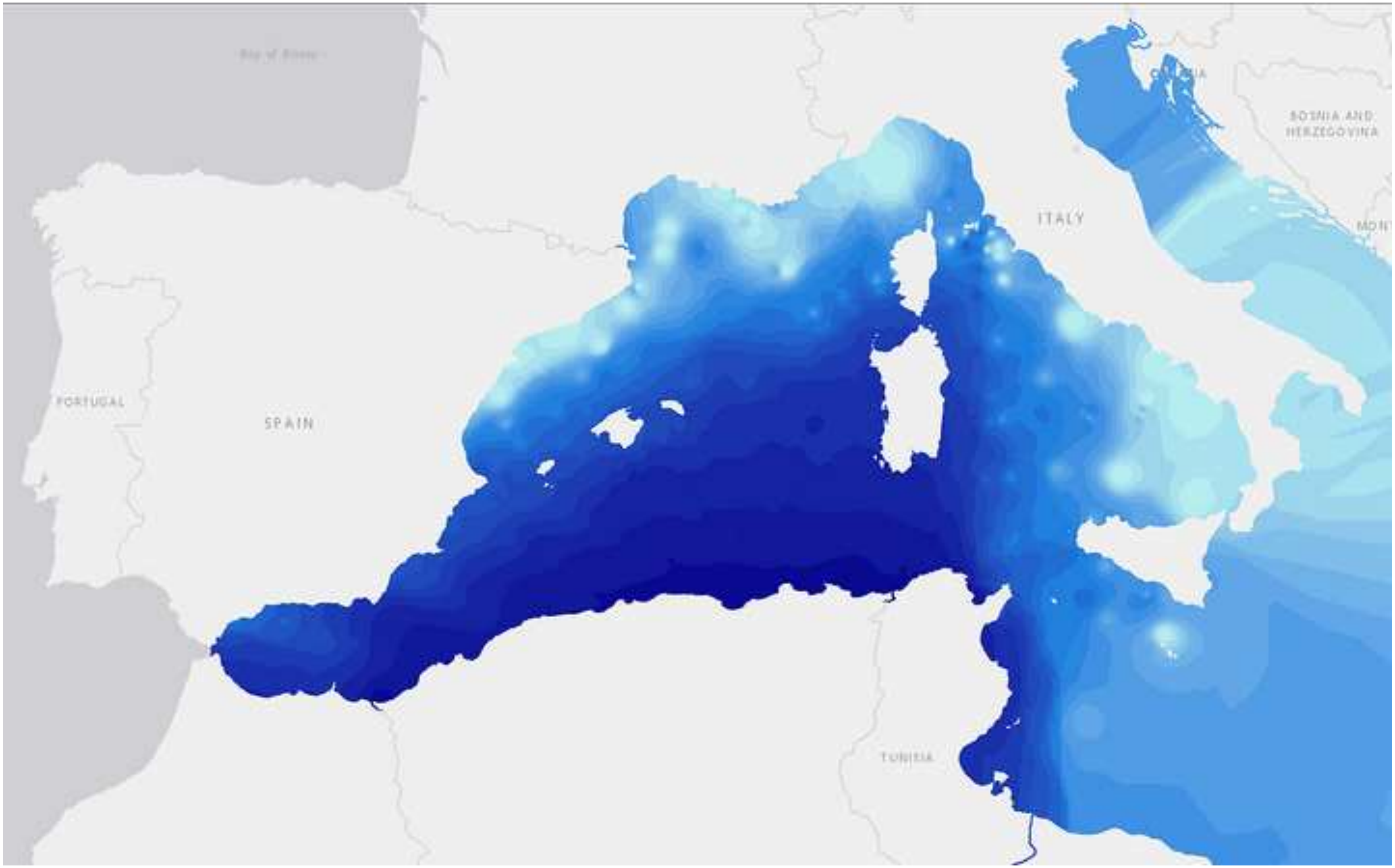
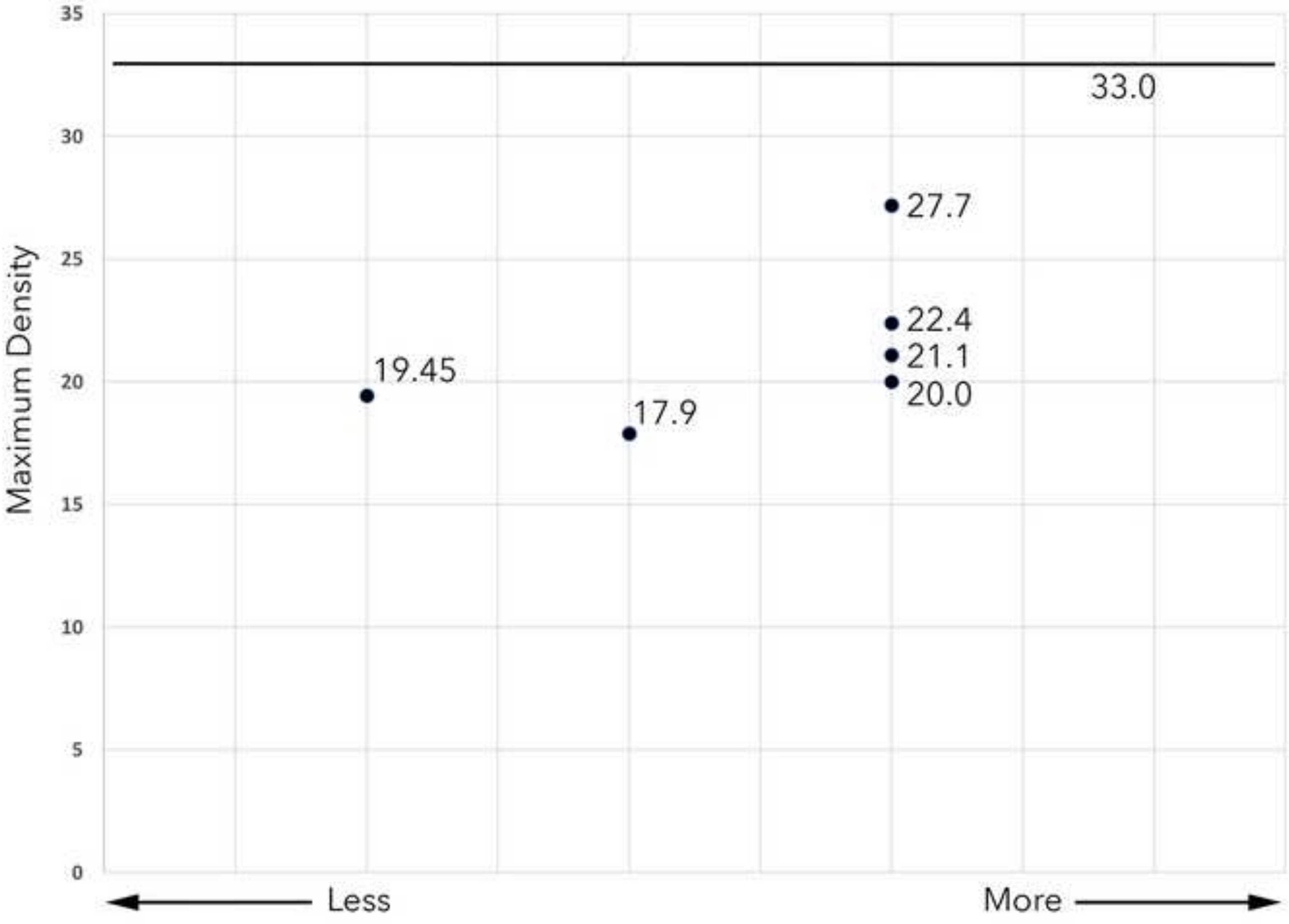


**Graph 1**



Maximum Density
35
30
25
20
15
10
5
0
33.0
27.7
22.4
21.1
20.0
19.45
17.9
Less
More

**Graph 2**

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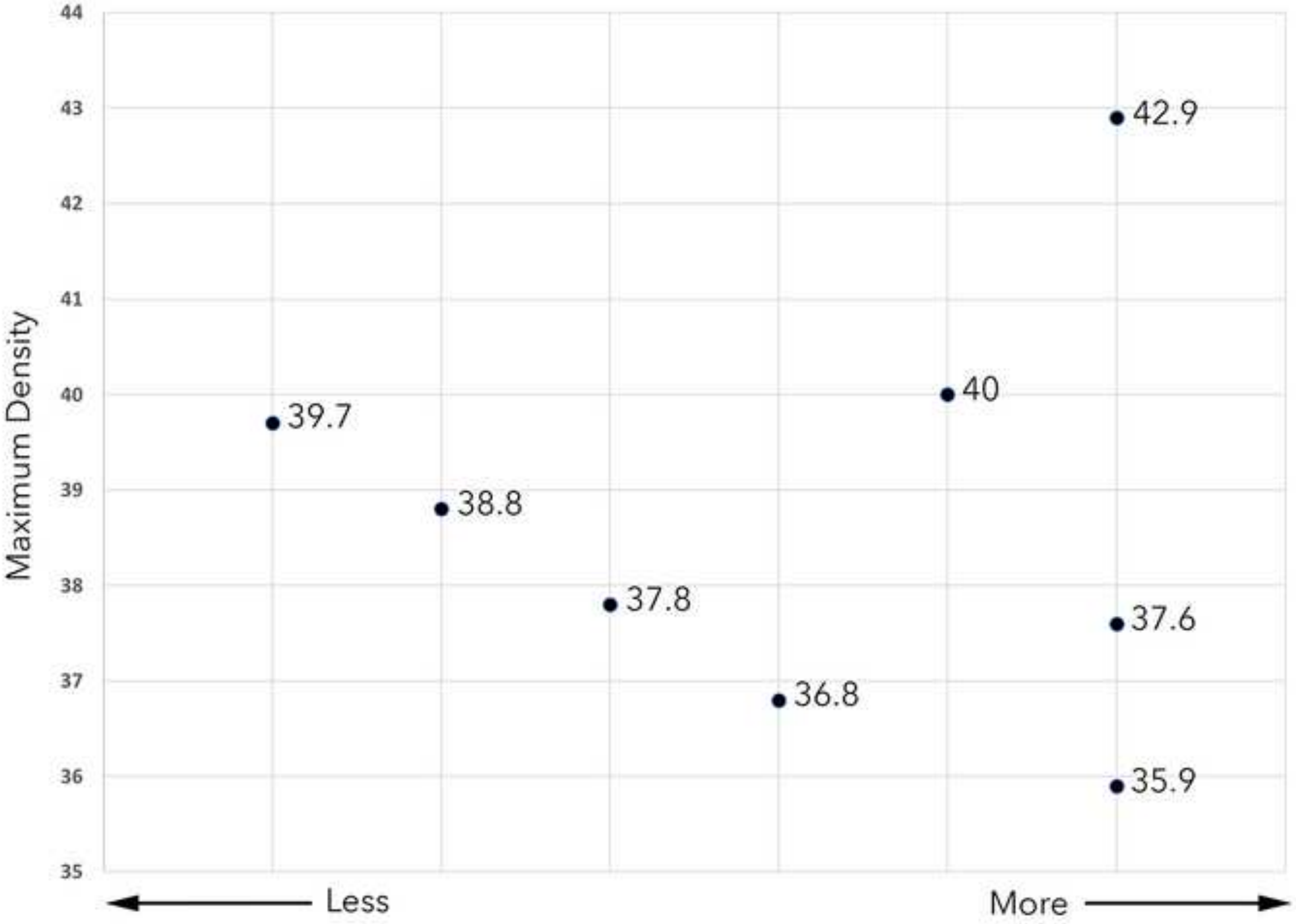

**Graph 3**

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