Cross-Border Crime Patterns Unveiled by Exchange of DNA Profiles in the European Union

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Abstract

The aim of this study was to make a head start with unveiling transnational spatial patterns in offending. To that end, data are used from DNA profile exchange between The Netherlands and eighteen other EU member states that have implemented EU legislation on forensic cooperation. Information was collected on all DNA stains entered into the database, including the region in The Netherlands where the stain was secured, the type of crime, and how many matching DNA profiles had been identified in each of the other eighteen countries. The results suggest that currently the profiles of offenders who are active in other Prüm countries make up for about 4 percent of all DNA stain profiles in the Dutch DNA database. The highest share of cross-border matches is found in the southeastern part of The Netherlands, where The Netherlands borders one of the most densely populated regions of Germany.

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Introduction

While cross-border mobility within the European Union (EU) related to education and employment has been extensively documented (e.g., Geddes, 2003; Papatsiba, 2006), knowledge of cross-border criminal mobility has lagged behind. The scarce empirical material is limited either to specific transnational activities involving illegal cross-border trafficking of goods and people (e.g., art, arms, drugs, money, undocumented aliens) or to specific offender categories based on nationality or country of birth, in particular offender groups from Eastern and Central Europe (Van Daele and Vander Beken, 2010; Van Daele, Vander Beken, and Bruinsma, 2012; Siegel, 2014). What lacks is a more comprehensive and systematic assessment of the involvement of individuals in crime in multiple EU member states.

The paucity of available data on offender mobility is unfortunate. It reduces opportunities to mitigate criminal mobility. It might also give rise to exaggerated or underrated estimates of the volume of criminal mobility and to biased views of the real geographical patterns, and it could even lead to misguided policies.

The present article seeks to make a start in unveiling patterns of offender mobility in the EU. The aim is accomplished by analyzing crime data that have become available through the exchange of DNA profiles between The Netherlands and eighteen other EU member states, according to the Treaty of Prüm and subsequent EU legislation. In this article, the nineteen countries involved in the exchange will be labeled 'Prüm countries'. Because DNA profiles can identify individuals with probabilities that approximate certainty, they can provide strong evidence on whether two crimes perpetrated in different Prüm countries involved the same offender[1].

Inspired by two contrasting models of offender mobility —the sedentary model and the nomadic model— the specific issue addressed in the present article applies to regional variations in cross-border crime in The Netherlands. We aim to answer the following questions. In which regions of The Netherlands are crimes committed that involve offenders who also committed crimes in other Prüm countries? What is the share of these cross-border crimes in the total regional crime rate? Which regions in The Netherlands 'exchange' crime with which areas in the EU?

[1] In this paper, reliability is assessed according to common criteria in social science research, where error margins of up to 5 percent are generally deemed acceptable. Obviously, legal procedures require much smaller error margins.

This introduction ends with a brief overview of what follows. The second section briefly reviews the literature, addressing prior research on criminal mobility and on the use of DNA to study criminal mobility. The third section describes the data and methods used in this study, including the history and structure of the Dutch DNA database and the DNA profile exchange procedures between the EU member states. The fourth section describes the findings, mostly by mapping regional shares of cross-border crime. The fifth and final section discusses the findings, addresses caveats and suggests promising avenues for future research.

Literature

Before addressing the relevant literature, it is necessary to be clear about definitions. In the present paper, *cross-border criminal mobility* is defined as the involvement in criminal activities of a single individual in multiple countries. In order to have been involved in these crimes, the individual must have crossed a border. Consistent with this definition, *cross-border crime* is crime committed by a criminally mobile individual, i.e., an individual who has perpetrated crimes in multiple countries.

These definitions do not specify the nature of the criminal activities. The activities may include traditional transnational crimes such as drug trafficking and illegal arms smuggling, in which crossing borders is part of the criminal activity, that are studied in the literature on organized crime (Passas, 2002; Kleemans and de Poot, 2008). Cross-border crimes also include serious violent crimes like homicide, armed robbery and rape, and they also include common offenses like theft from vehicles and burglary.

The definitions neither specify the residence or nationality of the offenders. This implies that cross-border crimes between, for example, France and The Netherlands can be committed by offenders that live anywhere in the EU, or in the world for that matter, and not necessarily in France or in The Netherlands. Finally, the definitions do not specify a maximum period of time during which an individual must commit crimes in multiple countries in order to be labeled a cross-border offender.

Criminal mobility

Most empirical work on the mobility of offenders supports a *sedentary offender model*. According to this model, offenders restrict their criminal activities to their local environment, i.e., to the area around their place of residence. Even ‘commuters’ (Canter and Larkin, 1993), offenders that commit crimes away from their home environment, usually do not travel very far. Empirical studies of the home-crime distance (sometimes referred to as ‘journey-to-crime’ studies) have demonstrated time and again that this distance is generally short (e.g., Wiles and Costello, 2000; Snook, 2004; Levine and Lee, 2013). Furthermore, the journey to crime is subject to distance decay, i.e., the frequency of crimes decreases with the distance from home. The implication of these findings is that offenders who commit multiple crimes will generally commit these crimes within fairly limited geographical boundaries.

The findings on distance decay and short home-crime distances have been criticized as being methodological artifacts of the tendency of most researchers to analyze police records from a

single city or region, which results in biased findings because such records generally underestimate crimes that local offenders commit outside the city or region, and certainly do not reveal any crimes committed abroad (Polišenská, 2008; Van Daele, 2008; Van Daele et al., 2012; Vandeviver, 2013).

The *nomadic offender model* describes the behavior of offenders who have no long-term fixed residence, who travel and perpetrate crime in groups, who commit mainly nonviolent property crimes at high rates and in multiple countries, and who travel frequently in groups over long distances. The term "mobile banditry" was adopted by the Council of the European Union (5 November 2010) to describe the activities of such groups. Recent empirical work in Belgium (Van Daele and Vander Beken, 2010; Van Daele et al., 2012) and in The Netherlands (Siegel, 2014) describes the activities of offender groups that originate from Eastern and Central Europe in terms of this nomadic offender model. In fact, the nomadic model has not been applied outside Europe and outside the context of mobility of criminals from East- and Central-Europe to West-Europe. Note that the main criminal activities attributed to these nomadic offender groups are quite different from the activities attributed to traditional 'organized crime groups' that specialize in illegal cross-border trafficking of goods and people (Kleemans and de Poot, 2008).

In a world where all crime is local, cross-border criminal mobility and cross-border crimes would be limited to a fairly small corridor around the borders between countries. The limited action radius of offenders would prevent them from committing crimes farther than a few kilometers beyond the border into a neighboring country. In a world where all crime is perpetrated by itinerant offenders who face few mobility restrictions, borders would not have any effect on where offenders travel to, or on where cross-border crimes are perpetrated. The world we live in is probably situated somewhere in between these two extremes, but we do not precisely know where. This lack of knowledge could hopefully be decreased by systematic empirical research on criminal mobility and cross-border crime.

Criminal mobility and DNA

The use of DNA profiles for identification based on biological material has very important implications for criminal investigations and in court. In addition, DNA profiles provide interesting opportunities for criminological research in general (e.g., Leary and Pease, 2003; Townsley, Smith, and Pease, 2006; Lammers, Bernasco, and Elffers, 2012), and for the spatial analysis of crime series in particular (Wiles and Costello, 2000; Lammers and Bernasco, 2013; Lammers, 2014). Possibly the most interesting criminological feature of DNA profiles is that, unlike traditional data sources on offenders, DNA traces provide information on the criminal careers and mobility patterns of unidentified offenders through the tracks they leave behind (Lammers and Bernasco, 2013).

To our knowledge, Wiles and Costello (2000) were the first to use data from a DNA database to study offender mobility. Based on DNA profiles data from the Forensic Science Service (FSS) database in the United Kingdom, the authors determined the geographical dispersion of pairs of matched DNA stains. The authors had no access of geographic details but established

from which division and from which police force the DNA profiles had been sent to the FSS. They calculated which percentage of pairs of DNA profiles that contained DNA of the same offender, had been collected (a) within the same police division (b) not within the same division but within the same police force (c) within an adjoining police force, or (d) not within an adjoining police force (i.e., farther away). Half the cases were committed within the same division, and another 36 percent were committed within the same police force. Of the remaining 14 percent, 7 were committed in an adjoining police force and 7 were not. The results made the authors conclude that the majority of offender movements are relatively short and that the crimes in question (mostly volume crime, in particular burglary) were local phenomena. However, these patterns varied by level of urbanization, such that police forces in urban areas had relatively larger percentages of offences with local matches and those in rural areas had more relatively more offences with non-local matches. Matches with non-adjacent forces were most likely in tourist areas, a finding consistent with those of a study on cross police force offending in the United Kingdom (Porter, 1996).

In The Netherlands, Lammers and Bernasco (2013) used data on linked DNA profiles in the Dutch DNA database to assess whether the spatial offending patterns of serial offenders (i.e. who had two or more crime scene stains in the DNA database) affected their likelihood of being arrested. Like Wiles and Costello (2000) they did not have access to details of the locations of crimes but only had information on the regions (corresponding to the 25 police forces in The Netherlands) where the crimes had taken place. Controlling for the number of offences in the series as a potential confounder, the results of survival analyses demonstrated that an individual's probability of arrest decreased with increasing geographical dispersion, measured as the number of distinct police force regions where the person had offended. The authors suggested the findings might reflect issues of coordination and cooperation between regional police forces that limit their efficacy in investigating and solving crime.

A third study (Lammers, 2014) also used the Dutch DNA database, but collected information on details of the location of the offences and calculated another measure of geographic dispersion, the mean inter-crime distance. In contrast to the dispersion measure based on regional police forces (Lammers and Bernasco, 2013), the purely geographic mean inter-crime distance hardly differentiated between arrested and non-arrested offenders.

Research question: International criminal mobility and DNA

The three studies discussed above used DNA traces to explore spatial offending patterns, but were limited to single countries and could thus not assess cross-border mobility. The Treaty of Prüm that was signed in 2005 by seven EU member countries and converted into EU-legislation in 2008 requires all EU-member states, among other things, to exchange data from national DNA -databases with other EU member states. Although the exchange program does not cover all EU member states, its existence provides a welcome opportunity to study cross-border crime patterns between the EU member states that have implemented the procedures. DNA data are suitable for this purpose not only because they allows us to study the mobility of both identified and unidentified offenders, but also for the practical reason that the

similarity of two DNA profiles provides enough evidence to decide that they belong to the same person[2], and therefore no other identifying information needs to be exchanged between countries. In sum, the international exchange of DNA profiles allows police forces in multiple countries to reduce 'linkage blindness' (Egger, 1984)', i.e. the failure to link multiple crimes that involve the same offender.

As is demonstrated below, some of the profiles secured form DNA stains that are secured at crime sites in The Netherlands, match with a stain or person profile in another Prüm country. This implies that the person has offended both in The Netherlands and abroad[3]. The question that we address in the present paper is where in The Netherlands traces are found of persons who also offended abroad. Where are they relatively overrepresented? The question does not focus on any attribute of the people involved (for the obvious reason that some of the people involved have never been identified) but only on their cross-border criminal behavior. For example, a Netherlands-Germany cross-border criminal can be a person of Dutch origin committing crimes in The Netherlands and in Germany, it could be a person of German origin committing crimes in both countries, but it could also be a person from Spain, Estonia or any other country in the world, committing crimes in The Netherlands and Germany. Thus, as mentioned in the Literature section, we do not define cross-border crime in terms of the nationality of the offenders, but define it without any reference to the geographic origin of the offenders.

Data

The Dutch DNA database

The Dutch DNA database was legally established in 1994 and started to take in DNA profiles in 1997. Initially the law allowed only DNA profiles of stains (biological material secured at the crime scene) and DNA profiles of suspects of serious crimes to be collected and included in the database, but in 2001 legislation was expanded to include the collection of DNA profiles in all crimes for which preventative custody is allowed in the Netherlands. This includes high-volume crimes such as burglary, car theft and theft from vehicles. Since 2005 convicted persons of such crimes have also gradually been obliged to provide DNA to be included in the DNA database. This has led to a spectacular increase in the size of the Dutch DNA database (documented at the website http://dnadatabank.forensischinstituut.nl/).

Persons have to be removed from the DNA database if they are no longer considered to be a suspect or if a conviction is overturned by an appeal in a higher court (or if the storage time

[2] Note that "enough evidence" in this context applies to criminological research, where some amount of measurement error (much larger than the potential error of false positives or false negatives in DNA profile matches) is accepted as a necessary fact of life. For obvious reasons, legal procedures require much smaller error margins and additional sources of evidence.

[3] Again, we emphasize that strictly speaking it merely says that probably the same person was the source of both stains, and that finding the stain probably means the person was involved in the crime as an offender.

has expired, but this is still many years ahead). Stains have to be removed if they have matched a person and the public prosecution office has notified the custodian of the Dutch DNA database that the case is closed. Hence the Dutch DNA database contains both stains which have not yet matched a person and stains which have already matched a person but for which the custodian of the Dutch DNA database has not yet received a notification from the public prosecution office that the case is closed. More than one stain can come from the same (unknown) person.

Prüm and DNA Exchange Procedures

In 2005 Germany, Austria, Belgium, the Netherlands, Luxembourg, Spain and France signed the Treaty of Prüm which provides for the automated exchange of DNA, fingerprint and vehicle registration data and mutual assistance in certain areas (for a brief history of DNA databases in Europe near the end of the twentieth century, see Martin, Schmitter, and Schneider, 2001). In the following years several other EU member states joined this treaty. In 2008 the treaty was converted into EU-legislation (Council Decisions 2008/615/JHA and 2008/616/JHA). As a consequence, all EU-member states are now required to establish DNA databases and to make them available for automated searches from other EU member states. Also Norway, Iceland, Switzerland and Liechtenstein can participate and Norway and Iceland have already indicated that they are willing to join the Prüm operation.

*** Insert Table 1 about here ***

The Netherlands started to exchange DNA profiles in 2008 after the Dutch Parliament had ratified the Treaty of Prüm. On 31rd December 2013, nineteen of the 28 EU-member states were operational[4]. Table 1 list these 'Prüm countries' and the dates at which they started to exchange DNA profiles with The Netherlands. Since the starting dates, DNA exchanges with all countries involved having been taking place daily. Figure 1 presents the locations of the 'Prüm countries' on a map of Europe, ordered in categories The Netherlands, Germany, northern Europe, eastern Europe and southern Europe.

*** Insert Figure 1 about here ***

When two countries start to exchange DNA profiles, they first send each other the profiles of all stains that have not yet matched a person's profile in their own DNA database. Subsequently both countries send each other all new profiles (of stains and of persons) on a daily (or less frequent) basis. This procedure ensures that all new profiles of each country are compared to all profiles of the other country, resulting in a complete coverage of all possible (new) matches. Both countries have access to the result of a comparison, so for the result it does not matter whether country A sends a profile to country B or country B sends a profile to country A.

[4] The Netherlands started to exchange DNA profiles with Malta on 30 June 2014 and with Belgium on 29 July 2014, after the analyses for this article had already been completed.

Data processing

The analyses presented here include all stains that were part of the DNA database until 31 December 2013, including stains that have been removed from the DNA database because they matched with the DNA-profile of a person. On 31 December 2013, the database included 80,299 stains secured at crime scenes, 57,801 of which were active because they had not yet matched to the DNA profile of a person. The other 22,498 had been removed from the active database because they had matched a person's profile, but they are included here.

The elementary unit of analysis in the present research is the *involvement of a person in a criminal event*, as evidenced by a stain that contains offender DNA and that was secured at the location of a crime scene. Thus, the unit of analysis is not a crime, because multiple offenders can be involved in the same criminal event and multiple DNA stains may have been secured at the same crime scene. The unit of analysis is neither an individual, because the same individual may have been involved in multiple crimes in The Netherlands.

The 80,299 DNA stains contain DNA profiles of 55,811 individuals. As Table 2 shows, the large majority of individuals (82.2 percent) have left DNA material at only a single crime scene. A substantial percentage (15.6 percent) has left DNA stains at 2–5 crime scenes. Very few have more than 5 DNA stains in the database.

*** Insert Table 2 about here ***

The DNA database does not contain information on the exact locations of the crime scenes where DNA stains were secured. It does contain, though, the name of the regional police force that secured the DNA stain and requested a DNA profile to be constructed, and thus the region where the crime took place. Until 1st January 2013 the Dutch police consisted of 25 regional forces and a national department (KLPD).

Of the 80,299 stains, 1128 (1.5 percent) could not be linked to one of the 25 regions, either because the DNA stains had not been collected in The Netherlands but abroad (120 cases, including stains secured on the Dutch islands of Bonaire, St. Eustatius or Saba), because the stains had been secured by the national police department KLPD (816 cases) and do not have a geographic reference, because the stains were secured before 1998 when region was not yet recorded (56 cases) or because information on the region requesting the DNA profile was not available for other reasons (242 cases). All other 79,171 DNA stains were assigned to one of the 25 regions. Figure 2 demonstrates the geographic distribution of the DNA stains. This map of the total number of secured DNA stains reflects variations in crime intensities across the regions, and it correlates .95 with the regional population size. The regions with most secured stains are those that include the major cities of Amsterdam, Rotterdam, The Hague and Utrecht, and one region in the south that contains a number of mid-size cities.

The total number of secured DNA stains per region is not the main focus of the analyses but serves as a baseline measure or denominator. The main focus is on the percentage of DNA stains per region that matches with a stain or person in another Prüm country, i.e. the number of Prüm matched stains per 100 secured stains.

*** Insert Figure 2 about here ***

To maximize the likelihood that for every stain in the database a Prüm match was identified if the stain's profile was identical to a profile in a DNA database of another Prüm country, two types of direct Prüm matches and one type of indirect Prüm matches were identified:

- (direct) DNA profiles of stains sent out by the Netherlands, that have matched a stain or a person in a foreign DNA database,
- (direct) DNA profiles of stains or persons in a foreign DNA database sent to the Netherlands, that have matched a stain in the Dutch DNA database
- (indirect) DNA profiles of stains in the Dutch DNA database that have matched a person within the Dutch DNA database who (previously) matched a stain or a person in a foreign database.

The latter match is called indirect because not the stain itself matched a stain or person in a foreign database, but the person profile in the Dutch database that was linked to this stain (when a person is linked to a stain, the stain is removed from the database). For some of these matches, the location of the stain could still be extracted from the database. No temporal distinctions were made, and a 'match' between two crimes can apply to crimes that took place within a single month, but also to crimes that were committed years apart.

A limitation of this retrospective procedure is that Prüm matches could not be established for stains that had been removed from the DNA database (because they matched with the profile of a suspect of convicted offender) before the country entered into the Prüm exchange program with The Netherlands. The implication is that comparisons between the Prüm countries (each of which started exchanging DNA profiles at different moments in time) are not very useful with these data, and will therefore not be part of the analyses.

The Prüm DNA-exchange procedures resulted in 3260 on a total of 79,171 DNA stains (4.1 percent) that match with a stain or person profile in one or more Prüm countries. In other words, 4 of every 100 DNA stains secured at a crime scene in The Netherlands, matches with a DNA profile in at least one other Prüm country (indicating the person who left the stain at the crime scene has also offended in that other country)[5]. As shown in Table 3, the large majority of matching stains match with only a single Prüm country.

*** Insert Table 3 about here ***

For each of the 18 other Prüm countries, Table 4 lists the number of matches with DNA stains from The Netherlands. Most matches are with Germany, France, Austria and Spain. Germany alone accounts for more than half of the matches. The total number of matches across countries does not have a straightforward interpretation in terms of criminal mobility. They

[5] Note that this result is not formulated simply in terms of a "percentage of crimes that match" because a single crime scene may contain DNA stains of multiple offenders (some of which may match with stains from one or more other countries) .

depend on many factors, including varying population sizes, the amounts of mobility between The Netherlands and each of the countries, as well as variations in legal constraints and policies and resources available for taking DNA samples from persons and crime scenes.

*** Insert Table 4 about here ***

Conditioning on these highly variable numbers of matches, our analysis focuses on differences between regions in The Netherlands with respect to the percentage of DNA stains that match DNA profiles in other Prüm countries, or, more colloquially, the share of internationally active offenders. Figure 3 shows where in The Netherlands crimes were committed that involved offenders also active in other EU member states. While there is clearly a correlation with the DNA stain totals in Figure 2, there are also marked differences, in particular in the most southeastern region that is situated between Belgium and Germany.

*** Insert Figure 3 about here ***

Findings: Cartography of Prüm matches

Using choropleth maps, the present section demonstrates differences between regions in The Netherlands in the percentage of DNA stains that match with a DNA profile from Prüm countries. In other words, it maps variations in the share of crime committed by offenders who also committed crimes in other Prüm countries. As the involvement of a person in a crime (as evidenced by the DNA stain) is the unit of analysis, we do not further consider the number of countries providing a match with a single DNA stain[6].

All matches

The most generic map shows the percentage of DNA matches per region, i.e. the regional number of DNA stains that have a match with another Prüm country, divided by the total regional number of DNA stains, and multiplied by 100.

*** Insert Figure 4 about here ***

Figure 4 clearly demonstrates that the two southeastern regions stand out, as in these two regions the share of matching stains is considerably higher than anywhere else in The Netherlands. These two regions share borders with both Belgium (not a Prüm country) and Germany (Prüm country) and are also situated closer to Luxemburg and France (both Prüm countries) than any of the other regions of The Netherlands.

The relatively large share of offender mobility with Germany in the southeastern regions of The Netherlands should probably be viewed as a consequence of the high rate of cross-border activity between Germany and The Netherlands in that particular region. The share of

[6] The large majority (85.4 percent) of the stains with a Prüm match did match with only one country, another 12.2 percent matched with two countries, the remaining 2.4 percent matched with 3–5 countries.

internationally active offenders is lower in the eastern and northeastern regions along the border with Germany. The difference between the southern and the northern part of the border with Germany is likely a consequence of the lower population density in the northern area on the German side of the border. The southeastern regions in The Netherlands are situated at just 20 kilometers from the densely populated metropolitan Ruhr area in Germany.

Matches by country and region

To verify the interpretation that the relatively high share of Prüm matches in the southeastern regions of The Netherlands is due to matches with Germany, a separate map was created that includes only DNA matches with Germany (see Figure 5). Noting that matches with Germany account for 42 percent of all Dutch Prüm-matches, the geographical pattern of matches with Germany appears similar to the general pattern, and the strong concentration of cross-border crime in the southeastern province of Limburg remains.

*** Insert Figure 5 about here ***

In addition, it is potentially useful to investigate geographic patterns of matches with other groups of Prüm countries. Because the absolute numbers of matches with some EU member states are quite small, the Prüm countries were assigned to the following geographic groups: North Europe (Finland, Sweden, Estonia, Latvia, Lithuania, Poland, Slovakia and Czech Republic), East Europe (Hungary, Austria, Slovenia, Romania and Bulgaria) and South Europe (Luxembourg, France, Spain, and Cyprus). The regional share of matches with these three European regions is mapped in Figures 6 (North), 7 (East) and 8 (South).

*** Insert Figure 6 about here ***

Interestingly, Figure 6 demonstrates that the northern regions of the Netherlands are characterized by larger shares of Prüm matches from the Scandinavian and Baltic EU member states. This finding seems to suggest a proximity effect that is in line with the high percentages of matches with Germany in the southeastern part of the Netherlands. However, given that the shortest overland distance between The Netherlands and the nearest point in the nearest country (city of Malmö in Sweden) is more than 750 kilometers, we would cast some doubt on the claim that sheer proximity explains the geographical pattern.

The regional patterns in Figures 7 and 8 do not seem to contain systematic variation and appear mostly geographically random. They do not demonstrate higher shares of Prüm matches in the eastern or southern regions of The Netherlands respectively. Both Figures show a relatively large share of Prüm matches in the region around Amsterdam though. This could be related to this region attracting larger shares of foreign temporary visitors than most other regions in The Netherlands, although again it should be emphasized that Prüm matches do not imply anything about the nationality or geographic origin of the offenders involved.

*** Insert Figure 7 about here ***

*** Insert Figure 8 about here ***

Other comparisons

DNA stains secured in the Netherlands may match with either DNA stains secured in another Prüm country (stain matches), or with DNA profiles of persons that were arrested, suspected or convicted in another Prüm country (person matches). Because stain matches and person matches both imply that the person was involved in a crime in the other EU country[7], the only difference is that in case of a stain match the offender involved in the crime has not yet been identified and arrested, while in the case of a person match s/he has arrested and a DNA profile has been determined.

To explore regional differences in The Netherlands between stain matches and person matches, we analyzed matches with stains abroad and matches with persons abroad, separately. There were no substantial differences with the results that were based on combined stain and matches and person matches that were presented in the previous sections. Also, the percentages of stain matches and percentages of person matches per region correlated .82.

Another potential source of regional variation concerns the type of crime committed. It might be suspected that cross-border high-volume crime is committed mostly by local residents of border regions on both sides of the border, whereas serious and violent crimes like homicide, armed robberies and rape would involve more nonlocal offenders and thus long-distance mobility between countries. Alternatively, various recent studies (e.g., Van Daele et al., 2012; Siegel, 2014) suggest that a nontrivial share of high-volume crime in The Netherlands, Belgium and other West-European countries is committed by residents from Romania, Bulgaria, and other East-European and Baltic countries.

To explore possible differences by crime type, regional patterns of Prüm matches of high-volume crimes were compared to those of other crime types. High-volume crimes constitute 77 percent of all crimes in the DNA database, and include burglary (48.3 percent), theft of/from vehicle (15.9 percent) and a variety of other common offences (together 12.8 percent). The differentiated analysis did not reveal any systematic differences between the geographic distributions of high-volume crimes and other types of crime. Thus, where in The Netherlands cross-border crimes are committed does not seem to bear any relation to the nature of the crimes

Discussion

The purpose of this paper was to make a start with unveiling geographic patterns of cross-border crime in Europe. To this end, DNA profiles from crime scene stains in 25 regions of the Netherlands were analyzed, and their location was related to whether or not the DNA profile was identical to any DNA profiles in the databases of other EU member states. A region's share of cross-border crime was defined as the number of Prüm-matching stains collected in that region divided by the total number of stains collected in that region. The most

[7] In the case of suspicion, this assumes the suspicion was correct.

remarkable finding concerns DNA stains that match with profiles from Germany. These stains make up for 6-7 percent of the stains in the two South-eastern regions in the Dutch province of Limburg, located some 20 kilometer west of the densely populated Ruhr- area in Germany. This finding suggests that a considerable proportion of cross-border crime in the area is of a local nature, committed by offenders that live in the area on either side of the border. The geographic distributions of the percentage of stains matching with East-European or South-European countries do not display these patterns pattern. The distribution of Prüm match percentages with North-European (Scandinavian and Baltic) countries suggested a similar concentration in the northern regions of The Netherlands (although less pronounced than in the case of Germany), but the distance between The Netherlands and the nearest place in the northern region (Malmö in Sweden) made us reluctant to reiterate our tentative conclusion regarding Germany (which has a border of 577 kilometer on land with The Netherlands). Crossing the border between The Netherlands and Germany can be just a single step, but crossing the border between Sweden and The Netherlands takes at least 750 kilometers. This distance is simply too large to fit a sedentary offender model.

We view these findings as tentative evidence that cross-border crime consists of mixtures of local and nonlocal offending patterns. As the evidence depends almost exclusively on the spatial patterns in The Netherlands of Prüm-matching stains with Germany, replications are required to further support this hypothesis. The planned entry of Belgium into the group of EU member states that exchange DNA profiles provides an opportunity, as it is the only other neighbor country of The Netherlands on the European mainland. In line with the concentrations of Prüm matches with Germany in the southeast of the Netherlands, concentrations of Prüm matches with Belgium should be expected in the southern part of The Netherlands, in particular in the Western parts close to the Belgian cities of Antwerp and Ghent, where population density is relatively high and where, unlike the southern part of Belgium, the Dutch language is spoken.

Because patterns of both legal and criminal mobility are hypothesized to be generic, additional evidence on the geography of cross-border crime might be found in DNA cartographies of other countries. In each country, we should expect high shares of cross-border crime in the border regions, and in particular high shares of Prüm-matching stains with the countries on the other sides of the borders. In fact, tentative findings from France[8] suggest that this is indeed the case. Standardized by population, DNA matches with Spain and Germany were shown to be strongly concentrated near the borders with these countries (Huet and Leplingard, 2014). Germany, which borders with Prüm countries Denmark, The Netherlands, Luxemburg, France, Austria, the Czech Republic and Poland, could be another suitable candidate country to further test the hypothesis (only two of its neighbors, Belgium and Switzerland, are not Prüm countries).

[8] France borders Prüm countries Spain, Germany and Luxembourg and non-Prüm countries Belgium, Switzerland, and Italy.

An even more comprehensive research project would transcend bilateral DNA matches between member states, as it would combine information from DNA databases of multiple EU member states to construct an overall DNA cartography of Europe. Such a cartography might demonstrate that cross-border crime concentrations of Prüm-matching stains are found on both sides of the borders, but might also demonstrate other patterns based on physical distances and cultural dissimilarities, or the existence of centers of attraction based on touristic attractions or employment opportunities.

On wrapping up this discussion, addressing a few caveats regarding the reported findings need to be made explicit. First, DNA stains are secured only in a very small fraction of crimes, crimes where DNA is secured are not representative of all crime, and indeed the level of representativeness is likely to vary between countries. Because legal procedures for requesting and using DNA in criminal investigations vary widely across countries, the percentages of crimes that involve securing DNA stains must also vary substantively between countries. Reflecting on our own use of the Dutch DNA database, it should be taken into account that our data burglary and vehicle crime are overrepresented.

Another caveat to be made regarding our findings is that the temporal dimension was not taken into account. In the analyses, a match between two DNA profiles may be based on two events that took place a few days, a few months or even many years apart. This distinction may be important for interpretations of cross-border mobility patterns. Cross-border crimes committed shortly after one another are likely to represent cases where the individual resides in a single place and commits crime in different countries. When cross-border crimes take place many years apart, another scenario is more likely. In this case we might expect that the original offender has moved to and settled in another country, and committed a crime there. In line with the extant literature on spatio-temporal crime patterns (Johnson et al., 2007), the spatial and the temporal dimensions of the crime events are likely to be correlated. Because in the international DNA profile exchange procedures, the dates that DNA profiles were created are not part of the data exchange, the only temporal indication is the date of the exchange of DNA profiles. Although this date may be a useful proxy measure for situations in which the exchange between two countries has started (presumably DNA profiles of stains and person profiles are created as soon as they arrive in the laboratory, and the resulting profile will presumably be exchanged within a week) it is useless for all profiles that had been collected before the exchange started (see Table 1), because the date recorded will be the date the countries started exchanging DNA profiles, and thus be inappropriate. Future work could take temporal variations into account. An important task would be to assess the extent to which cross-border crime reflects semi-permanent residential mobility of offenders, and to what extent it reflects short-term mobility patterns driven by the explicit purpose of committing crimes.

Throughout this paper, we have emphasized that our definition of cross-border crime does not involve any information on the identity, the nationality of country of residence of the offenders. For example, a match between countries A and B may involve a resident of country A, a resident of country B, or a resident of another country that has committed crimes in both

A and B. Because popular interpretations of cross border crime patterns tend to emphasize the 'import' of offenders from abroad rather than the 'export' of local offenders to elsewhere, it is important to stress that the reported findings do not implicate anything about the nationality or geographic origin of the individuals involved.

As a final note, it should be emphasized that our analyses were limited to DNA evidence, and did not include any other type of forensic data. Although DNA is probably more distinctive than any other type of forensic data, cross-border crime can also be detected by other types of evidence. For example, fingerprints have been collected by law enforcement agencies for many decades in most jurisdictions. A systematic cross-national exchange of fingerprint information might also substantially contribute to our understanding or patterns of cross-border crime patterns in the European Union.

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Tables

Table 1: Countries with which the Netherlands exchanged DNA-profiles in April 2014 and the dates on which this exchange started

No.	Country	Start date
1	Austria	22-07-2008
2	Germany	25-07-2008
3	Slovenia	09-09-2008
4	Luxembourg	24-10-2008
5	Spain	07-11-2008
6	Finland	11-11-2009
7	France	08-12-2009
8	Bulgaria	09-04-2010
9	Slovakia	26-11-2010
10	Romania	24-05-2011
11	Latvia	13-04-2012
12	Lithuania	25-05-2012
13	Hungary	12-10-2012
14	Poland	18-01-2013
15	Cyprus	28-03-2013
16	Estonia	18-07-2013
17	Sweden	12-11-2013
18	Czech Republic	12-12-2013

Table 2: Number of DNA stains per offender

Number of stains	N	%
1 DNA stain	45,889	82.2
2 DNA stains	5,390	9.7
3-5 DNA stains	3,338	6.0
6-10 DNA stains	871	1.6
11-55 DNA stains	323	.6
Total # offenders	55,811	100

Table 3: Number of countries that match DNA stains (total matches 3822)

Number of countries	N	%
none	75,911	95.9
1 country	2,788	3.5
2 countries	395	0.5
3 countries	66	0.1
4 countries	9	0.0
5 countries	2	0.0
Total # stains	79,171	100

Table 4: Numbers and Percentages (of Total Matches) by Country. N = 79,171 stains, 3822 matches (3260 stains matched with at least one country)

EU Member state	Matching stains	Percentage
Germany	1899	49,69
France	663	17,35
Austria	344	9,00
Spain	288	7,54
Lithuania	202	5,29
Sweden	111	2,90
Luxembourg	79	2,07
Finland	62	1,62
Poland	54	1,41
Romania	37	0,97
Slovenia	34	0,89
Czech Republic	14	0,37
Bulgaria	13	0,34
Latvia	7	0,18
Estonia	5	0,13
Slovakia	5	0,13
Cyprus	3	0,08
Hungary	2	0,05
	3822	100

Figures

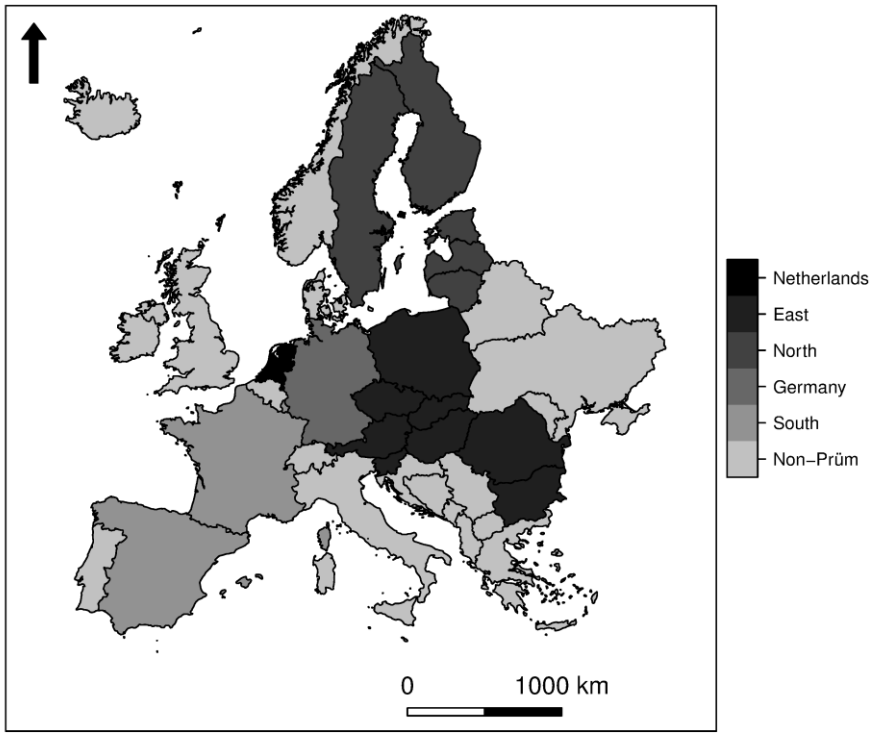

Figure 1. Countries exchanging DNA following Prüm Treaty and EU legislation

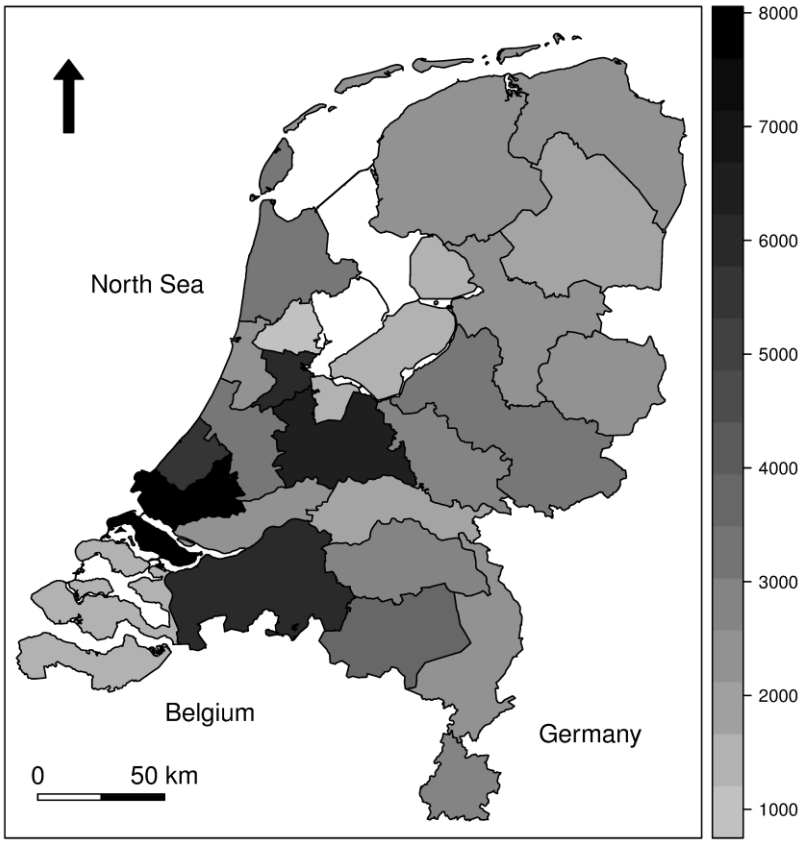

Figure 2. Geographic distribution of secured DNA stains in The Netherlands (79,171 stains, 25 regions)

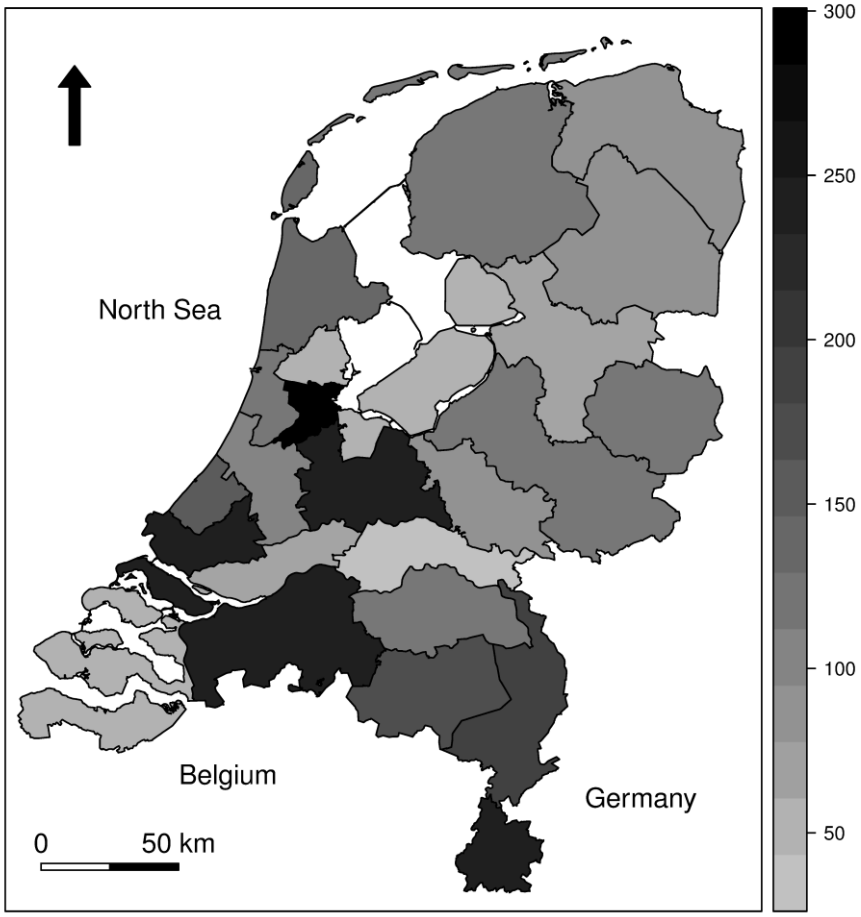

Figure 3. Geographic distribution Prüm matching stains

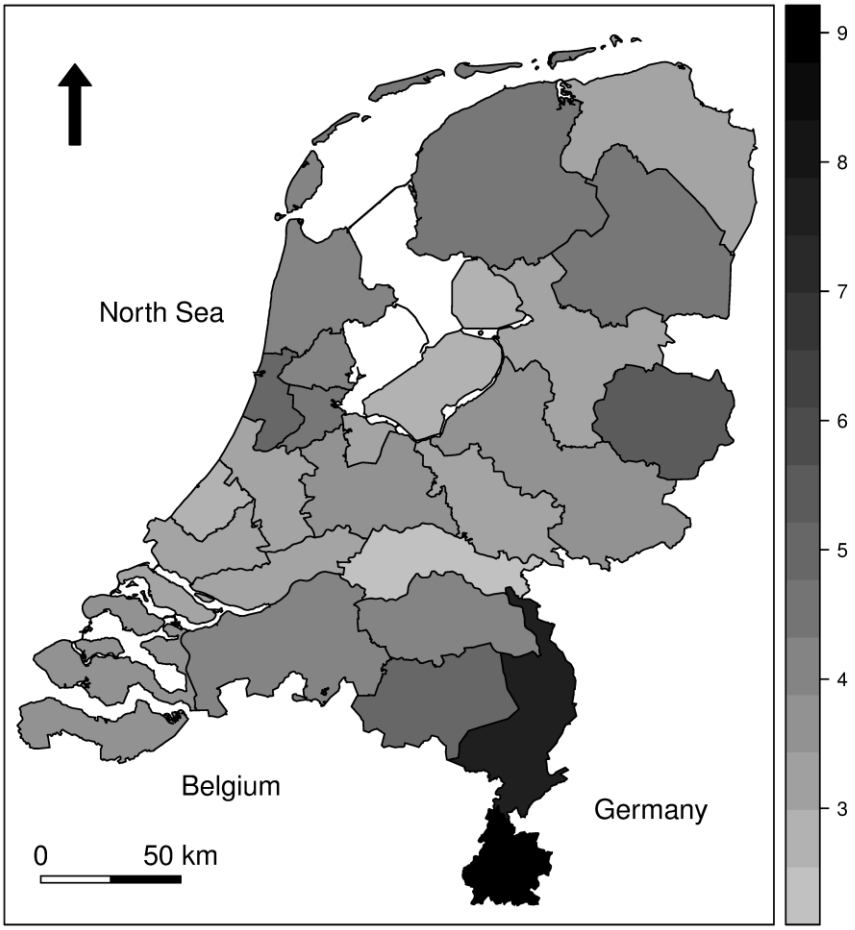

Figure 4. Percentage of Prüm matching stains

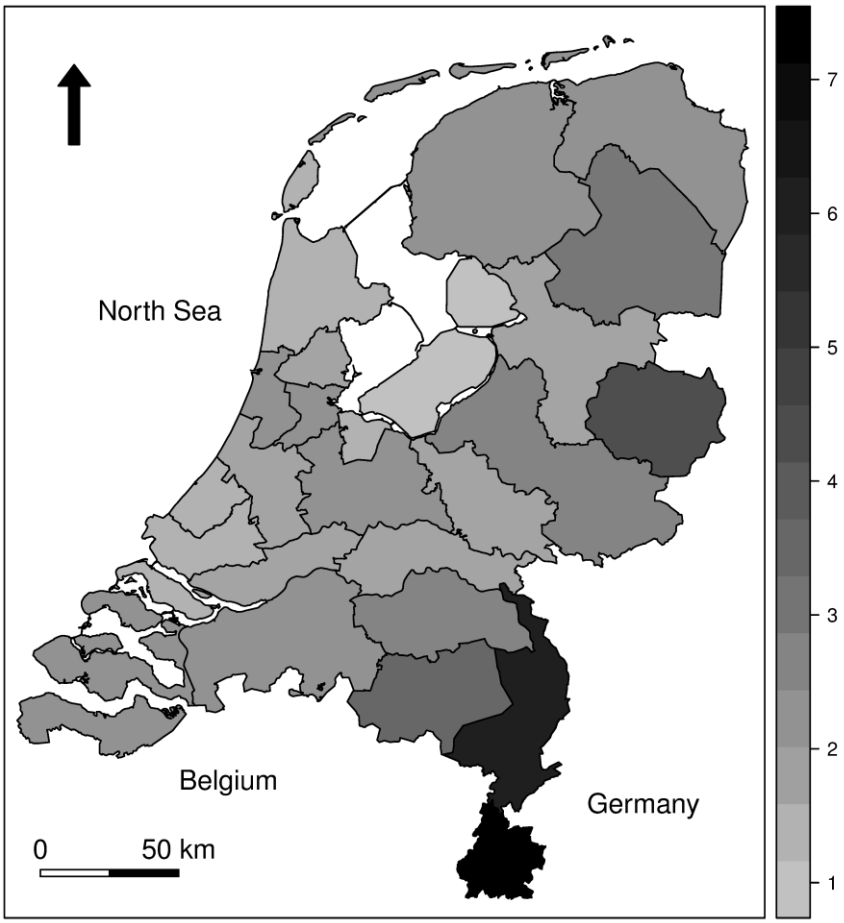

Figure 5. Percentages Prüm matching stains with Germany

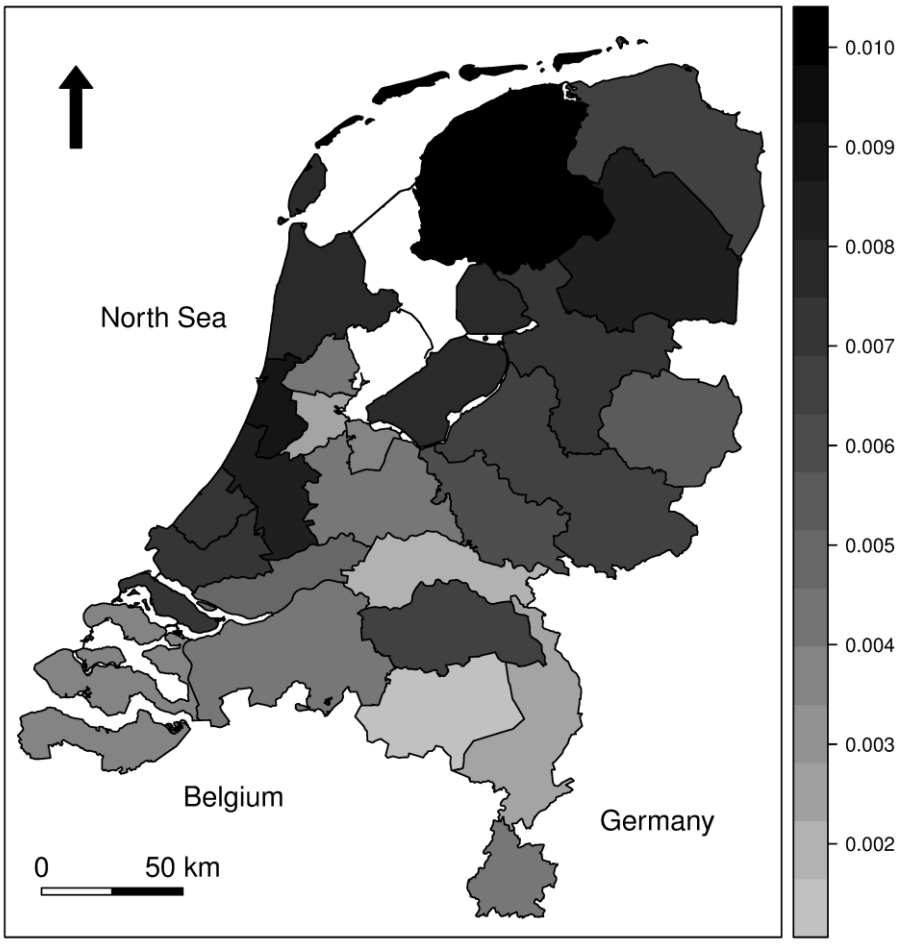

Figure 6. Percentages Prüm matching stains with northern Europe

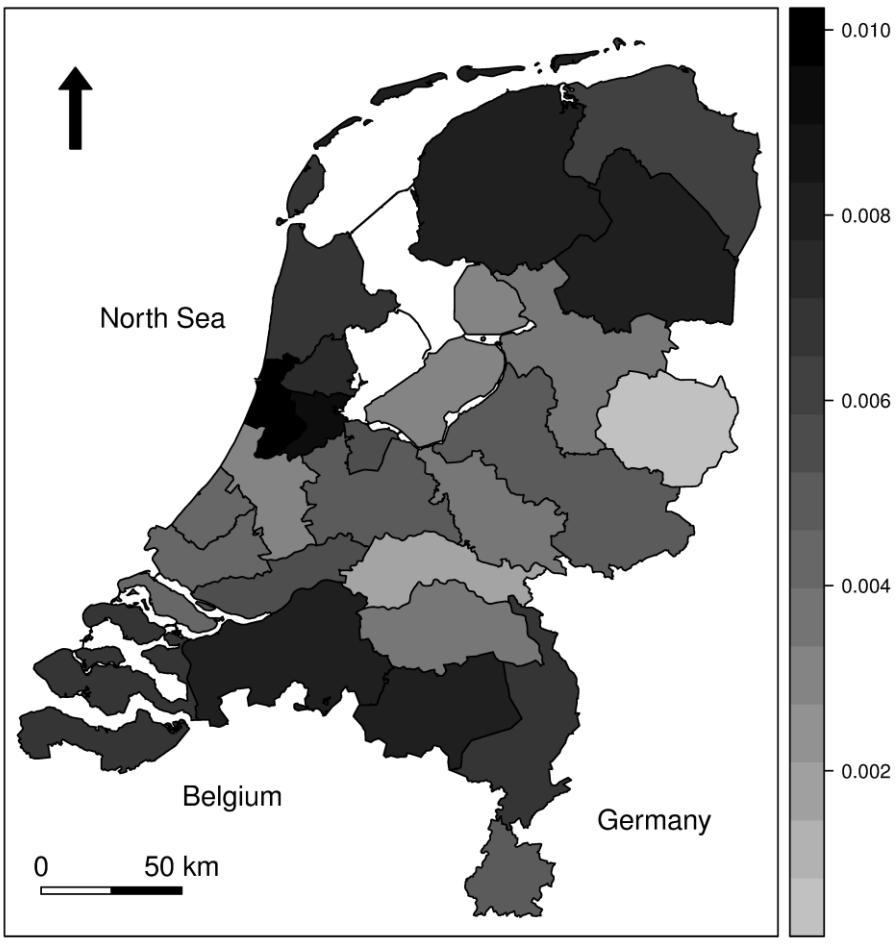

Figure 7. Percentages Prüm matching stains with eastern Europe

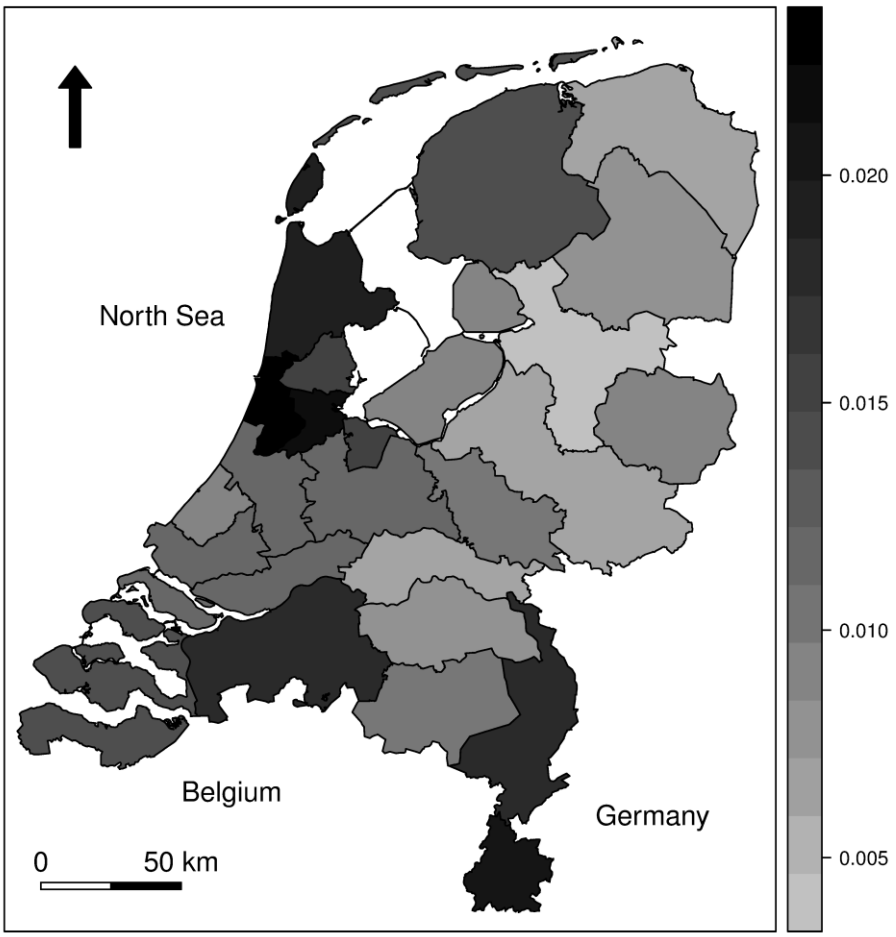

Figure 8. Percentages Prüm matching stains with southern Europe