

A Habitat Suitability Analysis for the golden jackal (*Canis aureus*) in the Netherlands

Joliene Wennink¹, Glenn Lelieveld¹, Henjo J. de Knegt² & Dick J.C. Klees³

¹ Dutch Mammal Society, Natuurplaza (Mercator III), Toernooiveld 1, NL-6525 ED Nijmegen, The Netherlands, e-mail: wennink.joliene@gmail.com

² Wageningen University and Research, Droevendaalsesteeg 3, NL-6708PB Wageningen, The Netherlands

³ Studio Wolverine, NL-4861 RK Chaam, The Netherlands

Abstract: The golden jackal (*Canis aureus*) is expanding its range towards Northern and Western Europe. In these parts of Europe, there is a lack of substantial knowledge about this animal's ecology and habitat requirements. The aim of this study was to determine the potential location and numbers of territories in the Netherlands suitable for the golden jackal. This article uses a literature study to review the habitat requirements of the golden jackal. Factors such as diet, roads, habitat size, land use and potential wolf (*Canis lupus*) territories were taken into account to assess the quality of potential habitat for golden jackal in a Habitat Suitability Analysis (HSA). Maps of the Netherlands were created to visualise possible core areas, highly suitable, and suitable areas. The main factors limiting establishment of the golden jackal would seem to be urbanisation and the presence of wolves. The results show that core areas in the Netherlands could support more than a hundred family groups, while highly suitable areas could potentially support an additional 150 family groups. The remaining suitable areas were found to be able to support up to around 1200 more family groups. In total, the Netherlands could support around 1450 golden jackal family groups, although the re-establishment of wolves could decrease these numbers to around 800 golden jackal family groups. This study only considered the most important parameters, which were set quite conservatively, so it is likely that our assessment of the amount of suitable habitat and potential golden jackal numbers are an underestimation.

Keywords: Golden jackal, *Canis aureus*, Habitat Suitability Analysis, habitat requirements, the Netherlands.

Introduction

The golden jackal (*Canis aureus*) is a canid species with a widespread range. Up until the year 1950 their habitat ranged from Indochina (Sillero-Zubiri et al. 2004), in the east, to the Balkans in the northwest (Hoffmann et al. 2018). Since the 1980s, the species has been expanding north-westward in Europe,

which has resulted in a genetic founder effect (Zachos et al. 2009): the golden jackal has established a thriving population in Hungary, with an estimated population in 2007 of more than 1500 individuals (Tóth et al. 2009). The first sighting in Germany was in 2000 (Möckel 2000). Reproduction of the golden jackal was confirmed in Italy in 2007 (Lapini et al. 2009) and in the Czech Republic in 2017 (Jirku et al. 2018). Factors that seem to drive the recent expansion of the golden jackal are land use change (Šálek et al. 2014), climate

© 2019 Zoogdiervereeniging. Lutra articles also on the internet: <http://www.zoogdiervereeniging.nl>

change (Arnold et al. 2012) and the persecution of wolves (*Canis lupus*), which has eliminated mesopredator control (Krofel 2017).

Historically, the golden jackal did not occur in these parts of Europe and therefore has not received much attention from ecologists or jurists compared to other terrestrial carnivores, such as the wolf (Chapron et al. 2014, Trouwborst et al. 2015). The golden jackal is included in the Annex V of the Habitats Directive of the European Union and thereby has less legal protection than the wolf (European Commission 1992). This indicates that Member States must ensure that their exploitation and hunting is compatible with maintaining a favourable conservation status of the golden jackal. This law requires Member States to anticipate what kind of management decisions will have to be taken for the golden jackal population in their State. For the Netherlands to meet this requirement it is necessary to identify what habitats the golden jackal would find suitable if it were to settle here.

The first sighting of a golden jackal in the Netherlands was documented in February 2016 on the Veluwe by means of a camera trap (WUR 2016). These pictures have been verified by international experts on carnivores (personal communication G. Lelieveld). The apparent northwestwardly expansion of this species, combined with this first sighting, makes the arrival of the golden jackal in the Netherlands almost a certainty.

In anticipation of this, this study will review literature on the habitat requirements of the golden jackal and perform a Habitat Suitability Analysis (HSA) in order to answer the following questions: 1. Where would this species find suitable habitat in the Netherlands? 2. How large are the areas with different classes of quality of suitable habitat?

The literature review on the habitat requirements will focus on the behaviour of the golden jackal, its diet and habitat selection, including how they deal with competitors, such as the red fox (*Vulpus vulpus*) and the wolf. This literature review is then used to construct an HSA for the golden jackal.

The golden jackal's biology: a literature review

Social and hunting behaviour

The behaviour of the golden jackal is very similar to that of the wolf. The species lives in packs consisting of a breeding pair and the cubs of previous years that assist their parents by providing food for the current litter. There are known cases of jackal families hunting together, but this only occurs when there is a high density of golden jackal in an area (Markov 2012). Usually, the golden jackal hunts solitarily (Sillero-Zubir et al. 2004), which affects the prey size they can handle, the largest wild prey in Europe being red deer calves (*Cervus elaphus*; Boskovic et al. 2013). The rest of its diet is rather flexible and differs over the seasons. A study showed that the primary food of the golden jackal in winter consists of livestock carcasses, with small live mammals as a secondary food choice (Cirovici et al. 2014). This study found golden jackals rarely eat plant materials during the winter. In contrast, a study on their diet over the whole year, conducted by Radovic & Kovačić (2010), shows a more varied diet. Meat was still the primary food source, but was supplemented by fruits, seeds and vegetables, which made up a third of their diet. A third study on their summer diet in an agricultural area, found small mammals to be their main food source (Markov & Lانسزki 2012). Hence, most land use types in the Netherlands would provide some kind of food source for the golden jackal.

Golden jackal's ability to thrive on a wide food range indicates a high flexibility in habitat selection. Apart from forests, they can colonise agricultural areas where they hunt small rodents (Šálek et al. 2014). They sometimes even visit urban areas at night, where they forage for garbage (Giannatos 2004, Sillero-Zubir et al. 2004, Hoffmann et al. 2018). A study conducted in Greece found that the mean distance of observed jackal groups to the nearest human settlement was 2.61 km

(0.1–4.5 km; $n=112$; Giannatos 2004).

The habitat size and population densities (Šálek et al. 2014, Boyce et al. 2015) of the golden jackal correlates with the amount of food resources present in the area. For example, in Israel jackal densities became very high at a garbage dump (Reichmann 2013). Giannatos (2004) found one group within a 12 km² area of poor quality habitat but also found one group/1 km² in high quality habitat. The average number of groups that he found was 2–3 groups/10–12 km².

Habitat preferences

Giannatos (2004) also found that the golden jackal does not occur on high elevations or mountainous terrain, due to winters with extended periods of snow cover. The Netherlands does not have mountains or cold winters with long periods of snow cover so these factors would not limit the golden jackal's habitat options in the Netherlands and have been excluded from this study. The golden jackal prefers small forests with open canopies (Giannatos 2004) and has a tendency to settle in dense parts of small forest patches near human settlements (Markov 2012). A study performed by Lanszki et al. (2018) tracked a young female while she was dispersing to start her own territory. She crossed two highways and found her own territory about 230 km away from her parents' den with a significant lower density of golden jackal. This study confirms the golden jackal's high dispersal ability and shows that while roads are a potential threat they are not an obstacle to the ongoing expansion of the golden jackal's range.

Interactions with wolf and red fox

Golden jackals' flexibility also becomes evident in their interactions with the red fox. There is an overlap between golden jackal and the fox in their preferred food sources and feeding

habits. When food sources are abundant, both species will consume small rodents (Lanszki & Heltai 2010). When they are less abundant, the two canids' food preferences seem to diverge. Lanszki et al. (2016) showed that this divergence leads to long-term coexistence of the two canids despite their apparent niche overlap. Another study supports this: they found that red foxes do not alter their behaviour when presented with the smell of the golden jackal but avoided an area where a golden jackal was present at that moment (Scheinin et al. 2006). This indicates that avoidance seems to lead to temporal divergence while their territories still have spatial overlap.

There has been less research on the interactions between the golden jackal and the wolf and the existing literature suggest that the two species do not readily co-exist. A study conducted by Mohammadi et al. (2017) observed a wolf kill a golden jackal in an agricultural area. Observations of an established golden jackal population in Greece, showed that it disappeared the moment a wolf pack of four individuals claimed the area (Giannatos 2004). These authors also observed that wolves were drawn to jackal sounds, presumably to chase them off.

To summarise, the literature shows that diet is not a limiting factor for the golden jackal due to its flexibility. The presence of foxes in their habitat is also no limitation to the golden jackal. However, presence of wolves can be fatal. The golden jackal prefers forested areas with clearings and near human settlements but can also thrive in agricultural areas. Urban areas are sometimes visited but do not provide rest areas and are therefore not permanently used by the golden jackal.

Method

Habitat Suitability Analysis

Our Habitat Suitability Analysis (HSA) (Boyce & McDonald 1999) is rule, or process, based,

Table 1. Habitat requirement rules.

Number	Rule	Explanation
1	Diet is not a limiting factor.	The literature indicates that the golden jackal is extremely adaptable in its diet and can adapt to seasonal changes (Markov & Lanszki 2012), the presence of the red fox (Lanszki & Heltai 2010) and the availability of different food sources in the area (Šálek et al. 2014).
2	Urban areas are not used as resting spots but will be visited during the night for foraging purposes.	The literature indicates that the golden jackal does not stay in prime urban areas. However, it will enter urban areas at night in search of garbage (Giannatos 2004, Sillero-Zubir et al. 2004, Hoffmann et al. 2018).
3	The territory of a family group in highly suitable areas is 6 km ² and in suitable areas is 12 km ² .	The literature indicates that the smallest habitat size is 6 km ² under natural conditions (Giannatos 2004, Šálek et al. 2014).
4	Roads are barriers but these are not insurmountable.	The literature indicates that roads pose a threat to the golden jackal but that it is able to overcome these (Lanszki et al. 2018).
5	Presence of wolves makes an area uninhabitable for the golden jackal.	The literature indicates that wolves actively chase and kill golden jackals (Giannatos 2004, Mohammadi et al. 2017).

Table 2. Summary of the basemap used, including a definition of the six suitability classes, population density and the corresponding ID codes from the LGN7.

Suitability class	Definition	Population density (family groups/km ²)*	ID codes from the LGN7**
0	The golden jackal cannot live here.	0	8, 16, 17, 18, 20, 25
1	The golden jackal cannot find food here but the area itself poses no limitation.	0	19, 24, 31, 35
2	The golden jackal is able to forage for food here but this is of low quality and there are usually no available resting areas.	0.01	3, 4, 6, 10, 26, 22, 23, 28, 32, 34, 36
3	The golden jackal is able to forage for food here, and resting areas are available.	0.08	1, 2, 5, 61, 9, 30, 33, 37, 38
4	The golden jackal is able to forage for food here, which is of good quality. There are resting areas.	0.16	62, 42
5	The golden jackal is able to forage for high quality food here and resting areas are abundant.	0.16	11, 12, 39, 40, 41, 43, 45

* Population density based on the studies from Giannatos (2004) and Šálek et al. (2014).

** The appendix describes the ID codes from the LGN7 and their reclassification in suitability classes.

due to the flexibility of the species and insufficient literature on the golden jackal to do any kind of powerful statistical analysis. Based on the available literature on the biology of the golden jackal (Giannatos 2004, Lanszki & Heltai 2010, Markov & Lanszki 2012, Šálek et al. 2014), it seeks to identify the factors that will limit the habitat of golden jackals in the Netherlands (table 1).

Study area and origin of data

The Habitat Suitability Analysis of the golden jackal in the Netherlands utilised the most recent land cover map of the Netherlands; “Landelijk Grondgebruiksbestand Nederland versie 7 (LGN7)” (Hazeu et al. 2014). Data regarding roads were retrieved from the Top10NL (Hazeu et al. 2014), the most recent and complete map of roads in the Nether-

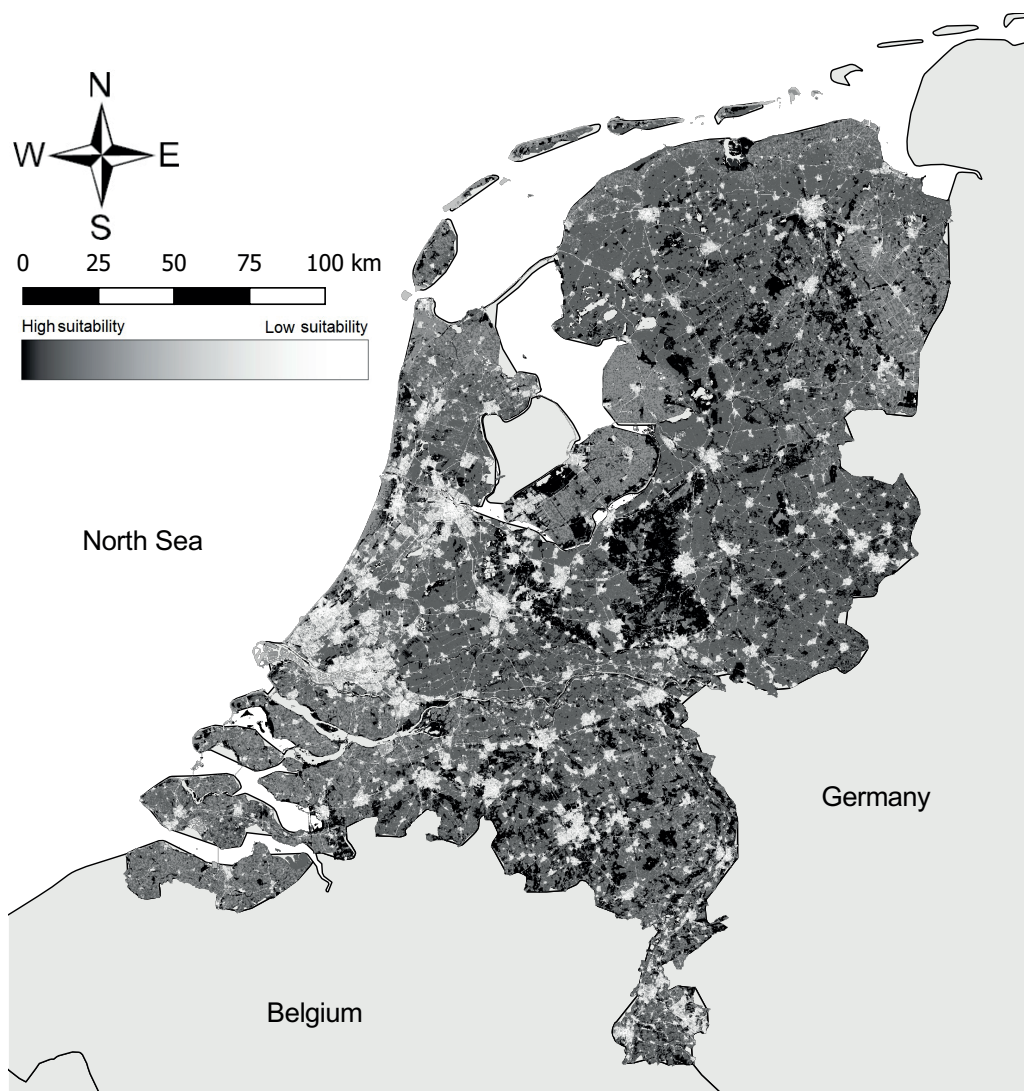


Figure 1. Habitat suitability for golden jackal in the Netherlands, based on land use types.

lands. The land cover of the LGN7 together with the road network from the Top10NL were combined to create a base map for this study. Data on potential wolf territories (derived from Lelieveld (2012), who found that the Netherlands can support at least 14 wolf packs with territories of at least 225 km²) were then added. QGIS software was used to perform the HSA using the raster, rgdal, SDMTools, rgeos, units, smoothr, maptools and PBSmapping packages from R version 3.4.0.

Modelling strategy

Creating a base map

The first step was to reclassify the base map according to how suitable the areas would be for the golden jackal. With the detailed data on land use contained within the LGN7, we chose a resolution of 25x25 metres. Each of the 39 land use types defined within LGN7 was assigned a class based on habitat suitability from 0 to 5 (table 2; figure 1; appendix). 0

was considered the lowest suitability class and depicted as white in the map, 5 was considered the highest suitability class and depicted as black. Table 2 provides an explanation and estimated population density for each of the habitat suitability classes. The second step was to conduct a Focal Window Analysis. The goal of this analysis is to soften and reduce small spikes in the data. For example, we reduced the negative impact of a building in an otherwise suitable environment but did not reduce the negative impact of primary and secondary roads, which were added to the map after the Focal Window Analysis. The resulting map showed the habitat suitability for the golden jackal in the Netherlands.

Identifying three area types

Three different area types were created to estimate the suitable habitat for, and thus potential territory size of, the golden jackal. The core areas consisted of all areas that were assigned suitability class 4 and 5, which were single adjacent areas, based on Rook connectivity, larger than 6 km², without any primary or secondary roads, in an attempt to reach a low disturbance level (Giannatos 2004, Šálek et al. 2014). An area size of 6 km² is conservative for a golden jackal territory, considering that several studies have found multiple golden jackal groups within 6 km² (Giannatos 2004, Šálek et al. 2014). We chose, 6 km² as the Netherlands has a high human population density which would increase disturbance levels. The only difference in assessment criteria between highly suitable habitats and core areas was that the latter did not contain any roads. When the two areas overlapped, they were designated as core areas. To be conservative, any remaining highly suitable areas after this subtraction, that were smaller than 6 km², were excluded from the analysis. The third area type was suitable areas. These areas consisted of areas which were assigned class 3 to 5, single adjacent areas, based on Rook connectivity, that were larger than 12 km². When suitable areas and highly suitable areas

or core areas overlapped, the suitable areas were considered to be less important. To be conservative, any suitable areas of less than 12 km² remaining after this subtraction, were excluded from the analysis. Lastly, potential wolf territories, derived from Lelieveld (2012) of 225 km² or more, were eliminated from the three area types to account for the effect wolves can have on golden jackals.

After the three area types were created, their total surface area and mean area size per polygon were calculated. Then a possible population density was estimated based on the two types of surface areas. First, the total surface area was multiplied by the corresponding population density (table 2). Second, the mean area size was divided by the corresponding territory size (6 km² for core and highly suitable areas and 12 km² for suitable areas) and then multiplied by the number of areas.

Results

The HSA showed that large parts of the Netherlands offer a potentially suitable habitat for the golden jackal, with the central, eastern and northern parts of the Netherlands providing more, and higher quality, habitat than other parts of the country. All urban areas are unsuitable for the golden jackal, while the forested and agricultural parts are more suitable (figure 1).

Figure 2 shows the next step in which the three area types in the Netherlands were created. Figure 3 shows the territory left for golden jackal to colonise after taking into account the likely re-establishment of wolves in the Netherlands. The distribution of the area sizes per area type shows that most of the areas are smaller than 100 km² (figure 4). The Pearson Chi-Square test for the core areas ($X=240$, $df=225$, $P=0.235$), highly suitable areas ($X=1332$, $df=1296$, $P=0.238$) and suitable areas ($X=3080$, $df=3025$, $P=-0.238$) showed that no significant differences were found whether or not wolves would be likely to be present.

The maximum amount of suitable habitat

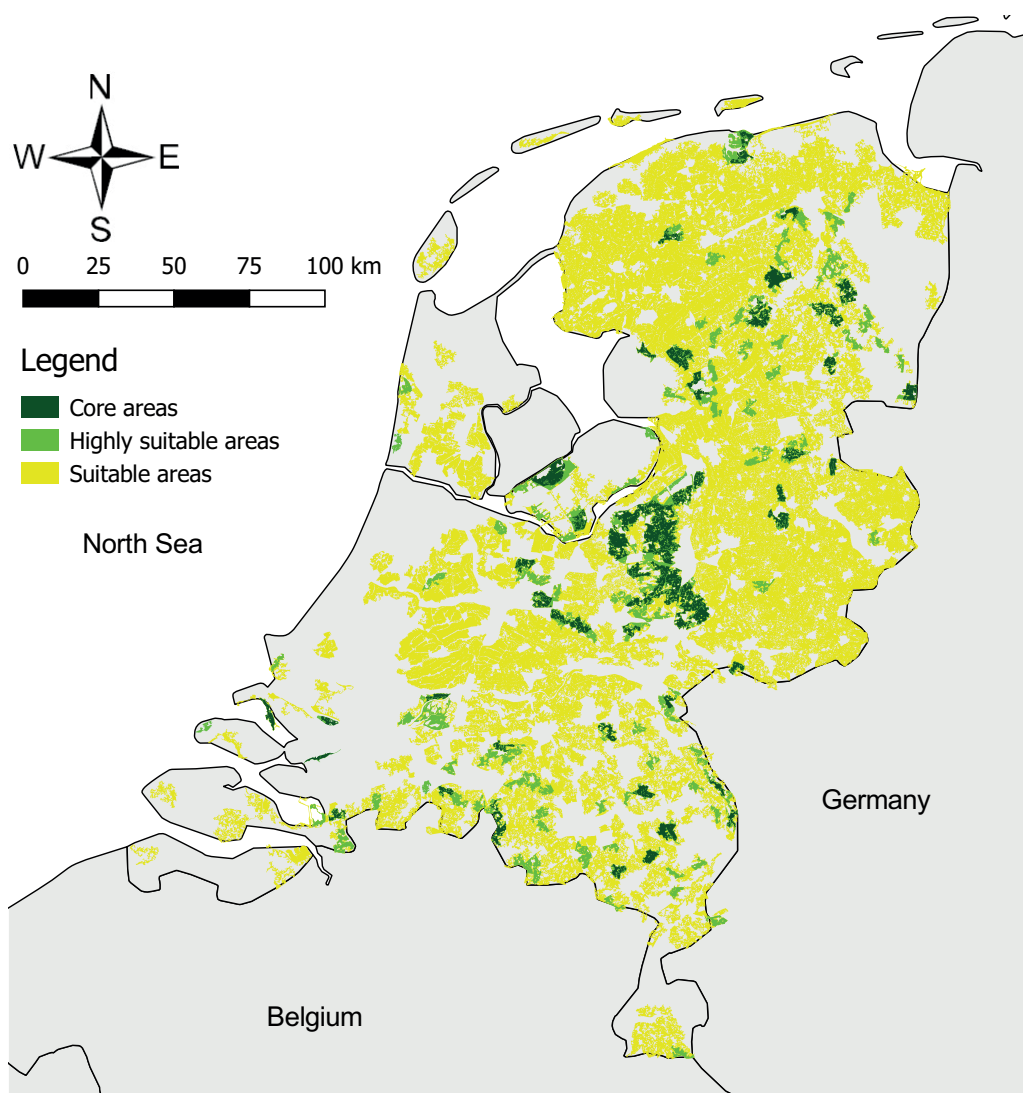


Figure 2. Potentially suitable habitat (core, highly suitable and suitable areas) for golden jackal in the Netherlands.

calculated per area and calculated from total area size show that the Netherlands could support 1432 to 1476 family groups. The first number was calculated with the minimum territory size in mind while the second was calculated from the total suitable area size. If wolves were to re-establish themselves in the Netherlands these numbers drop to 781 and 851 family groups respectively (table 3). Roughly half of the potential golden jackal population would disappear if, and when, wolves re-establish

themselves in the Netherlands, although only a about a third of the total area would disappear. This is because mostly core areas of the golden jackal would be used by the returning wolves.

Discussion

This study has investigated (1) where the golden jackal could settle in the Netherlands and (2) how large the areas with different suit-

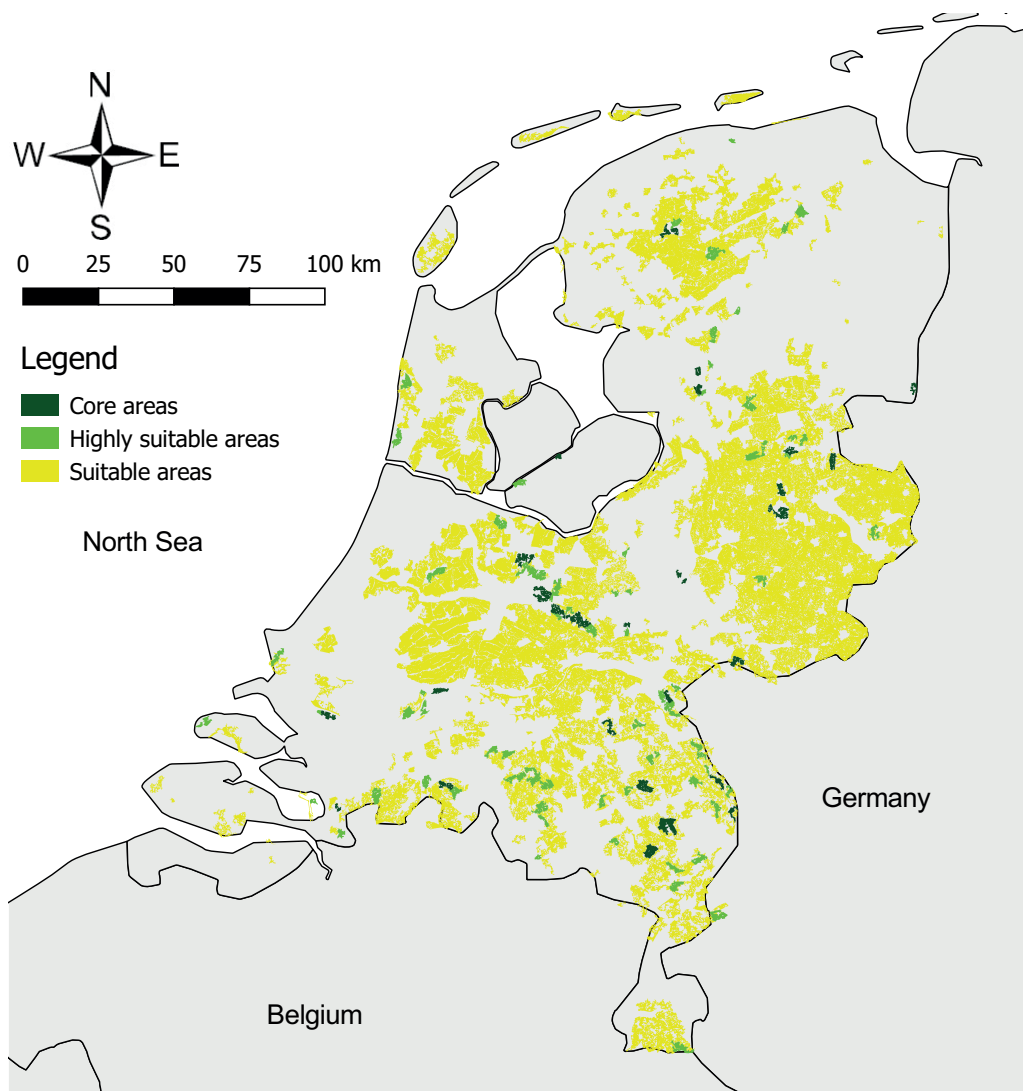


Figure 3. Potentially suitable habitat (core, highly suitable and suitable areas) for golden jackal in the Netherlands after excluding potential wolf territories.

ability classes are. Factors such as diet, roads, habitat size, land use and potential wolf territories were taken into account. The results show that the northern and eastern parts of the Netherlands, together with the Veluwe in the centre of the country, seem to be the best areas for the golden jackal (figure 1, figure 2). The potential re-establishment of wolves, would, however, reduce the suitable golden jackal areas by 6243 km². These potential wolf

areas mainly coincide with core areas for the golden jackal (figure 3).

Even though this study applied conservative methods when assessing the quality of areas in the HSA, the results showed that the Netherlands has around 7000 km² of suitable habitat which could support at least 1432 family groups (table 3). Such groups on average consist of four adults; one breeding pair and the cubs of the previous year (Markov

2012). This results in a possible population size of up to 5728 individuals. The number of family groups calculated from the mean area size and the total area size only differ by 44 family groups. This shows that most of the suitable habitats are large enough to hold at least one family group. In addition, figure 4 shows that the area sizes are mostly within a 100 km² range, there are two very large outliers in terms of size within the suitable areas, respectively of 8053 and 2279 km². These outliers cover most of the northern and eastern parts of the Netherlands, which indicates a large area of well-connected suitable habitat there. Some areas, that provide suitable habitat, would be harder to reach for the golden jackal due to large surrounding water bodies, such as the Province of Zeeland, or large urban areas, such as the area to the north of the Amsterdam metropolitan region (Giannatos 2004, Šálek et al. 2014). Apart from this, most of the areas deemed suitable are reachable, although time and more research is needed to be conclusive on this. However, the potential reestablishment of wolves would reduce the 1432 possible golden jackal family groups to around 781 family groups.

Taken together the results show that the Netherlands has enough suitable habitat for a thriving population of golden jackal. Despite the high human and road density, there are enough sheltered areas and food sources. Lanza et al's. (2018) tracking of a young dispersing female, which easily crossed highways in

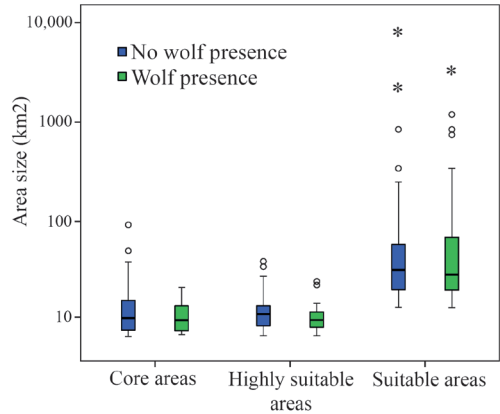


Figure 4. Boxplots (with median, first and third quartile, maximum and minimum) of area size per area type. Total core areas: $n=58$; Core areas with wolf presence (16); highly suitable areas: $n=78$; highly suitable areas with wolf presence: $n=37$; suitable areas: $n=58$; suitable areas with wolf presence: $n=56$. Y axis on logarithmic scale. Asterix * and circles ° are suspected outliers because these areas are larger than the other areas.

a cultural landscape, suggests a high flexibility in the dispersal of the species. The main reason why the Netherlands might become less suitable for the golden jackal would be the reestablishment of wolves in the country (Giannatos 2004, Mohammadi et al. 2017).

All the rules that we used for the HSA are supported by the literature. However, there is a serious lack of literature on the golden jackal in general, which means that this study is less well supported than we would prefer. As a result this study tried to be as conservative as

Table 3. Possible golden jackal population density per area (also accounting for potential wolf presence) in the Netherlands.

	No wolf presence				Including wolf presence			
	Core areas	Highly suitable areas	Suitable areas	Total	Core areas	Highly suitable areas	Suitable areas	Total
Number of areas	58	78	58	194	16	37	56	109
Average area size (km ²)	14.38	12.31	243.69	270.38	10.80	10.07	163.20	184.08
Total area size (km ²)	843.47	959.97	14133.81	15928.25	172.87	372.69	9139.15	9684.71
Potential number of family groups based on								
Average area size	116	156	1160	1432	16	37	728	781
Total area size	139	160	1177	1476	28	62	761	851

possible when assigning suitability classes to certain habitats. For instance, when there was any doubt about which suitability class should be chosen, we chose the lower class. This conservative method was also applied when assigning a population density to a certain suitability class. Therefore there is a strong possibility that we have underestimated the potential population size of the golden jackal in the Netherlands which could exceed the numbers that we have estimated, particularly when taking into account this species' flexibility with regard to habitat requirements, such as diet and resting areas (Lanszki & Heltai 2010, Markov & Lanszki 2012, Šálek et al. 2014). Other possible competitors such as the lynx (*Lynx lynx*) and brown bear (*Ursus arctos*) were not included because this study deemed it unlikely that these predators will reproduce sooner than the wolf or golden jackal in the Netherlands.

This study also excluded the border areas of the Netherlands from the HSA, although some golden jackal territories could overlap national boundaries with neighbouring countries

The future settlement of the golden jackal will have implications for Dutch society. The golden jackal is only slightly larger than a red fox and therefore is likely to be too small to be a direct threat to humans. However, it could be a potential threat towards sheep (Lanszki et al. 2006). Most literature on this topic is from eastern Europe, where herds are housed indoor during the night, protected by sheep-dogs or electric fencing to keep the cattle safe from wolves (Lanszki et al. 2006), which also prevents golden jackal from hunting sheep. However, sheep in the Netherlands are not protected and are therefore potential prey and this could potentially lead to high costs for farmers.

Further research could expand this study to the whole of Europe, since the expansion of the golden jackal is on-going. Factors such as elevation and cold winters would then be necessary to take into account. Also studies on potential diet composition, specifically tai-

lored to the Netherlands, could add value to the conclusions of this study. Findings from these kind of studies could strengthen the argumentation behind our assignment of suitability classes to certain habitats.

The main conclusion from this, conservative, study is that the Netherlands has suitable potential golden jackal habitats that could support at least 1432 family groups. This leads to an estimated population size of at least 5728 individuals. The central, northern and eastern parts of the Netherlands are the most suitable for this species. However, the potential re-establishment of wolves in the Netherlands would reduce the available habitat for the golden jackal, reducing the number of possible family groups from 1432 to 781 and the potential population size to around 3124 individuals. This study considered as many parameters as possible and used conservative parameter settings, so it is likely that we have underestimated suitable habitats and potential golden jackal numbers.

Acknowledgements: The authors would like to thank the staff of the Dutch Mammal Society, for the opportunity to work on this project, and everyone who provided (grey) literature. T.M. Koot is thanked for the input with the QGIS part of this study. Last, special thanks go out to all of the above, and two anonymous reviewers, for their guidance and constructive feedback during the process.

References

- Arnold, J., A. Humer, M. Heltai & D. Murariu. 2011. Current status and distribution of golden jackals *Canis aureus* in Europe. *Mammal Review* 42 (1): 1-11.
- Boskovic, I., M. Speranda, T. Florianjicic, N. Sprem, S. Ozimec, S. Degmecic & D. Jelcic 2013. Dietary habits of the Golden Jackal (*Canis aureus* L.) in Eastern Croatia. *Agriculturae Conspectus Scientificus* 78 (3): 245-248.
- Boyce, M.S., C.J. Johnson, E.H. Merrill, S.E. Nielsen, E.J. Solberg & B. van Moorter 2015. Review: Can

- habitat selection predict abundance? *Journal of Animal Ecology* 85 (1): 11-20.
- Boyce, M.S. & L.L. McDonald 1999. Relating populations to habitats using resource selection functions. *Trends in Ecology and Evolution* 14 (7): 268-272.
- Chapron, G., P. Kaczensky, J.D.C. Linnell, M. von Arx, D. Huber, H. Andrén, J.V. López-Bao, M. Adamec, F. Álvares, O. Anders, L. Balčiauskas, V. Balys, P. Bedő, F. Bego, J.C. Blanco, U. Breitenmoser, H. Brøseth, L. Bufka, R. Bunikyte, O. Ciucci, A. Dutsov, T. Engleder, C. Fuxjäger, C. Groff, K. Holmala, B. Hoxha, Y. Iliopoulos, O. Ionescu, J. Jeremić, K. Jerina, G. Kluth, F. Knauer, I. Kojola, I. Kos, M. Krofel, J. Kubala, S. Kunovac, J. Kusak, M. Kutal, O. Liberg, A. Majić, P. Männil, R. Manz, E. Marmoutin, F. Marucco, D. Melovski, K. Mersini, Y. Mertzanis, R.W. Mysłajek, S. Nowak, J. Odden, J. Ozolins, G. Palomero, M. Paunović, J. Persson, H. Potočník, P.-Y. Quenette, G. Rauer, I. Reinhardt, R. Rigg, A. Ryser, V. Salvatori, T. Skrbinšek, A. Stojanov, J.E. Swenson, L. Szemethy, A. Trajçe, E. Tsingarska-Sedefcheva, M. Váňa, R. Veeroja, P. Wabakken, M. Wölfl, S. Wölfl, F. Zimmermann, D. Zlatanova, L. Boitani 2014. Recovery of large carnivores in Europe's modern human-dominated landscapes. *Science* 346: 1517-1519.
- Cirovic, D., A. Penezic & M. Krofel 2016. Jackals as cleaners: Ecosystem services provided by a mesocarnivore in human-dominated landscapes. *Biological Conservation* 199: 51-55.
- Cirovic, D., A. Penezic, M. Milenkovic & M. Paunovic 2014. Winter diet composition of the golden jackal (*Canis aureus* L., 1758) in Serbia. *Mammalian Biology* 79: 132-137.
- Corlett, R.T. 2017. Frugivory and seed dispersal by vertebrates in tropical and subtropical Asia: An update. *Global Ecology and Conservation* 11 :1-22.
- Douglas, I., D. Goode, M.C. Houck & R. Wang (eds) 2011. *The Routledge Handbook of Urban Ecology*. Taylor & Francis (e-library), London, UK.
- European Commission 1992. Council Directive 92/43/EEC on the Conservation of Natural Habitats and of Wild Fauna and Flora, 21 May 1992, Brussels, Belgium.
- Giannatos, G. 2004. Conservation Action Plan for the golden jackal *Canis aureus* L. in Greece. WWF Greece.
- Hazeu, G.W., C. Schuiling, G.J. Dorland, G.J. Roerink, H.S.D. Naeff & R.A. Smidt 2014. Landelijk Grondgebruiksbestand Nederland versie 7 (LGN7); vervaardiging, nauwkeurigheid en gebruik. Alterra-rapport 2548. Environmental Research, Wageningen-UR, Wageningen, The Netherlands.
- Jirku, M., D. Dostal, J. Robovsky & M. Šálek 2018. Reproduction of the golden jackal (*Canis aureus*) outside current resident breeding populations in Europe: Evidence from the Czech Republic. *Mammalia* 82 (6): 592-595.
- Hoffmann, M., J. Arnold, J.W. Duckworth, Y. Jhala, J.F. Kamler & M. Krofel 2018. *Canis aureus*. The IUCN Red List of Threatened Species 2018: e.T118264161A46194820. URL: <http://dx.doi.org/10.2305/IUCN.UK.2018-2.RLTS.T118264161A46194820.en>; viewed 9 March 2019.
- Krofel, M., G. Giannatos, D. Cirovic, S. Stoyanov & T.M. Newsome 2017. Golden jackal expansion in Europe: a case of mesopredator release triggered by continent-wide wolf persecution? *Hystrix, the Italian Journal of Mammalogy* 28 (1): 9-15.
- Lanszki, J. & M. Heltai 2010. Food preferences of golden jackals and sympatric red foxes in European temperate climate agricultural area (Hungary). *Mammalia* 74 (3): 267-273.
- Lanszki, J., M. Heltai & L. Szabo 2006. Feeding habits and trophic niche overlap between sympatric golden jackal (*Canis aureus*) and red fox (*Vulpes vulpes*) in the Pannonian ecoregion (Hungary). *Canadian Journal of Zoology* 84 (11): 1647-1656.
- Lanszki, J., A. Kurys, L. Szabo, N. Nagypati, L.B. Porter & M. Heltai 2016. Diet composition of the golden jackal and the sympatric red fox in an agricultural area (Hungary). *Folia Zoologica* 65 (4): 310-322.
- Lanszki, J., G. Schally, M. Heltai & N. Ranc 2018. Golden jackal expansion in Europe: First telemetry evidence of a natal dispersal. *Mammalian Biology* 88: 81-84.
- Lapini, L., L. Dorigo, P. Molinari, A. Giovanni & P. Beraldo 2009. Reproduction of the golden jackal (*Canis aureus moreoticus* I. Geoffroy Saint Hilaire, 1835) in Julian Pre-Alps, with new data on its range-expansion in the high-Adriatic hinterland (Mammalia, Carnivora, Canidae). *Bollettino del*

- Museo Civico di Storia Naturale di Venezia 60: 169-186.
- Lelieveld, G. 2012. Room for wolf comeback in the Netherlands. A spatial analysis on the possibilities of settlement of wolves from European populations in the Netherlands. MSc internship report. Vrije Universiteit, Amsterdam, The Netherlands.
- Markov, G. 2012. Golden Jackal (*Canis aureus* L.) in Bulgaria: What is going on? Acta Zoologica Bulgaria 4: 67-71.
- Markov, G. & J. Lanszki 2012. Diet composition of the golden jackal, *Canis aureus* in an agricultural environment. Folia Zoologica 61 (1): 44-48.
- Möckel, R. 2000. Ein Goldschakal (*Canis aureus*) in Südbrendenburg - Erstnachweis für Deutschland. Säugetierkundliche Informationen 4: 477-481.
- Mohammadi, A., M. Kaboli & J.V. López-Bao 2017. Interspecific killing between wolves and golden jackals in Iran. European Journal of Wildlife Research 63: 61.
- Radović, A. & D. Kovačić 2010. Diet composition of the golden jackal (*Canis aureus* L.) on the Peljesac Peninsula, Dalmatia, Croatia. Periodicum Biologorum 12 (2): 219-224.
- Reichman, A. 2013. The population of gold jackal in northern Israel - demography, interface and monitoring. Summary of research and monitoring of jackals in years 2005-2010. Golan, Israel. [in Hebrew]
- Šálek, M., J. Červinka, O.C. Banea, M. Krofel, D. Čirović, I. Selanec, A. Penezić, S. Grill & J. Riegert 2014. Population densities and habitat use of the golden jackal (*Canis aureus*) in farmlands across the Balkan Peninsula. European Journal of Wildlife Research 60 (2): 193-200.
- Scheinin, S., Y. Yom-Tov, U. Motro & E. Geffen 2006. Behavioural responses of red foxes to an increase in the presence of golden jackals: A field experiment. Animal Behaviour 71 (3): 577-584.
- Sillero-Zubiri, C., M. Hoffmann & D.W. Macdonald (eds) 2004. Canids: Foxes, wolves, jackals and dogs. Status survey and conservation action plan. IUCN/SSC Canid Specialist Group, Gland, Switzerland.
- Tóth, T., L. Krecsák, E. Szűcs, M. Heltai & G. Huszár 2009. Records of the golden jackal (*Canis aureus* Linnaeus, 1758) in Hungary from 1800th until 2007, based on a literature survey. North-Western Journal of Zoology 5 (2): 386-405.
- Trouwborst, A., M. Krofel & J.D.C. Linnell 2015. Legal implications of range expansions in a terrestrial carnivore: the case of the golden jackal (*Canis aureus*) in Europe. Biodiversity and Conservation 24 (10): 2593-2610.
- WUR 2016. Eerste goudjakhals gezien in Nederland. URL: <https://www.wur.nl/nl/nieuws/Eerste-goudjakhals-gezien-in-Nederland.htm>; viewed 5 March 2018.
- Zachos, F.E., D. Čirovic, J. Kirschning, M. Otto, G.B. Hartl, B. Petersen & A. Honnen 2009. Genetic variability, differentiation, and founder effect in golden jackals (*Canis aureus*) from Serbia as revealed by mitochondrial DNA and nuclear microsatellite loci. Biochemical Genetics 47: 241-250.

Samenvatting

Habitatgeschiktheidanalyse voor de goudjakhals in Nederland

De goudjakhals (*Canis aureus*) verspreidt zich op natuurlijke wijze vanuit de Balkanlanden in noordwestelijke richting. Daarmee komt de soort ook richting Nederland. In deze studie vragen we ons af wat geschikt leefgebied is voor de goudjakhals en waar in Nederland potentieel geschikte leefgebieden aanwezig zijn. Allereerst is een literatuuronderzoek gedaan, om meer zicht te krijgen op de ecologie en habitatvoorkeuren van de goudjakhals. Vervolgens is een habitatgeschiktheidanalyse uitgevoerd, waarbij allereerst is gekeken naar het landgebruik in Nederland. Aan elk type landgebruik werd een waarde toegekend voor de mate van (potentiële) geschiktheid voor de goudjakhals. De hieruit voortkomende kaart vormde de basis voor het verdere onderzoek. Er werden drie verschillende typen gebieden aangewezen waar de goudjakhals zou kunnen leven. 1. Kerngebieden: hier is het landgebruik optimaal, zijn de gebieden minimaal 6 km² groot en komen geen primaire wegen (snelwegen en andere doorgaande wegen) voor. 2. Zeer geschikte

gebieden: deze lijken sterk op de kerngebieden, maar hierin komen wel primaire wegen voor. 3. Geschikte gebieden: het landgebruik is hier minder geschikt, gebieden zijn minimaal 12 km² groot en er komen primaire wegen in voor. Als volgende stap is uitgerekend hoeveel familiegroepen van de goudjakhals er in theorie in Nederland zouden kunnen leven wanneer potentiële wolfterritoria niet zijn meegerekend. Uit deze analyse blijkt dat Nederland ruimte heeft voor maximaal 1432 geschikte jakhalsterritoria, hetgeen zou betekenen dat er in ons land 5728 goudjakhalzen kunnen leven. Als wolven terugkomen zal dit aantal afnemen naar maximaal 781 territoria en 3124 dieren. Bij onze berekeningen zijn wij bij elke keuze steeds van de meest conservatieve optie uitgegaan. De hier gepresenteerde aantallen zijn daarom waarschijnlijk nog een onderschatting.

Received: 4 June 2018

Accepted: 14 December 2018

Appendix

Description of the reclassification of the ID codes of the LGN7 in suitability classes
The LGN7 was used as a base map for this study. Each of the 39 land use types were classified according to their suitability for the golden jackal.

Code 1 - Agricultural grass

Grassland utilised by farmers. This includes pastures for cattle and areas used to grow hay, including dikes, road sides and other grass covered areas. Graveyards outside urban areas are also included in this class.

The golden jackal can utilise these areas by hunting small mammals (Markov & Lanszki 2012), thus reducing pests (Cirovic et al. 2016). Therefore the assigned suitability class is 3.

Code 2 - Corn

All areas utilised by farmers for growing corn.

The golden jackal can utilise these areas by hunting small mammals (Markov & Lanszki 2012), thus reducing pests (Cirovic et al. 2016). Therefore the assigned suitability class is 3.

Code 3 - Potatoes

All areas utilised by farmers to grow potatoes.

The golden jackal can utilise these areas by hunting small mammals (Markov & Lanszki 2012) and thus reducing pests (Cirovic et al. 2016). Therefore the assigned suitability class is 3.

Code 4 - Beets

All areas utilised by farmers to grow beets.

The golden jackal can utilise these areas by hunting small mammals (Markov & Lanszki 2012). But rodent density is lower than with other crops. Therefore the assigned suitability class is 2.

Code 5 - Crop plants

All areas utilised by farmers to grow crop plants. This includes wheat, barley, hay, rye, etcetera.

The golden jackal can utilise these areas by hunting small mammals (Markov & Lanszki 2012) and thus reducing pests (Cirovic et al. 2016). Therefore the assigned suitability class is 3.

Code 6 - Other crops

All areas with agricultural crops that do not fall within the previous classes, excluding flower bulbs. Examples include horticultural crops, cabbages, hemp, oilseed rape, etcetera.

The golden jackal can utilise these areas by hunting small mammals (Markov & Lanszki 2012). The rodent density of these areas is difficult to determine. Therefore the assigned suitability class is a conservative 2.

Code 61 - Orchards (tree)

All areas utilised by farmers to grow trees (other than fruit trees).

The golden jackal can utilise these areas by hunting small mammals (Markov & Lanszki

2012). Therefore the assigned suitability class is 3.

Code 62 - Orchards (fruits)

All areas utilised by farmers to grow low-growing fruit trees. No distinction between different kinds of fruit are made.

The golden jackal can utilise these areas by hunting small mammals (Markov & Lanszki 2012) and eating fallen fruit (Radovic & Kovačić 2010). Therefore the assigned suitability class is 4.

Code 8 - Greenhouses

All areas utilised by farmers by growing crops in greenhouses.

It is assumed that the golden jackal cannot enter these buildings and is therefore unable to utilise these areas. Assigned suitability class for this habitat is 0.

Code 9 - Orchards

All areas utilised by farmers to grow trees.

The golden jackal can utilise these areas by hunting rodents (Markov & Lanszki 2012). Therefore the assigned suitability class is 3.

Code 10 - Flower bulb fields

All areas utilised by farmers for growing flower bulbs.

The golden jackal can utilise these areas by hunting small mammals (Markov & Lanszki 2012) and thus reducing pests (Cirovic et al. 2016). Therefore the assigned suitability class is 2.

Code 26 - Construction in rural area

All buildings classified for agricultural, forestry and nature purposes.

The golden jackal can utilise these areas by feeding on garbage but will not rest here (Giannatos 2004). Assigned suitability class for this habitat is 2.

Code 11 - Deciduous forest

This concerns deciduous forests outside urban areas. Forests in marshland and peat moor

areas have gotten their own classes. Deciduous forest can have the function of nature but not *per sé*.

The golden jackal can utilise these areas by hunting small mammals (Markov & Lanszki 2012), larger mammals (Boskovic et al. 2013) and foraging for fruits and seeds (Radovic & Kovačić 2010). In addition this habitat can provide resting spots which consist of dense vegetation and thereby difficult to penetrate by humans and domestic animals (Giannatos 2004). Therefore the assigned suitability class is 5.

Code 12- Coniferous forest

Coniferous forests outside urban areas. Forests in marshland and peat moor areas have their own classes. Deciduous forest can have some natural characteristics but are not natural *per se*.

The golden jackal can utilise these areas by hunting small mammals (Markov & Lanszki 2012), larger mammals (Boskovic et al. 2013) and foraging for fruits and seeds (Radovic & Kovačić 2010). In addition this habitat can provide resting spots which consist of dense vegetation which are difficult for humans and domestic animals to penetrate (Giannatos 2004). Therefore the assigned suitability class is 5.

Code 16 - Fresh water

All inland areas covered with fresh water, such as rivers, lakes, ditches, etcetera.

The golden jackal will drink from these areas but cannot live here. It is a land mammal. Therefore the assigned suitability class is 0.

Code 17 - Salt water

All areas covered with salt water such as the North Sea, Wadden Sea, Oosterschelde, Westerschelde, etcetera.

The golden jackal cannot live here because it is a land mammal. Therefore the assigned suitability class is 0.

Code 18 - Buildings in prime urban areas

All buildings within prime urban areas. Prime urban areas consist of shops, restaurants, company and industrial sites. These are typically located in the center of urban areas.

These areas generally have a high density of human population. Therefore the golden jackal will not enter these areas (Giannatos 2004). Therefore the assigned suitability class is 0.

Code 19 - Buildings in secondary urban areas

All buildings within secondary urban areas. Examples are airports, camp sites, buildings within military zones, buildings for electricity, etc. These are typically located at the edge of urban areas or not connected to cities.

These areas have a fluctuating human population. The golden jackal will enter these areas if the number is low to forage for garbage (Giannatos 2004, Sillero-Zubir et al. 2004, Hoffmann et al. 2018). Therefore the assigned suitability class is 1.

Code 20 - Forest in prime urban areas

All forests located within prime urban areas.

The golden jackal will not enter these areas due to the high human population density (Giannatos 2004). Therefore the assigned suitability class is 0.

Code 22 - Forest in secondary urban areas

All forests located within secondary urban areas.

The golden jackal will enter these areas to hunt for small rodents (Markov & Lanszki 2012) and forage for fruits and seeds (Radovic & Kovačić 2010). The quality of these areas is difficult to determine. However, these habitats do have potential to be of high quality. Therefore the assigned suitability class is 2.

Code 23 - Grass in prime urban areas

All grass areas within prime urban areas. These areas are construction sites, parks and sports facilities.

The golden jackal will visit these places at night, when there are less people around, to forage for garbage (Giannatos 2004, Sillero-Zubir et al. 2004, Hoffmann et al. 2018) and hunt small rodents (Markov & Lanszki 2012). Therefore the assigned suitability class is 2.

Code 24 - Bare soil in urban outskirts

All areas covered with bare soil in urban areas.

The golden jackal will not be able to forage for food in these areas. However, it is also not a limiting factor to them. Therefore the assigned suitability class is 1.

Code 28 - Grass in secondary urban areas

All grass areas within secondary urban areas. These areas are typically sports facilities, recreation areas, golf courts and garbage dumps.

The golden jackal will visit these places at night, when there are less people around (Giannatos 2004) to forage for garbage (Reichmann 2013) and hunt small rodents (Markov & Lanszki 2012). Some of these areas can be of high quality while others are of lower quality. Therefore the assigned suitability class is 2.

Code 25 - Infrastructure

This includes all major roads and train tracks. Highways, major roads and all roads broader than 7 meters are included. All roads are assumed to have a buffer zone that extends them to 12.5 meters. Train tracks have different buffer zones, depending on their type.

The golden jackal can profit from roads by feeding on roadkill, such as red fox (Douglas et al. 2011). However, roads can be lethal, therefore the assigned suitability class is 0.

Code 30 - Saltmarsh

All grass areas beyond the dikes.

The golden jackal can hunt for small rodents (Markov & Lanszki 2012) and seabirds in these areas (Lanszki et al. 2009). Therefore the assigned suitability class is 3.

Code 31 - Open sand

All areas along the coast without any vegeta-

tion, such as beaches and open dunes.

The golden jackal will not find any food here but this is also not an absolute limitation since human population is low (Giannatos 2004). Therefore the assigned suitability class is 1.

Code 32 - Dunes with low vegetation (<1 m)

Dunes in coastal areas with low vegetation <1 m.

The golden jackal can hunt for small rodents (Markov & Lanszki 2012) and birds (Lanszki et al. 2009). Therefore the assigned suitability classification is 2.

Code 33 - Dunes with high vegetation (>1 m)

Dunes in coastal areas with high vegetation >1 m.

The golden jackal can hunt for more rodents than in dunes with low vegetation (Markov & Lanszki 2012). Therefore the assigned suitability classification is 3.

Code 34 - Dunes with heathland

Dunes covered with heath.

The golden jackal can hunt for rodents here (Markov & Lanszki 2012). However, heathland is has a low production speed. Therefore the assigned suitability classification is 2.

Code 35 - Open sand (drift/ river sand)

All areas covered with open sand with no to almost none vegetation, not situated in coastal dunes. Mostly drift planes but also beaches along rivers.

The golden jackal cannot forage for food in these areas but they are not limiting since the human population is low (Giannatos 2004). In addition, beaches along rivers can provide carrion. However, the basemap did not differentiate between drift sands and beaches along rivers. Therefore the assigned suitability class is 1.

Code 36 - Heathland

All areas covered with heathland with less than 25% grass.

The golden jackal can hunt for small rodents but heathland is of poor quality (Markov & Lanszki 2012). Therefore the assigned suitability class is 2.

Code 37 - Moderate grassy heath

All areas covered with heathland with grassy elements making up between 25-75%.

The golden jackal can hunt small for rodents. While heathland is of poor quality, grassland is not (Markov & Lanszki 2012). Therefore the assigned suitability class is 3.

Code 38 - Grassy heath

All areas covered with heathland with more than 80% grassy elements.

The golden jackal can hunt for rodents. Heathland is of poor quality but grassland is not (Markov & Lanszki 2012). It is difficult to determine whether the slight increase in grass will affect the hunting possibilities of the golden jackal. Therefore the assigned suitability class is 3.

Code 39 - Peat moor

All areas covered with peat moor.

The jackal can hunt for rodents (Markov & Lanszki 2012), birds (Lanszki et al. 2009) and forage for fruits and seeds (Corlett 2017). In addition, this habitat can provide resting spots which consist of dense vegetation and thereby difficult to penetrate by humans and domestic animals (Giannatos 2004). Therefore the assigned suitability class for this habitat is 5.

Code 40 - Forest on peat moor

All areas covered with forest, situated on peat moor.

The jackal can hunt for rodents (Markov & Lanszki 2012), birds (Lanszki et al. 2009) and forage for fruits and seeds (Radovic & Kovačić 2010, Corlett 2017). In addition, this habitat can provide resting spots which consist of dense vegetation that are difficult for humans and domestic animals to penetrate (Giannatos 2004). Therefore the assigned suitability class for this habitat is 5.

Code 41 - Other marsh vegetation

All areas covered in vegetation that is not forest or reed. These vegetation types mainly consist of grasslands within marshland.

The jackal can hunt for rodents (Markov & Lanszki 2012), birds, water fauna (Lanszki et al. 2009) and forage for fruits and seeds (Radovic & Kovačić 2010). In addition, this habitat can provide resting spots which consist of dense vegetation that are difficult for humans and domestic animals to penetrate (Giannatos 2004). Therefore the assigned suitability class for this habitat is 5.

Code 42 - Reed vegetation

All areas covered with reed, situated in marshland.

In several countries the nickname of the golden jackal is reed wolf (Tóth et al. 2009). The jackal can hunt for rodents (Markov & Lanszki 2012), birds, water fauna (Lanszki et al. 2009) and forage for fruits and seeds (Radovic & Kovačić 2010). However, resting spots are less abundant as most of the ground is usually wet. Therefore the assigned suitability class for this habitat is 4.

Code 43 - Forest in marshland

All areas covered in forest, situated in marshland.

The jackal can hunt for rodents (Markov & Lanszki 2012), birds (Lanszki et al. 2009) and forage for fruits and seeds (Radovic & Kovačić 2010). In addition, this habitat can provide resting spots which consist of dense vegetation that are difficult for humans and domestic animals to penetrate (Giannatos 2004). Therefore the assigned suitability class for this habitat is 5.

Code 45 - Nature grasslands

Nature areas covered with grass. These areas are not managed intensively.

The jackal can hunt for rodents (Markov & Lanszki 2012) and forage for fruits and seeds (Radovic & Kovačić 2010). In addition, this habitat can provide resting spots which consist of dense vegetation that are difficult for humans and domestic animals to penetrate (Giannatos 2004). Therefore the assigned suitability class for this habitat is 5.