# A scale-sensitive connectivity analysis to identify ecological networks and conservation value in river networks

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2 **conservation value in river networks.**

3 **Connectivity analysis in river networks**

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24

25    **Abstract**

26    Existing methods for connectivity analysis still lack the accuracy required to cover both the necessary

27    resolution of explanatory factors and the dispersion events to explain functional connectivity over

28    larger territories or complex structures like dendritic river networks. To consider such relationships

29    between network structure and ecological patterns, we propose a method that allows dealing with this

30    problem of scale and resolution in the connectivity analysis of dendritic network structures, here

31    illustrated for the re-colonization of the French Loire river basin by the European otter. The ecological

32    niche factor approach is applied to infer favourable habitat in the river network based on large scale

33    data of land use and hydro-morphology of river segments for the entire river basin. Stressors to the

34    riparian zone of channel straightening, urbanisation and forest fragmentation are identified in this way

35    as the principal factors explaining otter occurrence. Based on this qualification of habitat favourability,

36    the integral index of connectivity quantifies habitat availability and connectivity in the dendritic river

37    network. When we calculate the integral index of connectivity over different spatial extents by

38    constraining network distances, the scale-sensitivity of the network's connectivity emerges. Counting

39    for high mobility (high connection distances) identifies conservation networks and priorities mainly in

40    downstream parts of the river basin, whereas zooming in on smaller network distances sorts more

41    restricted high quality areas in central and upstream parts. Finally, the presented approach performed

42    better than distribution modelling approaches in explaining species occurrence over the river network

43    and confirms the crucial aspect of connectivity in the otter re-colonization.

44

45 **Introduction**

46 Recent theoretical and experimental studies revealed how limits in network connectivity represent key

47 constraints for species persistence in dendritic networks (Fagan 2002; Carrara et al. 2012). In the real

48 world  this essential role of connectivity still needs to be evidenced, which is hampered by the large

49 variation in temporal and spatial scales of analysis (Hannah 2011), and by the lack of knowledge on

50 relationships between network structure and ecological patterns in dendritic networks (Ganio et al.

51 2005). The association of habitat quality and network structure with colonization processes in different

52 settings and species is still poorly understood, but essential to prioritize conservation and restoration

53 (Robles and Ciudad 2012; McCarthy et al. 2012; Carranza et al. 2012). For this challenge, ecological

54 network analysis shows a remarkable expansion of methods in modelling techniques (Thuiller et al.

55 2009) and concepts like the integration of graph methods (Minor and Urban 2008), but little progress

56 is made in bridging the gap between these methods and their applicability for the identification of

57 conservation networks at large scales (Chetkiewicz et al. 2006; Laita et al. 2011; Carroll et al. 2012).

58 Large-scale analysis for connectivity often still lacks the accuracy to integrate the relevant factors in

59 the coarse-grained maps, and the methods covering small areas cannot be applied over larger

60 territories (Beier et al. 2011).

61

62 To tackle this problem of scale and resolution in the design of conservation networks, we propose a

63 scale-sensitive approach based on a connection-constrained analysis of network connectivity. We

64 illustrate the developed approach with the distribution data of the European otter in the Loire River

65 basin. In the last 2 decades a recovery of otter is observed for most of its West-European distribution.

66 This recovery is recorded for Spain (Cortés et al. 1998), Italy (Loy et al. 2009) and France (Janssens et

67 al. 2008) after many decades of decline (Lodé 1993). In the Loire river basin a core of historical

68 population persisted and a strong re-colonization is observed (Janssens et al. 2008). We cross-examine

69 the species' distribution with land cover and environmental variables both at the river segment and the

70 sub-catchment scale, to identify available habitat with a graph-based method for connectivity analysis

71 (Saura and Rubio 2010; Eros et al. 2011; Minor and Urban 2008). Quantifying available habitat and

72 connections in networks over larger scales necessitates the integration of environmental variables at

73    different scales (Rouget et al. 2006). The choice of target species for prioritizing conservation

74    determines the resolution of environmental data needed and the connectivity required (Arponen et al.

75    2012), both with regard to resource selection and mobility (Moilanen and Hanski 2001), as to potential

76    biotic interactions (Godsoe et al. 2012). The otter is often presented as target species and indicator for

77    the connectivity and quality of the river ecosystem (Robitaille and Laurance 2002). Population

78    dynamics of the otter plays at the river basin scale, while individuals experience the local habitat and

79    its connectivity at the river segment scale. These two scale levels are the relevant scales to gather data

80    for the assessment of river corridor quality and functions (Allan 2004; Wiens 2002).

81    In this contribution we describe the proposed method of integrated network connectivity and habitat

82    availability assessment and compare it to more commonly used distribution model approaches both in

83    its power to predict species occurrence in the river network, and to its ability to highlight the

84    contribution of connectivity in relationship to the observed ecological pattern of the otter re-

85    colonization over the river network. For this validation the importance of connectivity for otter was

86    tested in a part of the river basin where the re-colonization was fully accomplished.

87

88

89    **Methods**

90    **Observational data for otter**

91    Data of otter presence was gathered in the Loire Basin by a network of associations' volunteers

92    gathered under the Loire Basin Mammal Network, and assembled by the services of the National

93    Wildlife Office (ONCFS). Harmonised protocols in data collection were adopted following the

94    internationally agreed otter census protocol (Lodé 1993). For the otter, presence was confirmed from

95    the observation of spraints (otter's droppings). The otter is a highly mobile animal with home ranges

96    of 2 - 100km (Ruiz-Olmo et al. 2001). In accordance to guidelines for the confirmation of otter

97    presence and to avoid overestimating accidental visits of individuals to small water courses (Kruuk

98    2006), only main water courses in fluvial systems and rivers starting from a minimum catchment of

99    >10km² were retained for the analysis. As otter spraints cannot provide information on otter

100   abundance, only about presence (Mason and Macdonald 1987; Sulkava et al. 2007), and furthermore

101   the frequency of spraints may be very low when otters are at low densities (Macdonald and Mason

102   1983), the species distribution analysis was limited to a presence only approach.

103   The consistent observation effort over the last 25 years allowed for a reconstruction in well-defined

104   time-steps (5 survey periods) of otter presence and the re-colonization of the river basin. Although the

105   re-colonization is surely not fully accomplished for the Loire basin - only 37% of the surveyed 17

106   000km are occupied - the outer bounds are all reached by now (Fig. 1). And as dispersing individuals

107   will preferably chose the best available sites as a residence, this analysis of non-fully achieved re-

108   colonization of the river network offered good perspectives to discriminate the essential factors in

109   dispersal and habitat selection (Clavero et al. 2010; Ruiz-Olmo et al. 2001). For the analysis of the

110   habitat selection, the presence in the most recent survey was retained (Fig. 1).

111

112   **Environmental and anthropogenic stressor data of the riparian corridor**

113   A systematic sectioning into river segments and assembling of hydromorphological and land cover

114   data for the riparian corridor in different buffer sizes (valley floor, floodplain, 100m, 30m, 10m) was

115   realised for the entire river network (Chandesris et al. 2008). Rivers were subdivided into hydro-

116   morphological units based on a semi-automatic sectioning that distinguished changes in geological

117    entities, channel form, sinuosity and valley floor width. Resulting river segments range from 1km on

118    average for small streams and up to 20km on average for large rivers. For each of these river

119    segments, information was collected from two spatial scales: the catchment's land cover information

120    was gathered for regional sub-catchments (i.e. hydrological units delimited by water divides and river

121    confluences) and locally information on land cover and hydromorphology was extracted for the

122    individual river segment in different dimensions for the riparian corridor (Table 1).

123

124    **Ecological niche factor network analysis**

125    The restriction to presence only data was the reason to apply the ecological niche factor analysis

126    (ENFA) in the definition of ecological networks for the species (Hirzel et al. 2001). This method also

127    allowed inferring key habitat factors from incomplete distribution data as was obviously the case for

128    this colonizing species' distribution (Clavero et al. 2010). ENFA allowed integrating the inferred

129    habitat factors in a network analysis to mark the potential network occupied by the species (Basille et

130    al. 2009). The marginality and specialisation of the species' presences was determined for the

131    environmental variables over the river segments to describe the ecological niche of the species. The

132    95% confidence intervals of the variables with significant marginality and specialisation for occupied

133    segments were selected as boundary values to consider segments as favourable. An extrapolation of

134    this ecological niche over the entire river basin was carried out. Distance criteria were applied to join

135    favourable segments based on the minimum home range values of 2km for otter, and this resulted in

136    networks of non-fragmented habitat patches over the river basin.

137

138    **Ecological network design based on connectivity analysis**

139    The dendritic river network structure needed an adequate topological definition for the analysis of its

140    potential as ecological network for the species (Grant et al. 2007). For this purpose and in agreement

141    with terrestrial network frameworks, the river segments were regarded as habitat nodes whereas the

142    true river network nodes (confluences and segment junctions) were considered as connectors in the

143    network (Eros et al. 2011). As we investigated species movement both in up- and downstream

144    direction, the full complexity of dendritic networks came in the picture. Starting from the topological

145    definition of the river segments in GIS, scripts were developed to derive neighbourhood matrices that

146    depicted the network structure. Figure 2 illustrates the resulting network structure that was applied in

147    the analysis.

148    We adopted the graph method of weighing network importance of nodes (Urban 2005), defined as

149    river segments in our case, by a specified application of the Integral Index of Connectivity (Pascual-

150    Hortal and Saura 2006). This index offered a measure that integrates the habitat quality of nodes with

151    the complexity and connectivity of the landscape. For our specific river network implementation,

152    integrating the habitat suitability output of the ENFA, the general formula of the Integral Index of

153    Connectivity was defined as follows:

154    $IIC = \Sigma_i \Sigma_j$ [favourability $_i$ x favourability$_j$/(1 + nl$_{ij}$ ) ]/ $A_L^2$

155

156    With $A_L$ the overall sum of favourability for all the segments of the entire river basin, and **nl$_{ij}$** the

157    number of segments between segments i and j, as connection distance present in the neighbourhood

158    matrix. The overall index ranges from 0 to 1 and increases with improved connectivity (Pascual-Hortal

159    and Saura 2006, 2008). The relative ranking of segments by their contribution to the overall index

160    value is the individual segment's qualification that is useful in this conservation approach. To

161    calculate the importance of each individual segment, we systematically removed each particular

162    segment and recalculated the IIC index. The percentage of index value loss (delta value dIIC)

163    measured the contribution of each segment to the overall index value (Pascual-Hortal and Saura 2008).

164    This dIIC can be considered a habitat availability index (Pascual-Hortal and Saura 2006). We

165    used the recently developed Conefor Sensinode 2.2 software (Saura and Torné 2009) to calculate dIIC

166    values for each river segment.

167

168    Constraining the connection distance **nl$_{ij}$** of number of segments, and thus the extent of the

169    neighbourhood matrix, allowed a scale-sensitive calculation of the index. With connection distance 0,

170    no integration took place of connectivity and habitat quality of the surrounding segments. In this way,

171    the classical habitat network analysis was performed as described above, based on local habitat

172 quality. For a connection distance of 2 and 5, local network structure integrating the habitat quality of

173 the segments was considered. With regard to the otter's home range this measure of 2 to 5

174 neighbouring segments corresponded to a relevant ecological network scale level covering river

175 lengths from 5 up to 100km, which was in agreement with the species' home range. To infer the scale-

176 sensitivity of this network qualification approach, the calculation was also performed with

177 constraining connection distances to 10.

178

179 **Validation importance of connectivity**

180 To evaluate the merits of the proposed connectivity analysis, its outcome was compared to both  the

181 ENFA approach described above and more dynamic distribution modelling approaches. We generated

182 five different data sets for this comparison. One set consisted of the presence–absence data directly.

183 Four other sets are probabilities of occurrence, generated with respectively the ENFA, a logistic

184 regression and the IIC with connection distances 2 and 5.

185 The dynamic logistic regression model was obtained from the otter presences over the five surveys.

186 The determining habitat factors detected with ENFA were entered in a logistic regression model to

187 derive a colonization likelihood estimate. For each time step (5 steps of 5 year) the neighbouring river

188 segments at the colonization front were simulated and confronted with the observed progression. With

189 this model probability of occurrence was inferred over the entire river network, and confronted with

190 the results of the other analyses for occurrence probability. For this comparison correlations were

191 tested for the river segments of the entire river network between the modelled ENFA habitat

192 favourability, the regression model occurrence probability and the integrated connectivity measures.

193 Afterwards, the model results were confronted with the recorded colonization process for the fully-

194 colonized upstream part of the basin, based on the detailed dataset of the regional nature park of the

195 Livradois-Forez (PNRLF). A measure of colonization speed for the PNRLF river network was

196 calculated over the three recent time steps in which the re-colonization took place: 1995-1999, 2000-

197 2004, and 2005-2009. Each newly occupied river segment was attributed a value of colonization

198 speed, by counting the number of segments traversed at first occurrence to the nearest previously

199    occupied segment. Correlation of the different model outputs to this colonization speed over the

200    PNRLF river network finally revealed the best predictor of otter occurrence.

201

202     **Results**

203     **Species niche**

204     Only 5 out of 22 environmental variables showed discriminating scores in the analysis of marginality

205     and specialisation (Fig. 3). The strongest explaining factor for species presence was the rate of channel

206     normalization ('channel straightening') with significant marginality and specialisation (M = 0.12, S =

207     1.16). This factor showed in the niche factor analysis the highest discriminating power on the river

208     network, as it qualifies 12% of the river segments as unfavourable. Strong marginality with little

209     specialisation though is observed for the forest cover in the floodplain (M = -0.13, S = 0.97) and in the

210     30m buffer (M = -0.16, S = 0.96). Urbanisation in the 100m buffer showed a high specialisation

211     (S=1.17) that allows a discrimination of 6% of the river basin's segments as unfavourable in the niche

212     factor analysis due to urbanization pressure in the river corridor. The favourable river segments

213     represent for the otter in the Loire basin 82% of the 17 000km selected river length (Fig. 4). Where

214     favourable conditions can be found in all parts of the basin, the most unfavourable conditions are

215     concentrated in the downstream part of the river basin.

216

217     **Network analysis**

218     The network analysis based on local habitat, without connectivity integration, determined with ENFA

219     as favourable segments joined to ecological networks (Fig. 5a), results in 452 patches of linked

220     favourable segments over the basin with a mean length of 29.3km but high variability (sd = 62.1km)

221     and a dominance of smaller patches. The longest favourable patches (max= 590.2km) are mainly

222     situated along the middle sectors of the main rivers Loire and Allier.

223     The network connectivity analysis based on the dIIC-connection distance 5 (Fig. 5b) shows a different

224     picture. The favourable networks in the centre of the basin (for the main rivers of Loire and Allier and

225     the south-western sub-catchment of the Vienne-Creuse) are also highlighted, but in this analysis the

226     lower parts of the basin are identified as most important in the river network.

227

228     **Scale-sensitivity of the method**

229   Constraining the neighbourhood matrix up to the second neighbours (dIIC_2) allows identifying

230   networks based on local habitat availability (Fig. 6). This result shows a higher differentiation at the

231   local scale level. It differs from the network qualification based solely on the individual segment

232   quality (Fig. 5a) as it integrates the favourability of the local network. It differs also from the larger

233   scale connectivity analysis (Fig. 5b) as it reflects more strongly the local habitat availability, but not so

234   much the larger scale network structure of the dendritic river network. With a higher connectivity of

235   connection distance 10, the effect of local habitat availability gets completely lost for our studied

236   network structure and only the overall river basin connectivity is highlighted with dIIC values

237   gradually increasing from upstream to downstream.

238   **Connectivity validation**

239   The logistic regression model predicted the likelihood of colonization accurately in 35% of the cases.

240   Its modelled occurrence probability over the entire river basin showed a negative correlation with the

241   dIIC_5 (R -0.046, p<0.05) and a positive correlation with dIIC_2 (R 0.14, p<0.05). For the 1501

242   segments in the upstream PNRLF-region, the modelled occurrence probability showed a positive

243   correlation with both the dIIC_5 (R 0.2, p<0.001) and with the dIIC_2 (R 0.23, p<0.001). Still these

244   correlations are quite weak and so the question remains for otter occurrence being more explained by

245   local habitat factors than by connectivity.

246   For the PNRLF-region, colonization speed of the occupied segments was between 1 and 16, with an

247   average of 3. This colonization speed of the segments was marginally correlated to the results of the

248   static ENFA favourability (R 0.21, p<0.05) and of the dynamic logistic regression modelled

249   occurrence probability (R 0.19, p<0.05). Much stronger correlation was observed for the connectivity

250   measure of the dIIC_2 (R 0.52, p<0.001). The higher scale connectivity measure dIIC_5 on the

251   contrary shows a negative correlation (R -0.17, p<0.05).

252

253   **Discussion**

254   **Integrated approach to network connectivity analysis**

255   The presented approach adopts the recent developments in river ecology of graph based methods (Eros

256   et al. 2011) and connectivity loss weighing (Moilanen et al. 2008; Hermoso et al. 2011). Yet, it differs

257    from existing connectivity analysis methods to prioritize conservation networks in its integrative

258    quantification of habitat availability and connections in the network. Furthermore, by integrating all

259    branches and connections in the neighborhood matrices we shifted from a linear to a branched river

260    network connectivity analysis (Fisher 1997; Grant et al. 2008). All neighbouring segments along the

261    branches of the dendritic network both in downstream as upstream direction are embedded in this

262    quantification. They are weighed by distance and constrained by a distance criterion to allow a scale-

263    sensitive analysis. So, although it does not provide a method that weighs up specific trajectories and

264    connections (Carroll et al. 2012), we do accomplish the main objective for the analysis of networks,

265    that is to quantify connectivity in relationship with the ecological processes within the network. Most

266    recently developed connectivity measures - even those adjusted to river networks - only count for a

267    distance criterion of connections (Hermoso et al. 2011; Moilanen et al. 2008). In contrast to this strong

268    distance-based interpretation and the barrier emphasis of the least-cost path approaches (Pinto and

269    Keitt 2009; Morzillo et al. 2011), we incorporate the evaluation of the branch density of the dendritic

270    structure in the network analysis (Ganio et al. 2005),  with the IIC that measures the density of

271    connectors, that is the 'branchiness' of the river network in our example. River segments are evaluated

272    at the same time as habitat and as connectors in our approach; which is a strong point in the

273    conservation context of ecological networks. In this way, the IIC is generally considered a habitat

274    availability index (Pascual-Hortal and Saura 2006) because it integrates topological properties

275    (network connectivity) with habitat quantity.

276

277    **Scale-sensitive ecological network analysis**

278    The scale-sensitive integration of river segment length and resolution of the network under study is in

279    accordance to species behaviour (Baguette and Vandyck 2007) and is the basis for the aggregation of

280    the local habitat with the connectivity over the drainage basin, a necessary step in ecological network

281    analyses for the otter (Ottaviani et al. 2009). This scale-sensitive approach demands the acquisition of

282    environmental variables from different scales according to the network structure. Most species

283    distribution studies at large scale start from raster-based landscape representations and metrics

284    (Barbosa et al. 2001, 2003; Loy et al. 2009; Clavero et al. 2010) that do not allow interpretation of

285    data gathered at  multiple scales to the dendritic network. Only recently the geometric network

286    analysis has been developed with the graph methods (Urban and Keitt 2001; Jordán et al. 2003). The

287    presented integration of scale-sensitivity by confining the extent of connections allows the

288    prioritization of conservation networks based on specific objectives, like sets of target species or

289    ecosystem processes and functions with specific spatial demands.

290    The presented case study shows some restrictions for the attribution of habitat quality to the

291    observations as the data of otter occurrence only allowed for a presence-only approach with its

292    weaknesses (Tsoar et al. 2007). Still we believe this dataset for the Loire basin is one of the best

293    documented examples of otter colonization globally, especially in view of its time span and the size of

294    the basin. The unique large scale dataset on environmental quality of the riparian zones proved

295    appropriate to infer the relevant ecological factors in the colonization process. Restrictions of this

296    environmental dataset concern aspects of water quality, food resources and the height of dams and

297    dikes. Yet, from earlier analyses in the Loire basin no relationship between otter expansion and water

298    quality, prey abundance or fish community could be inferred (Lemarchand et al. 2007; Janssens et al.

299    2008), neither proved the height of dams a significant obstacle to the species' progress (Varray 2011).

300    Therefore and also based on the limited data at hand for these variables, we did not include them in the

301    analysis.

302    The ecological potentials and targets for the river system in question will determine the scale of

303    connectivity to incorporate in the designation of conservation priorities. In our case for the Loire River

304    basin, a well-preserved aquatic biodiversity together with a high potential for conservation and

305    restoration of mobile riverine species like otter, beaver, salmon, sturgeon, osprey and river terns, calls

306    for the larger scale connectivity approach and identifies priorities principally in the downstream

307    reaches.

308

309    **Connectivity in river networks**

310    Our results confirm the conclusions of Moilanen and colleagues that realistic modelling of

311    connectivity has a major influence on the areas proposed for conservation, pointing out different parts

312    of river basins as high priority conservation targets (Moilanen et al. 2008). Same as several other

313    recent publications (Carranza et al. 2012; Hermoso et al. 2012), we supply evidence and methods to

314    integrate different scales and dimensions in connectivity measures, although not focussed on inter-

315    basin connectivity as these authors. The proposed method for the integrated connectivity measure

316    proves even more accurate in predicting species occurrence than the dynamic probability modelling

317    that sorted as best available method from earlier comparisons (Van Teeffelen, 2006).

318

319    The more classical habitat-based network analysis corresponds to the result without node network

320    connections ($nl_{ij} = 0$) in our approach. This result clearly deviates from the results with integration of

321    functional connections. For the analysis of ecological networks for the otter the local network-

322    focussed dIIC_2 provides the most accurate predictor for otter occurrence probability. Still, for the

323    long time population expansion and survival, as well as for the conservation prioritization, the dIIC_5

324    surely brings important additional information as well. The comparison to the observed colonisation

325    speed in the upstream part of the basin shows that the dIIC_5 measure is probably not the best

326    predictor for otter colonisation, but it might well be the best prospection for an ecological network to

327    assure otter survival in the long run. This assumption of course needs another type of analysis, or a

328    repeated analysis by the time the colonisation process is fully accomplished over the river basin. The

329    validation of the connectivity analysis with the comparison to the static and dynamic distribution

330    modelling approaches, showed the strength of our approach as it predicted better the otter

331    colonization. Where our approach starts from a static distribution modelling approach, this result

332    proves the strength of the proposed approach, as it even gives a better result than the dynamic habitat-

333    based colonization model that is based on the extended dataset on otter presence over time in the river

334    basin. We didn't integrate this more dynamic distribution model in the proposed method for

335    connectivity analysis, as obviously such a dynamic model needs to be based on temporally explicit

336    data and an exceptionally rich dataset as presented here is mostly not available.

337

338    In conclusion we can say that the presented method meets our goal to quantify connectivity in the river

339    network, considering both the complexity of the dendritic network structure and the scale-sensitivity

340    of relationships between network structure and ecological patterns in rivers. It even showed more

341     reliable results in predicting species colonization in the network than distribution modelling

342     techniques. The outcome proves the importance of connectivity for the otter,  as the movement and

343     occurrence in the river network was more explained by connectivity measures than just with habitat

344     quality aspects.  In this way it confirms the otter as a guiding species for connectivity and not solely

345     for habitat quality.

346     With the presented method insight can be gained into the choices for river restoration and conservation

347     prioritization. Allocation of financial resources for conservation and restoration can be based on this

348     kind of analyses with the integration of multi-species approaches (Schwenk and Donovan 2011).

349     Cross-examining resulting ecological networks for multiple species with multiple relevant scales for

350     connectivity can reveal priorities for conservation (Williams et al. 2005). The here presented approach

351     can also be used for fully aquatic species in river systems with integration of flow-directed

352     connectivity.

353

354     **Acknowledgments**

364
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500

501     Table 1. Environmental variables from the different spatial scales that were attributed to the river

502     segments.

503

**Watershed**

| | |
|---|---|
| urbanisation | percentage cover of urban land use class in CORINE land cover data of the sub-catchments |
| intensive agriculture | percentage cover of intensive agricultural CORINE land cover classes of the sub-catchments |
| Natural | percentage cover of near-natural CORINE land cover classes data of the sub-catchments |

**River segment**

| | |
|---|---|
| Altitude | elevation at downstream point of river segments |
| river slope | slope of the river bed over the segment |
| valley slope | valley slope perpendicular to the river |
| Discharge | mean annual discharge for gauging station or model prediction at river segment level |
| Sinuosity | sinuosity of the river bed over the segment |
| channel straightening | percentage of straight reaches over the segment, weighted by river type |
| density of bars | number of lateral bars over the segment, divided by river length |
| density of weirs/dams | number of weirs/dams per segment, divided by river length |
| density of bridges | number of river crossing bridges per segment, divided by river length |

**Alluvial plain**

| | |
|---|---|
| alluvial forest cover | percentage cover of forest patches over the alluvial plain of the river segment |
| Infrastructure | percentage cover of infrastructure over the alluvial plain of the river segment |
| urbanisation | percentage cover of urbanisation over the alluvial plain of the river segment |
| density of dikes | length of flood protection levees per segment, divided by river length |
| connected waters | percentage cover of connected standing waters over the alluvial plain of the river segment |
| Disconnected waters | percentage cover of disconnected standing waters over the alluvial plain of the river segment |

**River bank**

| | |
|---|---|
| riparian forest cover | percentage cover of forest patches for the 30m riparian buffer of the river segment |
| riparian forest canopy | percentage cover of forest patches for the 10m riparian buffer of the river segment |
| Infrastructure | percentage cover of infrastructure over riparian buffer of three river widths of the segment |
| urbanisation | percentage cover of urbanisation for the 100m riparian buffer of the river segment |
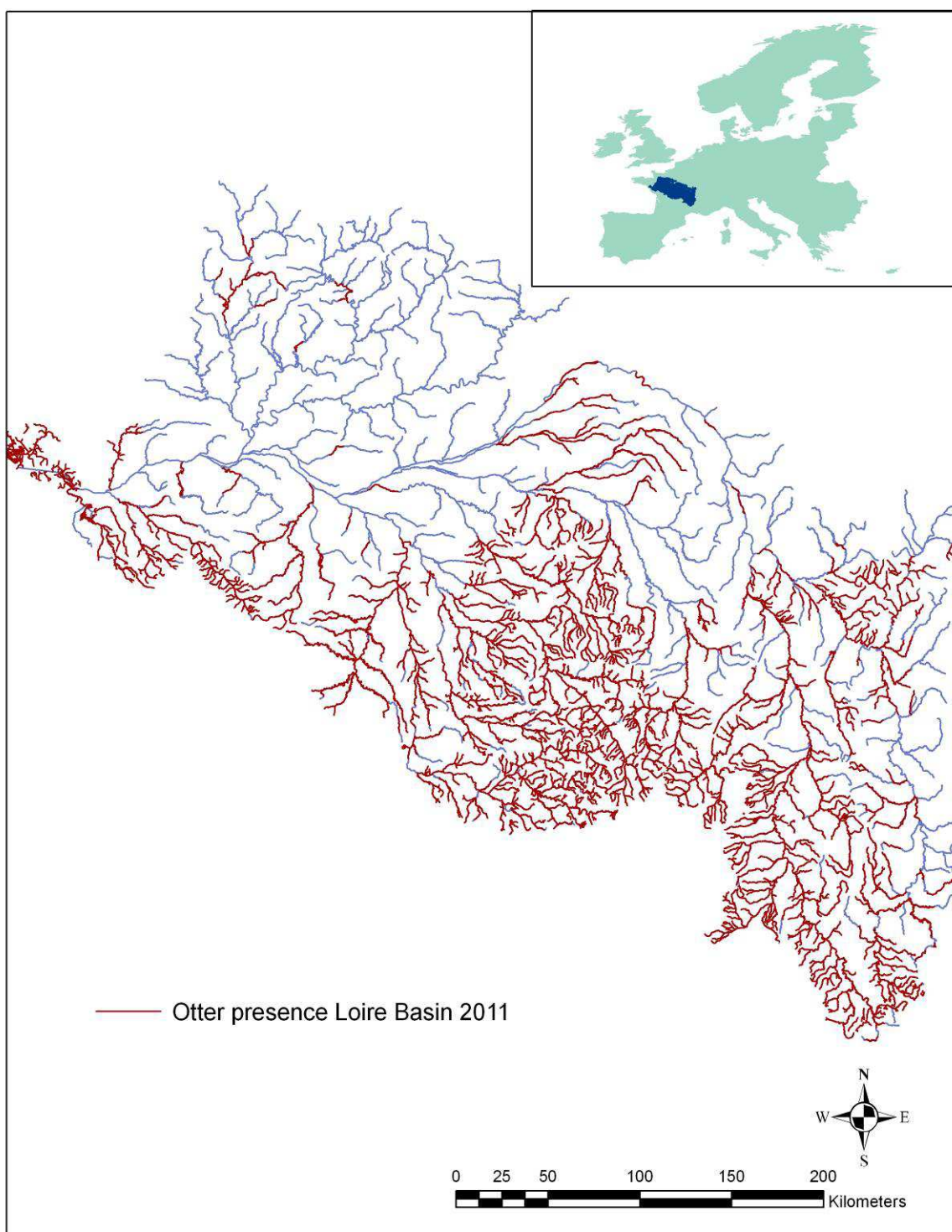
504

505     Figure 1.  Presence of the European otter in the Loire river basin in 2011
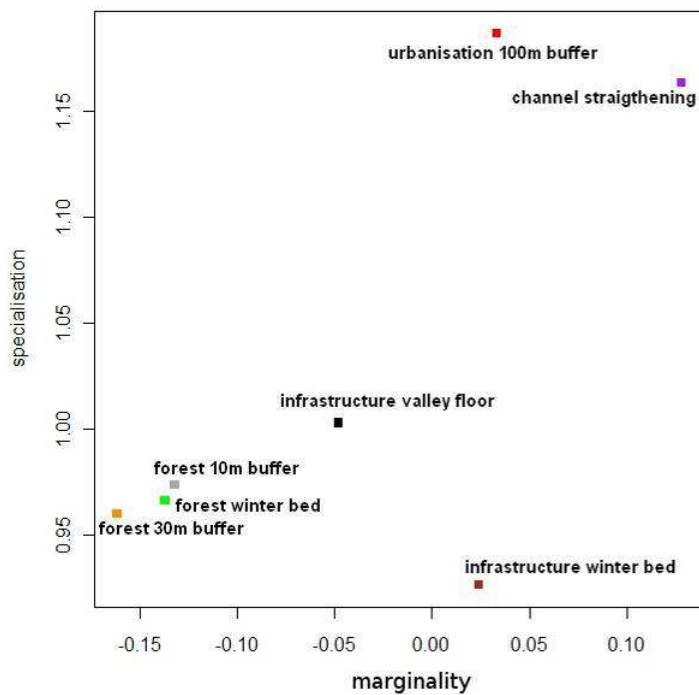
506
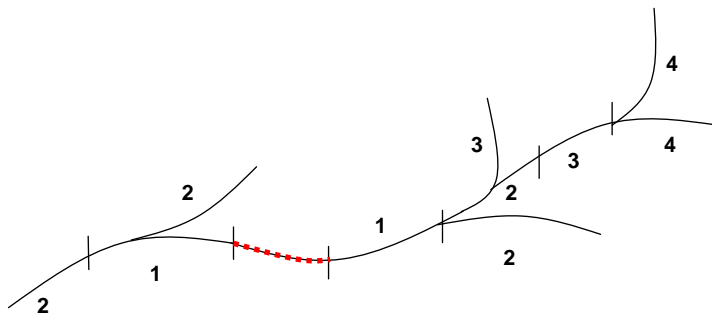


507

508    Figure 2. Illustration of the constructed river network topographical structure of node-

509    connector ranking for a river segment to neighbouring segments.
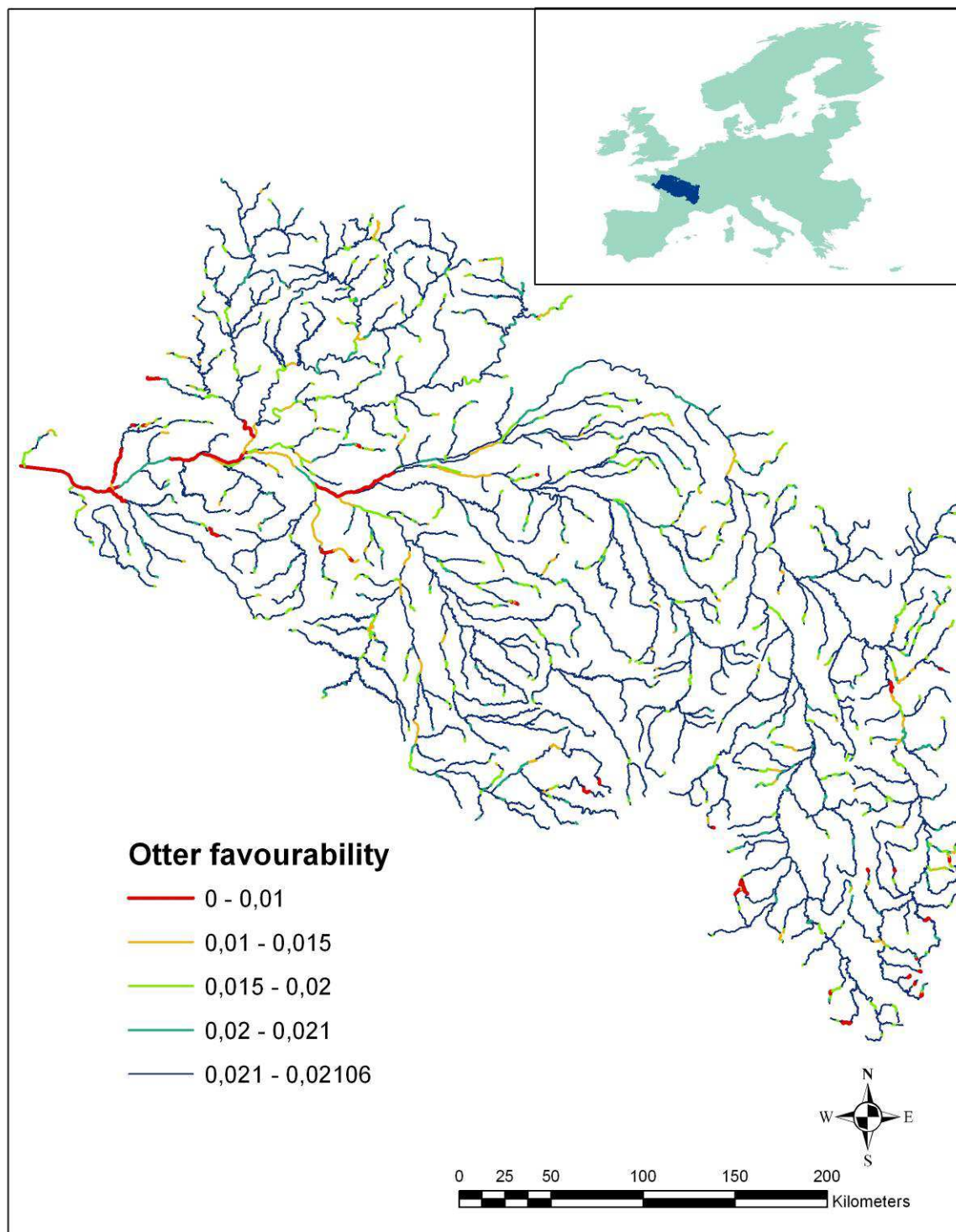
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514

515    Figure 3.  Ecological Niche Factor Analysis for the European otter.
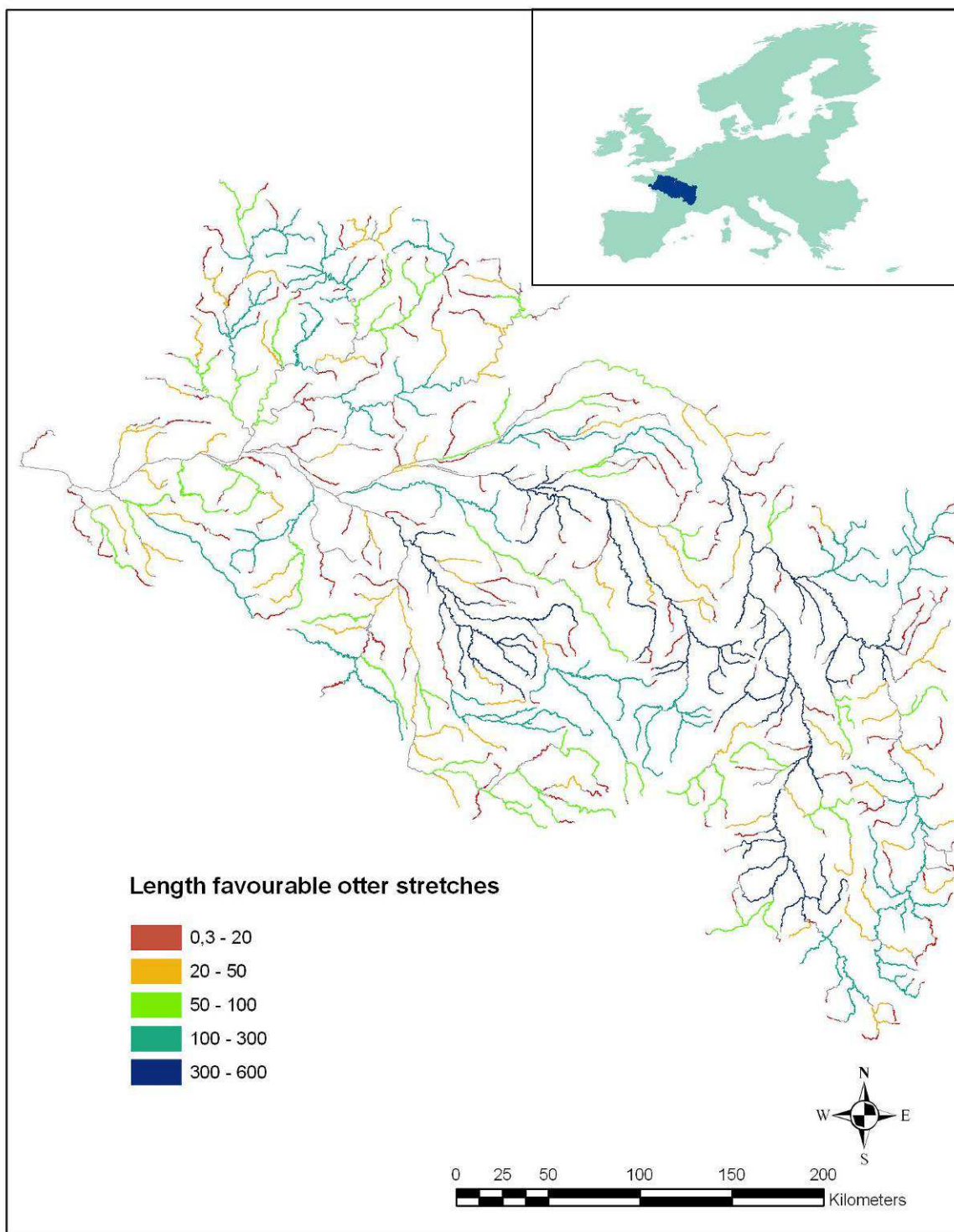
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520

521    Figure 4. Otter favourability of river segments in the network of the Loire basin

522    (favourability values present contribution of individual segments in percentage to total
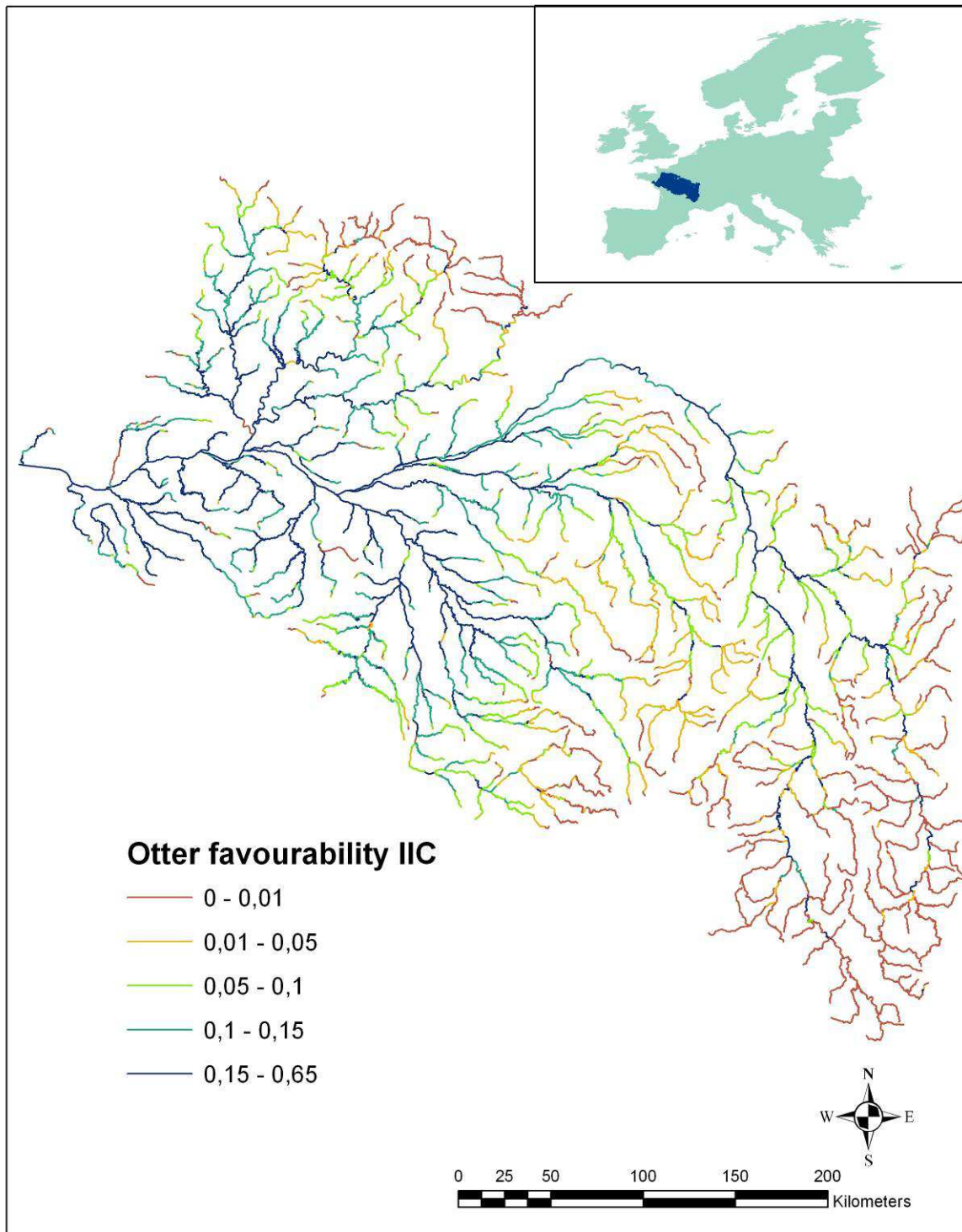
523    network).

524

525

526

527

528

529    (a).

530

**Otter favourability IIC**

— 0 - 0,01
— 0,01 - 0,05
— 0,05 - 0,1
— 0,1 - 0,15
— 0,15 - 0,65

531

532     (b).

533     Figure  5. The ecological networks based on local habitat quality - with connection

534     distance 0 - (a), and based on the Integral Index of Connectivity calculation for

535     connection distance 5 (b). The figure 5a presents length (km) of continuous favourable

536     habitat for otter (favourable segments gathered with barrier threshold 2km) in the Loire

537     basin (colours indicate km of linear in classes). Figure 5b presents the Integral Index of

538     Connectivity calculated dIIC network values. The dIIC values give an immediate

539     ecological network qualification (the values present contribution of individual segments in

540     percentage to total network) and representation.

541
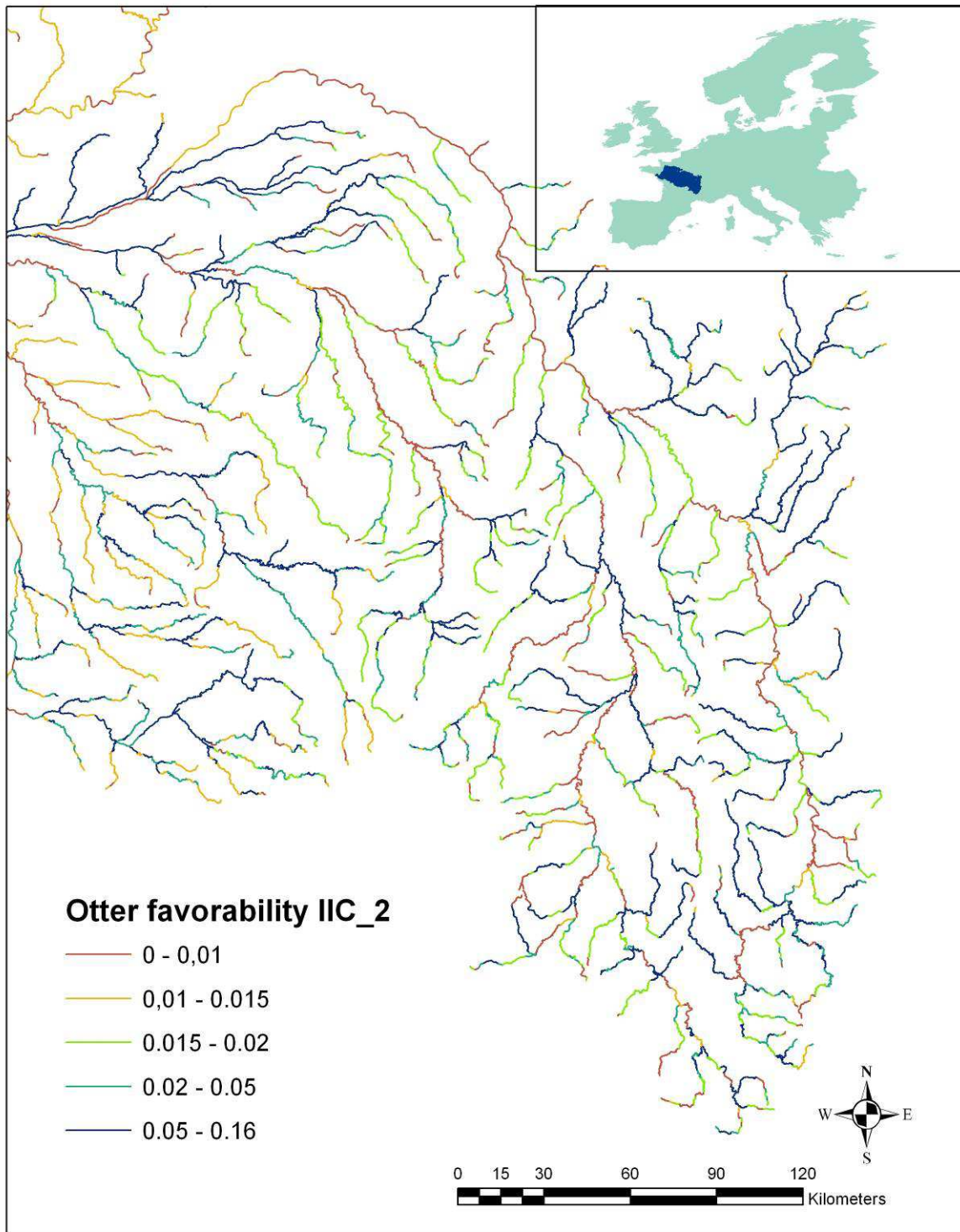
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543

544    Figure 6. The ecological network qualification based on the Integral Index of

545    Connectivity calculation for connection distance 2 for the central and upstream part of

546    the Loire River basin.

547

548