Impact of land reclamation and agricultural water regime on the distribution and conservation status of the endangered *Dryophytes suweonensis*

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Knowledge about the distribution and habitat preferences of a species is critical for its conservation. The Suweon Treefrog (*Dryophytes suweonensis*) is an endangered species endemic to the Republic of Korea. We conducted surveys from 2014 to 2016 at 890 potentially suitable sites across the entire range of the species in South Korea. We then assessed whether *D. suweonensis* was found in the current and ancestral predicted ranges, reclaimed and protected areas, and how the presence of agricultural floodwater affected its occurrence. Our results describe a 120 km increase in the southernmost known distribution of the species, and the absence of the species at lower latitudes. We then demonstrate a putative constriction on the species ancestral range due to urban encroachment, and provide evidence for a significant increase in its coastal range due to the colonisation of reclaimed land by the species. In addition, we demonstrate that *D. suweonensis* is present in rice fields that are flooded with water originating from rivers as opposed to being present in rice fields that are irrigated from underground water. Finally, the non-overlap of protected areas and the occurrence of the species shows that only the edge of a single site where *D. suweonensis* occurs is legally protected. Based on our results and the literature, we suggest the design of a site fitting all the ecological requirements of the species, and suggest the use of such sites to prevent further erosion in the range of *D. suweonensis*.

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2 **conservation status of the endangered *Dryophytes suweonensis***

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12 Running head: *Dryophytes suweonensis* range and threats

13 ABSTRACT

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15 conservation. The Suweon Treefrog (*Dryophytes suweonensis*) is an endangered species endemic

16 to the Republic of Korea. We conducted surveys from 2014 to 2016 at 890 potentially suitable

17 sites across the entire range of the species in South Korea. We then assessed whether *D.*

18   *suweonensis* was found in the current and predicted ancestral ranges, reclaimed and protected

19   areas, and how the presence of agricultural floodwater affected its occurrence. Our results

20   describe a 120 km increase in the southernmost known distribution of the species, and the

21   absence of the species at lower latitudes. We then demonstrate a putative constriction on the

22   species ancestral range due to urban encroachment, and provide evidence for a significant

23   increase in its coastal range due to the colonisation of reclaimed land by the species. In addition,

24   we demonstrate that *D. suweonensis* is present in rice fields that are flooded with water

25   originating from rivers as opposed to being present in rice fields that are irrigated from

26   underground water. Finally, the non-overlap of protected areas and the occurrence of the species

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29   requirements of the species, and suggest the use of such sites to prevent further erosion in the

30   range of *D. suweonensis*.

31   INTRODUCTION

32   Very few species have a cosmopolitan distribution, and most are likely to be under local

33   environmental pressure (Purvis et al. 2000). When the entire range of a species is threatened by

34   urbanization or other types of habitat modification, the risk of extinction increases exponentially

35   (Huxley 2013). As a result, the assessment of extinction risks depend on threat levels (Mace &

36   Lande 1991; see IUCN 2016), which may guide optimal conservation effort to prevent extinction

37   (Pimm et al. 2014).

38   Lack of knowledge of species' distributions has already resulted in extinctions that could

39   have been easily avoided. For example, the Tecopa pupfish (*Cyprinodon nevadensis calidae*)

40   became extinct following construction of man-made structures on the Tecopa Hot Springs, the

41   only site where the species occurred (Miller et al. 1989). Unfortunately, this information was not

42   available at the time of construction. Knowledge of species' habitat preferences provides

43   background information for the assessment of extinction risks (Manne & Pimm 2001), and can be

44   used to develop spatial models for species' distribution (Corsi et al. 2000). For instance, a

45   subspecies of Ursini's viper, *Vipera ursinii graeca*, was known to occur only in Greece and at a

46   single locality in Albania. However, eight new localities were found through landscape and

47   climate modelling, doubling the known range of the species (Mizsei et al. 2016).

48   Although critical, obtaining information about species' ranges and habitat preferences is

49   only a first step for any conservation effort. At risk species with clearly defined ranges still go

50   extinct in large numbers and a way to stem this loss is through the implementation of protected

51   areas (Pimm et al. 2014). The occurrence of a species within a protected area will significantly

52   increase its chance of survival, despite the debated effectiveness of currently located protected

53   areas (Abellán & Sánchez-Fernández 2015), and the need for the establishment of additional

54   protected areas (Brooks et al. 2004).

55   The Class Amphibia is currently the most endangered class of vertebrates (Stuart et al.

56   2004). Among the difficulties for amphibian conservation efforts are unknown distribution limits

57   and the absence of adequate breeding sites. Suitable natural wetlands for amphibians have been

58   converted into farmlands such as rice-paddies over the last century, especially in the Republic of

59   Korea (Juliano 1993; Czech & Parsons 2002; Machado & Maltchik 2010). Furthermore, those

60   farmlands still holding a fraction of the original biodiversity are being converted into residential

61   and commercial facilities at an alarming rate. In the Republic of Korea, rice production has

62   decreased by about 25 % since peak production in the 1970s (FAO 2016). Since then, there have

63   been clear negative repercussions on habitats available for amphibians (Park et al. 2014).

64   The Suweon Treefrog, *Dryophytes suweonensis* (previously attributed to *Hyla;* Duellman

65 et al. 2016), is an endangered, endemic treefrog species from the Korean Peninsula. As of 2012,

66 the species was known to occur in a very restricted range, limited to five valleys centred in

67 metropolitan Seoul (Kim et al. 2012). It is therefore possible that the largest populations of *D.*

68 *suweonensis* might have been historically present in and around the present Seoul area (Borzée et

69 al. 2015a). Yet, opportunistic observations of calling males in the Democratic People's Republic

70 of Korea (Chun et al. 2012) and further south than previously reported (Borzée et al. 2016c), lead

71 to the expectation of a broader distribution for the species.

72   *Dryophytes suweonensis* is an evolutionary important species due to its unusual ZW

73 karyotype, warranting special conservation efforts (Dufresnes et al. 2015). Here, we first aimed to

74 describe the extent of occurrence and distribution of the species through occurrence surveys, as

75 well as the loss of ancestral range because of urbanisation. We then assessed the overlap between

76 the range of the species and reclaimed tidal flats, and the overlap between range and protected

77 areas. Next, because the distribution of *D. suweonensis* is closely intertwined with rice

78 cultivation, we examined whether the origin of agricultural flood waters was critical for the

79 occurrence of the species. Finally, we extracted environmental variables collected from field

80 surveys and described optimal conservation sites for *D. suweonensis*.

81 MATERIAL AND METHODS

82   Field surveys were conducted during 2014, 2015 and 2016, only after the beginning of the

83 breeding season of the species (Roh et al. 2014) to prevent any false negative. Because

84 *Dryophytes suweonensis* has not been observed using other vegetation than rice seedlings as

85 supports from which to hang to produce advertisement calls (Borzée et al. 2016b), and because it

86 is not known to breed in any other wetland than rice paddies (Borzée and Jang 2015), the species

87 typically starts breeding after rice planting.

88   The setting of modern rice fields during the last decades led to a specific geometric

89   grouping of rice paddies, here referred to as rice-paddy complexes. A rice-paddy complex is

90   characterized by a central ditch running mostly straight through the complex for irrigation

91   purposes. Along this central ditch, and thus along the longest and straightest line available,

92   usually runs a cemented lane, typically following the centre of the valley. In this study, rice-

93   paddy complexes were considered spatially independent if further than 200 m apart, the

94   maximum daily dispersion distance for the species (Borzée et al. 2016a), or separated by

95   landscape barriers impermeable to treefrogs (Roh et al. 2014).

96   The Japanese Treefrog, *D. japonicus* is ubiquitously present on the wetlands of the

97   Korean Peninsula, and the two treefrog species are in sympatry at all sites. The advertisement

98   calls of *D. japonicus* and *D. suweonensis* are species specific (Jang et al. 2011; Park et al. 2013),

99   and we noted the presence or absence of *D. suweonensis* through acoustic monitoring. In calling

100 anurans, including Hylids, acoustic monitoring is known to be reliable to estimate population

101 size, and thus adequate to assess occurrence (Weir et al. 2005; Pellet et al. 2007; Dorcas et al.

102 2009; Petitot et al. 2014; Moreira et al. 2016). In a preliminary study, our aural survey protocol

103 with 5-min transects was accurate to estimate the occurrence of *D. suweonensis* (Borzée et al.

104 2017).

105 **Transect surveys**

106   We defined the general area for this study *a priori*, following the ecological requirements

107 of the species such as defined by Roh et al. (2014) and including all natural and man-made

108 wetlands west of 127.5° E and below 120 m above sea level. This pre-selection of potential

109 breeding sites through Google Earth Pro (Google Earth imagery, v7.1.2.2041, 2013) identified

110 789 sites in 2014 (Fig. 1). A previous study for the occurrence of this species had drawn the

111 southern limit of the range around the Bay of Asan, below 37° N (Kim et al. 2012; Fig. 1).

112 However, our surveys in 2014 demonstrated the southern limit of the range to be inaccurate

113 (Borzée et al. 2016c), and additional surveys were conducted further south in 2015 and 2016,

114 until reaching a point past where the species was no longer detected. In 2015, we surveyed 189

115 sites, composed of 90 new sites and 99 sites where the species was present in 2014. A single site

116 where the species was detected in 2014 could not be visited again due to its location within the

117 Civilian Control Zone (CCZ) adjacent to the border with the Democratic Republic of Korea and

118 the lack of permits for 2015 and 2016. In 2016, we surveyed a total of 122 sites (99 sites from

119 2014, 12 from 2015 and 11 new sites). All accessible sites where the species had been recorded in

120 2014 were surveyed in 2015 and 2016, even if the species was not detected in 2015. All sites

121 where the species had been detected in 2015 were kept in the list of sites to survey in 2016. In

122 total, 890 sites were surveyed at least once over the three years of surveys.

123   Surveys were conducted between 5 pm and 2 am, during the peak calling activity of the

124 species. After arrival at a survey site, five minutes were spent waiting quietly. For each site, aural

125 monitoring was conducted along a single transect along the centre of the rice-paddy complex. A

126 surveyor walked briskly at a maximum speed of *circa* 80 m/min along the transect, noting the

127 presence or absence of *D. suweonensis* at the rice-paddy complex. Before conducting the project,

128 we had empirically measured the detection range for advertisement calls of *D. suweonensis* ($n =$

129 20), resulting in a 250 ± 45 m range. The farthest rice paddies in rice-paddy complexes were

130 typically within this detection range.

131   At the end of each transect survey we recorded water pH and water conductivity (μS) to

132 define the ecological preferences of *D. suweonensis*. We also estimated surface area and longest

133 straight line within sites to determine a sphericity ratio for the occurrence of the species. This is

134 important for determining the likelihood of a species' presence because a circular site will better

135 retain a species than a narrow and linear site. We then recorded the length of continuity with

136   rivers and forests, defined as the continuous line between the edge of rice-paddy complexes and

137   the aforementioned landscape feature, and finally, we noted the presence of buildings and

138   greenhouses within the rice-paddy complexes. These variables were collected through the

139   drawing of polygons or visual inspection of sites in Google Earth Pro (Google Earth imagery,

140   v7.1.2.2041, 2016), at a 10 m resolution, on map dated from 2015 at the latest.

141   **Reclaimed lands and protected area**

142   To correlate the presence of the species with shifting landscape use, we recorded the

143   presence of the *D. suweonensis* at sites located on reclaimed lands. Here, reclaimed lands used to

144   be mudflats and sea beds, which have been converted into rice-paddy complexes. To record the

145   presence of reclaimed lands, we compared maps from 1950-51 drawn by the US Army (Center of

146   Military History 1990) downloaded in Google Earth and present satellite pictures from Google

147   Earth Pro (Google Earth imagery, 6.2.2.6613, 2016). The 1950-51 maps were selected due to

148   their precision. A land was considered reclaimed if it was not usable for breeding by *D.*

149   *suweonensis* in 1950-51, but converted into rice paddies before 2016.

150   We then compared the presence of protected areas and the localities where *D.*

151   *suweonensis* occurred. Data on protected areas were downloaded from the Protected Planet

152   database, set by the IUCN and UNEP-WCMC (2016). We subsequently noted the number of sites

153   within any protected area, as well as "sites that do not meet the standard definition of a protected

154   area but do achieve conservation in the long-term under national and international agreements"

155   (IUCN and UNEP-WCMC 2016).

156   **Origin of agricultural flood waters**

157   To analyse the impact of agricultural flood water on *D. suweonensis* distribution, we

158   asked rice farmers for the origin of the water used to flood their rice paddies. This survey was

159   restricted to the general riverine basin surrounding the city of Iksan, south of the Geum River. To

160   be included in the analysis, the origin of the water for a rice paddy complex had to be confirmed

161   by at least two different farmers (Fig. 2). Data collection was limited to sites where surveys for

162   *D. suweonensis* were conducted. The area surveyed south of the city of Gunsan and the

163   Mankyeong River had to be excluded from the analysis due to lack of traceability of the origin of

164   agricultural flood water (Fig. 2).

165   **Data analysis and optimal conservation sites**

166   For subsequent analyses, we binary encoded the presence of the species, the presence of

167   greenhouses and the presence of permanent human infrastructures within the rice-paddy

168   complexes. We first determined the range of the species, based on presence data points (Fig. 1).

169   We defined the potential range of the species based on the non-interruption of landscape variables

170   that are within the range used by the species. We also delineated the ancestral range of the

171   species, defined as the potential range of the species before human development. Namely, a site

172   was considered potential for the species if < 120 m of altitude and within the same water basin as

173   a known population, excluding cities and urban area > 1 km^2 (Fig. 1).

174   We then defined the overlap between species range and reclaimed area to estimate the

175   land use by the species, and calculated the overlap between species range and protected areas.

176   Descriptive statistics were used to characterise the impact of these landscape variables in both

177   cases.

178   We hypothesised the origin of the water to be important if linked to the Geum River. This

179   geographic area was chosen due to the clear segregation between areas flooded with water from

180   different origins. We indexed the occurrence of *D. suweonensis* at the sites surveyed in relation to

181   the binary encoding of the origin of flood water, from the Geum River. We subsequently assessed

182   whether distribution of *D. suweonensis* was random in relation to agricultural flood water.

183   Finally, we developed a plan for an optimal site for the protection of the species. From

184   survey presence data, we calculated averages for water quality (pH and conductivity) as proxies

185   for a larger set of values important for the species (Borzée et al. in review-b), the continuity with

186   rivers and forests, and the sphericity of sites. For sites surveyed over multiple years, the abiotic

187   variables used for the calculation of the species' preferences were restricted to the latest data

188   point. This choice to restrict the analysis to the survey presence data followed recent documented

189   local extinctions, and the potential for other undocumented local extinction due to water quality,

190   salinity, competition and land-use among others, and because these variables are important to

191   ecological preferences of species. All analyses were conducted with SPSS (v. 21.0, SPSS, Inc.,

192   Chicago, IL, USA), and maps were generated with ArcMap 9.3 (Environmental Systems

193   Resource Institute, Redlands, California, USA).

194   RESULTS

195   During the surveys conducted in 2014, only 358 sites out of the 789 sites pre-selected

196   were potentially habitable for the species as urban development and agricultural conversion

197   eliminated the 431 remaining sites. That is, these sites were beyond the ecological requirements

198   of the species as there was no standing water; instead the sites were mostly greenhouses,

199   apartment complexes or dry crops. Within the 358 habitable sites, we found calling *Dryophytes*

200   *suweonensis* at 100 sites, while the species was not detected at 258 sites. In 2015, calling *D.*

201   *suweonensis* were detected at 106 sites total, from 94 of the 100 sites where the species was

202   detected in 2014, and 12 of the new sites. In 2016, the species was detected at 109 sites total, 94

203   of the 2014 sites, 12 of the 2015 sites and three of the new sites. The 94 sites originating from the

204   2014 dataset where the species was detected in 2015 and 2016 were the same. The species was

205   not detected at the five remaining sites where it had been found in 2014. The 12 sites where the

206   species was detected in 2015 were included in the surveys in 2016, and the species was again

207   detected at all 12 sites. For all subsequent analyses, we assess the species to be present at the 114

208   sites where the species was detected at least once. This includes the 113 sites surveyed over three

209   years and the site behind the CCZ and these sites are distributed over *circa* 4300 km^2 (Fig. 1).

210   However, this species is under significant threats of local extinction at the five sites where the

211   species was detected in 2014 only; a new motorway was built during the study period in the (Fig.

212   1, Bay of Asan).

213   **Range, ancestral range and current optimal range**

214   The southern boundary of *D. suweonensis'* distribution was extended 120 km southwards

215   from the previous assessment (Kim et al. 2012). The distribution of *D. suweonensis* ranges from

216   the southern banks of the Imjin River to the northern banks of the Mankyeong River, on a 220 km

217   north-south transect. The range of the species spans 95 km longitudinally, with the westernmost

218   known population in Hongseong area and the easternmost in Wonju (Fig. 1).

219   The potential range of the species, defined as the area where ecological preferences of the

220   species are matched, is situated at the same latitude as the one where the species was detected,

221   but extends 25 km further west from the westernmost site where the species was detected,

222   towards the reclaimed Cheonsu bay. In addition, the corridor of low lands between Nonsan,

223   Gongju and Cheongju matches with the habitat required for the species, but no surveys were

224   conducted in that area, as primarily estimated too far and disconnected from the range of the

225   species to be a potential breeding area. When compared with the potential range of the species

226   before human development, referred here as ancestral range, the land surface area usable by the

227   species decreased by 729 km^2 (Fig. 1).

228   **Overlap between reclaimed lands and protected area**

229   Out of the 114 sites where *D. suweonensis* was detected, a total of 30 sites were enlarged

230   and 15 sites were created through land reclamation. The remaining 69 sites were not impacted by

231   land reclamation. When combining all sites impacted by land reclamation, they represent 39.47

232   % of the sites where *D. suweonensis* was present. When focusing on the overlap between the

233   occurrence of *D. suweonensis* and protected areas, only a single site was selected, South of

234   Pyeongtaek, protected under "Water Source Protection Area". In this protected site, only the

235   riverine system at the edge of the site is protected, putatively used by *D. suweonensis* for

236   hibernation and not for breeding.

237   **Origin of agricultural flood waters**

238   This analysis is based on a subset of sites in the southern distribution of the species (Fig.

239   2). A total of 53.3 % of sites where *D. suweonensis* was present overlapped with agricultural

240   floods originating from the Geum River (Fig. 2), highlighting the non-random occurrence of the

241   species in this area. Few sites surveyed in the putatively suitable areas using water from the

242   Mankyeong River had *D. suweonensis* (1/15 sites; 7%), while those in areas using water from the

243   Geum River had higher presence (8/17 sites; 49%) and an even high proportion of sites showed

244   presence in the areas utilising underground water (6/8 sites; 75%). Autocorrelation of the origin

245   of flood water is likely, although of minor importance in this study and unlikely to impact the

246   result of the statistical analyses.

247   **Assessment of optimal conservation site**

248   The environmental variables for *D. suweonensis* (Table 1) showed an average pH of 8.32

249   and average conductivity of 792.19 μS. The average sphericity was 1.15, meaning that sites were

250   more round than elongated in general. The majority of sites where *D. suweonensis* occurred had

251   permanent man-made infrastructures (52.9 %) and temporary structures (*i.e.* greenhouses, 68.9

252   %) within the rice-paddy complexes.

253   Depiction of the sites adequate for the conservation of *D. suweonensis* (Fig. 3) was

254   supplemented by vegetation lists from Borzée and Jang (2015), and landscape information

255   matching the current habitat of *D. suweonensis*. Rice paddies are delimited by levees roughly 40

256   cm wide and 20 to 60 cm high, covered with grasses, and used by treefrogs for basking, foraging,

257   and sheltering (Borzée et al. 2016a). The overhead view of the designed site highlights the need

258   for continuity with forests and rivers to match the preferences of the species (Fig. 3a), while the

259   lateral view (Fig. 3b) describes depth and vegetation characteristics required for the species.

260   DISCUSSION

261   This study highlights the importance of analysing data on the presence/absence and

262   habitat characteristics of species for their conservation. The known range of *Dryophytes*

263   *suweonensis* was doubled by the data collected over this three years study, highlighting the need

264   for a different approach to the selection of sites for the conservation of the species. These new

265   data show that the increase in known range is due to the inclusion of a large number of sites in

266   reclaimed area from post-war agricultural governmental development. The apparent expansion of

267   the species' known range is, however, countered by several potential local extirpations, such as

268   all the sites in the area of Suweon where the holotype for *D. suweonensis* was described

269   (Kuramoto 1980; Park et al. 2013).

270   The species still matches the criteria B1ab(i,ii,iii,iv) for listing as "endangered" under the criteria

271   of the International Union for Conservation of nature (IUCN) red list of endangered species. It

272   has an extent of occurrence < 5000 km^2, a severely fragmented population with a continuing

273   observed decline for extent of occurrence, area of occupancy, quality of habitat and the number of

274   locations or subpopulations. At present, the protection of *D. suweonensis* is not ensured because

275   no populations are located within a protected area. Only the edges of a single site are overlapping

276   with a protected area, south of Pyeongtaek. A single protected site is inadequate for the

277   conservation of an endangered species.

278   The description of the potential range for *D. suweonensis* shows that an area around

279   Cheongju may be adequate for the species to thrive. However, that area was not included in the

280   initial surveys, due to the lack of knowledge of such a potential wide range for the species.

281   Similarly, sites such as Baengnyeong or Seogmo Islands may be suitable but could not be

282   accessed due to their limited access to non-military personnel. Another potential significant range

283   increase would be within the Democratic People's Republic of Korea, as the species is known to

284   occur around Pyongyang (Chun et al. 2012).

285   Encroachment on the species' range by development (431 sites), such as at the sites

286   around the city of Suweon, has been partially counter-balanced by the land reclamation projects

287   for rice agriculture (15 sites) implemented at a very large scale in the Republic of Korea during

288   the second half of the last century. The presence of *D. suweonensis* on reclaimed land shows that

289   the species possesses the potential for dispersal despite a lower dispersal ability than the

290   sympatric *Dryophytes japonicus* (Borzée & Jang 2016). This shift in range is thus linked to rice

291   cultivation and may have been an on-going process since early human agriculture *circa* 5000

292   years ago (Fuller et al. 2007; Fuller et al. 2008).

293   Furthermore, numerous *D. suweonensis* populations are isolated from each other, with

294   urbanization resulting in multiple landscape barriers within and among potential metapopulations.

295   This calls for a long-term study of population dynamics and network analysis for the species. We

296   would expect the population to be larger at reclaimed sites, due to lower levels of encroachment

297   and fragmentation.

298   The water origin analysis showed that frogs occur at sites flooded by water originating

299   from the Geum River and underground water sources. However, the species was not detected at

300   sites flooded by water originating from the Mankyeong River. Thus, water originating from

301   underground water bodies and pumped to the surface for agricultural purposes may be adequate

302   for *D. suweonensis*. The areas flooded by river water may be the ones that were seasonally

303   flooded before landscape modifications by humans, and the absence of *D. suweonensis* at some

304   sites could relate to water quality. This idea is potentially supported by the absence of individuals

305   at the only site flooded by water originating from the Geum River south of the Mankyeong River.

306   However, as the water is brought by aerial channels, it is possible that some individuals *D.*

307   *suweonensis* will drift south to this area in the future and establish new colonies, or perhaps

308   hybridise with the *D. japonicus* present at the site (Borzée et al. 2015b).

309   Conservation of a species often requires the restoration of the species' habitat (Rannap et

310   al. 2009). The design of an optimal site for the protection of *D. suweonensis* highlights the need

311   for very large continuous flood plains. However, such large plains are becoming frequently

312   uncommon because of encroachment, and management plans have to be set before these sites

313   disappear. Furthermore, the presence of bullfrogs in the southern part of the range, may have a

314   known negative impact on the species (Borzée et al. in review-a), and demonstrates that the first

315   steps of conservation management plans for the species have to be conducted at any site where

316   the species would be protected/re-introduced. Finally, as the species is still present across a range

317   similar to its ancestral range, we do not recommend ex-situ conservation projects at this time, nor

318   translocations to new sites that would be outside of the ancestral range for the species.

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438 TABLES

439 **Table 1:**

440 Descriptive statistics for abiotic variables of interest collected from all sites where *Dryophytes*

441 *suweonensis* was present.

	N	Min	Max	Mean	Std
Water pH	114	7.20	10.20	8.32	0.32
Water conductivity (μS)	114	83.50	5720.00	792.19	740.47
Surface area (m²)	114	0.31	26.09	4.78	4.36
Max. length (km)	114	1.10	301.00	6.30	27.89
Continuity with forests (km)	114	0.00	14.10	3.87	2.83
Continuity with rivers (km)	114	0.00	9.20	1.17	1.79
Sphericity	114	0.01	2.87	1.15	0.65

442

443   FIGURES

444   **Figure 1:**

445   Summary of the 890 sites surveyed at least once over the three years of surveys. *Dryophytes*

446   *suweonensis* was detected at least once at 114 sites, and 421 sites were too excessively urbanised

447   for the species to occur. Here, potential current range is defined as the range where the species

448   could currently occur, while the potential ancestral range is the range where the species could

449   have occurred before urban development. Pyeongtaek is the area where the only protected area

450   with *D. suweonensis* is found.

Imjin River

Dryophytes suweonensis present
Dryophytes suweonensis absent
Excessive urbanisation
Potential range
Ancestral potential range
Only protected area with *D. suweonensis*

38° N

Wonj
u

Bay of
Asan

37° N

Cheongju

Hongseong

Gongju

Cheonsu Bay

Nonsan

25 Km

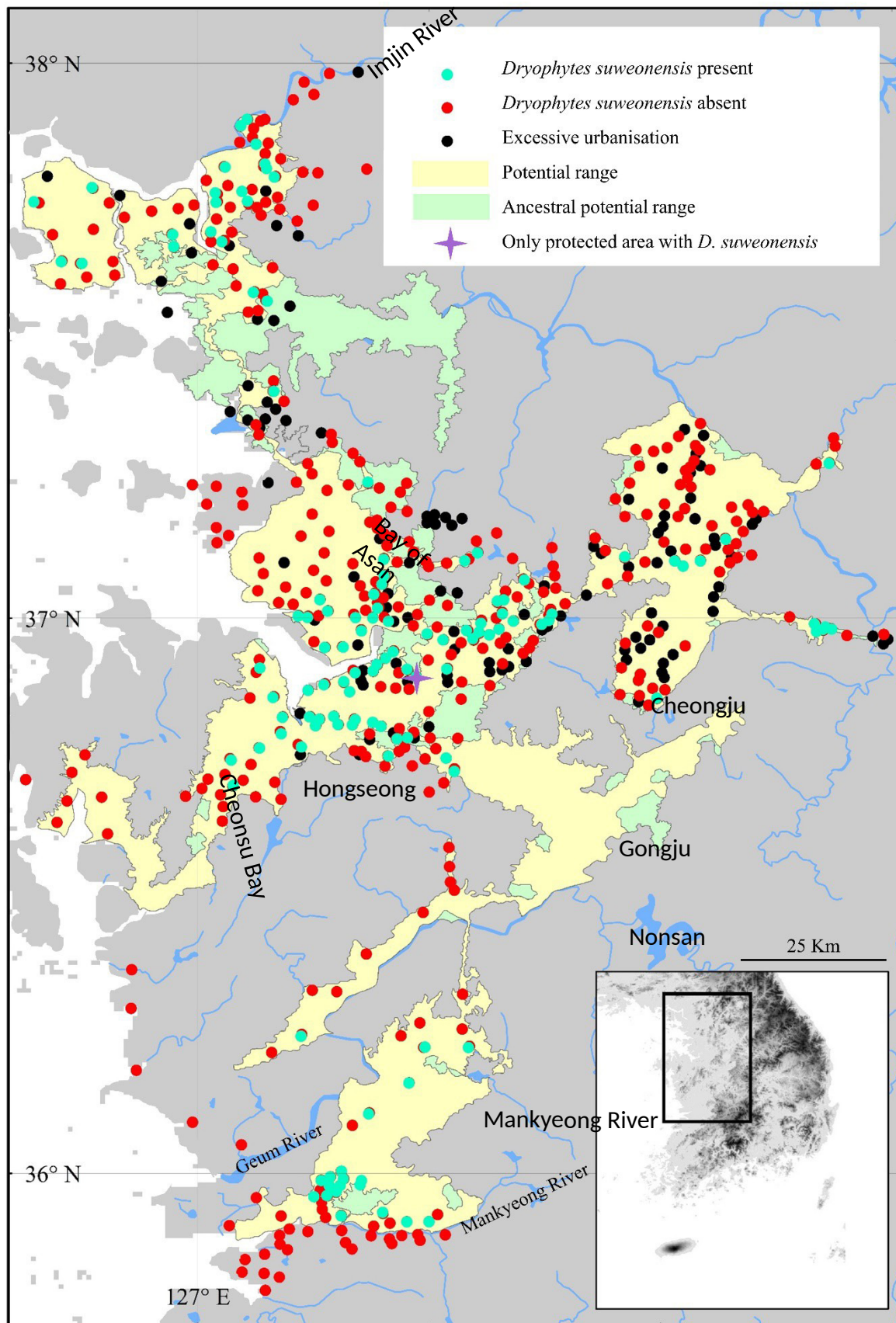
36° N

Mankyeong River

Geum River

Mankyeong River

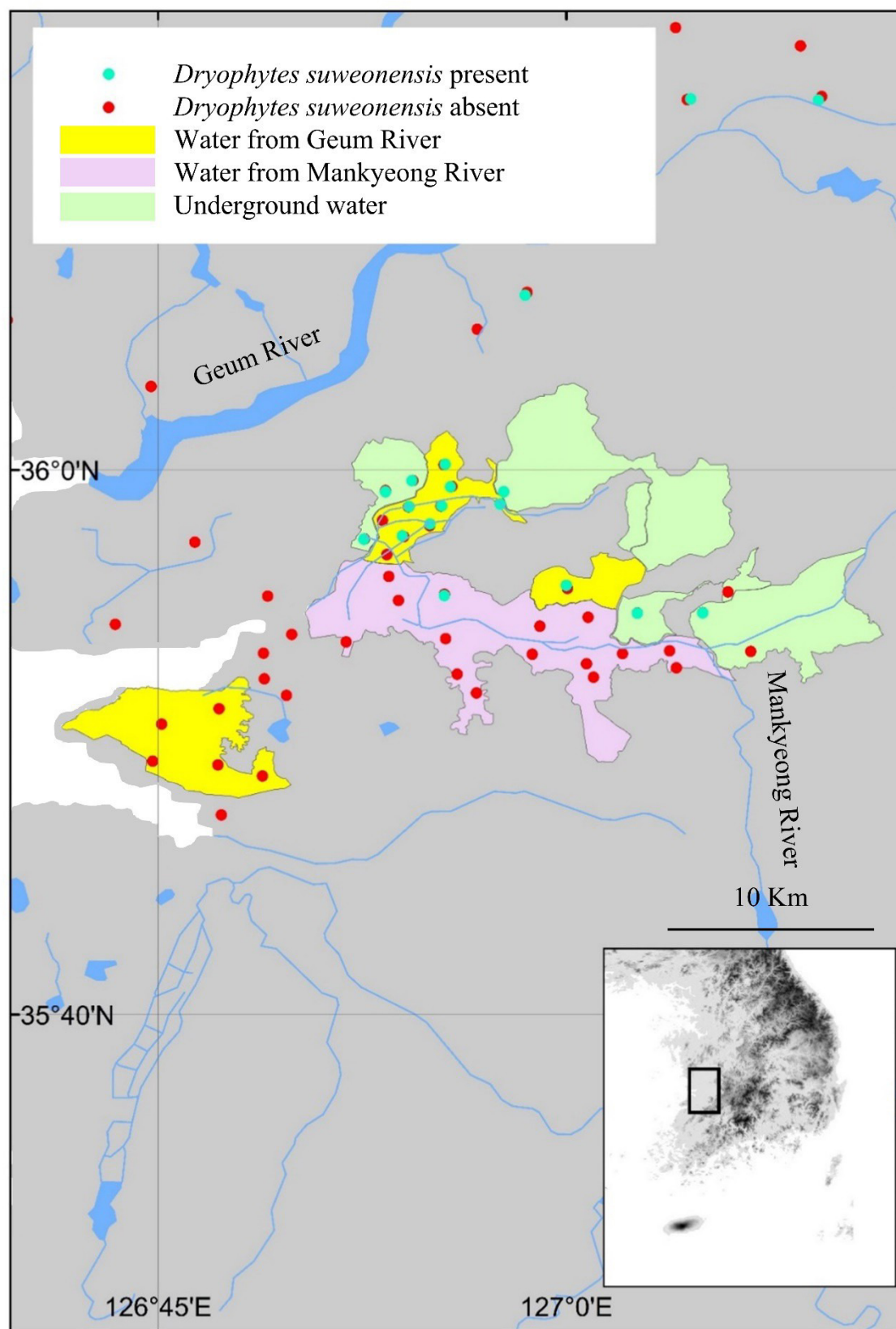
127° E

451 **Figure 2:**

452 Relationship between flood water origin and species presence. Most of the flood water matching

453 with the occurrence of *Dryophytes suweonensis* originated from the Geum River (53.3 %),

454 followed by underground water (40 %), while the remaining 6.7 % of sites were flooded by the

455 Mankyeong river. This analysis is restricted to the area shown on the map.

456

457   **Figure 3:**

458   (A) Overhead view of the site optimally designed to follow ecological preferences demonstrated

459   by *Dryophytes suweonensis*. The cut AA' is reported in Fig. 3b. The figure is not to scale. Water

460   depths indicated are matching with the average depth of rice paddies, and therefore acceptable if

461   not optimal for the species, and vegetation data is extracted from Borzée and Jang (2015). (B)

462   Lateral view of the site optimally designed to follow ecological preferences demonstrated by

463   *Dryophytes suweonensis*. Water level (WL) originates from the only known natural site with

464   *Dryophytes suweonensis* (Borzée and Jang 2015).

⊖	*Phragmites communis*
⊕	*Typha spp.*
⊗	*Oryza spp.*
⊘	*Alopecurus aequalis*

A

Salix koreensis

0 cm
-10 cm
-20 cm
-30 cm

WETLAND

A

A'

RIVER

B

AVERAGE WIDTH = 6.3Km

A

A'

Phragmites communis

Typha spp.

Oryza spp.

Alopecurus aequalis

PADDY SOILS

Salix koreensis

W·L

WATER DEPTH
MAX. 30 cm