



LJMU Research Online

Mulkeen, CJ, Gibson-Brabazon, S, Carlin, C, Williams, CD, Healy, MG, Mackey, P and Gormally, MJ

Habitat suitability assessment of constructed wetlands for the smooth newt (*Lissotriton vulgaris* [Linnaeus, 1758]): A comparison with natural wetlands

<http://researchonline.ljmu.ac.uk/id/eprint/6785/>

Article

Citation (please note it is advisable to refer to the publisher's version if you intend to cite from this work)

Mulkeen, CJ, Gibson-Brabazon, S, Carlin, C, Williams, CD, Healy, MG, Mackey, P and Gormally, MJ (2017) Habitat suitability assessment of constructed wetlands for the smooth newt (*Lissotriton vulgaris* [Linnaeus, 1758]): A comparison with natural wetlands. *Ecological Engineering*. 106

LJMU has developed **LJMU Research Online** for users to access the research output of the University more effectively. Copyright © and Moral Rights for the papers on this site are retained by the individual authors and/or other copyright owners. Users may download and/or print one copy of any article(s) in LJMU Research Online to facilitate their private study or for non-commercial research. You may not engage in further distribution of the material or use it for any profit-making activities or any commercial gain.

The version presented here may differ from the published version or from the version of the record. Please see the repository URL above for details on accessing the published version and note that access may require a subscription.

For more information please contact researchonline@ljmu.ac.uk

<http://researchonline.ljmu.ac.uk/>

1 Habitat suitability assessment of constructed wetlands for the Smooth Newt (*Lissotriton*
2 *vulgaris* [Linnaeus, 1758]): a comparison with natural wetlands

3

4 C.J.Mulkeen^{1,2*}, S.Gibson-Brabazon¹, C.Carlin¹, C.D.Williams³, M.G.Healy², P.Mackey¹,
5 and M.J.Gormally¹

6

7 ¹ Applied Ecology Unit, School of Natural Sciences, National University of Ireland, Galway,
8 Ireland

9 ² Civil Engineering, National University of Ireland, Galway, Ireland

10 ³ School of Natural Sciences and Psychology, Liverpool John Moores University, Byrom
11 Street, Liverpool, L3 3AF. UK

12 *Corresponding author. Email address: collettemkn@gmail.com

13

14 **Abstract**

15 Given the current decline of natural wetlands worldwide and the consequent negative impacts
16 on amphibians, wetlands constructed for the treatment of wastewaters have the potential to play
17 a role in the protection of these animals. However, there is a paucity of information regarding
18 the value of constructed wetlands (CWs) to amphibians, particularly relating to the terrestrial
19 phase of the life-cycle. This study compares the terrestrial habitats of natural wetlands (NWs)
20 and CWs as refuges for the smooth newt (*Lissotriton vulgaris*) with the aim of developing
21 recommendations for CWs (both new and existing) to enhance their usefulness as newt-friendly
22 habitats. Terrestrial habitats surrounding NWs and CWs, including barriers to newt movement
23 and features which could act as potential newt refuges, were mapped using ArcGIS. Natural
24 wetlands had significantly more terrestrial habitat types than CWs and while woodlands at both

25 wetland types were most likely to contain features of benefit to newts, almost twice as many
26 grids (20 m x 20 m) in the terrestrial habitats of NWs contained features compared to those of
27 CWs. The application of a Habitat Suitability Index resulted in seven of eight NWs compared
28 to only two of eight CWs receiving “good” scores, the lower scores for CWs being due
29 primarily to the presence of a barrier to newt movement. Recommendations for enhancing the
30 design and management of CWs for smooth newts include less intensive ground maintenance,
31 reduction of barriers to newt movement, judicious planting and the provision of additional
32 refuges.

33

34 *Keywords:* Smooth newt, constructed wetlands, natural wetlands, Habitat Suitability Index

35

36 **1. Introduction**

37 Natural wetlands (NWs), one of the most important ecosystems on earth (Mitsch & Gosselink,
38 2007), have been described as ‘transitional environments’ occurring between terrestrial and
39 aquatic systems (Lehner & Doll, 2004). The ecosystem services provided by NWs include
40 biodiversity support, water quality improvement, flood abatement (Zedler, 2000) and
41 sequestration / long-term storage of carbon dioxide (Mitsch et al., 2013). In addition, extensive
42 numbers of bird, mammal, fish, amphibian and invertebrate species are entirely dependent on
43 NW habitats across the globe (Zedler & Kercher, 2005). It is estimated that 50% of the Earth’s
44 original NWs have been destroyed (Mitsch & Gosselink, 2007) and in Ireland alone, areas
45 covered by NWs decreased by almost 2.5% between 2000 and 2006 (CORINE, 2006).

46

47 While NWs have been used as convenient wastewater discharge sites since sewage was first
48 collected (for at least 100 years in some locations) (Kadlec & Wallace, 2008), it is only in the
49 last fifty years (approximately) that wetlands have been recognised for their wastewater

50 treatment capabilities (Vymazal, 2011). Since then various types of artificial wetlands
51 (constructed wetlands; CWs) have been designed to intercept wastewater (after conventional
52 treatment processes) and remove a range of pollutants before discharging into natural water
53 bodies (Hsu et al., 2011). Constructed wetlands are being recognised increasingly as a
54 relatively low-cost, energy-efficient method for treating wastewaters such as sewage,
55 agricultural / industrial wastewaters and storm water runoff (Campbell & Ogden, 1999). While
56 much attention has been paid to the waste water treatment capabilities of CWs, relatively little
57 attention has been given to the incorporation of biodiversity features in the design and
58 construction of CWs and their surroundings. A number of studies have been undertaken on the
59 biodiversity of existing CWs including studies on freshwater invertebrates (Speiles & Mitsch,
60 2000; Jurado et al., 2010), amphibians (Korfel et al., 2010), birds (Andersen, et al., 2003) and
61 mammals (Kadlec et al., 2007). However, these studies have generally focussed on the CW
62 itself and not on the surrounding habitats in which the CW is situated, although the latter are
63 often critical for fauna, such as amphibians, with biphasic life cycle requirements.

64
65 Amphibians typically require terrestrial and aquatic environments to complete their semi-
66 aquatic life cycle (Dodd & Cade, 1997). However, they are currently experiencing striking
67 global declines in recent decades due, in part, to the destruction of wetland habitats (Stuart et
68 al., 2004) and fungal disease (Voyles et al., 2009). The importance of terrestrial habitats and
69 microhabitats for amphibian breeding site selection has been highlighted by Marnell (1998).
70 *Lissotriton vulgaris* (Linnaeus, 1758) (the smooth newt), while widespread across most of
71 Europe, is the sole native species of newt found in Ireland (Meehan, 2013), with breeding
72 invariably taking place in water during spring, and sometimes extending into early summer.
73 After metamorphosis, juveniles of *L. vulgaris* can spend several years on land, before reaching
74 maturity between the ages of three and seven years (Bell, 1977), at which stage they return to

75 water bodies to breed. Smooth newts are known to use a variety of water bodies during the
76 breeding season, which include lakes, natural ponds, garden ponds and slow-moving drainage
77 ditches (Meehan, 2013), with aquatic newt larvae rarely being found in running water (Bell &
78 Lawton, 1975). Even water bodies with a surface area of no more than 400 m² (considerably
79 smaller areas than many CWs for wastewater treatment) have been known to support up to
80 1,000 individual adult smooth newts (Bell & Lawton, 1975). While breeding takes place in
81 water, the majority of newts overwinter on land, although there is evidence that some adults
82 may remain in water during winter (Kinne, 2004). Upon emigration from the water body, newts
83 tend to travel towards favourable habitat patches in the vicinity (Malmgren, 2002). On land,
84 they tend to travel in straight lines, since movement here is slower and requires more energy
85 than movement in water where the newt is buoyed up by the surrounding medium (Griffiths,
86 1996). When on land, suitable refuges must be sought from predation, desiccation and
87 temperature extremes (Griffiths, 1984). Habitats that provide such shelter and protection, such
88 as scrub and woodland (both deciduous and coniferous), unimproved grassland and gardens,
89 are considered newt-friendly habitats (Oldham, 2000) (Table 1). Although habitats thought to
90 be less suitable for newts in the UK include water bodies containing fish (Aronsson & Stenson,
91 1995) and acidic habitats such as peatland (Marnell, 1998), it appears that newts can be catholic
92 in their approach to habitat selection. In Ireland, for example, where *L. vulgaris* is at the most
93 westerly edge of its range, and lacks competition for habitats from other newt species, it has a
94 tendency towards a wide niche occupation, including lakes of a considerable size containing
95 fish in addition to acid peatland pools (Meehan, 2013). In addition, microhabitats such as dead
96 wood and stone features can be important in amphibian breeding site selection (Marnell, 1998),
97 while roads and rivers adjacent to the breeding water body have been shown to interfere with
98 newt migration (Oldham, 2000).

99

100 The movement of smooth newts on land, which tends to be short distances from breeding water
101 bodies (Griffiths, 1984), has been described as philopatric i.e. individuals remain or return to
102 relatively few permanent hiding places throughout the year and/or on an annual basis (Dolmen,
103 1981; Sinsch & Kirst, 2015). Although individuals of *L. vulgaris* have been found in terrestrial
104 habitats at distances exceeding 500 m from water bodies (Kovar, et al. 2009), this is likely to
105 be the exception rather than the rule. Bell (1977) found that over forty times more newts were
106 captured in pitfall traps within 5 m of a wetland edge compared with pitfalls placed 50 m from
107 the wetland edge. In addition, Bell (1977) released sixty-one marked *L. vulgaris* juveniles 22.5
108 m from a pond edge and recaptured over 50% within ten meters from the point of release thirty-
109 five days later. In another study, Dolmen (1981) observed that no recaptured smooth newts
110 ventured further than 7.5 m from the original capture point on land, suggesting that adult newts
111 tend to settle close to the water body in which they were born (Bell, 1977). Most smooth newts
112 will remain relatively close to the breeding pond, provided that habitat quality immediately
113 surrounding the breeding water body is optimal and connectivity is excellent. Terrestrial
114 habitats surrounding wetlands can, therefore, serve as wildlife corridors and are important in
115 the conservation and management of semi-aquatic species such as amphibians (Semlitsch &
116 Bodie, 2003) including *L. vulgaris*.

117

118 The Habitat Suitability Index (HSI), first developed by Oldham et al. (2000) in Britain (and
119 later modified by the National Amphibian & Reptile Recording Scheme, 2007), is used by
120 Natural England and Natural Resources Wales and the Department of Environment, Food and
121 Rural Affairs (UK) to assess the likelihood of the presence of the great crested newt (*Triturus*
122 *crystatus* [Laurenti, 1768]) in a given area in the UK (Department of Environment, Food and
123 Rural Affairs, 2016) (Table 2). This species, which is larger than the smooth newt, has been
124 found to travel further (> 200m) from ponds (Kinne, 2004). Since the great crested newt is

125 absent from Ireland, *L. vulgaris* occupies a similar range of habitats, in addition to which there
126 is considerable overlap in the timing of seasonal and diel activities (Griffiths and Mylotte,
127 1987). Both species also seem to have similar requirements in terms of the quality of the
128 terrestrial habitats surrounding water bodies for dispersal (Malmgren, 2002) and these habitats
129 include areas of trees, scrub and long grass (Griffiths, 1996). It has been suggested that the
130 presence of *T. cristatus* in ponds in the UK is usually a good indicator that the ponds will also
131 contain *L. vulgaris* (Griffiths, 1996), although *L. vulgaris* can be found in a wider range of
132 localities (Skei et al., 2006). Due to the similarities in terms of habitat requirements that exist
133 between the two species, and in the absence of a smooth newt HSI for Ireland, the applicability
134 of the UK HSI for *T. cristatus* was seen by the authors of this article as an initial starting point
135 to assess habitat suitability for *L. vulgaris* at a landscape-scale and prioritise areas for action.

136

137 In Ireland, drainage and infilling of NWs (Staunton et al., 2015), in conjunction with excessive
138 clearing of vegetation around breeding sites, remains a threat to smooth newt populations (King
139 et al., 2011). *Lissotriton vulgaris* is currently on the International Union for the Conservation
140 of Nature (IUCN) Red list of threatened species in Ireland (King et al., 2011), and loss of
141 suitable terrestrial habitats for overwintering or refuge remains a concern. The value of CWs
142 as a conservation strategy for amphibians has been highlighted by previous studies (Denton &
143 Richter, 2013), given the current decline of NWs. However, the suitability of terrestrial habitats
144 surrounding CWs for wastewater treatment for the terrestrial phase of the newt life-cycle has
145 yet to be addressed.

146 The aim of this study was to compare, for the first time, the suitability of terrestrial habitats
147 surrounding CWs and NWs for *L. vulgaris*. The results are discussed in the context of providing
148 definitive guidelines for engineers regarding the design of CWs, which incorporate features
149 that support the conservation of the species.

150

151

152 **2. Methods & Materials**

153

154 2.1 Site descriptions

155 Eight CWs and eight NWs were selected in counties Mayo, Galway, Roscommon and Leitrim
156 in the west of Ireland (Fig. 1). The CWs, built for the tertiary treatment of municipal
157 wastewater, each consisted of surface flow reed beds planted with either *Phragmites australis*
158 (Cav.) Trin. ex Steud. or *Typha latifolia* L. Natural wetlands, all of which contained areas of
159 *P. australis* and/or *T. latifolia*, and which were within 20 km of each CW, were selected for
160 comparison (Appendix A). All wetlands contained some form of suitable, newt-friendly
161 habitats such as hedgerows, scrub, drainage ditches, woodland or grasslands within a 500 m
162 radius of the wetland.

163

164

165 2.2 Habitat mapping

166 Between August and October 2015, habitats were mapped at all sites. A colour orthoimage,
167 sourced from ArcGIS (Release Version 10.3; Environmental Systems Research Institute
168 [ERSI], California, USA) and produced in 2012, was printed for each wetland at a scale of
169 1:2650. Given that a minimum mapable polygon size of 400 m² is recommended by Smith et
170 al. (2011) for small-scale field mapping, orthoimages were printed with a 20 m × 20 m grid
171 superimposed on the image to aid with mapping in the field. The photograph was used as a
172 base map in which habitats were recorded. All habitats within 40 m of the water's edge were
173 documented, since most of the *L. vulgaris* population will confine normal intra-habitat
174 wanderings to short distances from a pond (Griffiths, 1984).

175 Habitats were identified, described and classified according to a standard habitat classification
176 scheme used in Ireland covering terrestrial, freshwater and marine environments (Fossitt,
177 2000). This classification scheme is hierarchical and operates at three levels comprising eleven
178 broad habitat groups at Level 1; thirty habitat sub-groups at Level 2; and 117 individual habitats
179 at Level 3 e.g. “Grassland and marsh” (Level 1) → Semi-natural grassland (one of three sub-
180 groups at Level 2) → “wet grassland” (one of seven habitats at Level 3).

181 During the surveys of terrestrial habitats, it was noted that grasslands which would normally
182 be classified as “improved agricultural grassland” under Fossitt’s classification (Fossitt, 2000),
183 often consisted of poorly drained fields which supported abundant *Juncus* species. For the
184 purposes of this study, such sites were classified as “improved agricultural grassland with
185 abundant *Juncus* spp.” to separate them from truly improved fields i.e. “intensively managed
186 or highly modified agricultural grassland” with rye grasses (*Lolium perenne* L.) usually
187 abundant (Fossitt, 2000). Notable features of importance to smooth newts such as wood or
188 stone features (Marnell, 1998) were recorded as present or absent for each 20 m × 20 m grid
189 square. These features included woody features such as tree stumps, dead/fallen branches,
190 fallen trees, and stone features including boulders or loose rock.

191
192 Field survey recorded data were later digitised using ArcGIS 10.3 and the areas for each habitat
193 calculated. Wood and stone features were recorded as point features. Linear features such as
194 treelines, hedgerows and drains, were assigned an arbitrary width of 1 m (reflecting the
195 minimum width of linear habitats encountered), so that areas of different habitats could be
196 compared. As the total areas for each wetland varied, the wetlands in this study have been
197 numbered consecutively from the largest to the smallest for each wetland type i.e. CW1 – CW8
198 and NW1 – NW8 (Appendix 1). Maps were created using ArcGIS 10.3 and the extent of all
199 habitats were determined. Using the UK’s HSI for the great crested newt, CWs and NWs were

200 scored and ranked in order of their potential value to the smooth newt. Those at the lower end
201 of the scale are evaluated and recommendations on how their suitability can be improved are
202 proposed.

203

204 2.3 Statistical analysis

205 A Kolmogorov-Smirnov test was performed to test for normal distribution of the residuals. A
206 General Linear Model (GLM) was used to test whether there was a significant effect of area
207 and wetland type on habitat richness. A Pearson's Correlation was used to test if there was any
208 correlation between area of the wetland and the number of habitats present.

209

210 3. Results

211 A total area of 2.25 km² (including open water) was mapped across sixteen CW and NW sites.
212 Areas of open water and surrounding terrestrial habitats mapped at CWs range from 0.008 km²
213 to 0.020 km², while those of the generally larger NWs range from 0.008 km² – 1.45 km²
214 (Appendix A). Using Level 1 (Fossitt, 2000), “freshwater” habitats dominate the NWs overall
215 (74%) compared to only 13% at the CWs, where “grassland & marsh dominated” (54%) (Fig.
216 2). This is not surprising, given that a more in-depth analysis of freshwater habitats at Level 3
217 (Fossitt, 2000) reveals that the open water of the NWs (primarily lakes) is reflected by the
218 dominance (82% cover) of “mesotrophic lakes” compared to the, not unexpected, dominance
219 of “reed & large sedge swamp” (74%) at the CWs, represented at the NWs by a cover of just
220 16%. “Woodland & scrub” have similar percentage covers of 13% and 15% at the NWs and
221 CWs, respectively (Fig. 2), but “exposed rock & disturbed ground” and “cultivated and built
222 land”, a total of < 2% combined at the NWs, has a cover of 8% and 10%, respectively, at the
223 CWs.

224

225 Given that the focus of this paper is the terrestrial phase of the smooth newt, which spends less
226 than 50% of the year (generally March – July) (Bell, 1977) in still water for breeding, suitable
227 terrestrial habitats are examined in more detail, since they form an essential component of the
228 newt life cycle (Denoël & Lehmann, 2006). With this in mind, less optimal habitats for newts
229 from August to February (i.e. the “freshwater” habitats above with the exception of “freshwater
230 swamps”) were removed from the analysis to examine the remaining habitats in detail for
231 suitability for newts. “Freshwater swamps” were included in the analysis because these are not
232 areas of fully open water, but generally occupy a zone at the transition from open water to
233 terrestrial habitats (Fossitt, 2000). An examination of the order of dominance of terrestrial
234 habitats (Fig. 3) at Level 1 (Fossitt, 2000) reveals a similar pattern to those in Figure 2, with
235 the exception that percentage cover of “freshwater swamp” at the NWs is almost co-dominant
236 with “woodland & scrub” (32% and 33%, respectively). In the CWs, “freshwater swamp” has
237 the same percentage cover as “cultivated and built land” (Fig. 3), which along with “exposed
238 rock and disturbed ground”, have an overall percentage cover of 10% and 9%, respectively. In
239 NWs, both categories, along with “heath and dense bracken”, have an overall percentage cover
240 of <2%.

241

242 The number of newt friendly terrestrial habitats recorded at Level 3 (Fossitt, 2000) varies
243 within each wetland type, with those in NWs ranging from 17 at the largest NW1 (Appendix
244 A) to seven at NW5 and from 12 habitats at CW3 to six at CW 8. To test for normal distribution,
245 a Kolmogorov–Smirnov test was used and results were $P > 0.05$ indicating that the data are not
246 significantly different from a normal distribution (CW area = 0.690, CW number of habitats =
247 0.473; NW area = 0.808, NW number of habitats = 0.598). A Pearson’s correlation confirmed
248 that the correlation between area of CWs and number of habitats present is not significant ($P >$
249 0.05, $\rho = 0.602$) in comparison to the correlation between area of NWs and number of habitats

250 present, which is significant ($P < 0.05$, $\rho = 0.898$). Using a General Linear Model (GLM),
251 there is a significant effect of both area and wetland type on habitat richness. The GLM displays
252 a positive relationship between number of habitats and the covariate, area, and NWs have
253 significantly more habitats than CWs (Table 3).

254

255 Given that “grassland & marsh” represents over a quarter of the cover of terrestrial habitats at
256 both wetland types (26% and 54% for NWs and CWs, respectively) and that long grass and
257 rough grassland are among those considered as some of the best habitats for the terrestrial phase
258 of newts (Table 1), these are examined in more detail at Level 3 (Fossitt, 2000) (Fig. 4). Nine
259 different “grassland and marsh” habitat types are found in the current study. “Wet grasslands”
260 represent more than half (52%) the cover of the grasslands at the NWs, but less than a quarter
261 (24%) at CWs where “improved agricultural grassland” is dominant (44%). “Improved
262 agricultural grassland with abundant *Juncus* spp.” represents 13% and 22% cover at NWs and
263 CWs, respectively, while “freshwater marsh”, present at the NWs (6%), is absent from the CWs
264 (Fig. 4).

265

266 Since woodland, damp woodland, scrub and hedgerows are also considered excellent terrestrial
267 habitats for smooth newts (Table 1), these are examined further (Fig. 5) at Level 3 (Fossitt,
268 2000). Twelve “woodland and scrub” habitat types are present at CWs and NWs. “Mixed
269 broadleaved woodland” and “mixed broadleaved conifer woodland” cover combined dominate
270 both wetland types with 48% and 60% cover at the NWs and CWs, respectively (Fig. 5). These
271 are followed by “wet willow-alder-ash” (17%) and “scrub” (15%) at the NWs and “scrub”
272 (22%) and hedgerows (7%) at the CWs. “Riparian woodland” and “bog woodland” are
273 exclusive to NWs with 13% cover in total.

274

275 Given that, regardless of habitat type, barriers to movement by newts play a pivotal role in
276 newt survival, these are also examined at the CW and NW sites. Potential barriers to movement
277 for the smooth newt in this study were identified at both CWs and NWs. These include roads
278 and rivers, which are classed as serious barriers to newt migration (Oldham, 2000). Other
279 barrier habitats (directly bordering breeding sites) identified include “buildings and artificial
280 surfaces”, “improved agricultural grassland”, “exposed sand, gravel and till”, and “spoil and
281 bare ground”. Forty-four percent of the total perimeter of the CW sites in this study constitutes
282 potential barriers to newt migration compared to just under 2% at NW sites. While six out of
283 eight CWs have barriers of some kind, only two out of eight NWs have barriers at the edge of
284 the water body.

285
286 The significance of terrestrial microhabitats or features such as wood and stone which can act
287 as potential refuges for newts, can contribute significantly to amphibian conservation when
288 selecting breeding sites (Marnell, 1998). Twenty-eight percent of the 20 m × 20 m grids
289 surrounding the NWs which were surveyed in this study contain features compared to just 18%
290 for the CWs. Habitats such as “Mixed broadleaved woodland” and “mixed broadleaved conifer
291 woodland” account for the greatest percentage frequencies (5 – 11%) of features at both
292 wetland types, with “wet willow-alder-ash woodland” within the same range for NWs only
293 (Table 4). Within a range of 1 – 4%, frequency of features is “riparian woodland” for NWs
294 only and “recolonizing bare ground”, “improved agricultural grassland” and “wet willow-
295 alder-ash-woodland” for CWs only.

296
297 Using the HSI (Table 2), only two CWs receive the highest score of 1 (*Good*) (Appendix C),
298 while seven NWs receive a *Good* score (1) in that there are no barriers present (Table 5). One
299 hundred percent of the perimeter lines of all CWs and NWs which receive *Good* scores, contain

300 extensive areas of habitat that offers good opportunities for foraging and shelter completely
301 surrounding the wetland. One CW (CW4) received a *Moderate* score of 0.67, where 17% of
302 the perimeter line of the CW is made up of “buildings and artificial surfaces”, while one NW
303 (NW4) received a *Moderate* score (0.67) due to the presence of “buildings and artificial
304 surfaces” (0.4%) of the perimeter directly bordering the lake. Five of the CWs received *Poor*
305 scores (0.33) (Appendix D), while no NWs received a *Poor* score.

306

307

308 **4. Discussion**

309 The results of this study indicate that the NWs have significantly more terrestrial habitat types
310 than CWs and that the number of terrestrial habitat types present in NWs is significantly
311 correlated with the size of the area containing the terrestrial habitats. Both NWs and CWs were
312 selected on the basis of the presence of reed and large sedge swamps; their location i.e. paired
313 CWs and NWs ≤ 20 km apart; and the presence of newt friendly terrestrial habitats within 500
314 m of the wetland. Nevertheless, given that most of the NWs were lakes (Appendix A), the
315 generally larger size of aquatic habitats, including open water, resulted in comparatively larger
316 areas of terrestrial habitats being surveyed within 40 m of the water’s edge than in the smaller
317 CWs. In addition, while similar woodlands at both wetland types were most likely to contain
318 features of benefit to newts, almost twice as many grids (20 m \times 20 m minimum mappable
319 areas) in the terrestrial habitats of NWs contained features compared to those of CWs.
320 Furthermore, “wet grassland” dominated the grasslands around NWs, while “improved
321 agricultural grassland” dominated the grasslands around CWs. The latter grasslands, which are
322 generally managed through intensive grazing regimes, cutting and the application of fertilizer
323 / herbicides, may result in the absence of structural diversity such as that of rough grassland
324 and meadows – habitats which can offer cover and foraging for the terrestrial phase of the newt

325 (Oldham, 2000). “Wet grassland” (often occurring on sloping ground with poorly drained soils)
326 with abundant rushes, tall grasses and a high broadleaved herb component (Fossitt, 2000) may,
327 in comparison to “improved agricultural grassland”, offer more potentially suitable terrestrial
328 habitats. Areas of “marsh” unique to NWs in this study (along lake shores) also offer good
329 structural habitats, particularly for immature newts, given the presence of high moss cover in
330 conjunction with rushes (*Juncus* spp.), sedges (*Carex* spp.) and a high proportion of
331 broadleaved herbs. This is reflected in the HSI scores, where seven of the eight NWs, but only
332 two of the eight CWs, received a “good” score. A number of CWs received lesser scores
333 primarily because of the presence of a barrier to movement, which could potentially impact on
334 the migration of the newt from aquatic to terrestrial habitats. This is reflected by almost one
335 fifth of the surface area of the CWs examined in this study consisting of “cultivated and built
336 land” and “exposed rock and disturbed ground”, some of which is necessary for machinery
337 access to the site.

338 Previous studies have emphasized the value of using CWs as a conservation strategy for
339 amphibians and the need for future research and monitoring in these areas (Denton & Richter,
340 2013). While our study focussed on suitable terrestrial habitats for newts and did not involve a
341 survey of smooth newt abundance, a single adult specimen of the species was recorded on the
342 edge of one CW during the study (Mulkeen & Gibson-Brabazon, *pers. obs*). The presence of
343 newts in CWs in Ireland (Scholz et al., 2007) also suggests that water quality in CWs treating
344 wastewaters, at least in some cases, is not an issue and can support breeding in the species. In
345 addition to this, newts have been recorded in natural ponds and wetlands as small as 25 m²
346 (Skei et al., 2006) and with up to 1,000 individuals recorded in ponds less than 400 m² (Bell &
347 Lawton, 1975). Regardless of waterbody size, if aquatic and terrestrial conditions are
348 favourable for breeding, shelter, food and overwintering, it may not be unreasonable to suggest
349 that newts may colonise and breed in these areas. However, small changes to the design of new

350 CWs and the management of the lands surrounding both new and existing CWs could enhance
351 their dual role as water treatment systems and suitable habitats for the newt and other
352 amphibian species.

353 In the design of new CWs, the overall size of the site should be considerably larger than the
354 actual wetland itself to ensure that the area surrounding the wetland is of sufficient size to
355 provide adequate refuges for the terrestrial phase of the newt. While lands outside the CW
356 fence may provide suitable refuges for the newt when the CW is being constructed, there is no
357 guarantee that this area will not be lost to development at some time in the future. As a
358 guideline, and based on the evidence observed by previous authors of smooth newt migration
359 distances (Bell, 1977; Dolmen, 1981), it is desirable that a buffer zone around a CW be
360 incorporated within the site. By way of example, the inclusion of 20 m buffer zone (providing
361 suitable terrestrial habitats for smooth newts) around a 20 m × 20 m (400 m²) CW, would result
362 in the purchase of just an additional 0.32 ha. However, other authors have suggested that a
363 distance of 300 m of forested areas surrounding vernal pools will favour the persistence of
364 amphibian species such as wood frog and salamander (Calhoun et al., 2014), suggesting that
365 perhaps recommendations may need to be amphibian species specific. Large areas of open
366 habitat offering little cover can act as a barrier during newt migrations to and from water bodies
367 for breeding. Habitats such as “amenity grassland”, “improved agricultural grassland”, “spoil
368 and bare ground” and “buildings and artificial surfaces”, offer little cover, shelter, hibernation,
369 foraging or overwintering sites for newts. By their very nature, CWs built for the tertiary
370 treatment of wastewater also contain areas covered with artificial surfaces such as tarmac or
371 concrete, built structures for wastewater treatment and unpaved areas for access points and
372 driveways. These should, however, be reduced to a minimum, particularly immediately
373 adjacent to the edge of the CW. If hard surfaces are required adjacent to the CW, they ideally
374 should be at one side only, leaving the other three sides with direct access to terrestrial habitats.

375 Prior to construction taking place, a habitat survey should be undertaken to determine the value
376 of existing habitats to newts. The proximity of the proposed construction to the nearest NWs
377 should be considered, as suggested by other authors such as Drayer & Richter (2016). In
378 particular, habitats identified in this study such as “mixed broadleaved woodland”, “mixed
379 broadleaved conifer woodland”, “wet willow-alder-ash woodland” and scrub should be
380 retained, where possible, as should “wet grassland” and “improved agricultural grassland with
381 abundant rushes”. In sites undergoing construction, judicious planting with suitable trees and
382 shrubs and / or the creation of wet grassland using membranes beneath the soil surrounding the
383 CW would also be beneficial. In particular, the availability of terrestrial cover around breeding
384 sites in the form of logs and deadwood was found to be an important habitat parameter in
385 discriminating between sites used or unused by the smooth newt during its life cycle (Marnell,
386 1998). Skei et al. (2006), Marnell (1998) and Oldham (2000) suggest that woodland and scrub
387 offer newts suitable terrestrial habitats to complete the terrestrial phase of the life cycle. By
388 their very nature, woodland and scrub habitats usually present a highly structured habitat,
389 which could offer shelter and refuge in the form of large amounts of deadwood, often in the
390 form of tree stumps, fallen branches, or logs. At existing CWs, less frequent mowing of
391 “improved” or “amenity grasslands” would encourage the growth of a greater proportion of
392 tall, coarse or tussocky grasses, and a broadleaved herb component which could offer suitable
393 refuge or foraging areas for newts. The addition of features such as stones or wood into all
394 types of existing habitats would also enhance these areas as newt refuges. Even a reduction in
395 the management (cutting and herbicide applications) of unpaved surfaces or gravel would
396 facilitate the colonisation of plants over time. Therefore, without compromising the vital
397 function of access to the CW and wastewater treatment areas, these unconsolidated surfaces
398 with plant cover may also assist newts during their migrations from aquatic to terrestrial
399 habitats.

400

401 An indication of the variability of CWs vis-à-vis their suitability for newts can be seen in the
402 contrasting HSI scores for two CWs, one scoring “good” and one scoring “poor” (Appendix C
403 and D). The CW which received a “good” score (Appendix C) is completely surrounded by
404 favourable terrestrial habitats, which provide good structure for the smooth newt during
405 migrations (scrub; earth bank; treeline; and dry meadows & grassy verges). No barriers were
406 identified on the wetland edge and despite it being located in an urban area, an adult specimen
407 of the smooth newt was recorded on the edge of the wetland within the “scrub” habitat under a
408 wood feature during the study (Mulkeen & Gibson-Brabazon, *pers. obs*). The CW which
409 received a “poor” score (Appendix D) is surrounded by an unsuitable terrestrial habitat for
410 newts, “spoil and bare ground”, which could act as a barrier to newt migration. “Spoil and bare
411 ground” includes areas of bare ground due to ongoing disturbance or maintenance,
412 unconsolidated surfaces which are regularly trampled or driven over, and areas which are
413 largely unvegetated (<50% cover) (Fossitt, 2000). Areas such as these are open and provide
414 little structure or protection for the smooth newt during migrations from the wetland to
415 favourable terrestrial habitats. The relocation (where possible) of bare ground or unconsolidated
416 surfaces with trampling activities, away from the edge of a CW, along with the creation of a
417 grassland / woodland (with a diversity of structures) plus the simple addition of wood and/or
418 stone features could, at minimal cost, support successful newt migrations from aquatic to
419 terrestrial habitats.

420

421 **Conclusions**

422 Natural wetlands have significantly more terrestrial habitat types than CWs, which are
423 significantly correlated with the size of the areas containing the terrestrial habitats. Seven of
424 the eight NWs received a “good” score using the HSI in comparison to two of the eight CWs.

425 Constructed wetlands received lower scores primarily because of the presence of unsuitable
426 habitat types or barriers which could potentially impact the migration of the newt from aquatic
427 to terrestrial habitats. Therefore, in the future design of new CWs, it is important that the overall
428 size of the site be larger than the actual CW itself to facilitate the incorporation of newt friendly
429 habitat which is immediately adjacent to the edge of the CW. Appropriate management of the
430 areas surrounding new and existing CWs along with the addition of features such as stones or
431 wood, could also enhance these areas for newts and other amphibian species.

432

433 **Acknowledgements**

434 The authors acknowledge funding from the Irish Environmental Protection Agency (EPA)
435 (Project number 2013-B-PhD-12). Special thanks to Dr. Ronan Hennessy and Dr Gesche
436 Kindermann for GIS assistance, co-operative landowners and Galway, Mayo, Roscommon and
437 Leitrim County Councils.

438

439 **References**

- 440 Andersen, D.C., Sartoris, J.J., Thullen, J.S. & Reusch, P.G. (2003) The effects of bird use on
441 nutrient removal in a constructed wastewater-treatment wetland. *Wetlands*, 23(2),
442 pp.423–435.
- 443 Aronsson S. & Stenson J.A.E. (1995) Newt-fish interactions in a small forest lake. *Amphibia-*
444 *Reptilia*, 16, pp.177-184.
- 445 Becerra Jurado, G., Johnson, J., Feeley, H., Harrington, R. & Kelly-Quinn, M. (2010) The
446 Potential of Integrated Constructed Wetlands (ICWs) to Enhance Macroinvertebrate
447 Diversity in Agricultural Landscapes. *Wetlands*, 30(3), pp.393–404.
- 448 Bell, G. (1977) The life of the smooth newt (*Triturus vulgaris*) after metamorphosis.
449 *Ecological Monographs* 47, pp.279 – 299.
- 450 Bell, G. & Lawton, J.H. (1975) The Ecology of the Eggs and Larvae of the Smooth Newt
451 (*Triturus vulgaris*) *Journal of Animal Ecology*, 44 (2) pp.393 – 423.

- 452 Calhoun, A.J.K., Arrigoni, J., Brooks, R.P., Hunter, M.L., Richter, S.C. (2014). Creating
453 successful vernal pools: a literature review and advice for practitioners. *Wetlands* 34, pp.
454 1027–1038
- 455 Campbell, C.S. & Ogden, M.H. (1999) *Constructed Wetlands in the Sustainable Landscape*.
456 1st ed. – Wiley, New York.
- 457 CLC2006 / GMES FTSP Land Monitoring; Corine Landcover Inventory update 2006, Final
458 report - Ireland.
- 459 Denton, R.D., Richter, S.C. (2013). Amphibian communities in natural and constructed ridge
460 top wetlands with implications for wetland construction. *J. Wildl. Manage.* 77, pp. 886–
461 889.
- 462 Department for Environment, Food and Rural Affairs (UK), 2016. Great Crested Newt
463 Habitat Suitability Index. <http://www.narrs.org.uk/documents/HSI%20guidance.pdf>
464 (accessed 09.02.2017)
- 465 Denoël, M. & Lehmann, A. (2006) Multi-scale effect of landscape processes and habitat
466 quality on newt abundance: Implications for conservation. *Biological Conservation*. 130,
467 pp.495 – 504.
- 468 Dodd, C.K. & Cade, B.S. (1998) Movement Patterns and the Conservation of Amphibians
469 Breeding in Small, Temporary Wetlands. *Conservation Biology*, 12(2), pp.331 – 339.
- 470 Dolmen, D. (1981) Local migration, rheotaxis and philopatry by *Triturus vulgaris* within a
471 locality in Central Norway. *British Journal of Herpetology*. 6, pp.151 – 158.
- 472 Drayer, A.N., Richter, S. (2016). Physical wetland characteristics influence amphibian
473 community composition differently in constructed wetlands and natural wetlands. *Ecol.*
474 *Eng.* 93, pp. 166–174
- 475 Flood K.W. (2012) *The National Newt Survey Completion Report 2011*. The Irish Wildlife
476 Trust, Dublin, Ireland
- 477 Fossitt, J.A. (2000) *A Guide to Habitats in Ireland*. The Heritage Council, Kilkenny, Ireland.
- 478 Griffiths, R.A. (1984) Seasonal behaviour and intrahabitat movements in an urban population
479 of smooth newts (*Triturus vulgaris*) (Amphibia:Salamandridae). *Journal of Zoology, London*,
480 203, pp.241 – 251.
- 481 Griffiths, R.A. & Mylotte, V.J. (1987) Microhabitat selection and feeding relations of smooth
482 and warty newts, *Triturus vulgaris* and *T.cristatus*, at an upland pond in mid-Wales. *Holarctic*
483 *Ecology*, 10, pp.1-7.
- 484 Griffiths, R. A. (1996) *Newts and Salamanders of Europe*. T & A D Poyser Ltd, London

- 485 Hsu, C.-B., Hsieh, L.-H., Yang, L., Wu, S.-H., Chang, J.-S., Hsiao, S.-C., Su., H.C., Yeh, C.-
486 H., Yeh, C.-H., Ho., Y.-S. & Lin, H.-J. (2011) Biodiversity of constructed wetlands for
487 wastewater treatment. *Ecological Engineering*, 37(10), pp.1533–1545.
- 488 Kadlec, R.H., Pries, J. & Mustard, H., 2007. Muskrats (*Ondatra zibethicus*) in treatment
489 wetlands. *Ecological Engineering*, 29, pp.143–153.
- 490 Kadlec, R.H. & Wallace, S.D., 2008. Treatment Wetlands, 2nd ed. CRC Press, Boca Raton,
491 FL.
- 492 King, J.L., Marnell, F., Kingston, N., Rosell, R., Boylan, P., Caffrey, J.M., FitzPatrick, Ú.,
493 Gargan, P.G., Kelly, F.L., O’Grady, M.F., Poole, R., Roche, W.K. & Cassidy, D. (2011)
494 Ireland Red List No. 5: Amphibians, Reptiles & Freshwater Fish. National Parks and
495 Wildlife Service, Department of Arts, Heritage and the Gaeltacht, Dublin, Ireland.
- 496 Kinne, O. (2004). Successful reintroduction of the newts *Triturus cristatus* and *T. vulgaris*.
497 *Endangered Species Research*, 4, pp 1 -16.
- 498 Korfel, C.A., Mitsch, W.J., Hetherington, T.E. & Mack, J.J. (2010) Hydrology,
499 Physiochemistry, and Amphibians in Natural and Created Vernal Pool Wetlands.
500 *Restoration Ecology*, 18(6), pp.843–854.
- 501 Kovar, R., Brabec, M., Radovan, V. & Radomir, B. (2009) Spring migration distances of
502 some Central European amphibian species. *Amphibia-Reptilia*, 30, pp.367-378.
- 503 Lehner, B. & Döll, P., 2004. Development and validation of a global database of lakes,
504 reservoirs and wetlands. *Journal of Hydrology*, 296, pp.1–22.
- 505 Malmgren, J.C. (2002) How does a newt finds its way from a pond? Migration patterns after
506 breeding and metamorphosis in Great Crested Newts (*Triturus cristatus*) and Smooth
507 Newts (*T.vulgaris*). *Herpetological Journal*, 12. pp.29-35.
- 508 Marnell, F. (1998) Discriminant analysis of the terrestrial and aquatic habitat determinants of
509 the smooth newt (*Triturus vulgaris*) and the common frog (*Rana temporaria*) in Ireland.
510 *Journal of Zoology, London*, 244, pp.1-6.
- 511 Meehan, S.T. (2013) The Irish Wildlife Trust National Smooth Newt Survey 2013 report.
512 The Irish Wildlife Trust, Dublin, Ireland.
- 513 Mitsch, W.J., & Gosselink, J.G. 2007. Wetlands 4th ed. – Wiley, New Jersey.
- 514 Mitsch, W.J., Bernal, B., Nahlik, A.M., Mander, Ü., Zhang, L., Anderson, C.J., Jørgensen,
515 S.E., & Brix, H. (2013). *Landscape Ecol.* 28: pp.583-597.
- 516 National Amphibian & Reptile Recording Scheme (2007). Great Crested Newt Habitat
517 Suitability Index. Comments from HSI workshops held at the Herpetofauna Workers’
518 Meeting in January 2007.
519 <http://www.narrs.org.uk/documents/HSI%20guidance.pdf>

- 520 Oldham , R.S., Keeble, J., Swan, M.J.S. & Jefcote, M. (2000) Evaluating the suitability of
521 habitat for the Great Crested Newt (*Triturus cristatus*). *Herpetological Journal* 10 (4),
522 pp.143 - 155
- 523 Scholz, M., Harrington, R., Carroll, P., & Mustafa, A. (2007) THE INTEGRATED
524 CONSTRUCTED WETLANDS (ICW) CONCEPT. 27(2), pp.337–354.
- 525 Schulse, C.D., Semlitsch, R.D., Trauth, K.M., Williams, A.D., (2010). Influences of Design
526 and Landscape Placement Parameters on Amphibian Abundance in Constructed
527 Wetlands. *Wetlands*, 30: 915-928.
- 528 Semlitsch, R.D. & Bodie, J.R., (2003). Biological Criteria for Buffer Zones around Wetlands
529 and Riparian Habitats for Amphibians and Reptiles. *Conservation Biology*, 17(5),
530 pp.1219–1228.
- 531 Sinsch, U. & Kirst, C., (2015) Homeward orientation of displaced newts (*Triturus cristatus*,
532 *Lissotriton vulgaris*) is restricted to the range of routine movements. *Ethology Ecology*
533 *& Evolution*, 28(3), pp.312-328.
- 534 Skei, J.K., Dolmen, D., Rønning, L., Ringsby, T.H. (2006). Habitat use during the aquatic
535 phase of the newts *Triturus vulgaris* (L.) and *T. cristatus* (Laurenti) in central Norway:
536 proposition for a conservation and monitoring area. *Amphibia-Reptilia*, 27 pp. 309-324
- 537 Smith, G.F., O'Donoghue, P., O'Hora, K. & Delaney E. (2011) Best Practice Guidance for
538 Habitat Survey and Mapping. The Heritage Council, Kilkenny, Ireland.
- 539 Spieles, D.J. & Mitsch, W.J., (2000). Macroinvertebrate Community Structure in High- and
540 Low-Nutrient Constructed Wetlands. *Wetlands*, 20(4), pp.716–729.
- 541 Staunton, J., Williams, C.D., Morrison, L., Henry, T., Fleming, G.T.A. & Gormally, M.J.
542 (2015). Spatio-temporal distribution of construction and demolition (C&D) waste
543 disposal on wetlands: A case study. *Land use Policy*, (49), pp. 43-52.
- 544 Stuart, S.N., Chanson, J. S., Cox, N.A., Young, B.E., Rodrigues, A.S.L., Fischman, D.L. &
545 Waller, R.W. (2004) Status and trends of amphibian declines and extinctions worldwide.
546 *Science (New York, N.Y.)*, 306(2002), pp.1783–1786.
- 547 Voyles, J., Young, S., Berger, L., Campbell, C., Voyles, W.F., Dinudom, A., Cook, D.,
548 Webb, R., Alford, R.A., Skerratt, L.F. & Speare, R. (2009) Pathogenesis of
549 Chytridiomycosis, a cause of catastrophic amphibian declines. *Science*, 326, pp. 582–
550 585.
- 551 Vymazal, J., 2011. Constructed wetlands for wastewater treatment: Five decades of
552 experience. *Environmental Science and Technology*, 45(1), pp.61–69.
- 553 Zedler, J.B., 2000. Progress in wetland restoration ecology. *Trends in Ecology & Evolution*,
554 15(10), pp.402–407.

555 Zedler, J.B. & Kercher, S., 2005. WETLAND RESOURCES: Status, Trends, Ecosystem
556 Services, and Restorability. *Annual Review of Environment and Resources*, 30, pp.39–
557 74.

558
559
560
561
562
563
564
565
566
567
568
569
570
571
572
573
574
575
576
577
578
579
580

Formatted: English (United Kingdom)

581 **Table 1.** Terrestrial habitats identified in the literature as suitable for the terrestrial phase of *Lissotriton vulgaris*

<i>Terrestrial habitat</i>	<i>Reference</i>
Meadows / long grass	Oldham et al., 2000; Flood, 2011; Marnell, 1998; Meehan, 2013
Rough grassland	Oldham et al., 2000
Hedgerows	Oldham et al., 2000
Scrub	Oldham et al., 2000; Flood 2011; Marnell, 1998
Woodland	Oldham et al., 2000; Flood, 2011; Meehan, 2013
Gardens	Oldham et al., 2000
Damp woodland	Flood, 2011;
Bogland	Flood, 2011;
Dense vegetation in water/lake margins	Meehan, 2013

582

583

584

585

586

587

588

589 **Table 2.** Great Crested Newt (*Triturus cristatus* [Laurenti, 1768]) Habitat Suitability Index used for scoring terrestrial habitats around ponds
590 (National Amphibian & Reptile Recording Scheme, 2007)

591

Category	SI	Criteria
Good	1	Extensive area of habitat that offers good opportunities for foraging and shelter completely surrounds pond (e.g. rough grassland, scrub or woodland).
Moderate	0.67	Habitat that offers opportunities for foraging and shelter, but may not be extensive in area and does not completely surround pond.
Poor	0.33	Habitat with poor structure that offers limited opportunities for foraging and shelter (e.g. amenity grassland).
None	0.01	Clearly no suitable habitat around pond (e.g. centre of large expanse of bare habitat).

592

593 **Table 3. General Linear Model (GLM) of the effect of wetland type and area on habitat richness**

594

595 **Tests of Between – Subjects Effects**

596 Dependant variable: Number of habitats

Source	Type III Sum of squares	df	Mean square	F	Sig.
Model	1580.473 ^a	3	526.824	132.916	.000
Total area	82.223	1	82.223	20.745	.001
Wetland type	830.759	2	415.380	104.799	.000
Error	51.527	13	3.964		
Total	1632.000	16			

597 ^a R squared = .968 (Adjusted R squared = .961)

598

599 **Table 4.** Percentage frequency of occurrence of features (wood and stone) in habitats at constructed and natural wetlands

600

<i>Habitat code (Level 3)</i>	<i>% frequency CWs</i>	<i>% frequency NWs</i>
(Mixed) broadleaved woodland (WD1)	5.3	10.3
Mixed broadleaved conifer woodland (WD2)	5.3	6
Recolonising bare ground (ED3)	1.8	0.04
Improved agricultural grassland (GA1)	1.1	0.1
Wet willow-alder-ash woodland (WN6)	1.1	6.2
Dry-humid and acid grassland (GS3)	0.4	0
Wet grassland (GS4)	0.4	0.4
Scrub (WS1)	0.4	0.1
Rich fen and flush (PF1)	0	0.1
Reed and large sedge swamps (FS1)	0	0.7
Marsh (GM1)	0	0.2
Hedgerows (WL1)	0	0.1
Riparian woodland (WN5)	0	3
Cutover bog (PB4)	0	0.05
Conifer plantation (WD4)	0	0.1
Bog woodland (WN7)	0	0.3
Recently-felled woodland (WS5)	0	0.05
Exposed sand, gravel or till (ED1)	0	0.2
Treelines (WL2)	0	0.05
Improved agricultural grassland with abundant <i>Juncus</i> spp	0	0.1

601

602 **Table 5.** Constructed and natural wetlands and their potential value to the terrestrial phase of the life cycle of the smooth newt using the Great
603 Crested Newt Habitat Suitability Index (his; Table 2) (National Amphibian & Reptile Recording Scheme, 2007)

Constructed wetland	Score	Natural Wetland	Score
CW1	1	NW1	1
CW2	0.33	NW2	1
CW3	0.33	NW3	1
CW4	0.67	NW4	0.67
CW5	1	NW5	1
CW6	0.33	NW6	1
CW7	0.33	NW7	1
CW8	0.33	NW8	1

604

605

606

607

608


609

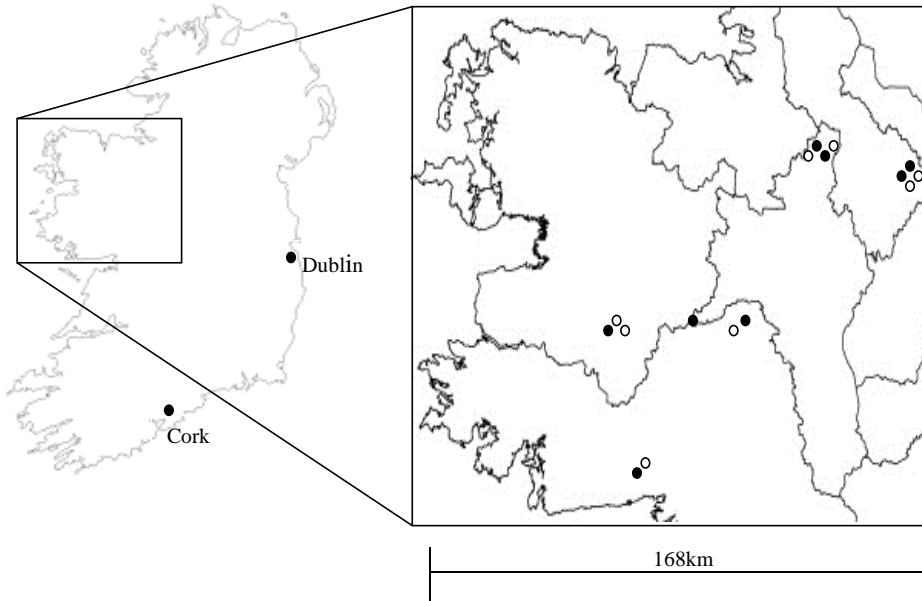
610

611

612

613

614 



615

616

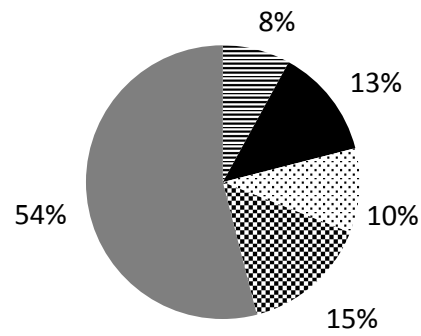
617

618

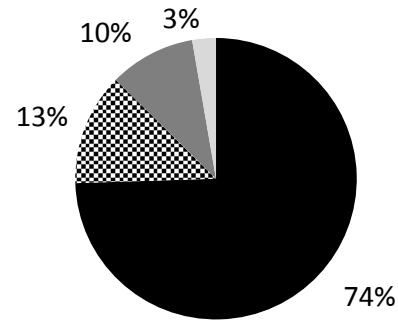
619 **Fig. 1** Locations of constructed (●) and natural (○) wetlands in the west of Ireland (see Appendix 1)

620 Constructed wetlands

621

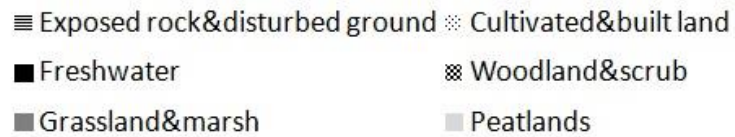


Natural wetlands



622

623



624

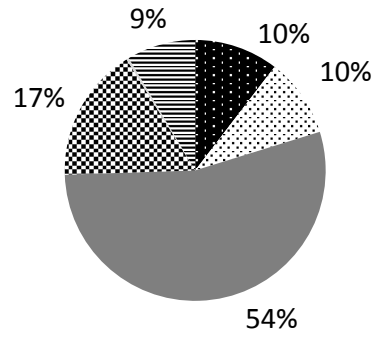
625

626

627 **Fig. 2** Percentage cover of terrestrial and aquatic habitats at constructed and natural wetlands (Level 1) (Fossitt, 2000) (percentages rounded to
628 nearest whole number)

629

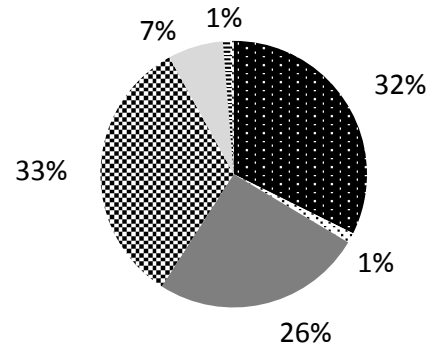
Constructed wetlands



630

631

Natural wetlands



- Freshwater swamps
- Grassland & marsh
- Peatlands
- ⊘ Heath & dense bracken
- ⊘ Cultivated & built land
- ⊘ Woodland & scrub
- ⊘ Exposed rock & disturbed ground

632

633

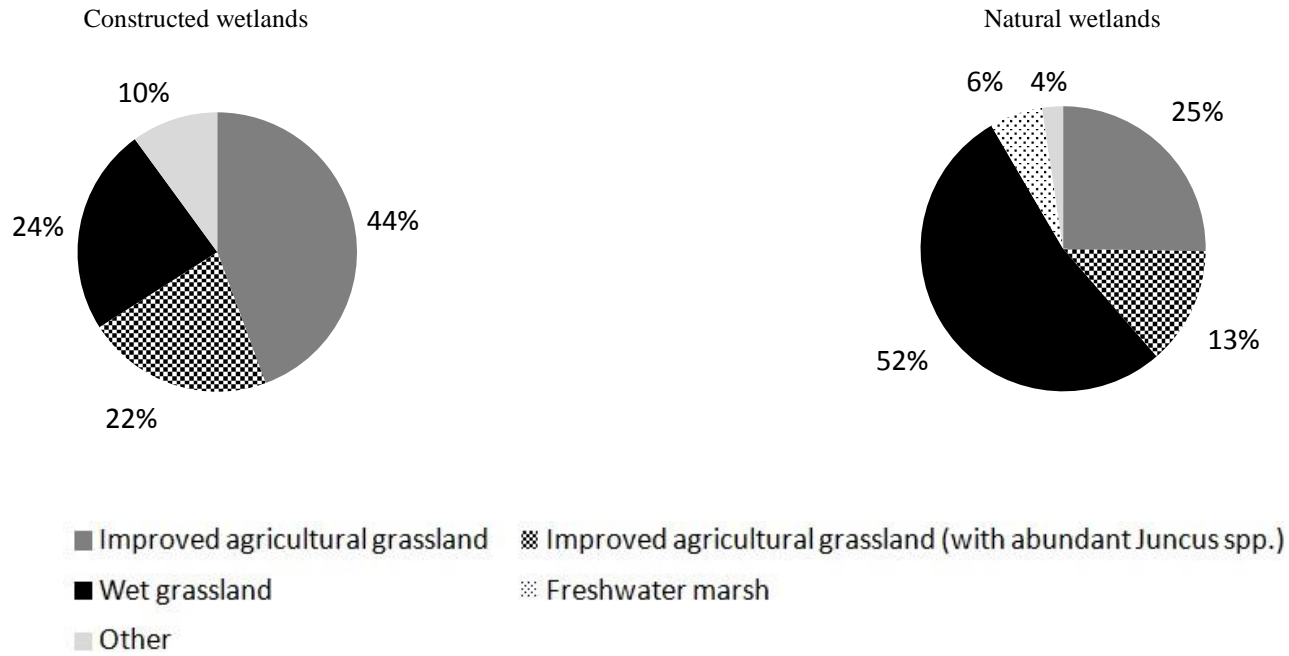
634

635

636 **Fig. 3** Percentage cover of terrestrial habitats (Level 1) (Fossitt, 2000) at constructed and natural wetlands excluding freshwater habitats (with
 637 the exception of freshwater swamps)

638

639



640

641

642

643

644

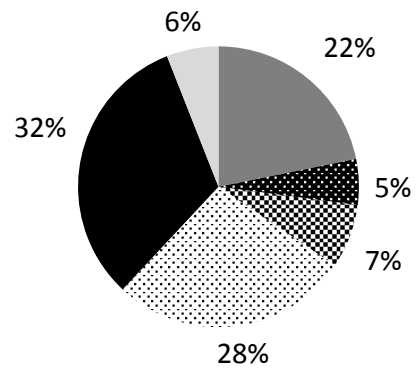
645 **Fig. 4.** Percentage cover of “grassland & marsh” habitats ($\geq 5\%$ cover) at constructed and natural wetlands (Level 3) (Fossitt, 2000). Breakdown
646 of “grassland & marsh” habitats with $<5\%$ cover (Other) is presented in Appendix B

647

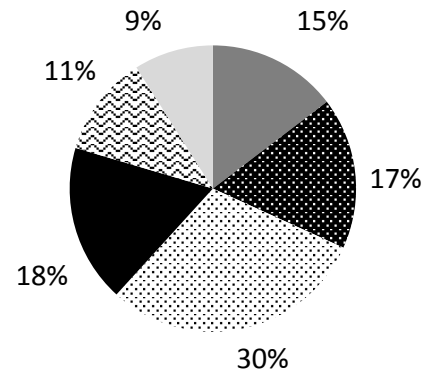
648

649

Constructed wetlands

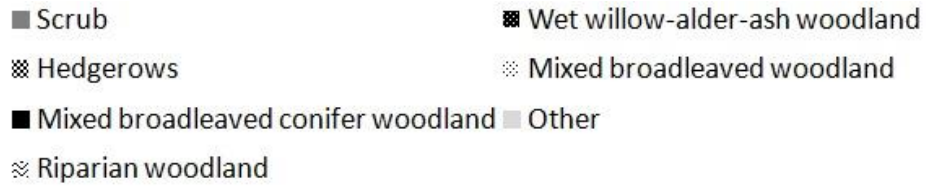


Natural wetlands



650

651



652

653

654 **Fig. 5.** Percentage cover of “woodland and scrub” habitats ($\geq 5\%$ cover) at constructed and natural wetlands (Level 3) (Fossitt, 2000).

655 Breakdown of “woodland & scrub” habitats with $<5\%$ cover (Other) is presented in Appendix B

656

657

