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

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Abstract

Given the current decline of natural wetlands worldwide and the consequent negative impacts on amphibians, wetlands constructed for the treatment of wastewaters have the potential to play a role in the protection of these animals. However, there is a paucity of information regarding the value of constructed wetlands (CWs) to amphibians, particularly relating to the terrestrial phase of the life-cycle. This study compares the terrestrial habitats of natural wetlands (NWs) and CWs as refuges for the smooth newt (*Lissotriton vulgaris*) with the aim of developing recommendations for CWs (both new and existing) to enhance their usefulness as newt-friendly habitats. Terrestrial habitats surrounding NWs and CWs, including barriers to newt movement and features which could act as potential newt refuges, were mapped using ArcGIS. Natural wetlands had significantly more terrestrial habitat types than CWs and while woodlands at both wetland types were most likely to contain features of benefit to newts, almost twice as many grids (20 m x 20 m) in the terrestrial habitats of NWs contained features compared to those of CWs. The application of a Habitat Suitability Index resulted in seven of eight NWs compared to only two of eight CWs receiving “good” scores, the lower scores for CWs being due primarily to the presence of a barrier to newt movement. Recommendations for enhancing the design and management of CWs for smooth newts include less intensive ground maintenance, reduction of barriers to newt movement, judicious planting and the provision of additional refuges.

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

1. Introduction

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

While NWs have been used as convenient wastewater discharge sites since sewage was first collected (for at least 100 years in some locations) (Kadlec & Wallace, 2008), it is only in the last fifty years (approximately) that wetlands have been recognised for their wastewater treatment capabilities (Vymazal, 2011). Since then various types of artificial wetlands (constructed wetlands; CWs) have been designed to intercept wastewater (after conventional treatment processes) and remove a range of pollutants before discharging into natural water bodies (Hsu et al., 2011). Constructed wetlands are being recognised increasingly as a relatively low-cost, energy-efficient method for treating wastewaters such as sewage, agricultural / industrial wastewaters and storm water runoff (Campbell & Ogden, 1999). While much attention has been paid to the waste water treatment capabilities of CWs, relatively little attention has been given to the incorporation of biodiversity features in the design and construction of CWs and their surroundings. A number of studies have been undertaken on the biodiversity of existing CWs including studies on freshwater invertebrates (Spieles & Mitsch, 2000; Jurado et al., 2010), amphibians (Korfel et al., 2010), birds (Andersen, et al., 2003) and mammals (Kadlec et al., 2007). However, these studies have generally focussed on the CW itself and not on the surrounding habitats in which the CW is situated, although the latter are often critical for fauna, such as amphibians, with biphasic life cycle requirements.

Amphibians typically require terrestrial and aquatic environments to complete their semi-aquatic life cycle (Dodd & Cade, 1997). However, they are currently experiencing striking global declines in recent decades due, in part, to the destruction of wetland habitats (Stuart et al., 2004) and fungal disease (Voyles et al., 2009). The importance of terrestrial habitats and microhabitats for amphibian breeding site selection has been highlighted by Marnell (1998). *Lissotriton vulgaris* (Linnaeus, 1758) (the smooth newt), while widespread across most of Europe, is the sole native species of newt found in Ireland (Meehan, 2013), with breeding invariably taking place in water during spring, and sometimes extending into early summer. After metamorphosis, juveniles of *L. vulgaris* can spend several years on land, before reaching maturity between the ages of three and seven years (Bell, 1977), at which stage they return to water bodies to breed. Smooth newts are known to use a variety of water bodies during the breeding season, which include lakes, natural ponds, garden ponds and slow-moving drainage ditches (Meehan, 2013), with aquatic newt larvae rarely being found in running water (Bell & Lawton, 1975). Even water bodies with a surface area of no more than 400 m^2 (considerably smaller areas than many CWs for wastewater treatment) have been known to support up to 1,000 individual adult smooth newts (Bell & Lawton, 1975). While breeding takes place in water, the majority of newts overwinter on land, although there is evidence that some adults may remain in water during winter (Kinne, 2004). Upon emigration from the water body, newts tend to travel towards favourable habitat patches in the vicinity (Malmgren, 2002). On land, they tend to travel in straight lines, since movement here is slower and requires more energy than movement in water where the newt is buoyed up by the surrounding medium (Griffiths, 1996). When on land, suitable refuges must be sought from predation, desiccation and temperature extremes (Griffiths, 1984). Habitats that provide such shelter and protection, such as scrub and woodland (both deciduous and coniferous), unimproved grassland and gardens, are considered newt-friendly habitats (Oldham, 2000) (Table 1). Although habitats thought to be less suitable for newts in the UK include water bodies containing fish (Aronsson & Stenson, 1995) and acidic habitats such as peatland (Marnell, 1998), it appears that newts can be catholic in their approach to habitat selection. In Ireland, for example, where *L. vulgaris* is at the most westerly edge of its range, and lacks competition for habitats from other newt species, it has a tendency towards a wide niche occupation, including lakes of a considerable size containing fish in addition to acid peatland pools (Meehan, 2013). In addition, microhabitats such as dead wood and stone features can be important in amphibian breeding site selection (Marnell, 1998), while roads and rivers adjacent to the breeding water body have been shown to interfere with newt migration (Oldham, 2000).

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

The Habitat Suitability Index (HSI), first developed by Oldham et al. (2000) in Britain (and later modified by the National Amphibian & Reptile Recording Scheme, 2007), is used by Natural England and Natural Resources Wales and the Department of Environment, Food and Rural Affairs (UK) to assess the likelihood of the presence of the great crested newt (*Triturus cristatus* [Laurenti, 1768]) in a given area in the UK (Department of Environment, Food and Rural Affairs, 2016) (Table 2). This species, which is larger than the smooth newt, has been found to travel further (> 200m) from ponds (Kinne, 2004). Since the great crested newt is absent from Ireland, *L. vulgaris* occupies a similar range of habitats, in addition to which there is considerable overlap in the timing of seasonal and diel activities (Griffiths and Mylotte, 1987). Both species also seem to have similar requirements in terms of the quality of the terrestrial habitats surrounding water bodies for dispersal (Malmgren, 2002) and these habitats include areas of trees, scrub and long grass (Griffiths, 1996). It has been suggested that the presence of *T. cristatus* in ponds in the UK is usually a good indicator that the ponds will also contain *L. vulgaris* (Griffiths, 1996), although *L. vulgaris* can be found in a wider range of localities (Skei et al., 2006). Due to the similarities in terms of habitat requirements that exist between the two species, and in the absence of a smooth newt HSI for Ireland, the applicability of the UK HSI for *T. cristatus* was seen by the authors of this article as an initial starting point to assess habitat suitability for *L. vulgaris* at a landscape-scale and prioritise areas for action.

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

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

2. Methods & Materials

2.1 Site descriptions

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

2.2 Habitat mapping

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

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

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

Field survey recorded data were later digitised using ArcGIS 10.3 and the areas for each habitat calculated. Wood and stone features were recorded as point features. Linear features such as treelines, hedgerows and drains, were assigned an arbitrary width of 1 m (reflecting the minimum width of linear habitats encountered), so that areas of different habitats could be compared. As the total areas for each wetland varied, the wetlands in this study have been numbered consecutively from the largest to the smallest for each wetland type i.e. CW1 – CW8 and NW1 – NW8 (Appendix 1). Maps were created using ArcGIS 10.3 and the extent of all habitats were determined. Using the UK’s HSI for the great crested newt, CWs and NWs were scored and ranked in order of their potential value to the smooth newt. Those at the lower end of the scale are evaluated and recommendations on how their suitability can be improved are proposed.

2.3 Statistical analysis

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

3. Results

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

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

The number of newt friendly terrestrial habitats recorded at Level 3 (Fossitt, 2000) varies within each wetland type, with those in NWs ranging from 17 at the largest NW1 (Appendix A) to seven at NW5 and from 12 habitats at CW3 to six at CW 8. To test for normal distribution, a Kolmorogov–Smirnov test was used and results were $P > 0.05$ indicating that the data are not significantly different from a normal distribution (CW area = 0.690, CW number of habitats = 0.473; NW area = 0.808, NW number of habitats = 0.598). A Pearson's correlation confirmed that the correlation between area of CWs and number of habitats present is not significant ($P > 0.05$, rho = 0.602) in comparison to the correlation between area of NWs and number of habitats present, which is significant ($P < 0.05$, rho = 0.898). Using a General Linear Model (GLM), there is a significant effect of both area and wetland type on habitat richness. The GLM displays a positive relationship between number of habitats and the covariate, area, and NWs have significantly more habitats than CWs (Table 3).

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

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

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

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

Using the HSI (Table 2), only two CWs receive the highest score of 1 (*Good*) (Appendix C), while seven NWs receive a *Good* score (1) in that there are no barriers present (Table 5). One hundred percent of the perimeter lines of all CWs and NWs which receive *Good* scores, contain extensive areas of habitat that offers good opportunities for foraging and shelter completely surrounding the wetland. One CW (CW4) received a *Moderate* score of 0.67, where 17% of the perimeter line of the CW is made up of "buildings and artificial surfaces", while one NW (NW4) received a *Moderate* score (0.67) due to the presence of "buildings and artificial surfaces" (0.4%) of the perimeter directly bordering the lake. Five of the CWs received *Poor* scores (0.33) (Appendix D), while no NWs received a *Poor* score.

4. Discussion

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

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

Previous studies have emphasized the value of using CWs as a conservation strategy for amphibians and the need for future research and monitoring in these areas (Denton & Richter, 2013). While our study focussed on suitable terrestrial habitats for newts and did not involve a survey of smooth newt abundance, a single adult specimen of the species was recorded on the edge of one CW during the study (Mulkeen & Gibson-Brabazon, *pers. obs*). The presence of newts in CWs in Ireland (Scholz et al., 2007) also suggests that water quality in CWs treating wastewaters, at least in some cases, is not an issue and can support breeding in the species. In addition to this, newts have been recorded in natural ponds and wetlands as small as 25 m^2 (Skei et al., 2006) and with up to 1,000 individuals recorded in ponds less than 400 m^2 (Bell & Lawton, 1975). Regardless of waterbody size, if aquatic and terrestrial conditions are favourable for breeding, shelter, food and overwintering, it may not be unreasonable to suggest that newts may colonise and breed in these areas. However, small changes to the design of new

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

In the design of new CWs, the overall size of the site should be considerably larger than the actual wetland itself to ensure that the area surrounding the wetland is of sufficient size to provide adequate refuges for the terrestrial phase of the newt. While lands outside the CW fence may provide suitable refuges for the newt when the CW is being constructed, there is no guarantee that this area will not be lost to development at some time in the future. As a guideline, and based on the evidence observed by previous authors of smooth newt migration distances (Bell, 1977; Dolmen, 1981), it is desirable that a buffer zone around a CW be incorporated within the site. By way of example, the inclusion of 20 m buffer zone (providing suitable terrestrial habitats for smooth newts) around a 20 m × 20 m (400 m^2) CW, would result in the purchase of just an additional 0.32 ha. However, other authors have suggested that a distance of 300 m of forested areas surrounding vernal pools will favour the persistence of amphibian species such as wood frog and salamander (Calhoun et al., 2014), suggesting that perhaps recommendations may need to be amphibian species specific. Large areas of open habitat offering little cover can act as a barrier during newt migrations to and from water bodies for breeding. Habitats such as “amenity grassland”, “improved agricultural grassland”, “spoil and bare ground” and “buildings and artificial surfaces”, offer little cover, shelter, hibernation, foraging or overwintering sites for newts. By their very nature, CWs built for the tertiary treatment of wastewater also contain areas covered with artificial surfaces such as tarmac or concrete, built structures for wastewater treatment and unpaved areas for access points and driveways. These should, however, be reduced to a minimum, particularly immediately adjacent to the edge of the CW. If hard surfaces are required adjacent to the CW, they ideally should be at one side only, leaving the other three sides with direct access to terrestrial habitats.

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

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

Conclusions

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

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

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

Terrestrial habitat	***Reference***
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

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

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).

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

Tests of Between – Subjects Effects

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			

[a] R squared = .968 (Adjusted R squared = .961)

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

***Habitat code* (Level 3)**	***% frequency CWs***	***% frequency NWs***
(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 *Juncus* spp	0	0.1

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 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

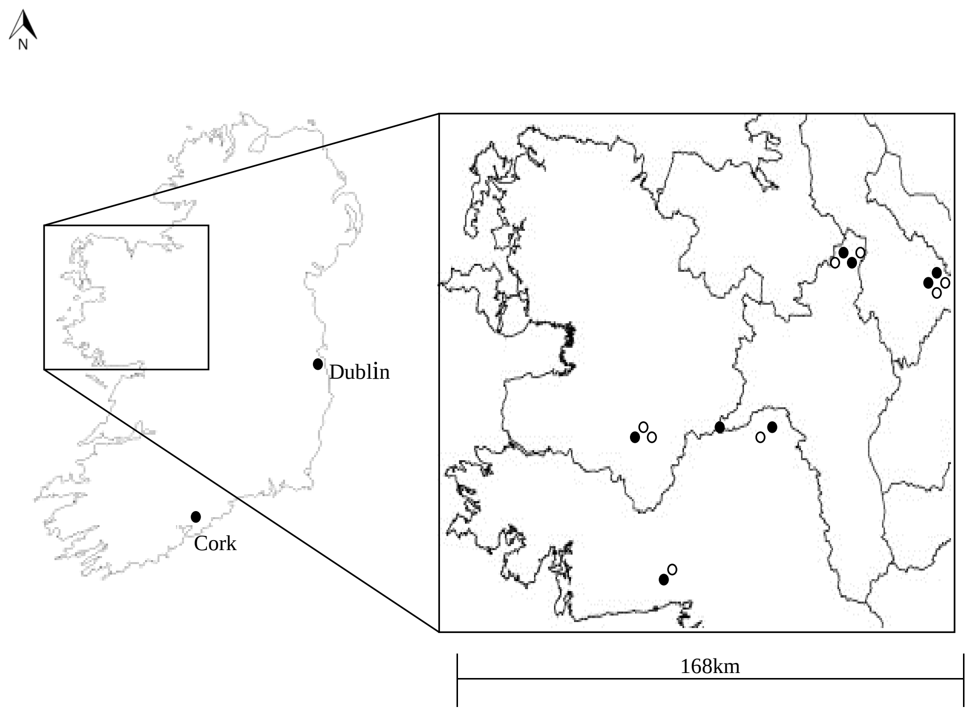

Fig. 1 Locations of constructed (●) and natural (○) wetlands in the west of Ireland (see Appendix 1)

Constructed wetlands Natural wetlands

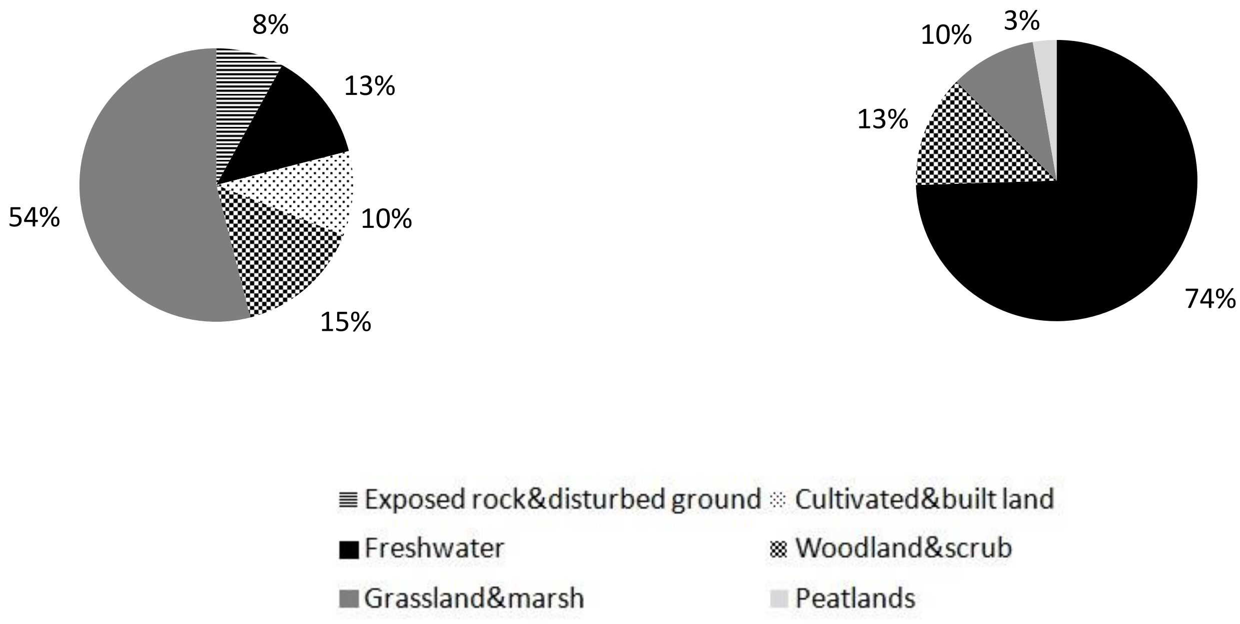

Fig. 2 Percentage cover of terrestrial and aquatic habitats at constructed and natural wetlands (Level 1) (Fossitt, 2000) (percentages rounded to nearest whole number)

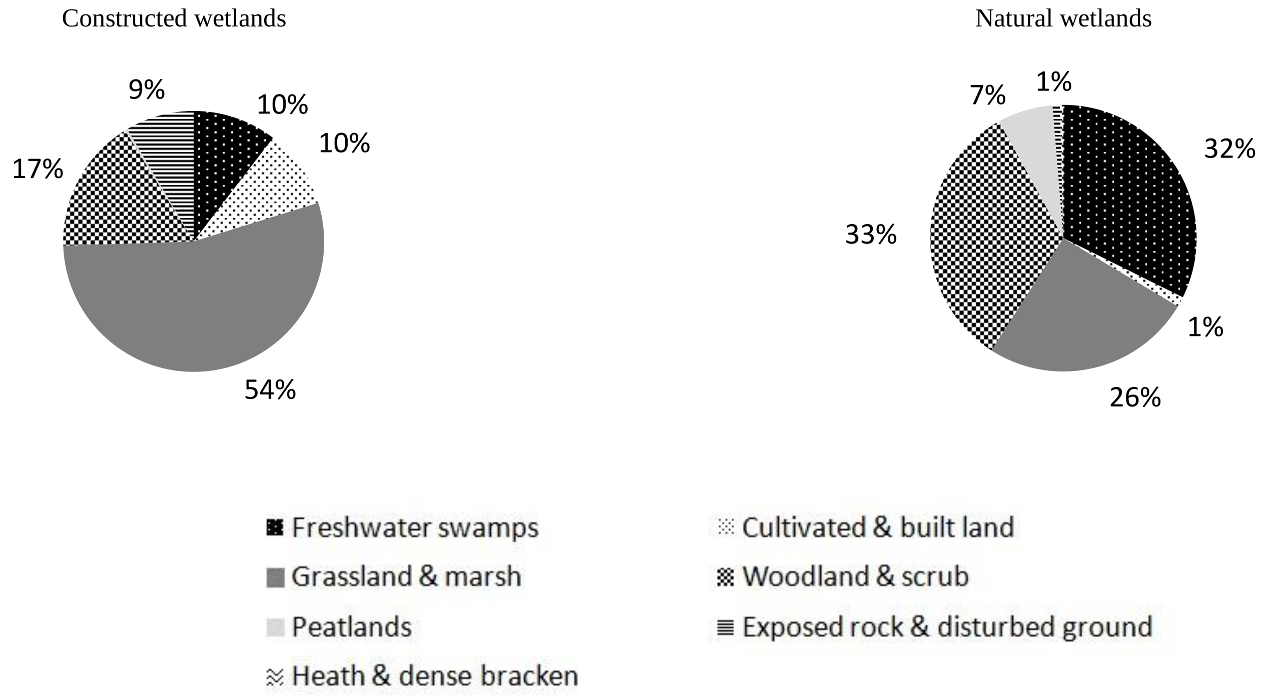

Fig. 3 Percentage cover of terrestrial habitats (Level 1) (Fossitt, 2000) at constructed and natural wetlands excluding freshwater habitats (with the exception of freshwater swamps)

Constructed wetlands Natural wetlands

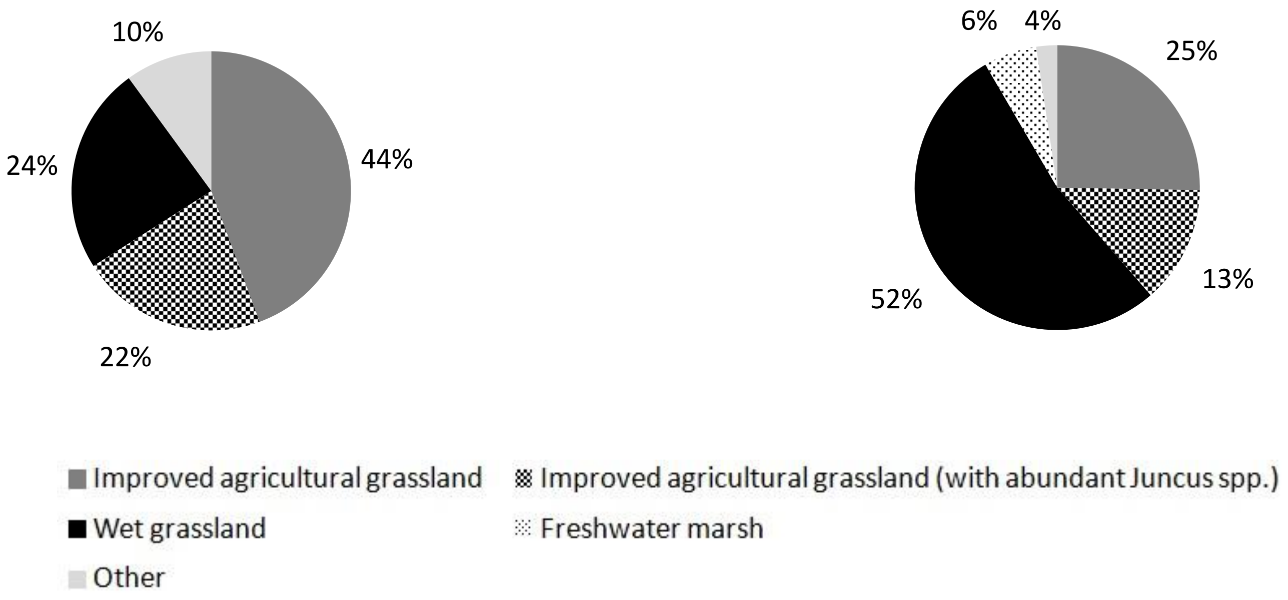

Fig. 4. Percentage cover of “grassland & marsh” habitats (≥ 5% cover) at constructed and natural wetlands (Level 3) (Fossitt, 2000). Breakdown of “grassland & marsh” habitats with <5% cover (Other) is presented in Appendix B

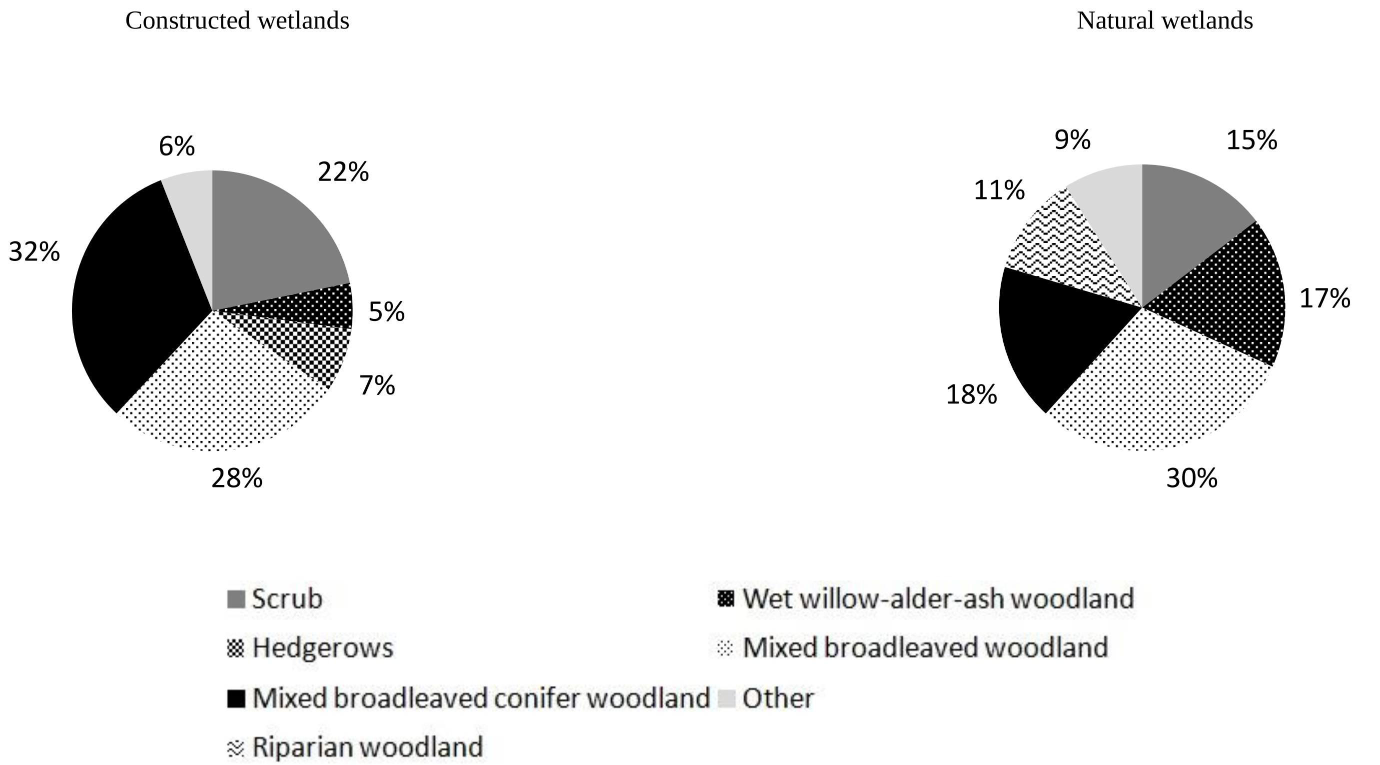

Fig. 5. Percentage cover of “woodland and scrub” habitats ($\geq$ 5% cover) at constructed and natural wetlands (Level 3) (Fossitt, 2000). Breakdown of “woodland & scrub” habitats with <5% cover (Other) is presented in Appendix B