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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 their life-cycle. This study compares the terrestrial habitats of natural wetlands (NWs) and CWs as refuges for the smooth newt (*Lissotriton vulgaris*, [L., 1758]) 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 were mapped using ArcGIS. Potential barriers to newt movement in addition to the presence of features such as wood or stone which could act as potential newt refuges were also mapped. 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, terrestrial habitats of NWs contained more features compared to those of CWs. The application of a Habitat Suitability Index, which assesses the likelihood of the presence of newts, 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 of suitable trees or shrubs and the provision of additional refuges such as wood or stone.

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 worldwide 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 increasingly recognised as a relatively low-cost method for treating wastewaters such as sewage, agricultural / industrial wastewaters and storm water runoff (Campbell & Ogden, 1999), requiring minimal operation and maintenance (Zhang et al., 2009). While most 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. Constructed wetlands can also act as multifunctional ecological systems assisting in the restoration of aquatic flora and fauna (Greenway, 2005) and 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; Fleming-Singer & Horne, 2006) 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) and the importance of terrestrial habitats and microhabitats for amphibian breeding site selection has been highlighted by Marnell (1998). However, amphibians 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). *Lissotriton vulgaris* 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* are solely terrestrial, spending 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 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). The smooth newt life cycle has complex requirements. Adults require aquatic habitats for breeding as well as terrestrial habitats for foraging and overwintering although adults have been found to overwinter in ponds in Italy (Fasola & Canova, 1992). In some cases larvae have even been recorded in water bodies during the winter but this is usually the result of a combination of factors such as late egg production, high population densities, competition for food resources and low water temperatures in countries such as Northern England, Poland and Montenegro (Jehle et al., 2011). While juveniles leaving the waterbody for the first time can travel further on land (Joly et al., 2001), adult smooth newts generally move towards favourable habitat patches in the vicinity (Malmgren, 2002). Although terrestrial behaviour of smooth newts is still not fully understood, diverse structural habitats (Vuorio et al., 2015) in addition to climatic and landscape factors (Joly et al., 2001) may drive patterns of movement (Pittman et al., 2014) and survival (Griffiths et al., 2010). Smooth newts tend to travel in straight lines on land 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). Once 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 acidic habitats such as peatland (Marnell, 1998) and water bodies containing fish are thought to be less suitable for smooth newts in the UK (Aronsson & Stenson, 1995) and Lombardy, Italy (Ficetola & de Bernardi, 2004), it appears that habitat selection in smooth newts may be limited by barriers and competition. In Ireland, for example, where *L. vulgaris* is at the most westerly edge of its range, and it 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; Matos et al., 2017).

The movement of adult 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 smooth 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 smooth 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, 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 from ponds (> 200 m and > 500 m) (Redgrave, 2009); (Kinne, 2004); (Stoefer & Schneeweiss, 2001). Within their range, great crested newts have been recorded with smooth newts more than other newt species (Jehle et al., 2011). Both species also seem to have similar requirements in terms of the variety of the terrestrial habitats surrounding water bodies for dispersal (Malmgren, 2002; Griffiths, 1996) and the presence of *T. cristatus* in ponds in the UK usually seems to be a good indicator for the presence of *L. vulgaris* (Griffiths, 1996) although, *L. vulgaris* can be found in a wider range of localities (Skei et al., 2006). Given the absence from Ireland of the great crested newt , *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 & Mylotte, 1987) and environmental responses (Vuorio et al., 2015). For these reasons, the UK HSI for *T. cristatus* was adopted by the authors of this article as an initial starting point to assess habitat suitability in Ireland 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. While the value of CWs as a conservation strategy for amphibians has been highlighted by previous studies (Denton & Richter, 2013), the suitability of terrestrial habitats surrounding CWs for the terrestrial phase of the smooth 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). Each CW, built for the tertiary treatment of municipal wastewater, consisted of surface a flow reed bed planted with either *Phragmites australis* (Cav.) Trin. ex Steud. or *Typha latifolia* L. Natural wetlands, containing areas of *P. australis* and / or *T. latifolia*, within 20 km of each CW, were selected for comparison (Appendix A). Suitable newt friendly habitats such as hedgerows, scrub, drainage ditches, woodland or grasslands occurred within 500 m of each wetland (Appendix A).

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 m^2 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 habitats 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. Wood features referred to tree stumps, dead/decaying/fallen branches, fallen trees and stone features referred to boulders and 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 A). Maps were created using ArcGIS 10.3 and the extent of all habitats was determined. Using the UK 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 whether 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 dominated 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) revealed 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" had 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, had 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 were 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) revealed a similar pattern to those in Fig. 2, with the exception that the percentage cover of "freshwater swamp" at the NWs was almost co-dominant with "woodland & scrub" (32% and 33%, respectively). In the CWs, "freshwater swamp" had the same percentage cover as "cultivated and built land" (Fig. 3) which along with "exposed rock & disturbed ground", had overall percentage covers of 10% and 9% respectively. In NWs, both categories, along with "heath & dense bracken", had an overall combined percentage cover of < 2%.

The number of newt friendly terrestrial habitats recorded at Level 3 (Fossitt, 2000) varied 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 CW8. To test for normal distribution, a Kolmorogov – Smirnov test was used ($P > 0.05$) 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 was not significant ($P > 0.05$, R squared = 0.602) in comparison to the correlation between area of

NWs and number of habitats present which was significant (*P* < 0.05, R squared = 0.898). Using a General Linear Model (GLM), there was 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 had significantly more habitats than CWs (Table 3).

Given that "grassland & marsh" represented 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 were examined in more detail at Level 3 (Fossitt, 2000) (Fig. 4; Appendix B). Nine different "grassland & marsh" habitat types were found in the current study. "Wet grasslands" represented more than half (52%) of the cover of the "grassland & marsh" habitats at the NWs, but less than a quarter (24%) at CWs, where "improved agricultural grassland" was dominant (44%). "Improved agricultural grassland with abundant *Juncus* spp." represented 13% and 22% cover at NWs and CWs, respectively, while "freshwater marsh", present at the NWs (6%), was absent from the CWs (Fig. 4; Appendix B).

Since woodland, damp woodland, scrub and hedgerows are also considered excellent terrestrial habitats for smooth newts (Table 1), these were examined further (Fig. 5; Appendix B) at Level 3 (Fossitt, 2000). Altogether, twelve "woodland and scrub" habitat types were present at CWs and NWs. "Mixed broadleaved woodland" and "mixed broadleaved conifer woodland" cover combined, dominated both wetland types with 48% and 60% cover at the NWs and CWs, respectively (Fig. 5; Appendix B). These were 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” were 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 were also examined at the CW and NW sites. These barriers include roads and rivers which are classed as serious barriers to newt migration (Oldham, 2000; Matos et al., 2017). Other barrier habitats (directly bordering breeding sites) identified include “buildings & artificial surfaces”, “improved agricultural grassland”, “exposed sand, gravel & till”, and “spoil & bare ground”. Forty-four percent of the total perimeter of the CW sites in this study constituted potential barriers to newt migration compared to < 2% at NW sites. While six out of eight CWs had barriers of some kind, only two out of eight NWs had 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 contained features compared to just 18% for the CWs. Habitats such as “mixed broadleaved woodland” and “mixed broadleaved conifer woodland” accounted 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). Features present within a range of 1 – 4% frequency (Table 4), included “riparian woodland” at the NWs, and “recolonising bare ground”, “improved agricultural grassland” and “wet willow-alder-ash-woodland” at CWs.

Using the HSI (Table 2), only two out of the eight CWs received the highest score of 1 (*Good*) (Appendix C), while seven of the eight NWs received a *Good* score (1), in that there were no barriers present (Table 5). One hundred percent of the perimeter lines of all CWs and NWs which received *Good* scores, contained extensive areas of habitat with 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 & artificial surfaces", while one NW (NW4) received a *Moderate* score (0.67) due to the presence of "buildings & artificial surfaces" (0.4% of the perimeter) directly bordering the lake. Five of the CWs received *Poor* scores (0.33) (Appendix D) while none of the NWs received a *Poor* score.

4. Discussion

The results of this study indicate that the NWs had significantly more terrestrial habitat types than CWs and that the number of terrestrial habitat types present in NWs was significantly correlated with the size of the area containing the terrestrial habitats. Both NWs and CWs were selected on the basis of: a) the presence of reed and large sedge swamps; b) their location i.e. paired CWs and NWs $\leq$ 20 km apart; and c) 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 mapable 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), can 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 & built land" and "exposed rock & 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 focused 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 by newts. In addition, 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 400m^2 (Bell & Lawton, 1975). Regardless of waterbody size, if aquatic and terrestrial conditions are favourable for breeding, shelter, food and overwintering, it is likely 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 minimum 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, the width of the buffer zone may be amphibian species specific (Rothermal, 2004) with Calhoun et al. (2014) recommending a buffer zone of 300m of forested areas surrounding vernal pools to favour the persistence of amphibian species such as wood frog and salamander in the USA (Calhoun et al., 2014). While buffer zones wider that 20m could also accommodate juveniles who appear to travel greater distances during dispersal, further research is required to substantiate this. 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 & bare ground" and "buildings & 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 should ideally 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 also be considered as suggested by Drayer & Richter (2016), which may strengthen connectivity across the landscape (Calhoun et al., 2014). 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 smooth 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 to 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 smooth newts during their migrations from aquatic to terrestrial habitats.

An indication of the variability of CWs vis-à-vis their suitability for smooth 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 i.e. "spoil & bare ground" which could act as a barrier to newt migration. "Spoil & bare ground" includes areas of bare ground due to ongoing disturbance or maintenance, unconsolidated 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 unconsolidated 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 and the size of NWs is significantly correlated with the number of surrounding terrestrial habitat types. 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 terrestrial 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 stone or wood features, could also enhance these areas for smooth 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* (L., 1758)

Terrestrial habitat	***Reference***
Meadows / long grass	Marnell, 1998; Oldham et al., 2000; Flood, 2011; Meehan, 2013
Rough grassland	Oldham et al., 2000
Hedgerows	Oldham et al., 2000
Scrub	Marnell, 1998; Oldham et al., 2000; Flood 2011
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 (from 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 (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

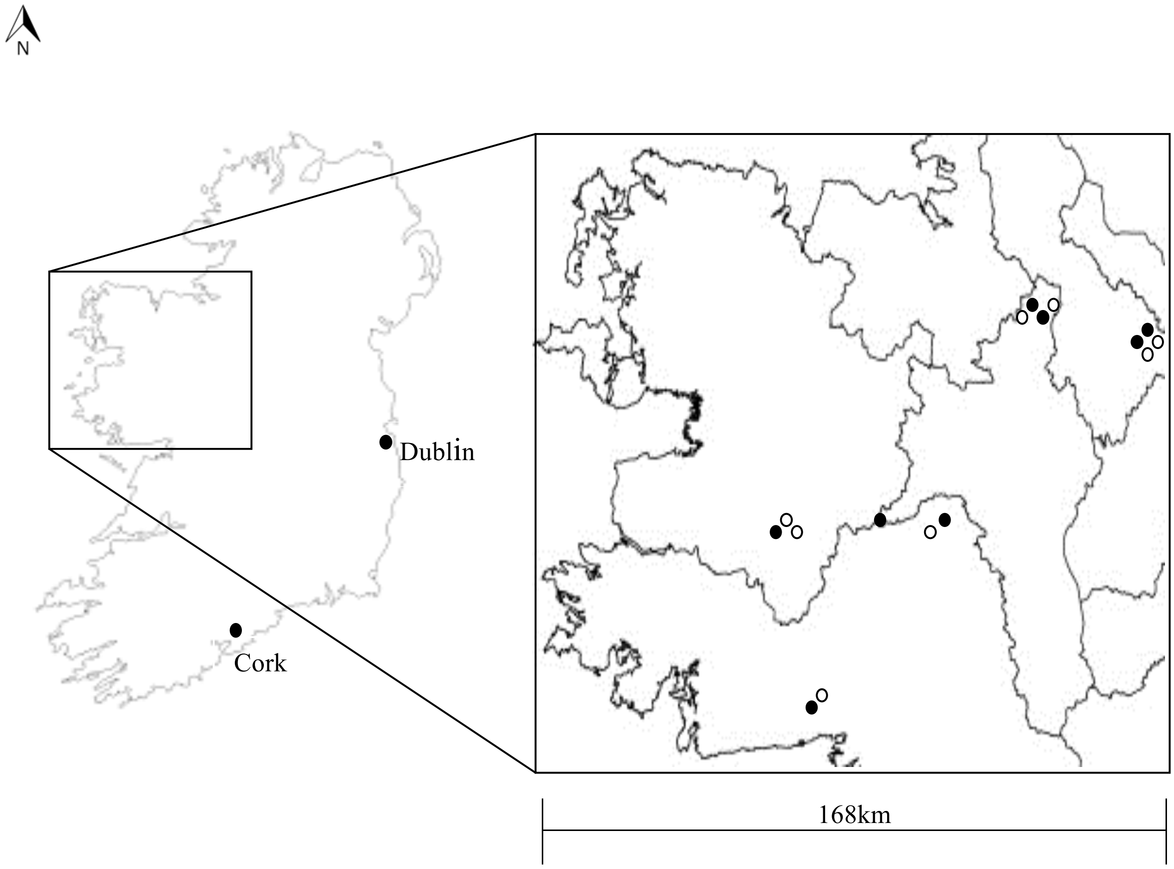

Fig. 1 Locations of constructed (●) and natural (○) wetlands in the west of Ireland (see Appendix A)

Constructed wetlands (CWs) Natural wetlands (NWs)

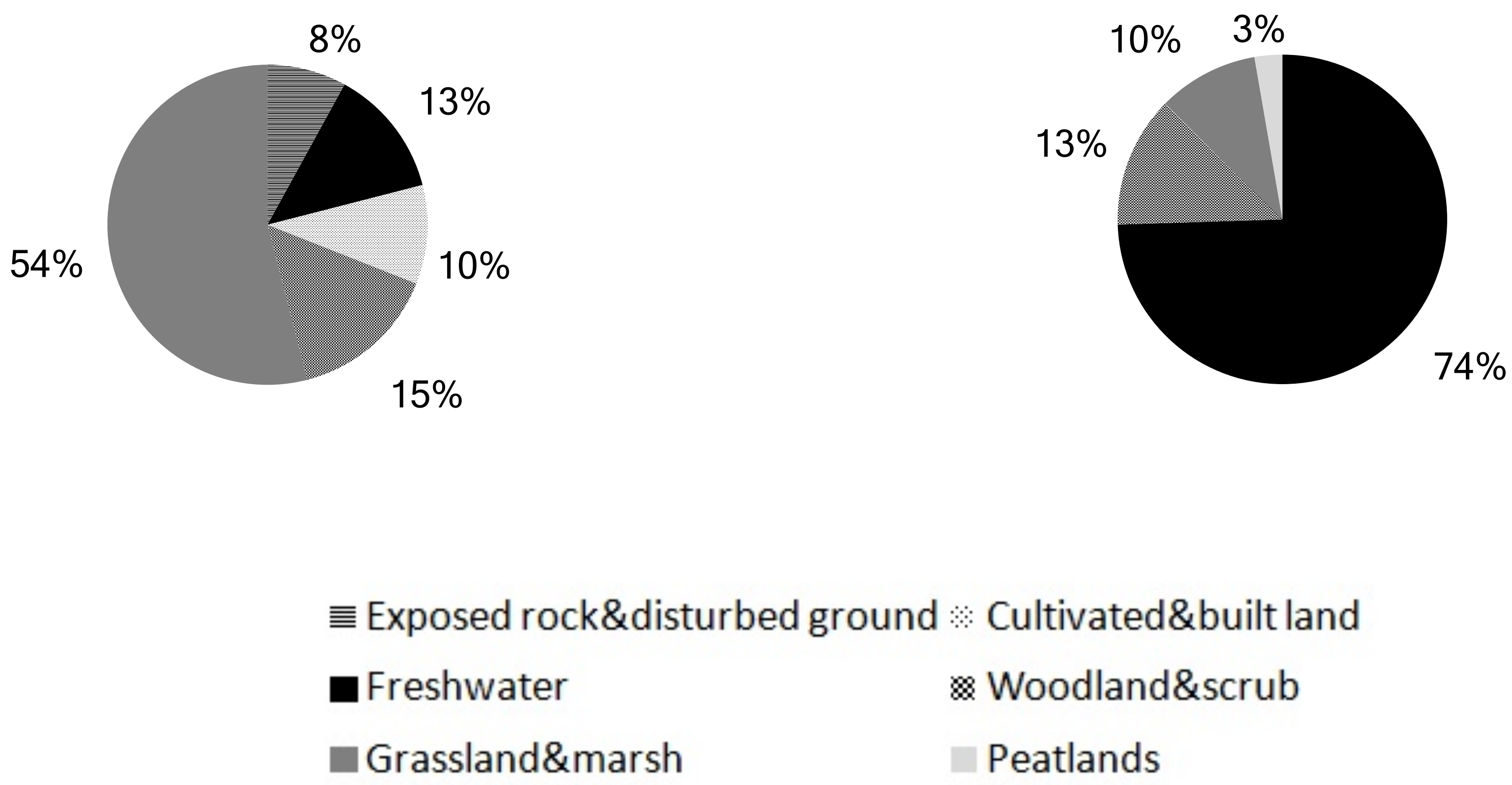

Fig. 2 Percentage cover of terrestrial and aquatic habitats at constructed (CW) and natural (NW) wetlands (Level 1) (Fossitt, 2000) (percentages rounded to nearest whole number)

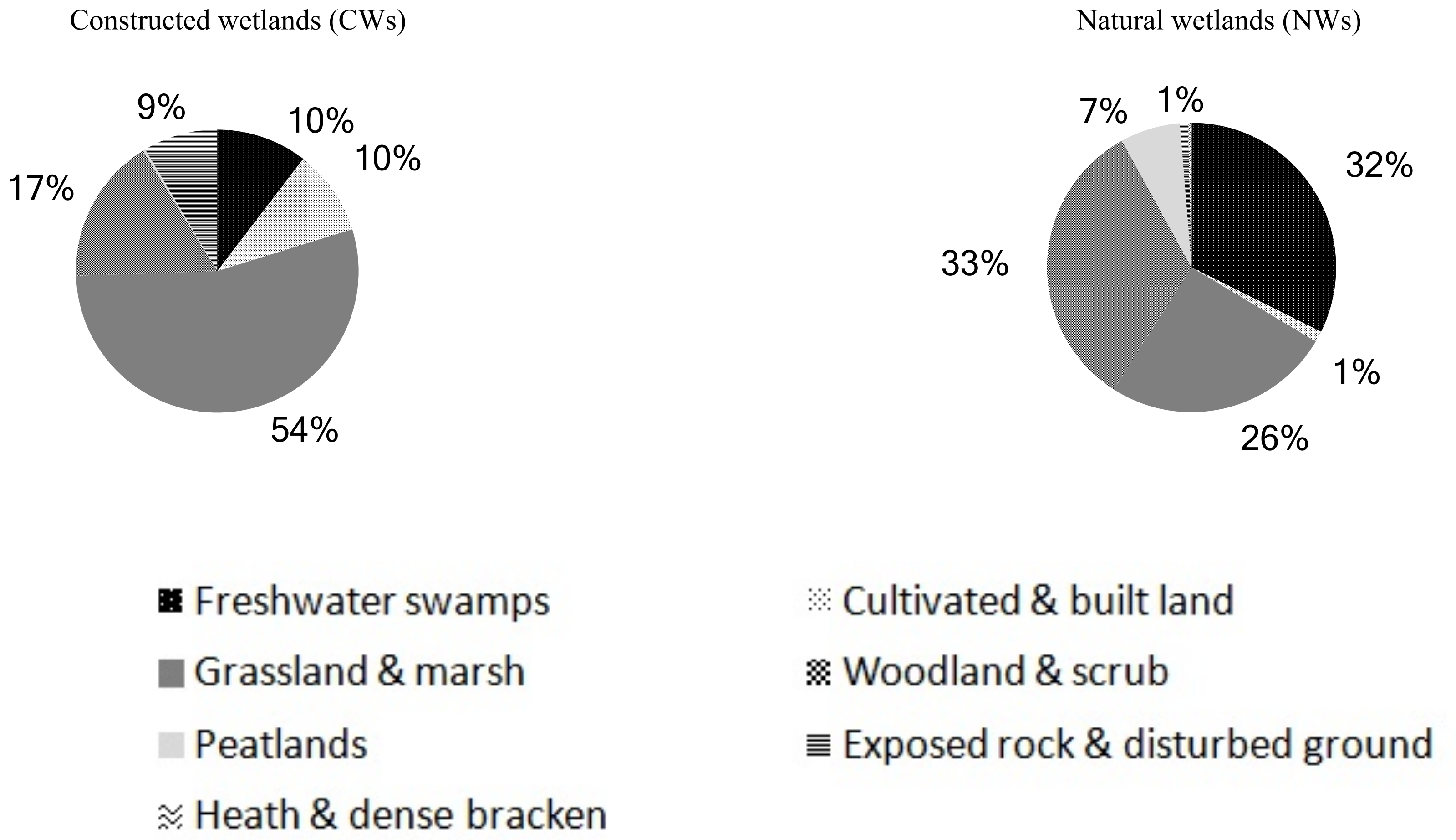

Fig. 3 Percentage cover of terrestrial habitats (Level 1) (Fossitt, 2000) at constructed (CW) and natural (NW) wetlands excluding freshwater habitats (with the exception of freshwater swamps). (Percentages rounded to nearest whole numbers).

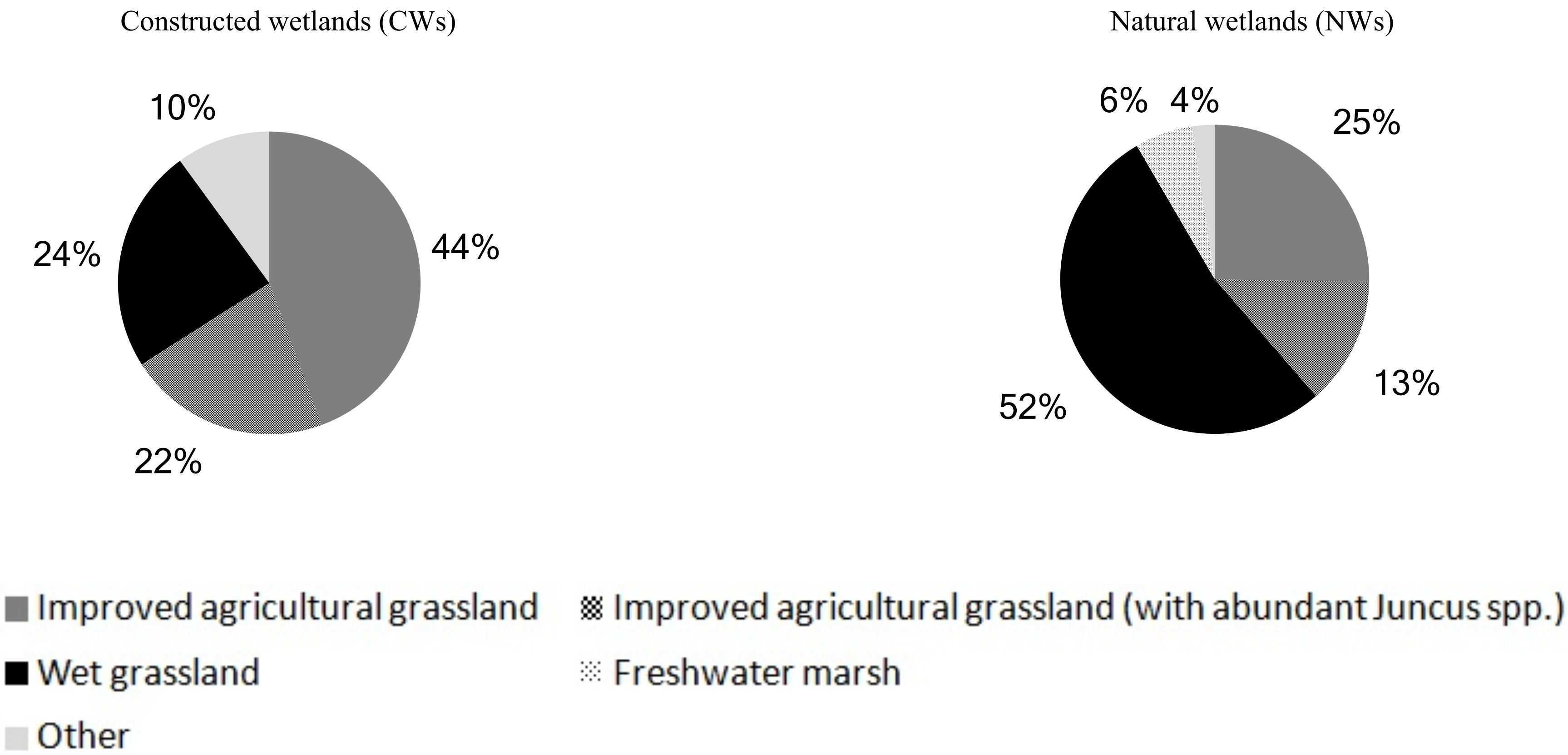

Fig. 4. Percentage cover of "grassland & marsh" habitats (> 5% cover) at constructed (CW) and natural (NW) wetlands (Level 3) (Fossitt, 2000). Breakdown of "grassland & marsh" habitats with < 5% cover (Other) is presented in Appendix B

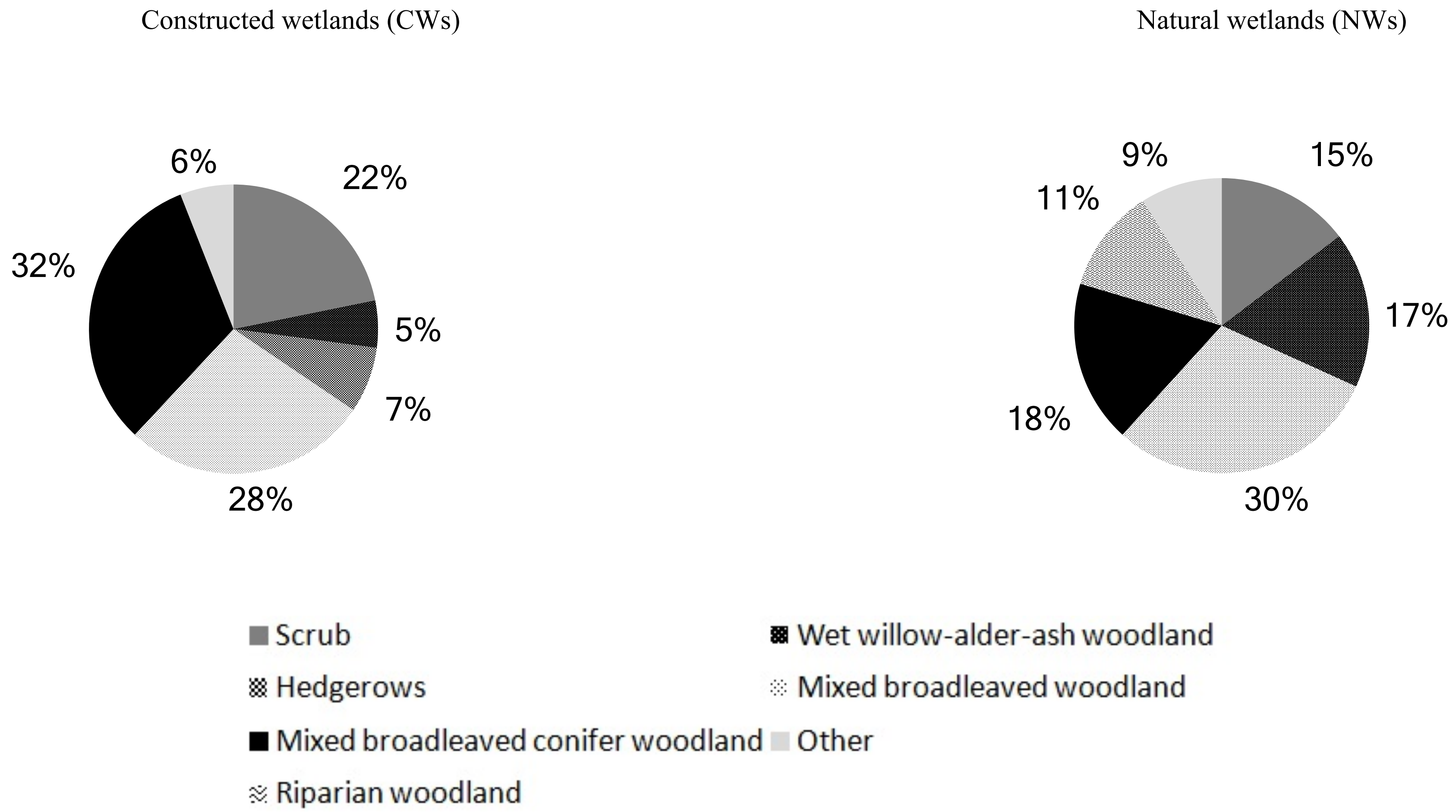

Fig. 5. Percentage cover of “woodland and scrub” habitats (≥ 5% cover) at constructed (CW) and natural (NW) wetlands (Level 3) (Fossitt, 2000). Breakdown of “woodland & scrub” habitats with <5% cover (Other) is presented in Appendix B