National Frog Survey of Ireland

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National Frog Survey of Ireland 2010/11

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Executive Summary

1) This is the first study to make a quantitative assessment of the conservation status of the EU Annex V Species 1213 *Rana temporaria* throughout the Republic of Ireland.

2) Numbers of farmland ponds (water bodies <2ha in size) declined by 53.9% between 1887-1913 and 2005-2011. Pond losses were greatest in the East with some counties, for example Co. Wexford, experiencing substantially greater declines than others.

3) Approximately 2% of the land area of Ireland was determined to be suitable as frog breeding habitat consisting of bog pools; drainage ditches; farmland ponds; lakes and reservoirs; rivers, streams and canals, marsh and temporary features.

4) A total of 405 water bodies were surveyed for spawn during spring 2011 in a total of 171 x 500m squares. Spawn occurred in 50% of all water bodies and 73% of all survey squares with greatest occurrence in the west & north-west (Counties Mayo, Sligo and Donegal).

5) Accounting for site occupancy, variance in frog density and the availability of suitable breeding habitat, the estimated mean frog density was 23.5 frogs/ha (95% CI 14.9 - 44.0 frogs/ha). This equates to a total breeding population in the order of 165M frogs (95%CI 104M - 310M frogs) throughout the Republic of Ireland. This represents the first baseline survey of frog density and abundance.

6) We infer that frogs are probably one of the most numerous vertebrates in Ireland representing a substantial component of biomass. They are also likely to provide a valuable ecosystem service predating large quantities of agricultural and garden pests, most notably slugs and diptera. Moreover, the frog is a key component of the diet of larger species. For example, it constitutes up to 19.2% of the diet of otters, a near threatened species of conservation concern.

7) Densities of frogs were highest in drainage ditches (86% of all breeding frogs occurred in this habitat) whilst <5% of frogs bred in farmland ponds suggesting that the widespread occurrence of drainage ditches throughout Ireland may have offset any impacts due to historic pond loss.

8) Frogs were widespread and their '*current distribution*', defined as occupied 10km Irish grid squares, remained stable and did not signficiantly differ between 1993-2006 and 2007-2011.

9) Frogs were most likely to breed in shallow water bodies surrounded by marsh, fen and wet flushes whilst the density of breeding adults was associated with water bodies surrounded by scrub and long grass. Densities of breeding adults were typically lower at water bodies inhabited by fish and waterfowl or those shaded by semi-natural woodland.

10) Frog occurrence and density were unaffected by levels of disturbance or water quality (pollution). Thus, there were no perceived *impacts* or *threats* that significantly affected frog occurrence or density.

11) Following EU Habitats and Species Directive Guidelines the current National Conservation Assessment for *Rana temporaria* was assessed as Favourable or 'good' (green). This apparent improvement from the Inadequate or 'poor' status assessment reported in 2007 is due to an improved understanding of how frogs use the Irish landscape.

12) A protocol for future monitoring is outlined that should ensure any signficiant declines in distribution or abundance are detectable.

13) The contents of this report have been peer-reviewed and published in the scientific literature as:

   i. Reid, N., Dingerkus, S.K., Stone, R.E., Buckley, J., Beebee, T.J.C., Marnell, F., Wilkinson, J.W. (2013) Assessing historical and current threats to common frog *Rana temporaria* populations in Ireland. *Journal of Herpetology* (awaiting pagination).

   ii. Reid, N., Dingerkus, S.K., Stone, R.E., Kelly, R., Pietravalle, S., Buckley, J., Beebee, T.J.C., Marnell, F., Wilkinson, J.W. (2013) Population enumeration and assessing conservation status in a widespread amphibian: a case study of *Rana temporaria* in Ireland. *Animal Conservation* (awaiting pagination).

   iii. Dingerkus, S.K., Stone, R.E., Wilkinson, J.W., Marnell, M. & Reid, N. (2011) Developing a methodology for the National Frog Survey of Ireland: a pilot study in Co. Mayo. *Irish Naturalists' Journal*, 31(2); 85-90.

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1. Introduction

Ireland has three native amphibians, the most widespread and abundant of which is the common frog *Rana temporaria* (Ni Lamhna 1979, Marnell, 1999). This species is found over much of northern and central Europe, ranging from Ireland in the west to Russia in the east, and from Italy and the Balkans to North Cape in Scandinavia (Beebee & Griffiths 2000). It is one of the most cold-tolerant amphibians in the world and a significant proportion of its distribution lies within the Arctic Circle. The common frog has low heat tolerance and, near its southern range edge, is confined to relatively high altitudes. In Britain and Ireland, it occurs from coastal regions to at least 1000 metres above sea level. Natterjack toads *Bufo calamita* are the only other anuran native to Ireland, but have a much more restricted distribution than the common frog. Native populations are confined to county Kerry, with one successful introduction near Wexford (Korky, 1999). Ireland's third amphibian, the smooth newt *Lissotriton vulgaris*, is as widespread as the common frog but generally less abundant (Marnell, 1998a).

The origins of frogs in Ireland have been controversial, with early suggestions that they were not native but were introduced from Britain in the 17th century (Smith, 1964). However, genetic studies indicate the existence of two distinct clades (Teacher *et al*., 2009), one similar to that found in Britain and a second, distinct group unique to the south-west of Ireland. These results imply two separate colonization events, probably both in the early postglacial period, one from the east and one from a Lusitanian refuge in or near county Kerry. Similar results have been found for the natterjack toad (Rowe *et al*, 2006). It is, therefore, considered that the common frog is a longstanding native of Ireland.

1.1 Species biology and ecology

Common frogs spend most of their lives on land, living and hunting in damp pastures, open woodlands or other habitats with suitable cover and generally not far from a pond or stream (Marnell 1998a). They hibernate at the bottom of ponds (mostly males) or in frost-free refugia, such as under logs or in dense piles of vegetation. Frogs prey on a wide range of invertebrates including arthropods, worms and molluscs (Blackith & Speight, 1974). In Ireland, males mostly mature at two years of age and females at three. Mortality rates are generally about 50% per annum with few animals surviving as long as seven years (Gibbons & McCarthy, 1984). A wide range of animals predate frogs including pike, crows, herons, gulls, rats, foxes and otters (Beebee & Griffiths, 2000).

Common frogs are among the earliest amphibians to breed as winter gives way to spring. Adults migrate to breeding ponds (unless they hibernated there) usually in February or early March, depending on latitude, altitude and local weather conditions. A comprehensive account of frog reproduction is given by Savage (1961). Spawning occurs in shallow water usually 15 - 30 cm deep and exposed to the sun (Cooke, 1975). One spawn clump per female is produced (Griffiths *et al.* 1999) but these usually aggregate into a communal egg mass or masses (Håkansson & Loman, 2004). Individual females produce up to two thousand eggs, with fecundity increasing as they become older and larger (Gibbons & McCarthy, 1986). Although males clasp females tightly 'in *amplexus*' prior to spawning, multiple paternity is common due to the activity of unpaired males close by when spawn is laid (Vieites *et al*., 2004).

Tadpoles hatch within a fortnight or so and grow in the natal pond over the following two or three months, metamorphosing into froglets in May or June. Individually secretive, the tadpoles feed mostly on algae or detritus on the pond floor. They are prey to a wide range of invertebrates (water beetles, dragonfly larvae, backswimmers) and vertebrates (fish, newts) so survival from egg to froglet is typically just a few per cent. Studies in Scandinavia have demonstrated large local differences in tadpole growth rates and size at metamorphosis, implying high levels of adaptive genetic variation (Palo *et al*., 2003). Froglets disperse during the summer into the same habitats as those used by adults. Females disperse more widely than males (Palo *et al*., 2004) although it is not clear whether this happens during the juvenile or adult life stages.

1.2 Amphibian declines and threats to the common frog

Amphibian declines have become a matter of international concern in recent decades with a third of all species across the globe seriously threatened or already extinct (Stuart *et al*., 2004). Major reasons for these declines include habitat loss and the emergence of previously unrecorded diseases, especially the pathogenic chytrid fungus *Batrachochytrium dendrobatidis* (Beebee & Griffiths, 2005). In Europe, amphibian declines became acute in the 1960s, earlier than in most other parts of the world, and were precipitated primarily by habitat damage due to agricultural intensification (Houlahan *et al*., 2000). Chytrid fungus was first detected in Europe within the last decade, causing major declines of midwife toads at high altitudes in Spain (Bosch *et al*., 2001), and has since been detected in many countries including Britain (Cunningham *et al*., 2005). However, common frogs seem resilient and are rarely infected compared with many other species. Thus far there have been no amphibian declines in Britain that can be definitively attributed to chytrid fungus.

Local frog populations are threatened by ecological succession and loss of ponds due to agricultural intensification, introduction of fish to breeding sites and development pressures (Beebee & Griffiths, 2000). Common frogs suffered substantial declines in Great Britain, together with other amphibians, during the post-WWII period characterised by agricultural development (Cooke, 1972). Some population losses, however, have been offset by a trend for creating garden ponds (Beebee, 1996) although these small and isolated habitats increase risks from inbreeding depression (Hitchings & Beebee, 1997). This may be why *Ranavirus*, another emerging disease that causes mass mortality of common frogs, has been particularly prevalent in garden environments. *Ranavirus* does not usually cause extirpation but recovery can take many years (Teacher *et al*., 2010). This infection appears relatively rare, or at least unreported, in Ireland. In Europe as a whole there is little conservation concern about common frogs but a study in Switzerland highlighted the difficulties in assessing amphibian declines. A time series of >25-years for three frog populations suggests that populations have been declining for most of that time with intermittent dramatic increases. This resulted in overall long-term stability for two populations but gradual decline, probably caused by fish introduction, at the third (Meyer *et al*., 1998).

In Britain there is no evidence for recent declines of frogs comparable with those in the post-WWII decades and anecdotal evidence of some recovery in the wider countryside, perhaps due to expanding agri-environment schemes. Certainly frogs fared much better than common toads *Bufo bufo* in the latter part of the twentieth century (Carrier & Beebee, 2003). The recently established National Amphibian and Reptile Recording Scheme (NARRS) is expected to provide more quantitative information on trends of all the British species over the coming years. Pond loss in Britain has been severe for many decades and, by the end of the 20th century, more than 75% of ponds present a hundred years earlier had disappeared. Despite increasing restoration and pond re-creation efforts resulting in a net increase in British ponds over the past 10 years, pond quality is continuing to decline and less than 10% were judged to be in good condition during a recent survey by Pond Conservation (www.pondconservation.org.uk). The pattern is similar across most of Europe as ponds are abandoned as watering holes for livestock (replaced by piped water) and allowed to silt up or become eutrophicated by run-off from fertilisers.

In Ireland, frogs are protected under the Irish Wildlife Act (1976, amended 2000) and are listed on Annex V of the Directive on the Conservation of Natural Habitats of Wild Fauna and Flora (92/43/EEC), hereafter referred to as the Habitats & Species Directive. Species are listed on Annex V in recognition of the fact that they may be exploited in certain EU countries, and to ensure that such exploitation is sustainable. Article 17 of the Directive requires that signatory states report regularly to the European Commission on the species' conservation status. Three surveys carried out between 1993 and 2003 suggested that the frog was present in almost every 10km square in the Republic of Ireland

and, where habitat was suitable; it was frequently abundant (IPCC, 2003). Nevertheless, the species was deemed to be in "unfavourable inadequate U1" or poor (amber) conservation status during the last Article 17 report due to ongoing threats to remaining suitable habitat, principally wetland drainage and intensive urban and suburban development, resulting in anecdotal reports of local extirpation (NPWS 2008). The report also identified concerns about our level of knowledge of frog abundance and the species' ability to adapt to habitat fragmentation.

1.3 Associated habitats

The common frog, being widespread, occurs in many habitats. Annex I of the Habitats & Species Directive lists at least 21 habitats that occur in Ireland that may also be associated with frogs (Table 1).

Table 1 *EU Annex I habitats associated with the common frog.*

#	EU Habitats Directive Code	Description
1	3110	(Lowland) Oligotrophic Lakes
2	3130	(Upland) Oligotrophic Lakes
3	3140	Hard Water Lakes
4	3150	Natural Eutrophic Lakes
5	3160	Dystrophic Lakes
6	3180	Turloughs
7	4010	Wet Heath
8	6210	Calcareous Grassland
9	6410	Molina Meadows
10	6430	Hydrophilous Tall Herb
11	6510	Lowland Hay Meadows
12	7110	Raised Bog (Active)
13	7120	Degraded Raised Bogs
14	7130	Blanket Bog (Active)
15	7140	Transition Mires
16	7210	Cladium Fens
17	7230	Alkaline Fens
18	91A0	Old Oak Woodlands
19	91D0	Bog Woodland
20	91E0	Alluvial Forests
21	2190	Humid dune slacks

1.4 National Conservation Assessment

The conservation status of a species is defined as the sum of the influences acting on the species that may affect its long-term viability. The Habitats & Species Directive requires that all species listed are maintained in *'favourable conservation status'* throughout member states; a species' status is taken as *favourable* only when:

a. population dynamics data on the species concerned indicate that it is maintaining itself on a long-term basis as a viable component of its natural habitats;

b. the natural range of the species is neither being reduced nor is likely to be reduced for the foreseeable future;

c. there is, and will probably continue to be, a sufficiently large habitat to maintain its populations on a long-term basis.

The '*Assessment, Monitoring and Reporting under Article 17 of the Habitats & Species Directive'* report (Anon, 2006) provided the first basic guidelines to assess the conservation status of the common frog. The *'Status of EU Protected Habitats and Species in Ireland'* report (NPWS, 2008) provided the first baseline assessment of the frog throughout Ireland.

To assess a species' conservation status, 4 parameters are objectively scored, namely: i) *range*, ii) *population*, iii) *habitat*, and iv) *future prospects*. Methods for assessing conservation status have been drawn up by the European Topic Centre for Bioloigcal Diversity (ETC/BD) in conjunction with EU Member States represented on the Scientific Working Group of the Habitats & Species Directive. A standard format was agreed at a European level during 2006 and was updated in 2011.

The format for the assessment of conservation status involves the application of a "traffic-light" system and brings together information on the four parameters to be assessed. Each parameter is classified as being "favourable FV" or good (green), "unfavourable inadequate U1" or poor (amber), "unfavourable U2" or bad (red) and "unknown" (grey).

Favourable reference values are set as targets against which future values can be judged. These reference values have to be at least equal to the value when the Habitats & Species Directive came into force, i.e. in 1994. The '*Favourable Reference Range'* for a species is the geographic range within which it occurs and which is sufficiently large to allow its long-term term survival. The Favourable Population is the value required for the long-term survival of the species in question.

The extent and quality of suitable habitat is assessed to determine whether the long-term survival of the species can be assured.

The major pressures and threats preceived to be affecting the species are also listed during each assessment. Their impacts are used to determine the *future prospects* of the species.

If any one of the four parameters i) *range*, ii) *population*, iii) *habitat*, and iv) *future prospects* are assessed as "unfavourable U2" or bad (red), then the overall assessment is also "unfavourable U2" or bad (red).

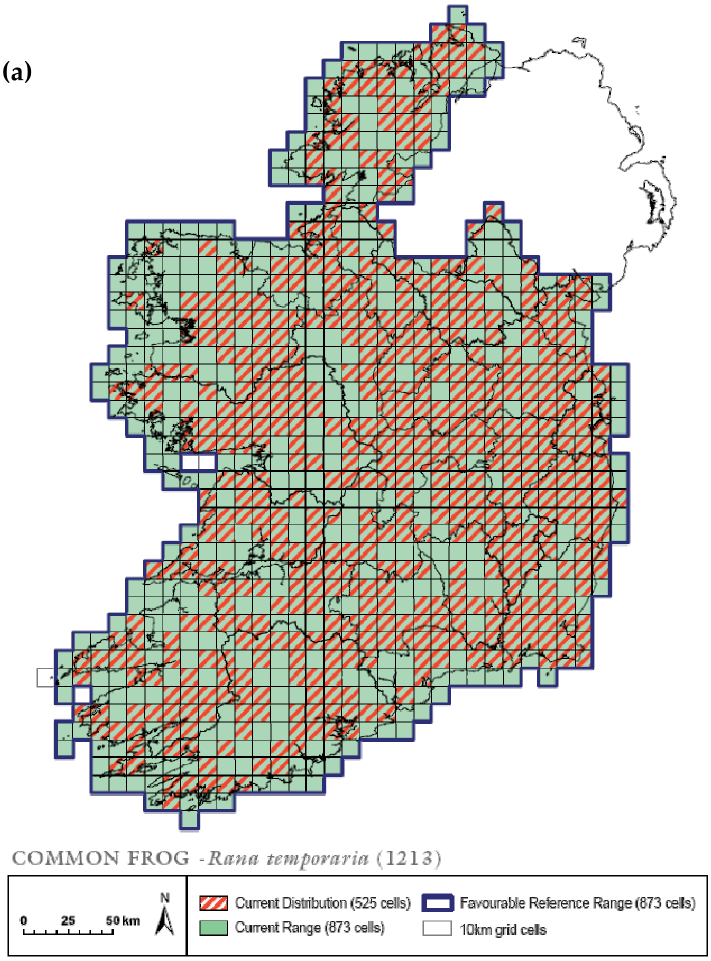
1.4.1 Current status

Frog and spawn records collated from 1950-1978 by Ní Lamhna (1979) demonstrated that the common frog was widespread throughout Ireland including a number of offshore islands. A survey of a stratified sample of 50 x 10km Irish grid squares during 1993-1994 by Marnell (1998b) found frogs to be present in 73% of squares, however, the main aim of the work was to locate the smooth newt so common frog occurrence may have been underestimated. Two further frog surveys, mainly aimed at school children, were conducted by the Irish Peatland Conservation Council (IPCC). The first was in 1997, the second from 2003-2007. The last Article 17 report on the species combined the data from the three surveys carried out between 1993 and 2007 and suggested that the species was present in 525 x 10km Irish grid squares (Fig. 1a). However, it was likely to occur in every 10km square throughout the country with any gaps being attributed to poor coverage and survey effort (NPWS, 2008)**.** Despite being widespread, wetland drainage and intensive urban and suburban development, particularly around cities, was perceived as a significant pressure removing terrestrial and aquatic habitats causing some local extinction. Therefore, the last Article 17 conservation assessment for the common frog in Ireland reported it to be in Inadequate U1 or 'poor' (amber) status (Fig. 1b).

1.4.2 Monitoring

The Habitats & Species Directive requires '*surveillance*' of designated species by Member States under Article 11. For the last Article 17 report all available historical data on the distribution of the frog from 1993-2007 were collated (NPWS 2008). For this reporting cycle, it was determined that a dedicated survey of frog breeding sites and surrounding habitats across the country would be required. A bespoke baseline survey was commissioned which would assess the conservation status of the frog and produce a robust and cost effective methodology for future monitoring.

(a)



(b)

COMMON FROG *Rana temporaria* (1213)	
Range	Good
Population	Good
Habitat	Poor
Future prospects	Good
OVERALL	POOR

Fig. 1 (a) *A 10km atlas of frog distribution in Ireland and* **(b)** *the most recent conservation assessment for the species (#1213) during the last Article 17 report to the European Commission.* [Source: NPWS, 2008]

1.4.2 Estimating density and abundance

In Britain, the National Amphibian and Reptile Recording Scheme (NARRS; www.narrs.org.uk) has been developed by Amphibian and Reptile Conservation (ARC). NARRS aims to establish a baseline of occurrence and distributional data for widespread amphibians and reptiles to facilitate the assessment of UK Biodiversity Action Plans and identify the threats posed to each species. Data collection at a series of randomly selected ponds (with a target of at least 400) spread across the UK started in 2007. The NARRS approach is based on recording presence or absence, not population size, for each species at each location. It is designed to assess changes in numbers of breeding populations over time. An alternative approach, choosing a selection of sites across the country and estimating population sizes at regular intervals at each site, was initiated in the Netherlands in the 1990s (Goverse *et al*., 2007). NARRS should be well-placed to detect changes in fine-scale distribution but the

Dutch method may be more sensitive to factors influencing populations before local extinction occurs. The ideal monitoring programme should probably include both approaches.

The monitoring of amphibian populations can vary according to the biology of the species concerned and there are numerous candidate methodologies. Recording the calls of breeding males is common in North America and Europe but is not suitable for the quiet, purring vocalisation of *Rana temporaria*. The main four techniques investigated for use with the widespread British amphibians include visual (daytime) survey for eggs, night-time searching with a spotlight, netting and live-trapping (Griffiths, 1985). Assessment of these methods concluded that four visits during the spring, using all four methods, were necessary to establish presence or absence of all species (frogs, toads and newts) with 90% confidence (Sewell *et al*., 2010). However, establishing the presence of the common frog by itself is relatively straightforward. Successful breeding of frogs can be determined at any given water body by observing spawn, tadpoles and/or metamorph froglets, and population size can be determined by counting individual spawn clumps or estimating total spawn clump area (Griffiths *et al.* 1996). Three visits are normally enough to establish with high confidence not only whether frogs are present but also an estimate of population size (Dingerkus *et al.* 2011).

1.6 Aims of the current study

Due to the general paucity of data on the frog in Ireland the current project aimed to develop a national survey that would:

1. *Quantify historical pond loss*
2. *Update the known distribution of the frog*
3. *Estimate the adult (specifically breeding) population size*
4. *Determine aquatic and terrestrial habitat use*
5. *Determine the future prospects for the species by identifying impacts, threats and pressures*
6. *Develop a baseline survey and recommend a robust protocol for the future monitoring of the conservation status of the frog in Ireland*

2. Methods

2.1 Quantifying historical pond loss

Maps from the Ordnance Survey Ireland (www.osi.ie) were used to examine 394 x 1km Irish grid squares. These squares were chosen from a well-established sampling regime adopted by the Countryside Bird Survey (CBS) conducted by Birdwatch Ireland (Coombes *et al.*, 2009). Their distribution made best use of available survey effort whilst being representative of habitat defined by CORINE 2006 (EEA, 2010). Farmland ponds, defined as discrete water bodies <2ha in size were identified using three sources of information: i) OSI Historic 25" maps were used to identify ponds during the period 1887-1913, ii) OSI Ortho-photographs were used to identify extant ponds during 2005 and iii) the status of those ponds was confirmed using a ground-truthed survey during 2011 plotted over the most recent OSI 1:2,000 scale 'Street Map beta' (Fig. 2). Large lakes >2ha in size were excluded as the majority of their water surface was deemed unsuitable breeding habitat for frogs. Ordnance survey maps had insufficient resolution to identify other water body types, for example, bog pools; drainage ditches; marsh or temporary features (e.g. large puddles etc.). Generally bog and other wetland habitats were marked with a symbol ('''''''') and no further details, including their boundaries, were apparent. Moreover, what today is accurately mapped as wetland may have been mapped a century ago simply as meadow and, therefore, appeared as grassland (Gimmi *et al.* 2011). Thus, only in well mapped areas, such as farmland where a water body contrasted to the landscape were they distinguished with any accuracy; thus the majority of water bodies were taken to be farmland ponds. The word 'farmland' in this context denotes the landscape within which ponds were located and does not infer that they were man-made or artificially maintained. Indeed, the majority were taken to be natural in origin due to the irregularity of their shape.

The number and location of ponds was recorded for each 1km square in both the historic sample (1887-1913) and the current sample (2005-2011) and the absolute net change was calculated. Spatial trends in pond loss or gain were mapped using ArcGIS 10 (ESRI, California, USA). The spatial heterogeneity of pond loss or gain was examined using High-low Value Clustering (or Getis-Ord General G) analysis. Ireland can be divided broadly into three regions of ecological relevance; i) the East - where the climate is moderately mild and dry, agriculture is intensive including large areas of arable farming, human population density is highest and there is the greatest coverage of urban and sub-urban development, ii) the South – where the climate is the warmest and mildest, agriculture is mostly pastoral farming, human population density is moderate and there are a few scattered urban centres and iii) the West & north-west - where climate is coolest and wettest, agriculture is extensive including large areas of pastoral farming interspersed with significant areas of natural vegetation, human population density is lowest and there are relatively few urban centres. Thus, variance in absolute net change in the number of ponds was examined between these three Regions using an Analysis of Variance (ANOVA) and Fisher's Least Significant Difference post-hoc tests (Fisher's LSD).

Fig. 2 A 1km Irish grid square (T1030, Co. Wexford) showing **(a)** five ponds (coloured red) during 1887-1913 (using the OSI Historic 25" digital map), **(b)** four extant ponds during 2005 (using the OSI Ortho-photographs) and **(c)** the status of ponds during 2011 using a ground-truthed survey mapped onto a 1:2,000 scale "Street Map *beta*". Ponds that were lost since 1887-1913 are circled in blue. Thus, absolute net change for this square was -1 ponds and relative net change was -20% of the original ponds.

2.2 Breeding frog surveys

2.2.1 Availability of suitable breeding frog habitat

A total of 171 x 1km Irish grid squares were selected throughout the Republic of Ireland from the 394 squares used to assess historical pond loss. To ensure this sample was representative of habitat types, a total of 8 parameters were used to describe the landscape of the candidate survey squares (n=171) compared to the wider countryside (n=70,300). The CORINE land cover map 2006 (EEA, 2010) was used to calculate the coverage of five landcover variables within each 1km square, namely, i) pastoral agriculture, ii) mixed agriculture (including arable and complex cultivation patterns), iii) forest (broad-leaved woodland, coniferous plantation and mixed woodland), iv) scrub and v) urban & suburban development. A further three wetland variables were examined including i) standing freshwater (ponds or lakes >2ha), ii) riparian length (kilometres) of rivers, streams, canals and lake edge and iii) bog, moor, heath & marsh. A MANOVA (Multiple Analysis of Variance) was used to examine variation in each variable fitted as a single group of dependent variables and Square status (i.e. included in the survey or the wider countryside) fitted as a 2-level factor. The mean values for the coverage of each landcover and wetland category were comparable between survey squares and those in the wider countryside (Table 2) and there was no significant difference (Table 3) suggesting that survey squares *were* representative of the Republic of Ireland as a whole. It was not possible to determine representativeness of survey squares for drainage ditches, farmland ponds or other frog breeding sites as these data were not available *a priori*. However, it can be assumed that if the sample was representative of the general landscape, including major wetland habitats types, then it was likely representative of finer scale habitats.

Table 2 Descriptive statistics for survey squares (*n*=171) and the wider countryside (*n*= 70,300 squares) in terms of landcover or wetland habitat types.

Descriptor	Explanatory variable	Unit	$\bar{x}$ in wider countryside (n=70,300)	$\bar{x}$ in survey squares (n=171)
Landcover	Pastoral agriculture	ha.km^2	51.1	50.8
	Mixed agriculture	ha.km^2	14.9	16.7
	Forest	ha.km^2	4.0	3.0
	Scrub	ha.km^2	4.6	3.7
	Urban & rural development	ha.km^2	1.8	1.3
Wetlands	Standing freshwater	ha.km^2	1.8	1.4
	Riparian length	m.km^2	433	446
	Bog, moor, heath & marsh	ha.km^2	16.6	19.9

Table 3 MANOVA results demonstrating that the sample of survey squares used in the current survey did not differ significantly in composition from those in the wider countryside throughout the Republic of Ireland.

Descriptor	Explanatory variable	*F*	df	*p*
Landcover	Pastoral agriculture	0.011	1,70,291	0.916
	Mixed agriculture	1.090	1,70,291	0.296
	Forest	1.159	1,70,291	0.282
	Scrub	0.900	1,70,291	0.343
	Urban & rural development	0.449	1,70,291	0.503
Wetlands	Standing freshwater	0.262	1,70,291	0.609
	Riparian length	0.201	1,70,291	0.654
	Bog, moor, heath & marsh	2.004	1,70,291	0.157

In each 1km square selected, the south-westernmost 500m square was surveyed. Surveyors mapped all water features, including: bog pools; drainage ditches; lakes and reservoirs; marsh; rivers, streams or canals and temporary features, for example, shallow surface flooding. The number of discrete water bodies of each type was recorded and the total length of linear features, for example drainage ditches, was measured using ArcGIS 10 (California, ESRI, USA). A copy of the data recording form used for habitat surveys is presented in Appendix I.

2.2.2 *Spawn surveys*

Three water bodies were selected randomly from each square for breeding frog surveys. In the case of linear features that were independent (i.e. not connected), including drainage ditches and rivers, streams or canals a 100m stretch was selected at random and treated as a discrete sample. Where three discrete water bodies were unavailable, a maximum of two 100m lengths of drainage ditch that were connected were selected though effort was made to choose stretches as far away from one-another as possible.

A total of three return visits were made to each selected water body to assess frog spawning activity. The first visit was shortly after the first appearance of spawn locally, the second approximately 7 days after the first, and the third approximately 14 days after the first. Griffiths *et al.* (1996) advocated three site visits as early surveys may not detect spawn at all sites due to spatial variance in onset of breeding whilst later visits may under-estimate frog activity as spawn may become camouflaged by algal growth, sink and/or begin to disintegrate after hatching (Beebee & Griffiths 2000). Consequently, the occurrence of breeding frogs (site occupancy) was recorded at each visit and the cumulative spawn mat area (cm^2), i.e. the total coverage of spawn in any one water body, was recorded as the maximum estimate during any one visit. Descriptive statistics were used to clarify trends in the coverage of various water body types within survey squares, the number of water bodies surveyed and frog occupancy. Variance in site occupancy was examined using a Generalized Linear Model (GLM) assuming a binomial error structure and a logit link function with spawn presence or absence fitted as the dependent variable with Water body type and Visit (1, 2 or 3) as fixed factors. A copy of the data recording form used for spawn data recording is presented in Appendix II.

2.2.3 *Estimating water body size*

The dimensions (maximum length and breadth) of each water body were estimated. In all cases, drainage ditches and rivers, streams or canals were assumed linear and their surface area (m^2) calculated using l x b where l = length (m) and b = breadth (m). In all other cases, the shape of a water body was inferred by its *1:b* ratio. Water bodies with a *1:b* ratio <0.5 i.e. their breadth was less than half their length were assumed linear. Water bodies with a *1:b* ratio >0.5 i.e. their breadth was greater than half their length were assumed elliptical and their surface area was calculated as π x $0.5l$ x $0.5b$. Any water body classed under “lakes and reservoirs” that was <2ha was reclassified as a “farmland pond”. Missing data for either water body length or width were assumed to be the mean for the specific water body that was missing. Water depth was estimated in metres.

2.2.4 *Estimating frog density*

Griffiths *et al.* (1996) demonstrated that cumulative spawn mat area (x) exhibited a significant linear relationship with the number of discrete spawn clumps (y_1) originally deposited ($F_{df=1,16}$ = 275.92, p<0.0001, adj. r^2=0.945, n=18) where $y_1 = 2.27 + 0.007x$ (Fig. 3). This equals the number of breeding females present in each water body as each female deposits only one clump per season (Savage, 1961). Assuming an effective sex ratio of 1:1 (Savage, 1961), the estimated frog density (y_2), expressed as frogs/m^2 per breeding site, was calculated using the formula $y_2 = 2\ (2.27 + 0.007x)\ /\ sa$ where sa equalled the surface area of the water body in m^2. Due to the intercept, these formulae assume 2.27 spawn clumps and, therefore, females (and 4.54 breeding adults) at sites without any observed spawn mat. Thus, to avoid inflating estimated densities these formulae were only used at sites where at least one spawn mat was observed; all other sites were assumed to have a breeding density of zero.

The availability of each water body type (i.e. total surface area available for spawn deposition) was calculated in each survey square. In the case of discrete water bodies, for example farmland ponds, the total number recorded during habitat surveys was multiplied by their mean surface area as estimated during spawn surveys. In the case of linear features, for example drainage ditches, the total length measured during habitat surveys or derived from GIS mapping was multiplied by their mean estimated breadth as estimated during spawn surveys. Thus, for each individual survey square an estimate of frog abundance was made by multiplying the total availability of each water body type by the estimated density of adult frogs using each as a breeding site. Frog density was therefore transformed from numbers per unit surface area of water body (i.e. frogs/m^2) to numbers per unit area within each survey square (i.e. frogs/ha) and was expressed as total frog abundance (i.e. numbers of frogs).

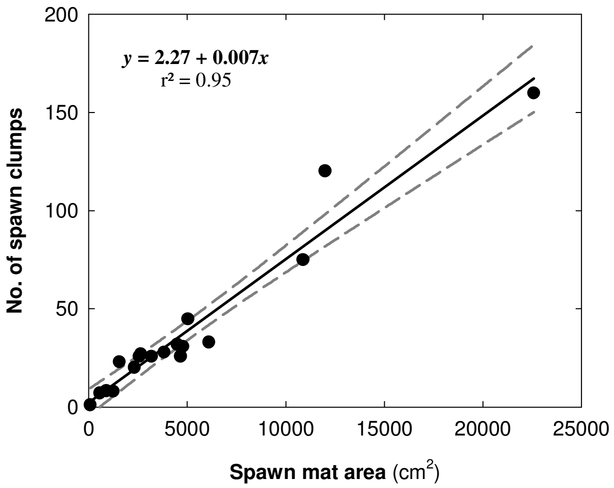


Fig. 3 Relationship between the number of frog spawn clumps originally deposited and the resultant spawn mat area (cm^2) after swelling and expansion providing a means by which to predict the original number of breeding females in each water body [extracted and modified from Griffiths *et al.* 1996 with the permission of Prof. Richard Griffiths, University of Kent and Trevor Rose, British Herpetological Society].

2.2.5 *Future prospects (preceived pressures)*

Perceived water quality was judged subjectively using the categories 'good', 'average' or 'poor' (based on water clarity and colouration), whilst disturbance was recorded as 'none', 'some' or 'heavy' (including agricultural disturbance such as ploughing). The *'pressures'* present at each site were categorised according to criteria listed in the *Natura 2000* Standard Data Form and recorded under EU Habitat Directive codes (Table 4). The presence or absence of each perceived pressure was recorded. Fish and waterfowl presence was also noted. Missing data for categorical variables were replaced with the mode for the specific water body for which data were missing.

Table 4 *Description of each* impact or threat *using the EU Habitat Directive codes relevant to the frog.*

High-level description		*Impact or threat* code	Specific-descriptions
A	Agricultural	A01	Cultivation
		A04.01	Intensive grazing
		A04.03	Abandonment
		A10.01	Removal of hedges/scrub
B	Agro-forestry	B02	Forestry
C	Mining, extraction of materials	C01.03.02	Mechanical peat extraction
E	Urbanisation, residential and commercial	E	Development
G	Human intrusions and disturbances	G01	Recreational activities
H	Pollution and other chemical changes	H01	Pollution
I	Invasive, other problematic species and genes	I01	Invasive species
J	Natural systems modification	J02.01.03	Infilling
		J02.03	Canalisation
K	Natural biotic and abiotic processes (without catastrophes)	K01.02/03	Drying / silting up
		K02	Ecological succession
		K03.04	Predation
O	Other	O	Other
X	No threat apparent	X	No threat apparent

2.2.6 *Aquatic and terrestrial habitats*

The percentage of the surface of each water body that was shaded by overhanging vegetation and the percentage coverage of aquatic plants was estimated. Environmental data were collected including the presence or absence of surrounding habitats (bog, fen or wet flushes, improved grassland, semi-improved grassland, marsh, semi-natural woodland or non-native woodland) and terrestrial refuges (dead wood, long grass, hedgerows, piles of stones, scrub or stone walls) within 100m of the site.

The large number of aquatic and terrestrial habitat variables and perceived *pressures* recorded were reduced using Principal Components Analysis (PCA) onto a number of hypothetical axes with significant relationships described using correlation coefficients. Only those variables that occurred at >10% of water bodies were included in analyses.

Breeding site occupancy was examined using a Generalized Linear Mixed Model (GLMM) assuming a binomial error structure and a logit link function. A total of 405 water bodies were surveyed for spawn but water body types that were notably rare were excluded from analysis including lakes and reservoirs (n=7), turloughs (n=2) and others (n=1) leaving a sample size of n=395. Frog occurrence was fitted as the dependent variable and Square_ID was fitted as a random factor to account for multiple water bodies in each 1km survey square. Water body type and the presence of fish and waterfowl were fitted as fixed factors and all Principal Component Axes were fitted as covariates. Frog density (i.e. frogs/m^2) was examined only at the subset of sites where frogs where present (n=199) using a GLMM as before but assumed a Gamma error structure and a logarithmic link function. All response variables were identical to those used in the model of site occupancy. All independent predictors were tested for multicollinearity using ordinary least squares regression to ensure that all tolerance values were >0.2 and all variance inflation factor (VIF) values were <5.0 (O'Brien, 2007). These indices are a measure of how much the variance of an estimated regression coefficient (the square of the estimate's standard deviation) is increased by collinearity between predictor variables. Tolerance values >0.2 and VIF values >5 indicate that multicollinearity is a problem (Quinn and Keough, 2002). All statistics were conducted using SPSS Statistics 19 (© IBM Company, USA).

2.3 Estimating total frog abundance

Frogs are generally highly aggregated during the breeding season with almost the entire population clustered at a few breeding sites; the majority of water bodies will have some frogs but many sites may not be used for breeding at all (Savage, 1961). Therefore, frog density was likely to be highly skewed. Thus, we fitted a set of candidate distributions to estimates of total frog abundance per survey square including: i) normal, ii) half-normal, iii) Poisson, iv) negative exponential and v) negative binomial. The fit of each distribution was assessed using a Kolmogorov-Smirnov goodness-of-fit test. We then generated a custom distribution (assuming identical fit parameters to that of the raw data) for the total number of available 500m squares in the Republic of Ireland (n=281,202). The sum of all generated values represented the total estimate of abundance accounting for the observed distribution. To account for variance in the mean estimate of total frog abundance per survey square associated with estimating the number of spawn clumps (i.e. breeding females), we repeated this procedure using both the upper and lower 95% confidence limits of total frog abundance per square associated with the linear relationship between cumulative spawn mat area and the number of discrete spawn clumps for individual survey squares. This method therefore extrapolated total frog abundance accounting for the likely skew in their distribution and the original error associated with estimating the number of breeding females creating asymmetrical margins of error.

To estimate the statistical power (1-β error probability) of our sampling regime to detect a small change (10%), intermediate change (30%) or large change (50%) in frog abundance between two consecutive surveys we conducted a power analysis. A subset of survey squares were selected at random from our sample of n=171 and a 'future' population for each square was simulated. The simulation used the current population estimate of each square and assumed a reduction of 10%, 30% or 50% respectively but also accounted for the uncertainty in the current population estimate by selecting 'current' values from a triangular distribution with the current estimate, lower and upper 95% confidence limits as the means and lower and upper limits of the distribution. A Generalized Linear Mixed Model (GLMM) assuming a quasi-Poisson distribution was fitted to test for the difference between simulated current and future populations. This was replicated 500 times to derive the power. In order to account for further uncertainty produced by the selection of various subsets of squares, the entire process was replicated a further 500 times to produce an envelope (or range) of power estimates. The median power was plotted against sample size with the 50% power envelope (i.e. 25th and 75th percentiles). Although the variance of the quasi-Poisson model is a linear function of the mean compared to a quadratic function for a negative binomial model (used to estimate frog abundance), it was less stringent in its assumptions and was, therefore, better able to incorporate the range of simulation scenarios. All statistics were performed using the software package R 2.15.1 (R Development Core Team 2012) and the package MASS (Venables & Ripley 2002).

2.4 Frog distribution

The last Article 17 report under the EU Habitats Directive established a baseline '*Favourable Reference Range*' for the common frog throughout the Republic of Ireland between the implementation of the Directive and the submission of the first report i.e. 1993-2006 (NPWS, 2008). This was described at a 10km square scale consistent with methods adopted by species atlases. The Directive requires that EU member states assess and report on conservation status on a cycle ≤6 years in duration constraining the period during which the '*Current Distribution*' could be assessed i.e. 2007-2011. This necessarily constrained the methodology that could be employed to describe the distribution of the common frog which had to be comparable to that of the previous report. Thus, we collated all available frog records throughout Ireland during the period 2007-2011. Multiple sources of information were available including a custom-made Amphibian and Reptile Conservation website created to solicit frog records from the public from 2010 to 2011 (www.arc-trust.org). Data was also sourced from the Irish Peatlands Conservation Council (IPCC), who ran the '*Hop-to-it*' survey from 2007 to 2011, the National Biodiversity Data Centre, the National Parks & Wildlife Service, Department of Arts, Heritage and the Gaeltacht (including dietary data from their recent National Otter Survey 2010/12) and www.biology.ie (courtesy of Paul Whelan).

The '*Current Distribution*' (number of occupied 10km grid cells) during 2007-2011 was compared to that recorded at baseline during 1993-2006 as reported in the last Article 17 report using a 2x2 contingency χ^2 test of association and the difference expressed as percentage change. Power Analysis, based on χ^2 distribution was used to calculate the number of occupied squares needed during future surveys so as to demonstrate that there has been no significant decline since baseline.

2.5 GIS biogeographical modelling

A presence-only maximum entropy approach was used to model the landscape associations of the frog throughout Ireland with the aim of predicting the species' unknown distribution, using a sample set of known occurrences and spatially explicit environmental parameters (Phillips, Dudik & Schapire, 2004; Phillips, Anderson & Schapire, 2006). A suite of landscape parameters including land cover, topography, climate, habitat and anthropogenic variables (Table 5) were extracted for each 500m square in Ireland buffered to 7 candidate spatial scales from 500m to 20.5km (Fig. 4).

To avoid model overfitting, we considered a combination of linear and quadratic functions only for all environmental parameters excluding product, threshold, hinged and discrete functions (Phillips and Dudík, 2008). All frog records collated for 2007-2011 (excluding those obtained during the spawn surveys) were used for modelling. Only those records which were associated with a 6-figure grid reference were retained (i.e. those to an accuracy of 100m). Due to the large number of remaining records we partitioned the dataset into a '*training set*' containing 50% of records selected at random and a '*test set #1*' containing 50% of records selected at random. We tested the model further using the true presence / absence data from the spawn survey during 2011 as an independent '*test set #2*'. Thus, we utilised all incidental frog records from 2007-2011 (with sufficient spatial resolution) to model frog-landscape associations before testing our model, not just with other incidentally collated data, but also data collected in the field during 2011 (i.e. all records were used).

Table 5 Explanatory variables extracted at a landscape scale for GIS biogeographical modelling of frog occurrence using incidental records.

Explanatory variables			Description	Spatial scale						
Type	**Name**	**Unit**		**500m**	**1.5km**	**2.5km**	**4.5km**	**6.5km**	**10.5km**	**20.5km**
Landcover	1. Arable	m^2	Coverage of non-irrigated arable land.	✓	✓	✓	✓	✓	✓	✓
	2. Bog, marsh, moor & heath	m^2	Coverage for a composite of bog, marsh, moor and heath	✓	✓	✓	✓	✓	✓	✓
	3. Broad-leaved woodland	m^2		✓	✓	✓	✓	✓	✓	✓
	4. Coniferous plantations	m^2		✓	✓	✓	✓	✓	✓	✓
	5. Freshwater	m^2		✓	✓	✓	✓	✓	✓	✓
	6. Mixed agriculture	m^2	Coverage for a composite of complex cultivation patterns and land principally occupied by agriculture with significant vegetation	✓	✓	✓	✓	✓	✓	✓
	7. Pasture	m^2		✓	✓	✓	✓	✓	✓	✓
Topography	8. Altitude	m	Elevation above sea level in metres	✓						
	9. Hilliness	m	Standard deviation in mean elevation above sea level in metres	✓	✓	✓	✓	✓	✓	✓
Climate	10. $Temp_{min}$	°C	Minimum temperature of the coldest month	✓						
	11. $Precipitation_{annual}$	mm	Total annual precipitation	✓						
Habitat	12. Riparian corridor	m	Total length of river and water body edge including lakes, reservoirs, ponds, rivers, streams and canals in metres	✓	✓	✓	✓	✓	✓	✓
	13. Soil pH	pH	Mean soil pH	✓	✓	✓	✓	✓	✓	✓
Anthropogenic	14. Urban	m^2	Coverage of urban landcover	✓	✓	✓	✓	✓	✓	✓
				80 predictor layers						

In the first instance, univariate models were run to select the most appropriate spatial scale at which frogs demonstrated a response to each variable. For example, the first model utilised only the variable '*arable*' but included seven variables which represented arable measured at the seven candidate spatial scales from 500m to 20.5km. The spatial scale which represented the highest 'percentage contribution' to the model was then chosen as the best scale representing the effect of arable on frog occurrence. This method was repeated for each parameter and the final model included variables at multiple spatial scales. Due to the high bias of records from urban areas (i.e. high recorder effort due to density of human occupation) the coverage of urban land cover at a spatial scale of 500m (the minimum scale) was fitted as a bias file during the modelling process to offset over-recording and negate any erroneous association with urban fabric.

The performance of the final model was judged using the Area Under the Curve (AUC) of a Receiver Operating Characteristic (ROC) curve. Analyses were performed using Maxent 3.2.1 (Phillips, Anderson and Schapire, 2006; Phillips & Dudík, 2008).

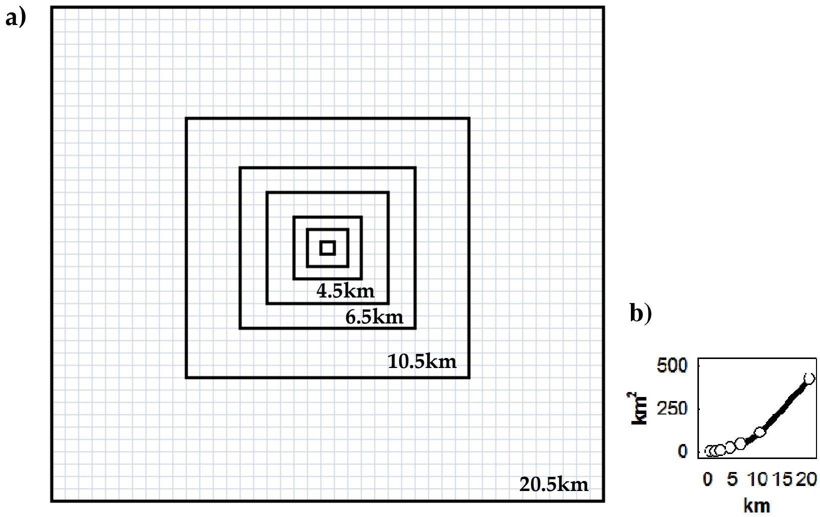


Fig. 4 a) Diagrammatic representation of seven hierarchical spatial scales for which environmental parameters were extracted for GIS biogeographical modelling of frog occurrence. Small cells represent 500m squares with the smallest bold square representing the central 500m with which each subsequent spatial scale was associated including 1.5km, 2.5km, 4.5km, 6.5km, 10.5km and 20.5km (where the scale was represented as the linear length of one side of each square). **b)** insert showing the relationship between the linear measurement of each spatial scale in km (x-axis) and the surface area from which each environmental parameter was measured in km^2 (y-axis).

2.6 National conservation assessment

An overall National Assessment for the common frog *Rana temporaria* was conducted following the most recent EU guidelines for the period 2007-2012 (Evans & Arvela, 2011). The species was assessed using the standard Annex D criteria including short-term and long-term trends in the species' Range and Population, Habitat for the Species, plus the main *pressures* including preceived *threats*. The standard "traffic-light" system was used to assess the main parameters.

3. Results

3.1 Quantifying historical pond loss

Seventy-three squares from the 394 examined (18.8%) experienced a decline and 43 (10.8%) an increase in the number of ponds. The range of net pond loss (-1 to -30 ponds/km^2) was greater than the range of pond gain (+1 to +7 ponds/km^2) in any one square. A total of 278 squares (71.5%) exhibited no change. Of these, 249 (63.2%) had no ponds in either the historic or current sample. Consequently, the overall decline in the percentage occurrence of ponds was relatively modest decreasing from 28.7 to 24.1% of squares containing at least one pond. However, the mean number of ponds per square decreased by 53.9% from 0.87 (range 0 - 30) to 0.40 (range 0 - 8) ponds/km^2. There was a high degree of spatial heterogeneity in the rates of pond change with significant high-low value clustering (Z = 9.31, P < 0.0001). Specifically, high rates of pond loss were clustered in the north-east and south-east (Fig. 5a). Clusters of pond gain were also evident but were of lower magnitude and were more spatially restricted than clusters of pond loss. Most notably, there was a cluster of pond gains in the East. Consequently, rates of change differed significantly between the Regions (ANOVA $F_{df=2,391}$ = 3.119, P = 0.045) with the East suffering significantly greater losses than either the South or West & north-west (Fisher's LSD P < 0.05). However, the latter two Regions did not differ in rates of pond loss (Fisher's LSD P > 0.05). There was also a significant degree of clustering in the current number of extant ponds (Z = 4.12, P < 0.0001). Specifically, high numbers of ponds were clustered in the East during 2005-2011 (Fig. 5b). Few squares in the West & north-west contained any ponds.

A total of 14 counties (53.8%) experienced a decline and 8 counties (30.8%) experienced an increase in the percentage occurrence of ponds within 1km squares between the historic and current samples (Table 6). A total of 4 counties (15.4%) exhibited no change. Ponds disappeared entirely from the sample examined in 3 counties (Laois in the East, Sligo in the West & north-west and Waterford in the South), however, the absolute numbers of ponds lost in each case was relatively modest (a maximum of 3 ponds in any one 1km square). In contrast, County Wexford exhibited the greatest absolute decline in pond numbers (-90.5%) from 5.71 to 0.54 ponds.km^2 (down from a maximum of 30 ponds to 4 ponds in any one 1km square). A total of 9 (34.6%) counties experienced an increase in the mean number of ponds per square but in these cases the absolute change was relatively modest compared to those counties that experienced absolute declines.

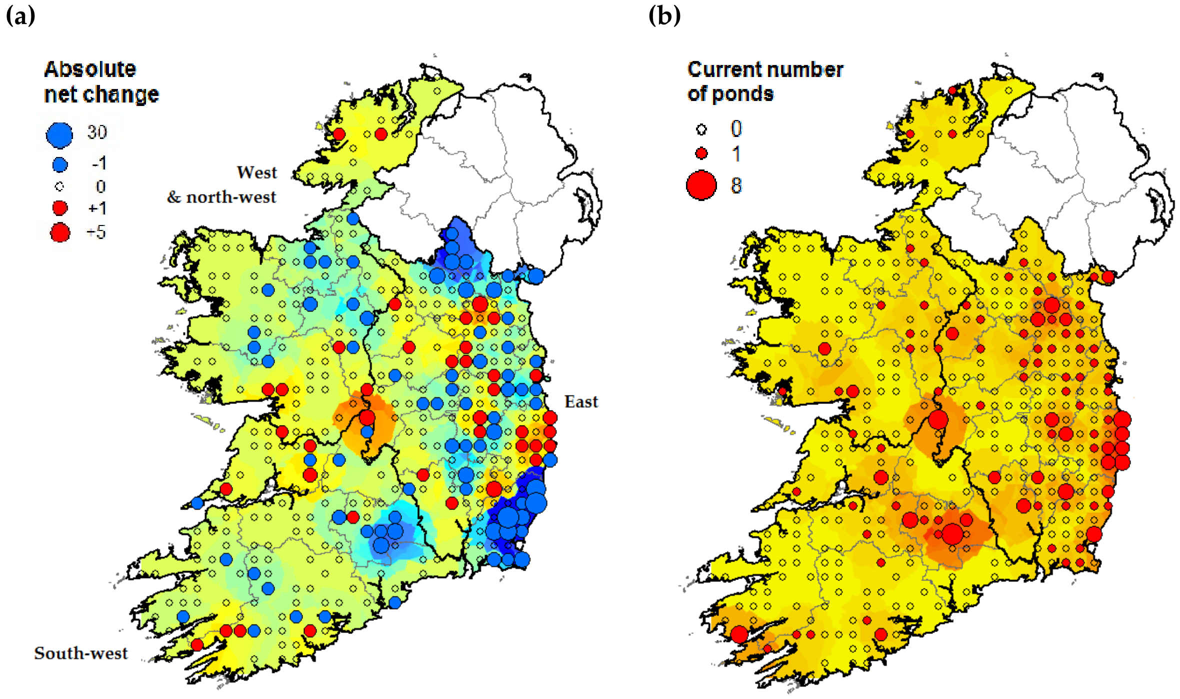


Fig. 5 (a) Pond loss in terms of absolute net change throughout Ireland between 1887-1913 and 2005-2011 (blue indicates pond loss, yellow/green indicates no change and red indicates pond gain). **(b)** The current number of extant ponds during 2005-2011. In both maps the sizes of each symbol indicates the number of ponds. White indicates no data.

3.2 Breeding frog surveys

On average, about 2% (5,000m^2) of the overall surface area of each 500m (25ha) survey square was determined to be suitable as frog breeding habitat (Table 7). A total of 405 water bodies were surveyed for spawn during 2011. Breeding site occupancy did not differ significantly between site visits (*Wald* $_{df=2,1206}$ = 1.04, *p*=0.596) with spawn occurring at 41.7% (95%CI 36.9 - 46.5) of water bodies during the first visit (median date = 28th February), 44.5% (95%CI 39.5 - 49.5) of during the second visit (median date = 8th March), 40.1% (95%CI 34.5 - 45.6) during the third visit (median date = 15th March) with a cumulative occurrence of 49.4% at all water bodies (Fig. 6). Site occupancy varied significantly between water body types (*Wald* $_{df=2,1206}$ = 41.47, *p*>0.001; Table 7). Frogs bred in 70.1% of independent survey squares (each containing a maximum of three water bodies). Their presence was widespread but greatest in the west and north-west (Fig. 6). Using the survey square as the unit of variance, frog densities at occupied sites varied between <0.01 frogs/m^2 in lakes and reservoirs to 1.51 frogs/m^2 in bog pools (Table 7). However, adjusting for site occupancy rates, frog density (including unoccupied water bodies) was generally high in temporary features, farmland ponds and bog pools but highest in drainage ditches (Table 7). Moreover, accounting for the coverage of each water body type per survey square resulted in an overall estimate of mean frog density = 23.5 frogs/ha of which 20.2 frogs/ha (86%) bred in drainage ditches (Table 7).

Table 6 Summary of pond loss within counties expressed as the percentage occurrence and mean number of ponds during the historic sample (1887-1913) and current sample (2005-2011). The mean percentage change in occurrence and numbers is provided in the final columns.

Region	Province	County	n	Historic sample (1889-1913)		Current sample (2005-2011)		% change	
				% occurrence	No. of ponds.km²	% occurrence	No. of ponds.km²	% occurrence	No. of ponds.km²
East	Leinster	Carlow	7	28.6	1.00 (0 - 6)	42.9	1.00 (0 - 4)	50.0	0.0
	Leinster	Dublin	9	66.7	1.11 (0 - 3)	33.3	0.33 (0 - 1)	-50.0	-70.0
	Leinster	Kildare	17	29.4	0.35 (0 - 2)	23.5	0.35 (0 - 3)	-20.0	0.0
	Leinster	Kilkenny	6	33.3	0.50 (0 - 2)	33.3	0.83 (0 - 3)	0.0	66.7
	Leinster	Laois	9	11.1	0.33 (0 - 3)	0.0	0.00 (0 - 0)	-100.0	-100.0
	Leinster	Longford	5	60.0	0.80 (0 - 2)	80.0	1.00 (0 - 2)	33.3	25.0
	Leinster	Louth	7	71.4	2.14 (0 - 8)	42.9	0.57 (0 - 2)	-40.0	-73.3
	Leinster	Meath	27	48.1	0.74 (0 - 3)	55.6	0.78 (0 - 4)	15.4	5.0
	Leinster	Offaly	11	36.4	0.36 (0 - 1)	27.3	0.82 (0 - 7)	-25.0	125.0
	Leinster	Westmeath	7	14.3	0.14 (0 - 1)	28.6	0.29 (0 - 1)	100.0	100.0
	Leinster	Wexford	24	58.3	5.71 (0 - 30)	37.5	0.54 (0 - 4)	-35.7	-90.5
	Leinster	Wicklow	19	36.8	1.16 (0 - 7)	52.6	1.37 (0 - 5)	42.9	18.2
	Ulster	Cavan	15	13.3	0.73 (0 - 6)	13.3	0.13 (0 - 1)	0.0	-81.8
	Ulster	Monaghan	7	71.4	2.00 (0 - 6)	28.6	0.29 (0 - 1)	-60.0	-85.7
	Sub-total / mean		**170**	**41.2**	**1.51 (0 - 30)**	**36.5**	**0.62 (0 - 7)**	**-11.4**	**-59.1**
South	Munster	Clare	16	12.5	0.13 (0 - 1)	18.8	0.31 (0 - 3)	50.0	150.0
	Munster	Cork	34	14.7	0.21 (0 - 2)	14.7	0.18 (0 - 2)	0.0	-14.3
	Munster	Kerry	25	12.0	0.28 (0 - 5)	4.0	0.20 (0 - 5)	-66.7	-28.6
	Munster	Limerick	14	28.6	0.29 (0 - 1)	28.6	0.29 (0 - 1)	0.0	0.0
	Munster	Tipperary	20	55.0	1.75 (0 - 9)	30.0	0.85 (0 - 8)	-45.5	-51.4
	Munster	Waterford	8	12.5	0.13 (0 - 1)	0.0	0.00 (0 - 0)	-100.0	-100.0
	Sub-total / mean		**117**	**22.2**	**0.48 (0 - 9)**	**16.2**	**0.32 (0 - 8)**	**-26.9**	**-34.1**
West & north-west	Connacht	Galway	28	7.1	0.11 (0 - 2)	14.3	0.18 (0 - 2)	100.0	66.7
	Connacht	Leitrim	9	33.3	0.67 (0 - 3)	22.2	0.22 (0 - 1)	-33.3	-66.7
	Connacht	Mayo	28	10.7	0.18 (0 - 3)	3.6	0.07 (0 - 2)	-66.7	-60.0
	Connacht	Roscommon	10	50.0	1.10 (0 - 4)	40.0	0.40 (0 - 1)	-20.0	-63.6
	Connacht	Sligo	10	30.0	0.40 (0 - 2)	0.0	0.00 (0 - 0)	-100.0	-100.0
	Ulster	Donegal	22	4.5	0.05 (0 - 1)	13.6	0.14 (0 - 1)	200.0	200.0
	Sub-total / mean		**107**	**15.9**	**0.28 (0 - 4)**	**13.1**	**0.15 (0 - 2)**	**-17.6**	**-46.6**
Grand total / mean			**394**	**28.7**	**0.87 (0 - 30)**	**24.1**	**0.40 (0 - 8)**	**-15.9**	**-53.9**

Table 7 Descriptive summary of frog survey results at various water bodies types.

Water body type	**Mean coverage of water bodies (m²) per 25ha square** (% of total area)	**No. of sites surveyed** (% of total)	**Site Occupancy** (%)	**Frog density** **per occupied water body** frogs/m2	**including unoccupied water bodies** frogs/m2	**Overall per unit area** frogs/ha (%)
Bog pool	113 (0.045)	38 (9.4)	63.2	1.51	0.25	0.8 (3.4)
Drainage ditch	935 (0.374)	182 (45.0)	52.7	0.83	0.55	20.2 (86.3)
Farmland pond	365 (0.146)	61 (15.0)	52.5	0.58	0.15	1.1 (4.7)
Lake or reservoir	2,052 (0.821)	7 (1.7)	71.4	<0.01	<0.01	0.1 (0.4)
Marsh	1,056 (0.422)	22 (5.4)	72.7	0.22	0.02	0.6 (0.0)
Natural spring	10 (0.004)	9 (2.2)	33.3	0.15	0.01	0.0 (0.0)
Other	2 (0.001)	1 (0.2)	100.0	0.02	<0.01	0.0 (0.0)
River/stream/canal	424 (0.170)	42 (10.0)	26.2	0.05	0.01	0.3 (1.3)
Temporary feature	18 (0.007)	41 (10.0)	26.8	0.97	0.16	0.2 (0.9)
Turlough	18 (0.007)	2 (0.5)	50.0	0.05	<0.01	0.0 (0.0)
Total / Mean	**4,992 (1.997)**	**405 (100.0)**	**49.4**	**0.44**	**0.11**	**23.5 (100.0)**

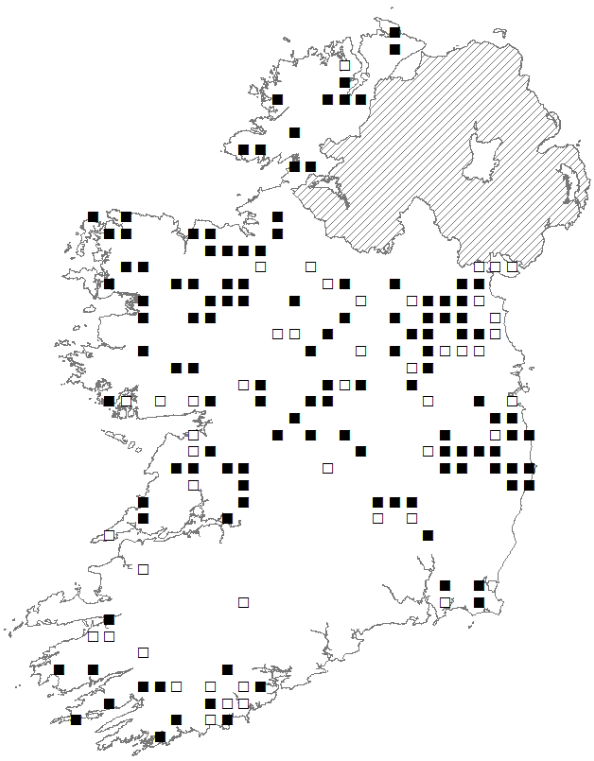


Fig. 6 The distribution of 171 x 500m survey squares successfully surveyed for breeding frogs (originally 394 candidate squares were chosen at random from the existing Common Bird Survey (CBS) methodology conducted by BirdWatch Ireland). Within each square a maximum of 3 water bodies were surveyed for frog spawn presence (filled squares) or absence (open squares) during February and March 2011.

3.2.1 *Aquatic & terrestrial habitats and Future prospects (preceived pressures)*

Twenty-eight aquatic and terrestrial habitat parameters including perceived *pressures* and *threats* were collected in the field (Table 8) and reduced to 11 descriptive variables using Principal Component Analysis (Table 9). The probability of a site being used by frogs for breeding and frog densities varied significantly between water body types (Table 10). Drainage ditches and farmland ponds represented the most commonly surveyed water body types accounting for 182 (45%) and 61 (15%) of sites examined. Drainage ditches and farmland ponds had similar occupancy rates and densities of breeding adults (Fig. 7a & b), but the former were notably more common in the landscape. Frogs were more likely to use sites that were surrounded by marsh, fen and wet flushes and less likely to occupy deep water bodies that lacked aquatic vegetation or those situated in improved grasslands (Table 10a). Frog densities were negatively associated with the presence of both fish (Fig. 7c) and waterfowl (Fig. 7d) and sites surrounded by semi-natural woodland (Table 10b). There was a strong positive trend between frog density and PC5 indicating the presence of scrub as a surrounding habitat and both scrub and long grass as terrestrial refuges within 100m of the breeding site (Table 10b). Occupancy rates and frog densities were notably unaffected by pollution or disturbance.

3.3 Estimating total frog abundance

The observed distribution of estimated frog abundance was significantly different from a normal (D=0.37, p<0.001), half-normal (D=0.55, p<0.001), Poisson (D=0.78, p<0.001) and negative exponential (D=0.47, p<0.001) distribution, but was not significantly different from a negative binomial (D=0.08, p=0.619) distribution (Fig. 8). Specifically, the data were characterized by an extreme degree of right-skew (i.e. positive skew) with an inflated number of zero estimates and a long right tail (i.e. low numbers of high value estimates). A negative binomial model accounting for error in the estimation of the numbers of breeding females at each water body yielded an asymmetric 95% confidence intervals of 23.5 (95%CI 14.9 - 44.0) frogs/ha and a total estimated abundance of 165M frogs (95%CI 104M - 310M) throughout the Republic of Ireland.

Table 8 Descriptive summary of the *perceived pressures* judged to be present at various types of water bodies surveyed for breeding frogs during 2011 throughout the Republic of Ireland (listed from left to right in alphabetical order). Those pressures occurring at >10% of sites are shown in bold.

		Water body type Number (%)										
Perceived ***Impact or threat***		**Bog pool**	**Drainage ditch**	**Farmland pond**	**Lake or reservoir**	**Natural spring**	**Other**	**River, stream or canal**	**Swamp or marsh**	**Temporary feature**	**Turlough**	**Total**
n		38	182	62	6	9	1	42	22	41	2	405
a) *Water quality*												
Poor		9 (23.7)	24 (13.2)	11 (17.7)	0 (0.0)	3 (33.3)	1 (100.0)	4 (9.5)	3 (13.6)	8 (19.5)	0 (0.0)	63 (15.6)
Average		14 (36.8)	115 (63.2)	29 (46.8)	5 (83.3)	4 (44.4)	0 (0.0)	17 (40.5)	9 (40.9)	21 (51.2)	0 (0.0)	214 (52.8)
Good		15 (39.5)	43 (23.6)	22 (35.5)	1 (16.7)	2 (22.2)	0 (0.0)	21 (50.0)	10 (45.5)	12 (29.3)	2 (100.0)	128 (31.6)
b) *Disturbance*												
None		20 (52.6)	82 (45.1)	31 (50.0)	2 (33.3)	3 (33.3)	0 (0.0)	22 (52.4)	5 (22.7)	20 (48.8)	1 (50.0)	186 (45.9)
Some		14 (36.8)	94 (51.6)	24 (38.7)	4 (66.7)	5 (55.6)	0 (0.0)	19 (45.2)	14 (63.6)	9 (22.0)	1 (50.0)	184 (45.4)
Heavy		4 (10.5)	6 (3.3)	7 (11.3)	0 (0.0)	1 (11.1)	1 (100.0)	1 (2.4)	3 (13.6)	12 (29.3)	0 (0.0)	35 (8.6)
c) *Aquatic species*												
Fish		0 (0.0)	15 (8.2)	6 (9.7)	3 (50.0)	0 (0.0)	0 (0.0)	5 (11.9)	1 (4.5)	0 (0.0)	0 (0.0)	30 (7.4)
Waterfowl		1 (2.6)	31 (17.0)	16 (25.8)	4 (66.7)	0 (0.0)	0 (0.0)	7 (16.7)	9 (40.9)	1 (2.4)	1 (50.0)	70 (17.3)
e) *Perceived pressure*												
A01	Cultivation	0 (0.0)	8 (4.4)	2 (3.2)	0 (0.0)	0 (0.0)	0 (0.0)	2 (4.8)	1 (4.5)	2 (4.9)	0 (0.0)	15 (3.7)
A04.01	**Intensive grazing**	**1 (2.6)**	**42 (23.1)**	**10 (16.1)**	**0 (0.0)**	**4 (44.4)**	**0 (0.0)**	**13 (31.0)**	**7 (31.8)**	**10 (24.4)**	**0 (0.0)**	**87 (21.5)**
A04.03	Abandonment	3 (7.9)	18 (9.9)	5 (8.1)	0 (0.0)	1 (11.1)	0 (0.0)	1 (2.4)	2 (9.1)	1 (2.4)	0 (0.0)	31 (7.7)
A10.01	Removal of hedges/scrub	1 (2.6)	20 (11.0)	4 (6.5)	0 (0.0)	0 (0.0)	0 (0.0)	3 (7.1)	2 (9.1)	1 (2.4)	0 (0.0)	31 (7.7)
B02	**Forestry**	**7 (18.4)**	**29 (15.9)**	**2 (3.2)**	**1 (16.7)**	**1 (11.1)**	**0 (0.0)**	**4 (9.5)**	**2 (9.1)**	**1 (2.4)**	**0 (0.0)**	**47 (11.6)**
C01.03.02	Mechanical peat extraction	16 (42.1)	11 (6.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	27 (6.7)
E	Development	1 (2.6)	5 (2.7)	3 (4.8)	0 (0.0)	1 (11.1)	1 (100.0)	1 (2.4)	0 (0.0)	0 (0.0)	0 (0.0)	12 (3.0)
G01	Recreational activities	0 (0.0)	3 (1.6)	6 (9.7)	1 (16.7)	2 (22.2)	0 (0.0)	0 (0.0)	0 (0.0)	3 (7.3)	0 (0.0)	15 (3.7)
H01	**Pollution**	**2 (5.3)**	**52 (28.6)**	**15 (24.2)**	**1 (16.7)**	**4 (44.4)**	**1 (100.0)**	**11 (26.2)**	**3 (13.6)**	**4 (9.8)**	**0 (0.0)**	**93 (23.0)**
I01	Invasive species	0 (0.0)	2 (1.1)	1 (1.6)	1 (16.7)	1 (11.1)	1 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	6 (1.5)
J02.01.03	Infilling	2 (5.3)	11 (6.0)	10 (16.1)	0 (0.0)	1 (11.1)	1 (100.0)	0 (0.0)	1 (4.5)	4 (9.8)	0 (0.0)	30 (7.4)
J02.03	Canalisation	0 (0.0)	3 (1.6)	2 (3.2)	0 (0.0)	0 (0.0)	0 (0.0)	4 (9.5)	1 (4.5)	1 (2.4)	0 (0.0)	11 (2.7)
K01.02/03	**Drying / silting up**	**12 (31.6)**	**55 (30.2)**	**19 (30.6)**	**0 (0.0)**	**3 (33.3)**	**0 (0.0)**	**3 (7.1)**	**8 (36.4)**	**21 (51.2)**	**1 (50.0)**	**122 (30.1)**
K02	Ecological succession	2 (5.3)	21 (11.5)	7 (11.3)	0 (0.0)	1 (11.1)	0 (0.0)	0 (0.0)	4 (18.2)	1 (2.4)	0 (0.0)	36 (8.9)
K03.04	**Predation**	**6 (15.8)**	**32 (17.6)**	**11 (17.7)**	**2 (33.3)**	**1 (11.1)**	**0 (0.0)**	**2 (4.8)**	**6 (27.3)**	**4 (9.8)**	**0 (0.0)**	**64 (15.8)**
O	Other	3 (7.9)	17 (9.3)	6 (9.7)	1 (16.7)	2 (22.2)	0 (0.0)	0 (0.0)	3 (13.6)	5 (12.2)	1 (50.0)	38 (9.4)
X	**No threat apparent**	**9 (23.7)**	**27 (14.8)**	**4 (6.5)**	**2 (33.3)**	**0 (0.0)**	**0 (0.0)**	**12 (28.6)**	**5 (22.7)**	**11 (26.8)**	**1 (50.0)**	**71 (17.5)**

Table 9 Reduction of 28 categorical input variables collected in the field to a set of 11 reduced variables using Principal Component Analysis (unless otherwise stated).

Input variables	Axis	Reduced variable set	Description
1.Water body type	n/a	1. Water body type	Bog pool; drainage ditch; farmland pond; natural spring; river, stream or canal, swamp or marsh and temporary feature
2. Fish	n/a	2. Fish	Presence of fish in each water body
3. Waterfowl	n/a	3. Waterfowl	Presence of waterfowl in each water body
4. Surface area (m^2) 5. Depth (m) 6. % of surface shaded 7. % cover of aquatic plants 8. Bog 9. Fen or wet flushes	PC1	4. Improved grassland	PC Axis #1 accounted for 8.9% of variance (eigenvalue = 2.857) and was positively correlated with improved grassland (r= 0.714) and hedgerows (r= 0.677) and negatively associated with bog (r= -0.770) as surrounding habitats
10. Improved grassland 11. Semi-improved grassland 12. Marsh 13. Semi-natural woodland 14. Scrub 15. Dead wood	PC2	5. Scrub	PC Axis #2 accounted for 8.5% of variance (eigenvalue = 2.474) and was positively correlated with scrub as the surrounding habitat (r= 0.802) and as a terrestrial refuge in the immediate vicinity (r= 0.775) with long grass (r= 0.566)
16. Long grass 17. Hedgerows 18. Piles of stones 19. Scrub 20. Stone walls 21. Good water quality 22. Poor water quality	PC3	6. Pollution	PC Axis #3 accounted for 8.0% of variance (eigenvalue = 1.978) and was positively correlated with perceived pollution (r= 0.514) and poor water quality (r= 0.593) and negatively associated with no disturbance (r= -0.648) and good water quality (r= -0.625)
23. Undisturbed 24. Heavy disturbance 25. Intensive grazing 26. Forestry 27. Pollution	PC4	7. Nearby stone refuges	PC Axis #4 accounted for 6.7% of variance (eigenvalue = 1.526) and was positively correlated with stone walls (r= 0.728) and piles of stones (r= 0.692) as terrestrial refuges
28. Drying or silting up	PC5	8. Semi-natural woodland	PC Axis #5 accounted for 6.4% of variance (eigenvalue = 1.376) and was positively correlated with semi-natural woodland (r= 0.659) as a surrounding habitat and deadwood (r= 0.714) as a terrestrial refuge
	PC6	9. Marsh, fen & wet flushes	PC Axis #6 accounted for 6.0% of variance (eigenvalue = 1.312) and was positively correlated with marsh (r= 0.619) and fens and wet flushes (r= 0.633) as surrounding habitats
	PC7	10. Water depth	PC Axis #7 accounted for 5.6% of variance (eigenvalue = 1.175) and was positively correlated with water depth (r= 0.602) and negatively associated with the perceived threat of drying out (r= -0.727)
	PC8	11. Disturbance	PC Axis #8 accounted for 5.1% of variance (eigenvalue = 1.076) and was negatively associated with heavy disturbance (r= -0.708) and positively associated with aquatic vegetation (r= 0.695)

Table 10 Generalized Linear Mixed Model of breeding site **a)** occupancy and **b)** frog density. A full description of each variable is given in Table 9.

		a) Site occupancy Binomial (logit) - presence / absence				**b) Density** Gamma (logarithmic) - Frogs/m²			
#	Independent variables	*F*	*β* ± s.e.	df	*P*	*F*	*β* ± s.e.	df	*P*
1	Water body type	2.355	Factor	6	**0.030**	4.486	Factor	6	**<0.001**
2	Fish	1.313	-0.591 ± 0.253	1	0.253	17.951	-1.473 ± 0.348	1	**<0.001**
3	Waterfowl	0.028	-0.058 ± 0.868	1	0.868	7.539	-0.772 ± 0.281	1	**0.007**
4	PC1 - Improved grassland	8.201	-0.423 ± 0.148	1	**0.004**	1.245	-0.155 ± 0.139	1	0.266
5	PC2 - Scrub	2.350	0.193 ± 0.126	1	0.126	3.807	0.229 ± 0.118	1	**0.053**
6	PC3 - Pollution	0.615	0.097 ± 0.124	1	0.433	0.152	-0.049 ± 0.126	1	0.679
7	PC4 - Nearby stone refuges	0.214	0.061 ± 0.132	1	0.644	2.366	-0.170 ± 0.110	1	0.126
8	PC5 - Semi-natural woodland	0.989	0.126 ± 0.126	1	0.321	8.221	-0.337 ± 0.118	1	**0.005**
9	PC6 - Marsh, fen & wet flushes	7.854	0.388 ± 0.138	1	**0.005**	0.147	-0.048 ± 0.126	1	0.702
10	PC7 - Water depth	9.068	-0.429 ± 0.142	1	**0.003**	0.233	-0.056 ± 0.116	1	0.630
11	PC8 - Disturbance	3.189	0.234 ± 0.131	1	0.075	0.340	-0.063 ± 0.108	1	0.561

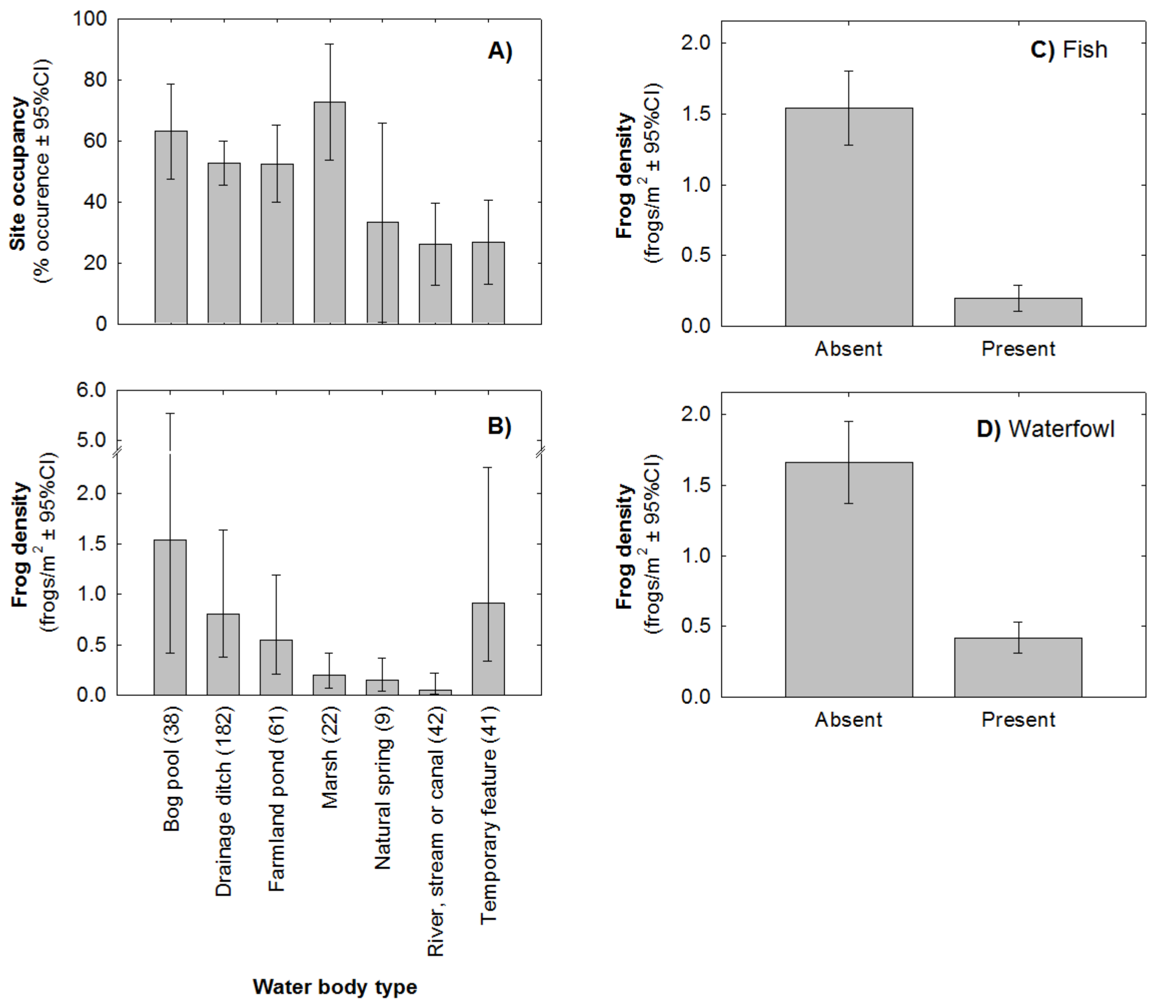


Fig. 7 Mean **a)** site occupancy and **b)** frog density at various water body types ± 95% confidence intervals. Sample sizes (*n*) are given in parentheses on the x-axis labels. Minor categories including Lakes or reservoirs (*n*=7), Turloughs (*n*=2) and other types (*n*=1) were excluded. The effect of the presence of fish and waterfowl on mean frog density ± 95% confidence intervals is shown in **c)** and **d)** respectively.

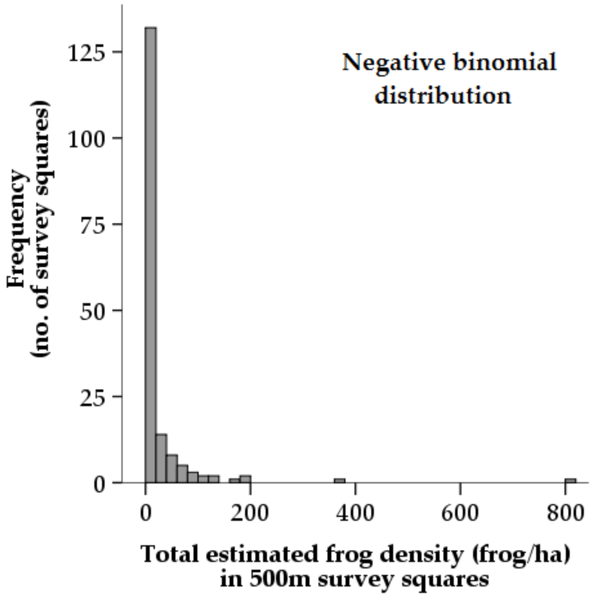


Fig. 8 Frequency distribution of observed frog densities at surveyed 500m squares (*n*= 171) exhibiting a negative binomial distribution.

3.3.1 *Population trends*

Power analysis suggested that if the current sample of 171 survey squares was *re*surveyed in the future and analysed using a paired GLMM (fitting Survey square ID as a random factor to account for multiple observations per square) there would be power of about 60% to detect a 10% change in frog abundance (Fig. 9). However, a subset of only 40-50 squares would be required to detect a 30% change in abundance at an 80% power. Also see *Proposed monitoring protocol*, page 51.

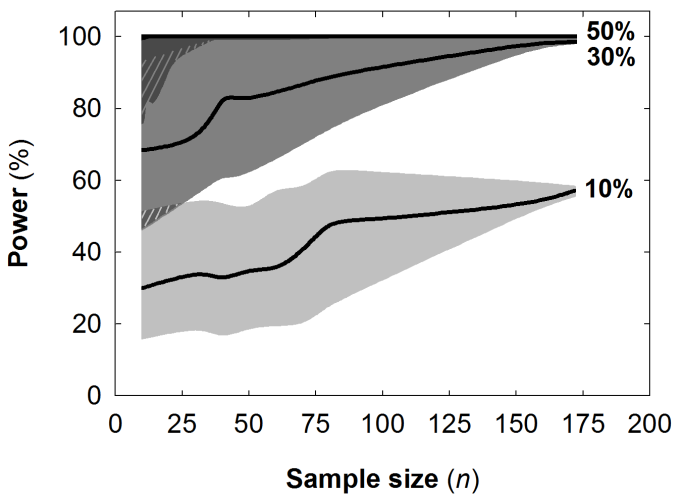


Fig. 9 Sample sizes required for the detection of future population trends assuming a 50%, 30% and 10% reduction in abundance (solid black lines) and their associated 25th and 75th percentiles (grey shading). Hatched areas indicate overlap in the 50% power envelopes.

3.4 Frog distribution

A total of 2,086 frog records were collated between 1st January 2007 and 21st July 2011. A total of 1,720 records (82.5%) were associated with 2-figure grid references or above (i.e. 10km resolution or better). These were used for updating the known distribution of the species at a 10km square resolution.

Frogs were widespread throughout Ireland during 1993-2006 (NPWS, 2008; Fig. 10a) and 2007-2011 (Fig. 10b) and the species' range was taken to be stable at 873 x 10km squares (cells), i.e. the entire land area. Although the '*current distribution*' for the species (i.e. occupied 10km cells) declined by -6.5% from 525 cells (60% occupancy) to 491 cells (56% occupancy) this was not statistically significant ($\chi^2_{df=1}$ = 2.72, p=0.099). In fact, given that the distribution records for the two reporting periods were obtained from many different sources and over different lengths of time, it is surprising they are so similar. Power Analysis suggested that 485-564 occupied cells are required in the Republic of Ireland (see *Proposed monitoring protocol*, page 51) to demonstrate that there has been no significant decline in the '*range*' of the species since baseline.

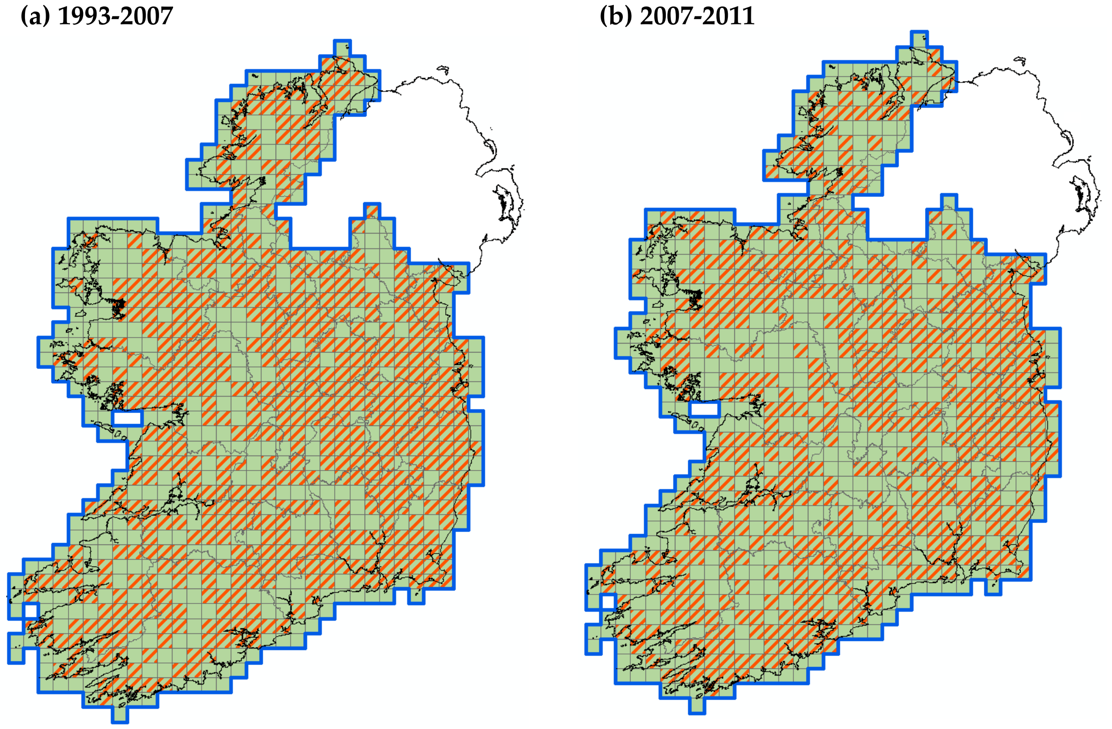


Fig. 10 Change in '*current distribution*' (hatched cells) for the frog throughout Ireland during two time periods: **a)** 1993-2007 (last Article 17 reporting period under the EU Habitats Directive) and **b)** 2007-2011 (current Article 17 reporting period). The bold blue line encompasses both the *Range* and '*Favourable reference range*', which remained the same during both periods.

3.5 GIS biogeographical modelling

A total of 1,693 records that were associated with a 6-figure grid reference or above (i.e. 100m resolution or better) were collated between 1st January 2007 and 21st July 2011. A total of 198 records were associated with surveys conducted during spring 2011 leaving 1,496 records from other sources. A total of 234 records either fell within 500m squares already occupied by other records or fell beyond the land area of Ireland in the sea. Thus, a total of 1,056 records remained within unique 500m squares and were retained for modelling.

Due to the large number of suitable records we partitioned the dataset into a '*training set*' containing 50% of records selected at random (n = 528) and a '*test set #1*' containing 50% of records selected at random (n = 528). We tested the model further using the true presence / absence data from the spawn survey during 2011 as an independent *'test set #2'* (n = 197).

The performance of the final model (Area Under the Curve) using the '*training set*' was AUC = 0.686 and for '*test set #1*' AUC = 0.681; suggesting that approximately 68% of incidentally collected records could be accurately predicted. However, the model's performance was considerably lower using the independent *'test set #2'* where the AUC = 0.529 suggesting that the model was no better than random in being able to predict true presence / absence data (53% success). The model was built using 14 predictor variables describing landscape each selected from 7 candidate scale scales. However, as the final model was no better than random, the full results of the spatial scale selection and final model will not be presented here.

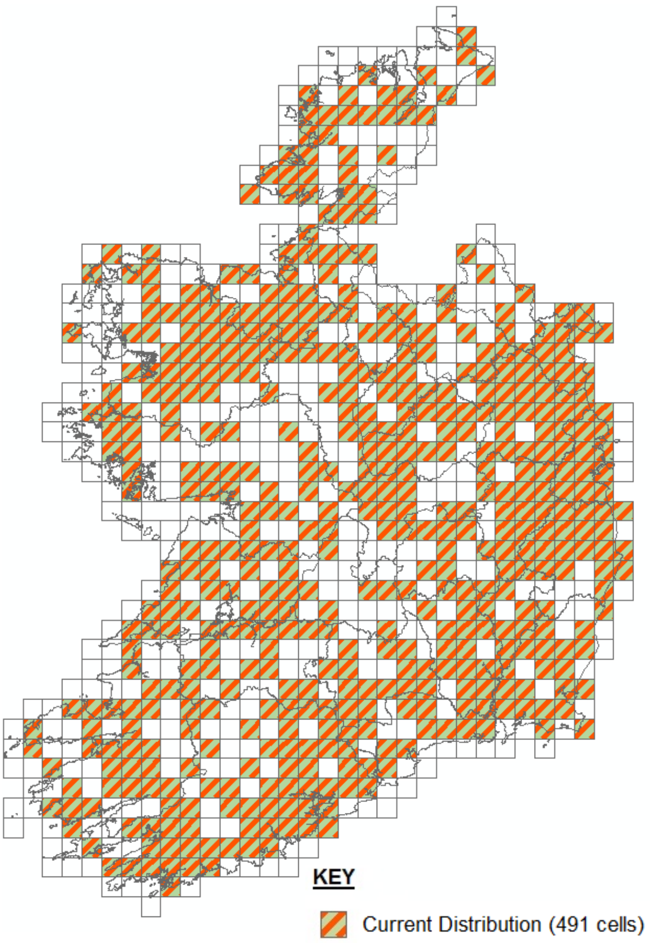
Frogs did not exhibit any discernable or predictable landscape associations and, therefore, their biogeographical distribution could not be adequately modelled. We can conclude that the Irish landscape is sufficiently suitable for frogs that they may occur in any 500m square and, by extension, any 10km square. Thus, despite the apparent failure of the model it provides a robust statistical justification for including all 10km Irish grid squares (cells) in the Ireland within the current and *'favourable reference range'* of the species.

3.6 National conservation assessment

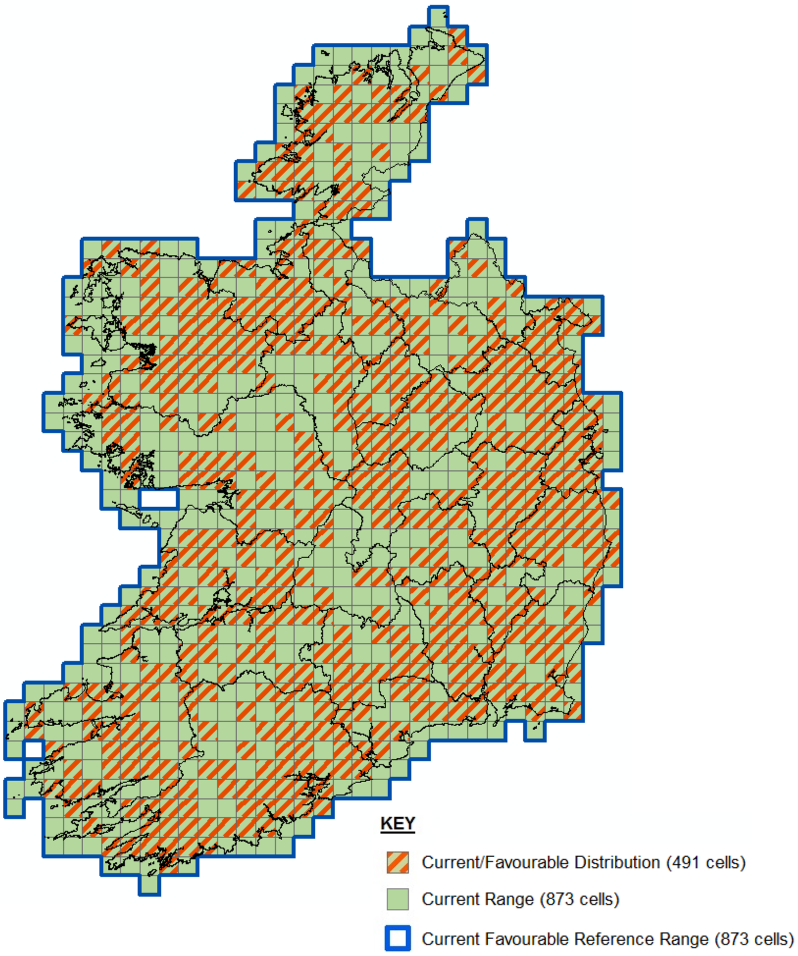
An overall national assessment of the *conservation status* of the frog was determined using the standard parameters derived by the European Comission (i.e. *Range, Population, Habitat* and *Future prospects*). This assessment updates the last Article 17 assessment from 2007 (Fig. 1b). The overall result from the current survey was determined to be Favourable (FV) yielding an apparent improving trend (Table 12) from the Inadequate (U1) status determined at the last assessment. This change can be attributed to improved knowledge of how frogs use the Irish landscape.

Table 12 *Annex B - Reporting format for the 'main results of the surveillance under Article 11' for Annex V species, in this case, the common frog* Rana temporaria *(EU Annex V Species #1213) for the current Article 17 assessment 2007-2013.*

Field name	*Brief explanations*	
0.1 Member State	IE	
0.2 Species	**0.2.1 Species code**	1213
	0.2.2 Species scientific name	*Rana temporaria*
	0.2.3 Alternative species scientific name Optional	n/a
	0.2.4 Common name Optional	Common frog

1 National Level		
1.1 Maps	Distribution and range within the MS concerned	
1.1.1 Distribution map	 **Map 1.1.1** Current distribution (10x10km ETRS grid cells) of the common frog *Rana temporaria* (1213) during the reporting period 2007-12. **Explanatory note** Frog records occupied a total of 491 cells (10km^2 grid squares) during 2007-2012.	Indicate if species is 'sensitive'[1] **NO**
1.1.2 Method used - map	3 = Complete survey	
1.1.3 Year or period	January 2007 - May 2011	

[1] See the definition of a sensitive species in section 1.1.1 of the EU Habitats Directive Guidelines

<table>
<tr><td>1.1.4 Additional distribution map
Optional</td><td>n/a</td></tr>
<tr><td>1.1.5 Range map</td><td>

Map 1.1.5 Range and Favourable Reference Range (10x10km ETRS grid cells) of the common frog Rana temporaria (1213) during the reporting period 2007-12.

Explanatory note
Gaps in the range were filled assuming suitable habitat was present within 3 cells distant between occupied cells (in a straight line) or within 2 cells at right angles in the oblique or, if beyond this, assumed suitability derived from GIS biogeographical modelling.</td></tr>
</table>

2 Biogeographical level Complete for each biogeographical region or marine region concerned		
2.1 Biogeographical region & marine regions	Atlantic (ATL)	
2.2 Published sources	1. Reid, N., Dingerkus, S.K., Stone, R.E., Buckley, J., Beebee, T.J.C. & Wilkinson, J.W. (2013) National Frog Survey of Ireland 2010/11. *Irish Wildlife Manuals*, No. 58. National Parks and Wildlife Service, Department of Arts, Hertiage and the Gaeltacht, Dublin, Ireland. 2. Dingerkus, S.K., Stone, R.E., Wilkinson, J.W., Marnell, F. & Reid, N. (2011) Developing a methodology for the National Frog Survey of Ireland: a pilot study in Co. Mayo. *Irish Naturalists' Journal*, 31(2); 85-90. 3. Reid, N., Dingerkus, S.K., Stone, R.E., Kelly, R., Pietravalle, S., Buckley, J., Beebee, T.J.C., Marnell, F., Wilkinson, J.W. (2013) Population enumeration and assessing conservation status in a widespread amphibian: a case study of *Rana temporaria* in Ireland. *Animal Conservation* (awaiting pagination). 4. Reid, N., Dingerkus, S.K., Stone, R.E., Buckley, J., Beebee, T.J.C., Marnell, F., Wilkinson, J.W. (2013) Assessing historical and current threats to common frog *Rana temporaria* populations in Ireland. *Journal of Herpetology* (awaiting pagination).	
2.3 Range	Range within the biogeographical region concerned	
2.3.1 Surface area Range	87,300 km². **Explanatory note** 873 (favourable reference range) x 100km² (area of each 10x10km grid cell) = 87,300 km² for the total surface area of the range.	
2.3.2 Method used Surface area of Range	2 = Estimate based on partial data with some extrapolation and/or modelling	
2.3.3 Short-term trend Period	2001-2012 (rolling 12-year time window)	
2.3.4 Short term trend Trend direction	0 = stable	
2.3.5 Short-term trend Magnitude Optional	**a) Minimum**	n/a
	b) Maximum	0%
2.3.6 Long-term trend Period Optional	n/a	
2.3.7 Long-term trend Trend direction Optional	unknown	
2.3.8 Long-term trend Magnitude Optional	**a) Minimum**	n/a
	b) Maximum	n/a
2.3.9 Favourable reference range	a) 87,300 km². A GIS shapefile has been provided.	
	b) n/a	
	c) n/a	
	d) n/a	
2.3.10 Reason for change Is the difference between the reported	a) genuine change? **n/a** (i.e. no change)	

value in 2.3.1. and the previous reporting round mainly due to…	b) improved knowledge/more accurate data? **n/a**	
	c) use of different method (e.g. "Range tool")? **n/a**	
2.4 Population		
2.4.1 Population size estimation (using individuals or agreed exceptions where possible)	**a) Units**	Absolute numbers (individuals)
	b) Minimum	104 million frogs
	c) Maximum	310 million frogs
2.4.2 Population size estimation (using population unit other than individuals) Optional *(if 2.4.1 filled in)*	**a) Unit**[2]	Density (frogs/ha)
	b) Minimum	15 frogs/ha
	c) Maximum	44 frogs/ha
2.4.3 Additional information on population estimates / conversion Optional	**a) Definition of "locality"**	n/a
	b) Method to convert data	Derived from a custom negative binomial model to generate the total population assuming the mean number of individuals per water body (derived from a complete survey) multiplied by the availability of water bodies (derived from a complete survey).
	c) Problems encountered to provide population size estimation	None
2.4.4 Year or period	2011	
2.4.5 Method used Population size	3 = Complete survey or a statistically robust estimate	
2.4.6 Short-term trend Period	2001-2012 (rolling 12-year time window)	
2.4.7 Short-term trend Trend direction	x = unknown	
2.4.8 Short-term trend Magnitude Optional	**a) Minimum**	x = Unknown
	b) Maximum	x = Unknown
	c) Confidence interval	x = Unknown
2.4.9 Short-term trend Method used	0 = Absent data	
2.4.10 Long-term trend – Period Optional	A trend calculated over 24 years.	
2.4.11 Long-term trend Trend direction Optional	x = unknown	
2.4.12 Long-term trend Magnitude Optional	**a) Minimum**	x = Unknown
	b) Maximum	x = Unknown
	c) Confidence interval	x = Unknown
2.4.13 Long term trend Method used Optional	0 = Absent data	

[2] If a population unit is used other than individuals or the unit of the list of exceptions this data set is recommended to be converted to individuals. The converted data should be reported in the field 2.4.1.

2.4.14 Favourable reference population	a) ≥15 frogs/ha or ≥ 104 million individuals **Explanatory note** Amphibian populations are characterisied by high interannual amplitude in abundance. Thus the favourable reference population has been taken as the lower 95% confidence interval for the baseline estimates during 2011. Consequently, conservation objectives should aim to maintain a mean density and abundance greater than the lowest estimate at baseline.
	b) ≥ equal to or greater than
	c) n/a
	d) mean population density and total estimate rather than minimum or maximum values as presented above
2.4.15 Reason for change Is the difference between the value reported at 2.4.1 or 2.4.2 and the previous reporting round mainly due to:	a) genuine change? **NO** **Explanatory note** The current study was the first baseline estimate of frog denisty and abundance in Ireland so no estimate of change can be made.
	b) improved knowledge/more accurate data? **YES** **Explanatory note** The current study was the first baseline estimate of frog denisty and abundance in Ireland.
	c) use of different method (e.g. "Range tool")? **YES** **Explanatory note** Previously, the number of occupied 10km squares (525 cells) was used as a proxy for population and was taken as the favourable reference population. Here we use data from a complete survey or a statistically robust estimate.
2.5 Habitat for the species	
2.5.1 Area estimation	70,300 km² (87,300 km² – 17,000 km² of sea included in the 873 x 10km squares) **Explanatory note** A total of 2% of the total land area was estimated to be suitable as frog breeding habitat (derived from a complete survey or a statistically robust estimate). Assuming the total land area of the Republic of Ireland is 70,300 km² then the total area estimated to be suitable <u>as breeding habitat</u> for the species is 1,406 km². However, it should be noted that any area may be suitable for frogs outside of the breeding season as no habitats appear to be avoided. Thus, the figure presented is the area estimated to be suitable throughout their life cycle.
2.5.2 Year or period	2011
2.5.3 Method used **Habitat for the species**	3 = Complete survey or a statistically robust estimate
2.5.4 Quality of the habitat	a) Good
	b) 2% of the landscape was suitable frog breeding habitat and water bodies had an average occupancy of approx. 50%. GIS biogeographical modelling suggested that frogs could occur practically anywhere. Other modelling suggested that only the perceived impacts and threats of intensive grazing and pollution negatively influence frog occurrence and these occurred singly at <25% of water bodies and together at just 8% of water bodies. Therefore, the availability of habitat and its suitability was generally perceived to be "Good".
2.5.5 Short-term trend **Period**	2001-2012 (rolling 12-year time window)
2.5.6 Short-term trend **Trend direction**	x = unknown
2.5.7 Long-term trend **Period** Optional	

2.5.8 Long-term trend **Trend direction** Optional	0 = stable **Explanatory note** Farmland pond occurrence has remained largely stable between 1887-1913 to 2005-2011, decreasing marginally from 28.7% to 24.1% of 1km squares containing at least one pond. Despite the mean number of ponds per 1km square decreasing -53.9%, estimates of breeding densities suggest that only 4.7% of frogs used farmland ponds for breeding with the majority using drainage ditches which are common. Thus, the availability of suitable habitat has probably remained stable over the long-term.
2.5.9 Area of suitable habitat for the species	a) 70,300 km²
2.5.10 Reason for change Is the difference between the value reported at 2.5.1 and the previous reporting round mainly due to	a) genuine change? **NO**
	b) improved knowledge/more accurate data? **YES**
	c) use of different method (e.g. "Range tool")? **YES**

2.6 Main pressures		
a) Pressure	**b) Ranking**	**c) Pollution qualifier**
A01 Cultivation	L	
A04.01 Intensive grazing	L	
A04.03 Abandonment	L	
A10.01 Removal of hedges/scrub	L	
B02 Forestry	L	
C01.03 Mechanical peat extraction	L	
E Development	L	
G01 Recreational activities	L	
H01 Pollution	L	P
I01 Invasive species	L	
J02.01. Infilling	L	
J02.03 Canalisation	L	
K01.02 Drying / silting up	L	
K02 Ecological succession	L	
K03.04 Predation	L	
O Other	L	
Explanatory note L = low importance – *Perceived pressures* P = Phosphate		
2.6.1 Method used – Pressures	3 = based exclusively or to a larger extent on real data from sites/occurrences or other data sources	

2.7 Threats		
a) Threat	**b) Ranking**	**c) Pollution qualifier**
A01 Cultivation A04.01 Intensive grazing A04.03 Abandonment A10.01 Removal of hedges/scrub B02 Forestry C01.03 Mechanical peat extraction E Development G01 Recreational activities H01 Pollution I01 Invasive species J02.01. Infilling J02.03 Canalisation K01.02 Drying / silting up K02 Ecological succession K03.04 Predation O Other **Explanatory note** L = low importance P = Phosphate	L L L L L L L L L L L L L L L L	P
2.7.1. Method used – Threats	1 = expert opinion	

2.9 Conclusions ***(assessment of conservation status at end of reporting period)***	
2.9.1. Range	Favourable (FV)
2.9.2. Population	Favourable (FV)
2.9.3 Habitat for the species	Favourable (FV)
2.9.4 Future prospects	Favourable (FV)
2.9.5 Overall assessment of Conservation Status	Favourable (FV)
2.9.6 Overall trend in Conservation Status	Improving **Explanatory note** Previous Article 17 assessment concluded an overall status of Inadequate U2, thus, the conservation status has improved, but this perceived change is due to improved knowledge of how frogs use the Irish landscape.

4. Discussion

4.1 National frog survey of Ireland

This is the first study to make a quantitative assessment of the conservation status of the common frog *Rana temporaria* (EU Annex V species 1213) throughout the Republic of Ireland based on standardised field survey methods. Although survey effort was low in a few areas (central/southern counties), the results nevertheless provided a robust assessment of the status of frogs in Ireland. Future work should include extra effort to secure data from the under-surveyed regions. Nevertheless, Ireland is now well-placed to assess future trends in the frog population and is therefore among the relatively few countries in a comparable position with respect to robust scientific information on amphibians at a national scale.

Just over half of Ireland's farmland ponds were lost from 1887-1913 to 2005-2011 with most ponds and greatest losses in the East. Declines were in the order of 0.5% per annum which, though significant, is substantially less than losses in other European countries. Such losses occurred during a period of extensive change to the agricultural landscape due to a well-funded programme of land drainage over several decades. The 'Land Project' (1944-1974), the 'Farm Modernisation Scheme' (1974-1985) and the 'Western Drainage Scheme' (1979-1988) drained over one million hectares and initiated unprecedented removal of natural wetlands throughout Ireland including ponds, marsh, fens and wet flushes as well as associated riparian corridors (Marnell, 1998b). Consequently, the loss of ponds should be taken as a proxy of the wider loss of natural wetland habitat more generally which would include other important frog breeding sites for which accurate data on losses was not available.

Frogs are associated with humid habitats and breeding adults are considered to be opportunistic in their choice of breeding site (e.g Arnold, 2002; Inns, 2009). Adult frogs do not always return to their natal pond for spawning and utilize any available and suitable water body (Savage, 1961). However, some mark-recapture studies suggest a high degree of site fidelity once a breeding location is chosen as an adult (Haapanen 1970; Alho *et al*., 2009). Nevertheless, colonization of new water bodies occurs readily when these are created near to existing breeding sites (Baker and Halliday, 1999). Synchronous with the land drainage projects of the mid-1900s was the installation of field margin ditches to channel water away from agricultural land. In the current study, such sites had comparable occupancy rates and breeding frog densities as farmland ponds and now represent the majority of available frog breeding habitat. Thus, the loss of natural wetland habitats throughout Ireland may have been partially or wholly mitigated by a synchronous expansion in the use of artificial field margin ditches associated with drainage.

Frogs in Ireland were opportunistic in their choice of breeding site which is a good strategy for a near-ubiquitous amphibian with broad habitat tolerances in light of environmental stochasticity (*sensu* Griffiths, 1997). It may be particularly effective in the absence of larval competition from other widespread anurans, as is the case in Ireland. This study did not explicitly include any measure of habitat fragmentation which can be important in explaining species distributions. Nevertheless, we posit that the extent of improved grassland is a reasonable proxy for habitat patch isolation as large areas of intensively farmed monocultural grassland are typically unfragmented effectively isolating any water bodies found therein. Indeed, intensively farmed landscapes have been shown to be barriers to frog movement (Vos *et al.*, 2007) and site occupancy rates in Ireland were negatively associated with water bodies situated in improved grassland. Frogs were associated with areas of marsh, fen and wet flush but they avoided deep water bodies. Shallow wetlands provide warm aquatic microhabitats for rapid development of spawn and tadpoles, plus an abundance of food for tadpole growth. Breeding frogs should be associated with permanent water bodies (Loman and Andersson, 2007), as recruitment in temporary features often fails totally due to drying out (Loman, 2002). However, sites that are particularly deep are likely to have cooler water temperatures than shallower sites which may slow egg hatching rates and tadpole development making them less suitable for breeding.

Some frogs populations are capable of fluctuating by a factor of 10-fold between years (Raithel *et al.* 2011). However, as this survey was restricted to one year (2011), calculated density was, therefore, treated as a spatial (rather than temporal) measure of relative abundance. Frog density was significantly lower at sites where fish and waterfowl where present. The former are likely to predate frog eggs and tadpoles whilst the latter alter water chemistry, increase water pH and generally cause euthrophication in small waterbodies by the addition of their faeces (Fleming & Fraser, 2001). Moreover, both fish and waterfowl are more likely to occur at large waterbodies and their effects are likely to be additive. Frog density was also negatively associated with water bodies surrounded by semi-natural woodland. Such water bodies are likely to be shaded keeping them cooler and less suitable as breeding habitat than water bodies in sunnier locations. There is much evidence that various types of pollution (e.g., Rouse *et al.*, 1999; Sparling *et al.*, 2001; Mann *et al.*, 2009) and intensive agricultural practices (e.g., Loman & Lardner, 2009; Johansson *et al.*, 2005), have negative effects on amphibian populations. Nevertheless, frog occupancy rates and breeding densities were unaffected by pollution or disturbance in the current study; though it should be remembered that the presence of these factors as threats was based on the perceptions of surveyors. Also, frog density may not necessarily correlate with high reproductive success. Breeding sites with high densities can be sinks that are fed by immigration rather than source populations with high recruitment. Thus, breeding densities may not necessarily correlate with habitat or water quality. Consequently, specific quantitative studies would be necessary to elaborate on the interaction of habitat or water quality and reproductive success and the influence of pollution or disturbance as threats in an Irish context.

Biogeographical modelling failed to reveal specific landscapes that could be used to predict the presence of frogs, implying that this species is a generalist capable of adapting to a wide range of microhabitats. Three surveys conducted between 1993 and 2003 suggested that *R. temporaria* was present in almost every 10km square throughout Ireland and that it was frequently abundant (Marnell, 1999; IPCC, 2003). Here, we demonstrate that the recorded distribution of the species did not change significantly throughout the Republic of Ireland since the last Article 17 assessment between 1993-2006 (NPWS, 2008). Gaps in the species' distribution may be attributed to poor coverage of survey effort (see NPWS, 2008). Moreover, some of the marginal decrease in 10km square occupancy can be attributed to the difference in the length of the two recording periods i.e. 13 years from 1993 to 2006 compared to 5 years from 2007 to 2011. Ideally, we would use periods of equal length and data derived from surveys with comparable survey effort. However, the EU Habitats Directive constrains the methodologies available to member states due to regulations requiring that distribution is set during previous reports and secondly by restricting future survey cycles to periods ≤6 years.

The current study estimated the density of breeding frogs only. Abundance estimates for breeding females were derived from the occurrence and coverage of spawn (accounting for error in the relationship between spawn mat area and the number of spawn clumps originally deposited) whilst the male population was extrapolated assuming a sex ratio of 1:1. Total frog density is likely to have been substantially higher as it will have included some non-breeding adults and non-breeding cohorts of young animals. Other sources of potential error include the application of a standard formula (extracted from Griffiths *et al.* 1996) to all sites for the calculation of the number of breeding females from spawn mat area. This was derived from a focal study of eighteen ponds situated mostly in farmland in Kent, England. It may be that the relationship between spawn mat area and the number of breeding females is contingent on the surface area of the breeding site and will, therefore, vary between types of breeding sites. For example, drainage ditches have a relatively narrow surface area often filled with vegetation which may constrain the swelling of the spawn post-deposition. Nevertheless, Griffiths *et al.* (1996) provided the only useful formula for estimating numbers of breeding females.

Accounting for error in the estimation of the numbers of breeding females at each water body and the distribution of frogs at breeding sites, the mean estimated frog density during 2011 was 23.5 frogs/ha (95%CI 14.9 - 44.0 frogs/ha). This figure is well within the range of values for temperate anurans with comparable ecology such as the common toad *Bufo bufo* for which Beebee (1996) and Wilkinson *et al.*

(2007) estimated densities at >20 toads/ha. Nevertheless, it is lower than estimates for *R. temporaria* elsewhere, for example, 64 - 80 frogs/ha in Finland (Pasanen *et al.* 1993) and 56 frogs/ha in 'good' habitat in Scotland (Langton & Beckett, 1995). In comparison, other similar species such as *R. pretiosa* can reach densities of up to 100 frogs/ha (Cuellar, 1994). However, it should be noted that variance in the densities reported in these studies may be as much to do with varying methodologies as interspecific and biogeographical differences in amphibian abundance. Our density estimate was also lower than a previous estimate in Ireland of 38 frogs/ha (Ferdia Marnell cited in NPWS 2008), but this was derived in apparently 'ideal' breeding habitat. However, this estimate was well within our confidence interval.

Pastoral agriculture covers >80% of Ireland (EEA, 2010) and our results suggest that field margin drainage ditches are common (935m per 500m survey square equated to 35m/ha). Moreover, Ireland's mild maritime climate and high rainfall make it particularly suitable for *R. temporaria*. Thus, 86.3% of frogs bred in drainage ditches with a total population estimated at 165M (95%CI 104M - 310M). We therefore infer that frogs are probably one of the most numerous vertebrates in Ireland (the only other likely contender being the wood mouse *Apodemus sylvaticus*) and are thus in favourable or good conservation status. Frogs prey on a wide range of invertebrates, most notably molluscs, larval lepidoptera, coleoptera and diptera (Savage, 1961; Houston, 1973; Blackith & Speight, 1974). It is therefore likely that they provide a valuable ecosystem service by predating large quantities of agricultural and garden pests. Moreover, the frog is a key element of the diet of larger species. For example, they may constitute up to 19.2% of the diet of otters, a species of conservation concern, in freshwater systems throughout Ireland (Reid *et al.* 2012b). Hence, *R. temporaria* is likely to be a key component in Ireland's biodiversity occupying a key trophic position in the food web.

4.2 Current conservation status

The overall conservation status of the common frog *Rana temporaria* (Annex V species 1213) was determined as Favourable FV or 'good' (green). The previous Article 17 assessment assessed the species status as Inadaquate U1 or 'poor' (amber). The change in conservation status is not, however, genuine change but is attributable entirely to 'improved knowledge and more accurate information' using different methods to the last assessment. In particular, given that perceived habitat loss was the main reason for the Inadequate assessment in 2007 (NPWS, 2008) the information gathered on habitat use by frogs in the national survey was particularly informative. This adaptable species has clearly embraced agricultural ditches for breeding purposes giving itself enormous areas of suitable breeding waters throughout the country. Our understanding of frog distribution and range has also improved.

Specifically, the last Article 17 assessment created a baseline distribution from incidentally collected records from various sources from 1993 to 2006. The current assessment drew not only on incidentally collected records but also has the benefit of a targetted field survey of frog distribution and abundance with some statistical extrapolation and modelling. The methodology employed here to survey frog distribution and the model developed to estimate total abundance, provides a model for other EU member states to follow when conducting future conservation assessments for *R. temporaria* and other clump spawning amphibians. We demonstrate that a network of surveyors deployed during just one season can provide the data necessary for fulfilling EU reporting obligations at a national scale.

4.3 Proposed monitoring protocol

The protocols employed during the National Frog Survey of Ireland 2010/11 (also see Dingerkus *et al.*, 2011) appeared appropriate and succeeded in generating baseline information against which future monitoring of *Rana temporaria* in Ireland can be judged. To ensure that future Article 17 reports are consistent with the current baseline and are simplified to ensure ease of reporting, a protocol for assessing the conservation status of the species is outlined below:

4.3.1 Surveyors

Future monitoring can be achieved most easily by co-opting the field support of NPWS Conservation Rangers. 500m survey squares can be allocated to each NPWS Conservation Ranger based on their inclusion within the districts for which those rangers are responsible.

4.3.2 Health & Safety

Survey teams should consist of a minimum of two persons for Health & Safety reasons. Water bodies are frequently in wet habitats including bogs or marshes where conditions underfoot may be difficult to traverse or the banks of water bodies may be steep and unstable making survey treacherous. It is important to carry a handheld GPS device (with spare batteries) and a 1:10,000 map to aid navigation and a mobile phone for communication should surveyors get into any difficulties. A Health & Safety risk assessment should be carried out in accordance with NPWS standard guidelines (or those of any contractor undertaking the work). Outdoor clothing is essential including waterproofs and sufficient water must be carried to remain hydrated as some sites are a considerable distance from the road.

4.3.3 Site access

Water bodies suitable for survey frequently occur on farmland. Therefore, it is important to respect people's rights and employ good practise to raise awareness of future surveys and to make contact with farmers and local landowners prior to accessing each site. Whilst locals may not be the owners of the land to be surveyed it may be important to make contact to allay any fears within Community Watch groups.

4.3.4 Technical support

Field teams should be supported by at least one person with appropriate IT skills including GPS and GIS expertise. Hardware required includes a laptop (preferably a notebook suitable for use in the field), Personal Digital Assistants (PDAs) and a handheld GPS device whilst software required includes Microsoft Excel, Microsoft Access (i.e. Microsoft Office), ArcGIS 10 (ESRI, California, USA). It is essential that data are collected in a fashion compatible with standard methods of data storage (principally, Microsoft Access).

4.3.5 Training

Training for potential field surveyors is essential. Fieldworkers should be familiar with the habitats that frogs are likely to use for breeding and the associated Health & Safety hazards. A clear understanding of the field survey methods is also required to ensure data is collected in a consistent manner. Generally, two training days are required; one located in the south and one in the north to enable access to training by all NPWS Conservation Rangers. An inventory should be kept of attendance as the quality of the data returns may vary and this is likely to be associated with whether a surveyor attended a training session. It is recommended that each training event has an indoor session to cover the theoretical basics including the layout of survey sheets, how they should be completed, relevant equipment, software etc and an outdoor session at a suitable water body (or multiple water bodies of different types) to demonstrate the field methods to ensure consistency between surveyors. The length of the training session should be tailored to the previous experience of the surveyors.

Training should include estimating spawn mat area, identification of all relevant aquatic and terrestrial variables and information on the guidelines relating to the presence of perceived imapcts and threats as listed by the EU Habtiats and Species Directive.

4.3.6 Timing

Key within this proposal is the use of multiple (three) well-timed visits to count spawn clumps and measure spawn mat area in order to determine the population size of breeding adults (Griffiths *et al.* 1996; Dingerkus *et al*. 2011). The first visit should be made shortly after the first appearance of spawn locally, the second approximately 7 days after the first and the third approximately 14 days after the first. Habitat surveys can be completed prior to spawn survey to ensure that field surveyors are familiar with their survey squares and can execute spawn surveys expediently.

4.3.7 Survey sheets

The survey sheets used to collect habitat and spawn data in the field during this survey (Appendices I and II) were relatively straightforward including 3 pages of tick boxes with some specific measurements required. Whilst we could recommend that these be refined further with variables restricted to only those found to statistically influence frog occurrence or abundance it seems more appropriate, for consistency, to collect the same data during the next round of monitoring. Moreover, all preceived pressures found during the current survey should be assessed during future monitoring to evaluate their frequency and any temporal change.

4.3.8 Quality assurance and data manipulation

It is a frequent problem in large, national surveys involving multiple surveyors that data quality may vary. Each surveyor should be individually responsible for ensuring that all their data are clear, complete, correct and in the right format prior to the end of the field season and returning the data for analysis. Any abbreviations used should be fully explained in accompanying notes and should follow accept standards e.g. EU Habitat Directive *impact and threat* codes.

4.4 Conservation Assessments

4.4.1 Range

Assessing the '*current distribution*' is most easily addressed by collating all possible sources of frog records during the assessment period. These include but are not limited to: the National Biodiversity Data Centre, the National Parks and Wildlife Service (including any other survey that may incidentally record frogs), the Irish Peatlands Conservation Council (IPCC) and www.biology.ie (courtesy of Paul Whelan). Consideration can also be given to providing a custom made website to solicit records during the assessment period.

An atlas of frog records should be created based on the 10km Irish grid system and the number of occupied cells compared with the baseline established during 1993-2006 (the first Article 17 report under the EC Habitats Directive for the frog).

4.4.2 Population

The European Commission advocates monitoring populations with a regime sufficient to detect a 10% decline over a period of 10 years. The current sampling regime provides just under 60% power to detect such a small change. However, a substantially larger sample to achieve the generally acceptable level of 80% power would be practically prohibitive in terms of manpower and time. A reduced sampling regime of 40-50 survey squares appears sufficient to detect a 30% decline (consistent with the IUCN Category of 'Vulnerable') at 80% power and is thus achievable with substantially less effort than the current survey. The EU Habitats Directive requires a reporting schedule of ≤6 years and, therefore, we advocate that frog surveys should be integrated into this schedule, however, it should be noted that this will not account for natural interannual variability. This would dictate that the next survey should occur in 2017 in advance of the 2019 Article 17 reporting round. In future surveys, when squares are being allocated, it would be wise to include a ~10% contingency should any allocated squares "fail" to be surveyed for any reason. To this end, a selection of survey squares (n=60) and specific water bodies are listed in Appendix III and are to be taken as the core sample for future monitoring. These recommendations are based on a power analysis between two discrete surveys representing snap-shots in time. We have no data on the potential interannual variability of frog populations which may result in wider confidence limits than otherwise expected.

In order for future population estimates to be comparable to the current baseline, habitat surveys will be required to quantify the total length of all linear water bodies and the number of discrete water bodies that occur in each survey square (see Appendix I). Two approaches could be taken: i) assume that the availability of water bodies is likely to remain the same (in which case no new habitat survey is required) or ii) a new survey is completed to assess rates of water body loss or gain. We advocate the latter approach.

Thereafter, spawn surveys (see Appendix II) are required to estimate the total spawn mat area at each water body within each square being monitored. We advocate following the methods of Griffiths *et al.* (1996) and Dingerkus *et al*. (2011) to convert cumulative spawn mat area into a population estimate for each water body to be expressed as frogs/m^2. This may then be multiplied by the total area of water body available for breeding in each square and subsequently expressed as frogs/ha.

Frog density exhibits a negative binomial distribution and a customised population model will be required. We advocate fitting a negative binomial distribution to the observed data before generating a new distribution (assuming identical fit parameters to that of the observed data) for the total number of available 500m squares in the Republic of Ireland (n=296,905). The sum of all generated values will represent the total estimate of abundance. This approach must be repeated using both the upper and lower 95% confidence limits of frog abundance associated with the linear relationship between cumulative spawn mat area and the number of discrete spawn clumps for individual survey squares to provide margins of error.

Alternatively, a paired test of difference (for example, a Wilcoxon test for matched pairs or a Generalized Linear Model assuming a negative binomial error structure fitting survey as a fixed factor) could be used to test whether relative abundance and/or density varies between surveys providing greater statistical power than simply comparing the overlap in 95% confidence intervals associated with absolute abundances.

4.4.3 Habitat

The response of frog occurrence and density should be modelled with respect to habitat variables collected in the field to detemine whether changes in suitable habitat have influenced frog populations.

4.4.4 Future propects (preceived pressures)

The *preceived pressures* present at each water body should be categorised according to those listed on the template survey form provided (Appendix II). The prevalence of each pressure should be expressed as a percentage of all water bodies and temporal trends assessed. Modelling of site occupancy may reveal if any of these preceived pressures negatively influence the occurrence of frogs at sites and these should be listed under future conservation assessments.

4.4.5 Overall assessment

The guidelines for the completion of the conservation assessments are regularly updated and made available on the European Topic Centre website: http://bd.eionet.europa.eu/ (EIONET, 2008).

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APPENDIX I - Habitat Data Recording Form

PLEASE COMPLETE ONE FORM PER SQUARE
PLEASE COMPLETE ALL DATA FIELDS

Survey square and surveyor details

Survey square ID	

Please shade in ¼km² surveyed for waterbodies

Surveyor	
Address	
Telephone	
E-mail	

Please tick the type of waterbodies present (500m)

Type	**Tick**	**Is waterbody likely to be permanent**
Bog pool		
Drainage ditch		
Lake or reservoir (>2ha)		
Natural spring		
Pond (>1m² and <2ha)		
River / stream / canal		
Swamp or marsh		
Temporary feature		
Turlough		
Other (please specify)		

Please check for ponds in your square (full 1 km²) (see map)

Pond Loss in 1km² square	**Number**
Number of ponds present pre-1913 i.e. highlighted on map	
Number of ponds still present on the ground	

Number of new ponds found in 1 km²	
Grid reference of any new pond	

On map use a red cross to highlight ponds that have been lost

APPENDIX II - Spawn Data Recording Form

PLEASE COMPLETE ONE FORM PER WATERBODY
PLEASE COMPLETE ALL DATA FIELDS (don't leave any blanks)

Water-body and surveyor

Survey square ID	
Water body grid ref. (6-figure)	

Surveyor	
Address	
Telephone	
E-mail	

Type, size and details

Type	Tick
Bog pool	
Drainage ditch	
Lake or reservoir (>2ha)	
Natural spring	
Pond (>1m^2 and <2ha)	
River / stream / canal	
Swamp or marsh	
Temporary feature	
Turlough	
Other (please specify)	

Measures		
Estimate water body length surveyed	m	
Estimate water body width	m	
% perimeter shaded to the south	%	
% surface covered by aquatic vegetation	%	
Maximum water depth	cm	

Details	Yes	No
Is there evidence of recent site management?		
Is the water-body likely to be permanent?		
Are there fish present?		
If so, what species?		
Fish abundance (few / many)		

Water quality (please tick)

	Poor	Average	Good
Water quality			

	Present	Absent
Waterfowl		

Site disturbance

None	Some	Heavy

Please turn over the page

Frog and spawn data

	Visit 1	Visit 2	Visit 3
Date			
% shoreline surveyed	%	%	%
Number of adult frogs			
Number of immature froglets			
Tadpoles (p= present or a= absent)			
Number of discrete spawn clumps			
Total cumulative area of spawn	cm^2	cm^2	cm^2
Newts (p= present, a= absent)			

Surrounding habitats, terrestrial refuges and threats

Habitat (within 100 m)	Tick
Bog	
Fen / flushes	
Heath / bracken	
Improved grassland	
Semi-natural grassland	
Marsh	
Broad-leaved/mix Semi-natural woodland	
Conifer plantation Non-native woodland	
Scrub	
Coastal habitat	
Cultivated / arable land	
Built land	
Other (please specify)	

Terrestrial refugia	Tick
Dead wood	
Long grass	
Hedgerow	
Piles of stones	
Scrub cover	
Stonewall	
Other (Please specify)	

Perceived threats	Tick
Cultivation	
Intensive grazing	
Abandonment	
Removal hedge / scrub	
Forestry	
Mechanical peat removal	
Development/ urbanisation	
Recreational activities	
Pollution	
Invasive species	
Infilling	
Canalisation	
Drying out / silting up	
Ecological succession	
Predation	
Other (please specify)	

APPENDIX III - Candidate list of 500m squares for future monitoring

A reduced sample of 40-50 survey squares appears sufficient to detect a 30% decline (consistent with the IUCN Category of 'Vulnerable') at 80% power. Any future survey should included a ~10% contingency should any allocated squares "fail" to be surveyed for any reason. Thus, a total of 55 squares have been selected from the current sample as candidate survey squares for the next National Frog Survey in 2017 (Table 13). Additionally, we have added a further 5 squares to fill in some of the gaps in the distribution to provide uniform coverage (Fig. 11). The decrease from *n*=171 to *n*=60 represents a 65% saving in survey effort.

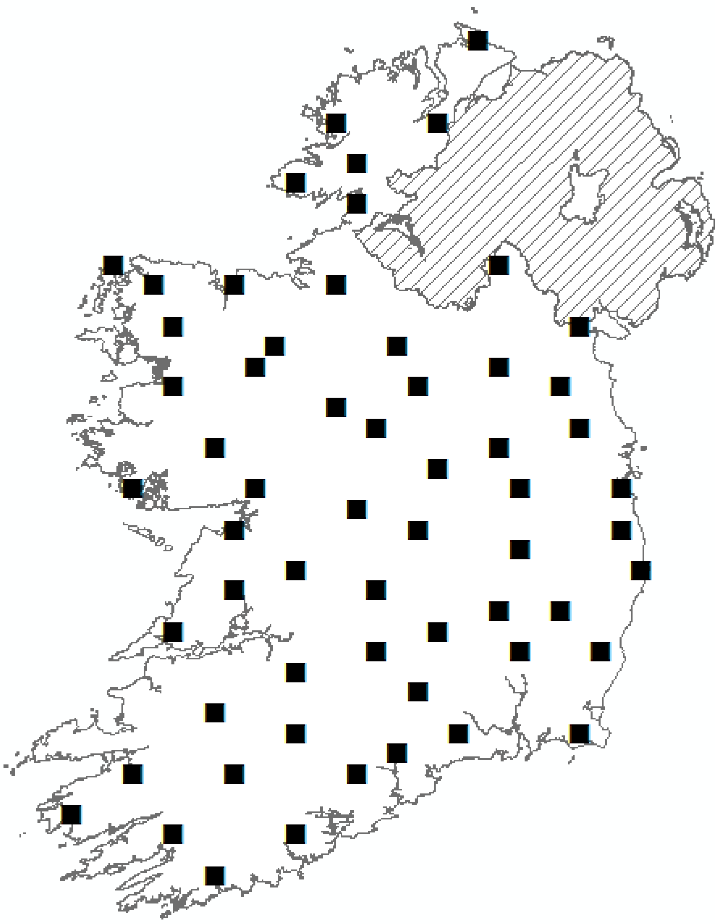

Fig. 11 The distribution of 60 x 500m squares which are candidates for inclusion in future monitoring to provide replication of the current baseline (*n*=55) and a geographically representative coverage (*n*=5).

Table 13 A list of 60 x 500m squares, their grid references and the identity of water bodies therein (for those successfully surveyed during the current baseline). Those not covered by the current survey (blank cells) will require baseline habitat surveys during the next round of monitoring scheduled for 2017.

#	SqID	County	Water	Type
1	B8010	Donegal	B803102	Bog pool
2	C3010	Donegal	C301103	Drainage ditch
			C302101	Drainage ditch
			C304104	Drainage ditch
3	C5050	Donegal	C501502	Drainage ditch
			C502502	Bog pool
			C504502	Drainage ditch
4	F7040	Mayo	F700402	Drainage ditch
			F703403	River, stream or canal
5	F9030	Mayo	F900300	Marsh
			F901300	Marsh
			F901305	Marsh
6	G0010	Mayo	G002101	Drainage ditch
7	G3030	Sligo	G303305	Natural spring
			G304302	River, stream or canal
8	G5000	Mayo	G501004	Drainage ditch
			G502004	Drainage ditch
9	G6080	Donegal	G602804	Drainage ditch
			G603801	River, stream or canal
			G603802	Bog pool
10	G8030	Leitrim	G801303	Marsh
			G803301	Farmland pond
			G804301	Drainage ditch
11	G9070	Donegal	G903703	Drainage ditch
			G904704	Farmland pond
			G901703	Marsh
12	G9090	Donegal	G904907	Drainage ditch
13	H1000	Leitrim	H101003	Drainage ditch
			H101004	Drainage ditch
			H104001	Drainage ditch
14	H6040			
15	J0010	Louth	J001101	River, stream or canal
16	L8030	Galway	L803308	Lake or reservoir
			L804308	Marsh
			L805308	Temporary feature
17	M0080	Mayo	M009800	Temporary feature
			M009801	Marsh
			M009802	Farmland pond
18	M2050	Mayo	M201505	Farmland pond
			M202503	Drainage ditch
			M204504	Natural spring
19	M3010	Clare	M308105	Natural spring
20	M4030	Galway	M405307	Farmland pond
			M406308	Drainage ditch
			M407307	Farmland pond
21	M4090	Mayo	M401901	Drainage ditch
			M402900	Drainage ditch
22	M8070	Roscommon	M807708	Drainage ditch
			M807708	Drainage ditch
23	M9020	Galway	M908207	Drainage ditch
			M909205	Temporary feature
			M909206	Drainage ditch
24	N0060	Longford	N008600	Lake or reservoir
25	N2010	Offaly	N202102	Bog pool
			N202103	Drainage ditch
			N204104	Drainage ditch
26	N2080	Longford	N201801	Drainage ditch
27	N3040	Westmeath	N301404	Drainage ditch
28	N6050	Westmeath	N601500	River, stream or canal
			N604502	River, stream or canal
			N604503	Temporary feature
29	N6090	Cavan	N604901	Drainage ditch
			N604903	Drainage ditch
			N603900	Drainage ditch
30	N7000	Kildare	N708000	Drainage ditch
			N709005	Bog pool

#	SqID	County	Water	Type
31	N7030	Kildare	N701303	River, stream or canal
32	N9080	Meath	N905801	Farmland pond
			N902804	Temporary feature
			N904803	Farmland pond
33	O0060	Meath	O006608	Farmland pond
			O005602	Temporary feature
			O002603	Drainage ditch
			O002601	Drainage ditch
34	O2010	Wicklow	O208108	Farmland pond
35	O2030	Dublin	O201306	River, stream or canal
36	R0060	Clare	R000603	Bog pool
			R001600	Bog pool
			R003603	Bog pool
37	R2020			
38	R3080	Clare	R307809	River, stream or canal
39	R6010	Cork	R604103	Farmland pond
			R604104	Temporary feature
			R604105	Temporary feature
40	R6040			
41	R6090	Clare	R600901	Farmland pond
			R602901	Marsh
			R602903	River, stream or canal
42	S0050			
43	S0080			
44	S1000			
45	S2030			
46	S3060			
47	S4010			
48	S6070	Kilkenny	S602702	Marsh
49	S7050	Kilkenny	S705505	Temporary feature
50	S9070			
51	T0010	Wexford	T007109	Drainage ditch
52	T1050			
53	T3090	Wicklow	T304900	Farmland pond
			T304900	Farmland pond
			T305900	Farmland pond
54	V5070	Kerry	V503702	Drainage ditch
			V503702	Drainage ditch
			V504703	Drainage ditch
55	V8090	Kerry	V800900	Temporary feature
			V801901	River, stream or canal
			V806907	Drainage ditch
56	W0060	Cork	W002600	Bog pool
			W002602	River, stream or canal
			W000603	Bog pool
57	W2040	Cork	W201404	River, stream or canal
			W204401	Drainage ditch
			W205404	Drainage ditch
58	W3090			
59	W6060	Cork	W603609	Farmland pond
			W603609	Farmland pond
60	W9090			