ISSN 1393 - 6670

NATIONAL PARKS AND WILDLIFE SERVICE

NATTERJACK TOAD (*EPIDALEA CALAMITA*) MONITORING AND CONSERVATION STATUS 2016-2018

Marina Reyne, Aurélie Aubry, Yvette Martin, Sarah Helyar, Mark Emmerson & Neil Reid

An Roinn Cultúir, Oidhreachta agus Gaeltachta
Department of Culture, Heritage and the Gaeltacht

IRISH WILDLIFE MANUAL 107

Front cover, small photographs from top row:

Coastal heath, Howth Head, Co Dublin, Maurice Eakin; **Red Squirrel** *Sciurus vulgaris*, Eddie Dunne, NPWS Image Library; **Marsh Fritillary** *Euphydryas aurinia*, Brian Nelson; **Puffin** *Fratercula arctica*, Mike Brown, NPWS Image Library; **Long Range and Upper Lake**, Killarney National Park, NPWS Image Library; **Limestone pavement**, Bricklieve Mountains, Co Sligo, Andy Bleasdale; **Meadow Saffron** *Colchicum autumnale*, Lorcan Scott; **Barn Owl** *Tyto alba*, Mike Brown, NPWS Image Library; **A deep water fly trap anemone** *Phelliactis* sp., Yvonne Leahy; **Violet Crystalwort** *Riccia huebeneriana*, Robert Thompson

Main photograph:

Natterjack Toad *Epidalea calamita*, Marina Reyne

Natterjack Toad (*Epidalea calamita*) Monitoring and Conservation Status 2016-2018

Marina Reyne, Aurélie Aubry, Yvette Martin, Sarah Helyar, Mark Emmerson & Neil Reid

Keywords: species monitoring; population trend; Habitats Directive; *Bufo calamita*; Kerry; constructed ponds

Citation: : Reyne, M., Aubry, A., Martin, Y., Helyar, S. Emmerson, M. & Reid, N. (2019) Natterjack Toad (*Epidalea calamita*) Monitoring and Conservation Status 2016-2018 *Irish Wildlife Manuals*, No. 107. National Parks and Wildlife Service, Department of Culture, Heritage and the Gaeltacht, Ireland.

The NPWS Project Officer for this report was: Ferdia Marnell, ferdia.marnell@chg.gov.ie

This IWM was edited by Ferdia Marnell

ISSN 1393 – 6670

An Roinn Cultúir, Oidhreachta agus Gaeltachta, 90 Sráid an Rí Thuaidh, Margadh na Feirme, Baile Átha Cliath 7, D07N7CV
Department of Culture, Heritage and the Gaeltacht, 90 North King Street, Smithfield, Dublin 7, D07 N7CV

Contents

Executive summary

- The current report represents the outcome of a three-year survey from 2016-18 of the Natterjack Toad (*Epidalea calamita*) population in Ireland. The goal was to provide information for the assessment of the conservation status of the species and provide recommendations for future management.

- A total of 169 water bodies, both traditional (natural) sites and artificially constructed ponds created as part of the National Parks and Wildlife Service (NPWS) Pond Creation Scheme, were surveyed for presence of Natterjack Toad breeding activity (egg strings, tadpoles, toadlets or adults) during each breeding season (April-July) 2016-18.

- There was substantial variation in fecundity between years with 3,222 egg strings ± 2% [95%CI 3,156 - 3,288] laid during 2016, 1,449 ± 1.6% [1,431 - 1,467] egg strings in 2017 and 2,681 ± 1.2% [2,639 - 2,723] egg strings in 2018. Low productivity during 2017 was likely due to fewer ephemeral ponds forming in sand dune slacks, most notably at the Maharees and Inch, due to low overwinter rainfall reducing the number of sites available for breeding.

- Translating egg string counts into total population estimates (as has been attempted previously) resulted in extremely wide estimates of potential error. Egg string counts allow the number of females that bred each year to be estimated but without data on the proportion of females that breed and the sex ratio in operation in Ireland synchronous with egg string counts, we strongly recommend that no attempt is made at estimating the total population.

- Toadlet abundance (the estimated number of individuals per pond) was highly correlated with egg string production (r^2=0.90) making it redundant as a second measure of population productivity i.e. it shows the same pattern despite requiring considerable additional survey effort. Thus, we recommend that egg string production is used as the sole measure of temporal trends in population productivity.

- Traditional (naturally occurring) breeding sites accounted for the vast majority (>90%) of egg string production with the single most productive area being the Maharees, north Dingle Peninsula.

- Variation in egg string counts was related to the preceding overwinter rainfall and the number of ephemeral ponds that formed by the beginning of the breeding season i.e. the availability of suitable sites, but appeared unaffected by spring temperatures.

- Natterjack Toad egg string production declined by 23% over the period 2004 to 2018 (using data from previous studies). After statistical correction for the effects of overwinter rainfall and the number of ephemeral ponds that formed each year, this decline was estimated to be as much as 66%.

- Ecological analyses suggested that the Natterjack Toad is more likely to breed in ponds with a large surface area, those in sand dune habitats, with high conductivity, and a high percentage cover of aquatic vegetation at the substrate with short terrestrial vegetation in the surrounding vicinity.

- Natterjack Toads colonised 22 artificial ponds (not all occupied every year) with breeding in 16 ponds during 2016, 10 during 2017 and 13 during 2018.

- Twenty new breeding sites (all adjacent to established breeding sites) were discovered resulting in the current species range increasing by 3 x 2km cells (+19%) compared to the previous survey during 2011-12 (Sweeney *et al.* 2013); representing better information and not reflective of actual range extension.

- The main threats and pressures that the Natterjack Toad faces in Ireland include land abandonment and lack of grazing (ponds must be surrounded by short swards); climate change altering

overwinter conditions and the onset of spring, for example, influencing the formation of ephemeral ponds and the risk of early drying out; as well as water pollution i.e. toxic, or deoxygenating, algal blooms.

- We make a series of recommendations for consideration in future studies to reduce survey effort making surveys more efficient whilst providing suggestions for priority actions to maintain or restore specific sites to good conservation status.

Acknowledgments

We are grateful to 4 field assistants who were part of the Natterjack Toad survey team from 2016 to 2018, namely: Raquel Lazaro, Marta Piasecka, Dara Sands and Nicholas Slatton; two work placement students from Queen's University Belfast (QUB): John Campbell and Harry McGuiggan and eight work placement students from the Institute of Technology (ITT), Tralee: Jason Cahill, Natasha Collins, David Crowley, Ian Egan, Kayleigh Hennessy, Elizabeth Hobbs, Robert McNamara and Rachel Toohler supervised by work placement Program Coordinator Fiona O'Flynn. We would like to thank John McLaughlin from Fota Wildlife Park and Louise Overy from Dingle Oceanworld Aquarium who were part of the Natterjack Toad Reintroduction and Head-start Programs. We are grateful to Dr Brian Nelson and Dr Aine O'Connor from National Parks and Wildlife Service (NPWS) who provided constructive comments on the aquatic macroinvertebrate sampling design and gave guidelines for species identification. We are also grateful to the land owners and farmers who provided access to their land. Final thanks to Dr Ferdia Marnell, the NPWS project officer, who provided guidance and direction throughout.

1 Introduction

1.1 Species ecology and breeding behaviour

The Natterjack Toad *(Epidalea calamita)* is widely distributed across Europe, ranging from the Iberian Peninsula in the west and as far east as the Baltic coast with several isolated populations in Ireland and Great Britain (Gasc *et al*. 1997). It prefers coastal marsh, heath and sand dune habitats where temporary shallow pools form. The Natterjack Toad is among the few amphibians that can tolerant brackish water. The lethal threshold for salinity is considered to be at 10-11ppt (Gomez-Mestre *et al.* 2003), even though research in UK suggests a lower tolerance of 4.5ppt (Beebee 1985). During the day, toads stay borrowed in moist sandy soil or under debris and stones. They are nocturnal being most active at night when they predate invertebrates and emerge *en mass* to breed. Adult toads do not have many natural predators due to poisonous glands on their skin which produce noxious compounds. Tadpoles are also toxic to avoid predation by fish (Boomsma & Arntzen 1985; Denton 1991).

The Natterjack Toad has an extended breeding period compared to other anurans. Spawning occurs between April and July in mainly ephemeral pools. The number of breeding female toads varies greatly depending on the weather conditions each year (warmth and rainfall), the height of the water table and the number of pools which form. Therefore, the species' reproduction can be highly successful in some years while failing in others (Beebee & Griffiths 2000, Baker 2011). Each female usually lays a single egg string during the breeding season. Fertility varies between populations from over 7,000 eggs in a string in the south of Spain to approximately 2,000 in Ireland (Beebee 1979, Bécart *et al*. 2007). Eggs usually hatch within 10 days if favourable environmental conditions are present i.e. warmth. Tadpoles feed on algae and detritus. Metamorphosis occurs approximately six weeks after hatching. Survival rates of egg strings and tadpoles are typically very low. Predation by invertebrates (e.g. predatory diving beetles) early pond desiccation (drying up) and fungal infections are among the main threats (Bécart *et al*. 2007).

1.2 Natterjack Toad conservation status

Despite its widespread distribution in Europe, the Natterjack Toad population is declining (Beja *et al.* 2009). There have been recent concerns about its current status, with its range having contracted by >50% during the latter half of the 20th century. Recent surveys indicate that the species' range may have contracted even further, with very poor and irregular breeding activity recorded in the most westerly parts of its current range (Bécart *et al.* 2007). The species is listed on Annex IV of the EU Habitats and Species Directive with EU member states where it is found (including the Republic of Ireland) required to report regularly to the European Commission on the species' conservation status [see Article 17, Habitats Directive 92/43/EEC]. The last two Article 17 reports assessed the species' conservation status throughout Europe as 'unfavourable' except for in the Mediterranean region (European Topic Centre, 2012).

In Ireland, the Natterjack Toad is the most range restricted and rarest amphibian; it is Red-listed as 'Endangered' (King *et al*. 2011). Prior to the initiation of the Pond Creation Scheme in 2008 by the National Parks and Wildlife Service (NPWS), toads were restricted to 12 discrete sites in County Kerry; all designated as Special Areas of Conservation or SACs (Bécart *et al*. 2007a). Natterjack Toads are protected under the Irish Wildlife Act 1976 amended in 2000. The last monitoring project for the species (Sweeney *et al*. 2013) evaluated the population trend as declining.

1.3 NPWS Natterjack Toad Pond Creation Scheme

Ireland lost 54% of its farmland ponds between the periods 1887–1913 and 2005–11 (Reid *et al.* 2014) with pond loss being identified as the single most important driver of Natterjack Toad population declines (Beebee 2002). One hundred new ponds have been created as part of the National Parks and Wildlife Service (NPWS) Pond Creation Scheme initiated in 2008. The programme's goal was to increase the number of suitable breeding sites around Castlemaine Harbour and Fermoyle and to restore the toad to its historical range. Most natural breeding sites occur on sand dune habitats or within associated scrub. Artificially created ponds are exclusively on links golf courses (i.e. amenity grasslands created on sand dunes) or have been created more recently as part of the Pond Creation Scheme in improved or semi-improved agricultural grasslands. Initial indications suggest that toads have started to colonise some of the new ponds. Breeding activity was recorded in 16% of constructed ponds during 2011-12 (Sweeney *et al.* 2013). In 2014, a translocation program was launched to enhance pond colonization rates where egg strings and tadpoles from four natural breeding sites were translocated to 10 artificial ponds that were part of the Pond Creation Scheme. There are no data available yet on the efficacy and success of these translocations.

1.4 Aims of this project

The main aim of the current project was to monitor all known natural (traditional) breeding sites and artificially created ponds for Natterjack Toad presence and breeding activity over a period of three years from 2016 to 2018 in order to update our knowledge on the species' distribution, population size, breeding behaviour and success, habitat quality, threats and pressures and to provide information for the next EU Habitats Directive Article 17 conservation assessment of the Natterjack Toad in Ireland (due in 2019). This will inform future recommendations for appropriate habitat and species management.

The following information was required in order to underpin the next EU Habitats Directive Article 17 conservation assessment:

- an up-to-date understanding of toad distribution in Co. Kerry;
- an evaluation of breeding success at each breeding site in 2016, 2017 & 2018 and overall;
- a robust estimate of the breeding population size;
- an estimate of the breeding population trend, taking into account the results of previous monitoring programmes (Becart *et al.* 2007; Sweeney *et al.* 2013);
- data on aquatic and terrestrial habitat extent and quality;
- an assessment of the success of the pond creation scheme;
- recommendations on whether further ponds should be created, and if so what areas should be prioritised;
- a report on threats and pressures facing the Natterjack Toad in Co. Kerry;
- recommendations on survey methods, future research and priority actions for understanding and achieving favourable conservation status for the Natterjack Toad in Ireland.

2 Methods

2.1 Study area

All traditional Natterjack Toad breeding sites were surveyed during the breeding season (April to July) during 2016, 2017 and 2018. These sites included:

- Fermoyle
- Castlegregory Golf Club (GCG) - referred to as Stradbally Golf Course by Bécart *et al.* 2007a
- Lough Gill
- The Maharees
- Tullaree
- Inch
- Roscullen Island
- Lough Yganavan
- Lough Nambrackdarrig
- Dooks
- Glenbeigh Quarry
- Glenbeigh Field
- Glenbeigh Marsh
- Caherdaniel

All 100 newly constructed ponds included in the NPWS Natterjack Toad Pond Creation Scheme were also regularly surveyed. In addition to these sites, a further twenty locations where Natterjack breeding activity was observed for the first time during the period 2016-18 were surveyed. The distribution of Natterjack Toad breeding sites in Co. Kerry is shown in Figure 1.

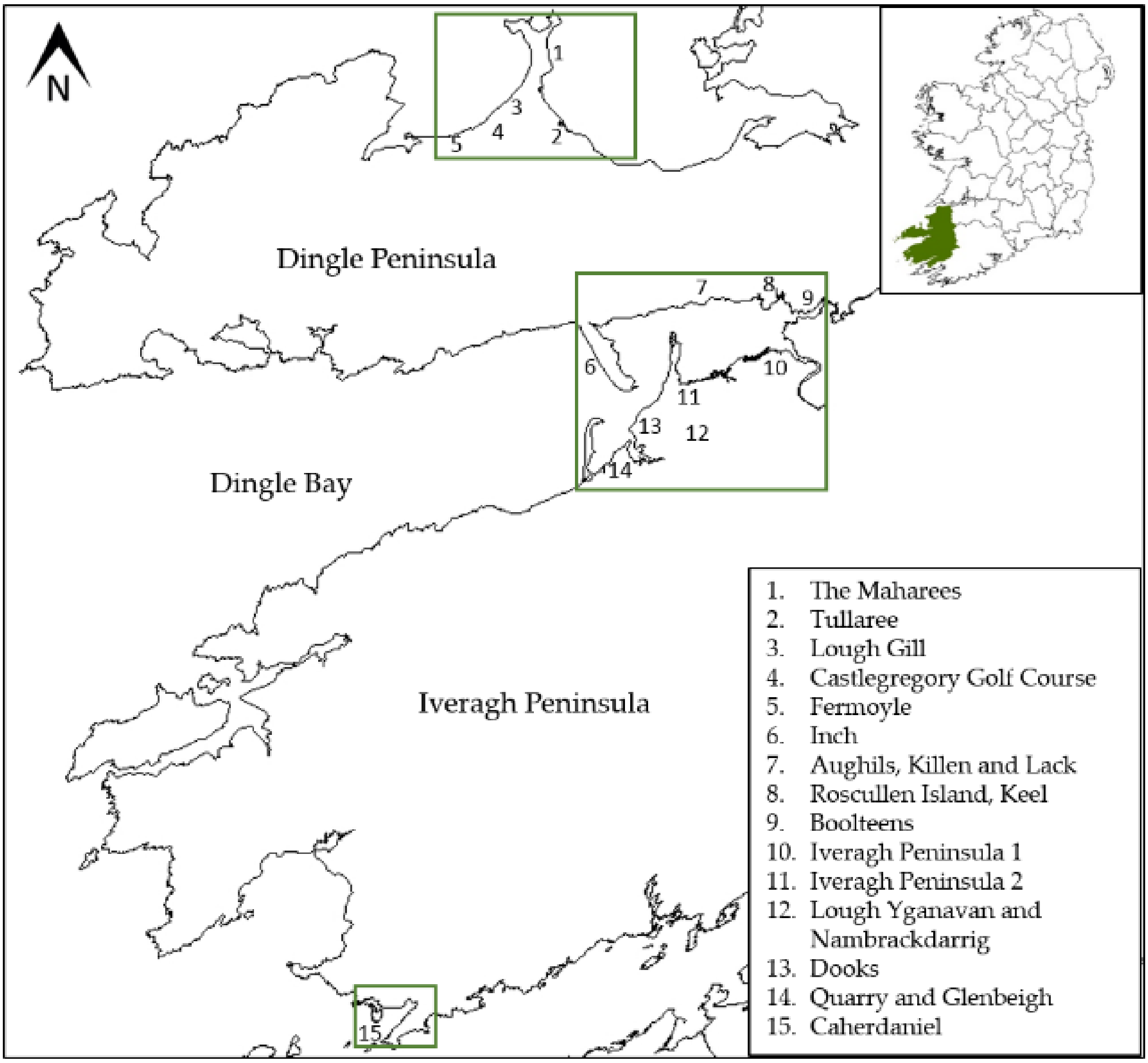


Figure 1 Natterjack Toad breeding areas in Co. Kerry, Ireland.

2.2 Breeding sites

Natterjack Toad breeding ponds varied in origin, hydroperiod and size.

Natural ponds that were traditional breeding sites (Figure 2) included large ephemeral pools that formed in sand dune slacks (Maharees, Inch and Caherdaniel), permanent ponds on links golf courses (Dooks Golf Course and Castlegregory Golf Course) and shallow bay areas along lake shores (Lough Yganavan, Lough Gill and Lough Nambrackdarrig). Traditional breeding sites were shallow (<1m deep) and greatly varied in size (between 24m^2 and 32,300m^2) (data from this study). Technically, golf course ponds are likely to have been artificially created but as they occurred on converted sand dunes systems adjacent to natural breeding sites and have been used by Natterjacks for some time they have been included within the traditional breeding sites of 'natural' origin.

All 100 artificial ponds in the NPWS Pond Creation Scheme were created on agricultural land within fields. Ponds were shallow (<1m deep), small (7-10m in diameter) and generally semi-permanent (e.g. >50% size reduction by the end of the breeding season) or permanent. Often grazing livestock were present to maintain a short sward.

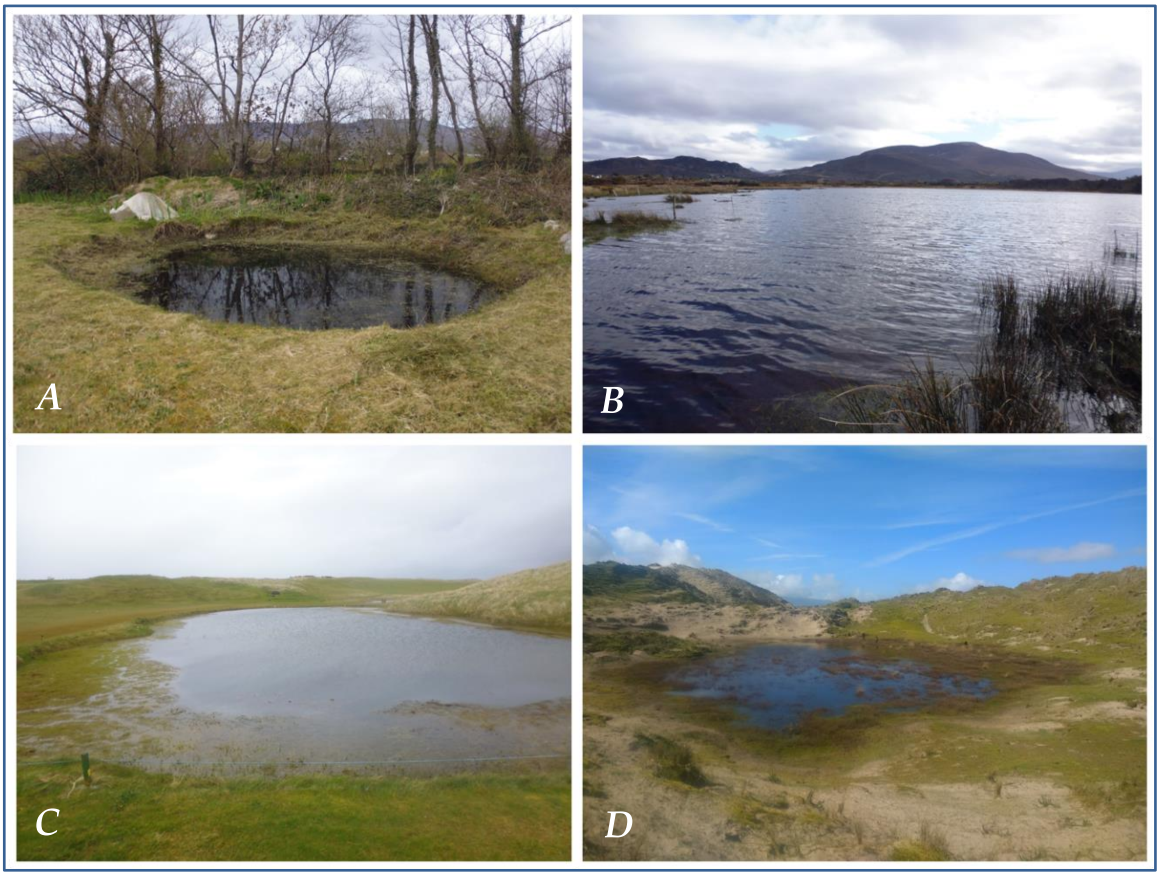


Figure 2 Four different types of Natterjack Toad breeding ponds surveyed during 2016-18. A) an artificially constructed pond on agricultural land (Pond 17B), B) permanent lakes (i.e. Lough Nambrackdarrig), C) permanent ponds on golf courses (Castlegregory Golf Course Pond 2), and D) ephemeral pools formed in sand dune slacks (Inch, Pond 4). Photographs © Marina Reyne.

2.3 Egg strings

The perimeter of each breeding pond was carefully surveyed by walking slowly around the water's edge and recording the number of egg strings observed. For large ponds, where it was not possible to count egg strings from the water's edge or to identify clear edges, waded zig-zag transects were carried out, where Health & Safety allowed. The total number of egg strings per each visit was recorded. The location and stage of development of each egg string were noted on a sketch map for each pond to avoid double counting at successive visits. We identified three stages of egg string development: the earliest stage consisted of two lines of recently laid eggs; the second stage had a single line of eggs; and the third stage consisted of well-developed embryos with defined tails (Figure 3). In this report, we present the cumulative unique number of egg strings throughout the breeding season per pond, site or area. Ponds where Natterjack Toad breeding activity was observed in the past and/or during the current survey were monitored intensively (every four to seven days), while artificially constructed ponds where Natterjack Toad presence had never been recorded were visited less often (twice per month). See Appendix B with the schedule of the field work for each year.

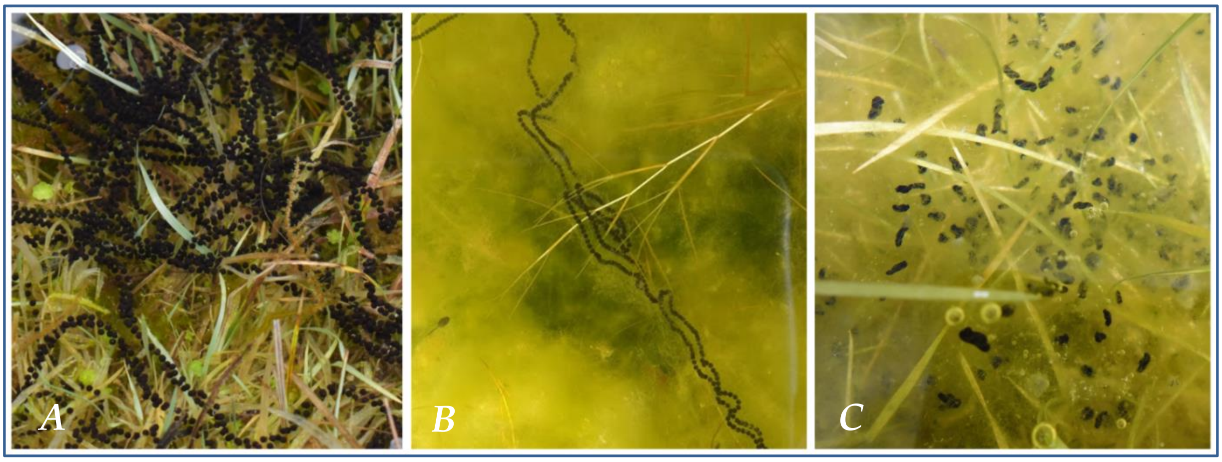


Figure 3 Stages of egg string development of the Natterjack Toad (*Epidalea calamita*): A) first stage, B) second stage C) third stage as observed at the Maharees, Co. Kerry. Photographs © Marina Reyne.

2.4 Tadpoles

Two methods were used to estimate tadpole abundance. For shallow ponds with clear water and sandy substrate in which tadpoles were clearly visible, the total number of tadpoles was calculated by multiplying the estimated number of tadpoles per m^2 by the pond area. Visual assessments followed the methods recommended by Denton *et al.* (1995) and Raw & Pilkington (1988). For ponds with poor water transparency and/or dense vegetation where tadpoles were not visible or difficult to distinguish from common frog tadpoles, three sweep samples per pond were taken to confirm presence and species. The Natterjack Toad tadpoles are small with uniform black coloration, while the common frog tadpoles are bigger and speckled with brown and gold. The number of tadpoles in each sweep was counted and multiplied by the sampled area. The tadpole abundance was enumerated and classed within orders of magnitude: 1s, 10s, 100s, 1,000s and 10,000s. All tadpoles were returned to the water immediately thereafter.

2.5 Toadlets

Only sites where egg strings and/or tadpoles occurred were surveyed for toadlets. Quadrats ($0.25m^2$) were placed regularly every 10m along the water's edge up to a distance of 5m. Toadlet numbers in each quadrat were recorded. Toadlet abundance was calculated by multiplying mean toadlet density by the area surveyed. The results were grouped within orders of magnitude: 1s, 10s, 100s, 1,000s and 10,000s. The exact toadlet counts were used to estimate mean toadlet density for each site and survey year.

2.6 Up to date toad distribution

Records of Natterjack Toad presence and breeding activity were recorded using a Garmin GPS handset. Data was used to update the Natterjack Toad's current distribution range in Ireland, using 2km grid squares in compliance with the Article 17 reporting using ArcGIS 10.5 (ESRI, California, USA).

2.7 Population size estimation

Counts of egg strings give a reliable indication of the number of *active breeding* females in the population (Banks & Beebee 1988, Gent & Gibson 1998). Previous Natterjack population estimation in Ireland has uniformly assumed that a *maximum* of 65% of female toads spawn annually as derived by Aubry & Emmerson (2005) after reviewing primary data collected by Denton (1991), published as Denton & Beebee (1993) and supported by subsequent modelling by Stephan *et al.* (2001). Thus, previous studies have estimated the adult female population size by $F=S/0.65$, where F is the adult female population size and S the number of observed eggs strings in the breeding season. Furthermore, a 1:1 sex ratio was assumed; as it is common among vertebrates i.e. the estimated female population was doubled to account for the presence of males yielding the total population estimate $F=(S/0.65)*2$.

2.8 Uncertainty in population estimation

We identified three potential sources of bias and error in estimating the Natterjack population size:

2.8.1 Error in enumerating egg strings

Egg string counts may have been vulnerable to Type 1 errors i.e. false positives where egg strings could have been double counted between successive pond visits due to the possibility of miscounting and/or misrecording or inaccuracy in either mapping of egg string location or stage of development. The magnitude of Type 1 errors is likely to be very small relative to the total population estimate as egg string counts were derived, not from a sample of sites extrapolated to the whole population (as is usual in surveys of more widespread and common taxa), but were absolute counts taken at each and every breeding site i.e. all eggs strings were enumerated. Risk of double counting was reduced by mapping the location of eggs strings during each visit and their state of development to be able, as far as possible, to identify the same egg string during successive visits by following its development through to hatching.

Egg string counts may also have been vulnerable to Type II errors i.e. false negatives where egg strings were not counted due to being missed. This could have occurred as some may have been well hidden within dense aquatic vegetation and obscured from sight or may have been deposited in parts of the waterbody that may have been inaccessible due to Health & Safety concerns. The chances of these errors also seems likely to be very small as most ponds were shallow (<1m) making them easily accessible. Virtually all egg strings that were found, were close to the water surface, making it unlikely that others were missed due to their depth. Egg strings may have been missed if the interval between pond visits was sufficiently long such that eggs may have been deposited, developed and hatched between visits. Error due to the latter was methodologically reduced as pond visits were made every 7-10 days; a period shorter than that needed for spawn to hatch. Finally, egg strings may have been missed where they were deposited *en mass* with multiple strings laid together in a clump making individual enumeration difficult; thus clumps may have been recorded as a single egg string despite several potentially being present.

Actual accrual of egg strings, due to spawning activity between pond visits, is a real source of inter-visit variability and whilst this may not be consistent between successive visits (i.e. mass spawning events can occur) over the course of the breeding season (four months) we expect an asymptotic accumulation of spawning. To capture this, the *cumulative* number of egg strings was plotted over each breeding season. The relationship between the rate of egg string accrual and survey effort (number of pond visits) was generalised using a 3-parameter sigmoidal relationship (incorporating the starting value, asymptote value and the slope of the line). The starting value was the number of egg strings on the first day of the survey season, the asymptote value was the plateau of the curve representing the total number of egg strings whilst the density of data points (i.e. number of pond visits) *and* the variability in their value (i.e. change in egg string count over time) allowed the variability across the season (i.e. the

95% Confidence Intervals) to be estimated. This method works where the data are sufficiently dense to parameterise the curve with precision i.e. at the Co. Kerry (whole population) level where there were thousands of pond visits (i.e. thousands of datum points). At the individual site (pond) or even metapopulation (area) level, the number of pond visits was substantially lower, for example, each pond had an average of 10 visits per breeding season (i.e. 10 datum points), resulting in poor parameterisation of the sigmoidal curve yielding low statistical power and correspondingly (erroneously) large confidence intervals. Thus, we report uncertainty in egg string counts for the whole population only.

2.8.2 Variability in the proportion of females that spawn

All previous Irish Natterjack Toad population estimates have assumed that 65% of females breed annually as adopted by Aubry & Emmerson (2005). This value was taken from a limited dataset collected from 100 Natterjack adults in a single, isolated, heavily female-biased population in Hampshire (UK) followed over 5 years (Denton 1991; Denton & Beebee 1993). "In any one year only 44-64% of females spawned" (Table 1). Stephan *et al.* (2001) working in Brandberge, Germany from 1992-1999 reported an *average* estimate of 63% of females spawning annually (Table 1) but within an entirely theoretical modelling exercise they adopted values as low as 10% indicative of near complete breeding failure and as high as 100% indicative of near complete breeding success; though neither the lower or upper estimates were based on any empirical data.

Table 1 The percentage of female Natterjack Toads in the population that are estimated to have bred annually as reported by two empirical studies.

Source	Location	Year	% of females that bred
Denton & Beebee (1993)	Hampshire, England	1988	55
		1989	64
		1990	44
		1991	63
		1992	61
Stephan *et al.* (2001)	Brandberge, Germany	1992-1999	63
Mean [95% CI]			**58 [52-65]**

<u>No data exist for Ireland</u>. From the literature (Table 1), the mean percentage of females that might breed annually was estimated at 58 ± 6% [95%CI 52-65%]. To translate the number of egg strings counted into the female population estimate, the lower confidence limit (LCL) was derived by $F_{LCL} = S/0.52$, the mean estimate by $F_{mean} = S/0.58$ and the upper confidence limit (UCL) by $F_{UCL} = S/0.65$, were F = the female population and S = the total number of egg strings counted. This provided some estimate of the potential error in estimating the female population size only.

2.8.3 Variability in sex ratios

Most vertebrates whose sex ratio is genetically determined generally have a sex ratio at birth (hatching) of 1:1 male:female. However, some taxa, for example reptiles, are known to be able to manipulate the sex ratio of their offspring by placing their eggs in environments of differing ambient temperature (Bull 1980). In other cases, new-borns or hatchlings may have different sex-specific survival rates which rapidly skew early life sex ratios (usually due to disease and/or predation). Stephan *et al.* (2001) reported a male-biased sex ratio in newly hatched Natterjack Toads of 1.3:1 males:females. In contrast, Denton & Beebee (1993) studied a population that was notably female-biased with ratios varying from 0.3:1 to 0.56:1 males:females depending on what subset of the data were analysed (Table 2). In reality, sex ratios are likely to vary substantially between cohorts, between locations and over time and are likely to be idiosyncratic of prevailing conditions at the time of study. Indeed, Günter & Meyer (1996) reviewed the published literature and reported Natterjack population sex ratios from as low as 0.84:1 to as high as 11.2:1 males:females.

Table 2 Natterjack Toad sex ratios as reported in the literature (note that those from Denton & Beebee 1993 were originally reported as Female:male ratios but have been transformed to Male:female ratios to be comparable to those reported from Stephan et al. 2001 and Gunther & Meyer 1996).

Source	Location	Year	Sex ratio			Comments
			Males	:	Females	
Denton & Beebee (1993)	Hampshire, England	1988	0.30	:	1	All sightings
			0.56	:	1	Sightings of known individuals only
		1989	0.33	:	1	All sightings
			0.47	:	1	Sightings of known individuals only
Stephan *et al.* (2001)	Halle, Germany	1992-1999	1.30	:	1	Newly hatched ratio
Gunther & Meyer (1996)	Various	-	0.84	:	1	Lowest reported
			11.20	:	1	Highest reported
Mean [95%CI]			**2.14 [0.00 - 5.11]**	**:**	**1**	

No data exist for Ireland. From the literature, the mean sex ratio was estimated at 2.14:1 males:females ± 139% [95%CI 0.00 - 5.11:1]. Despite the lower confidence limit (LCL) being zero, we know from egg string surveys that most eggs are usually fertilised and thus some males *must* be present i.e. a 0:1 male:female sex ratio is highly unlikely. Thus, for the purposes of our calculations we replaced the lower confidence limit of 0:1 with 0.3:1 males:females reflecting the lowest sex ratio as reported from the literature (Denton & Beebee, 1988; Table 2).

To translate the female population estimate into the total population estimate, the lower confidence limit (LCL) was derived by $P_{LCL} = F*0.30$, the mean estimate by $P_{mean} = F*2.14$ and the upper confidence limit (UCL) by $P_{UCL} = F*5.11$, were P = the total population and F = the female population estimate (as derived following Section 2.8.2 above). This provided some estimate of the potential error in estimating the total population based on variation in likely sex ratios only.

2.8.4 Additive uncertainties

Each of the three identified sources of potential error in the total population estimate are associated with some level of variability. We hypothesised that due to the methodological rigour of the field survey methods that error associated with annual egg strings counts would be low (± a few percent). Due to the limited availability of data and the spread of the values we expected error associated with the proportion of females that breed annually to be higher (± 10 percent) and the variability in the sex ratio assumptions would yield the largest error (± several 10s of percent). Moreover, these sources of error are *additive* i.e. the lowest total population estimate should assume the UCL for the percentage of females that breed plus the LCL for male:female sex ratio whilst the highest total population estimate should assume the LCL for the percentage of females that breed plus the UCL for male:female sex ratio. Additive errors are likely to result in extremely wide population confidence intervals most likely rendering the utility of translating egg string counts into the total population meaningless without Ireland-specific data on female breeding and sex ratios contemporaneous with egg string counts.

2.9 Temporal trends

Total Natterjack population estimates were associated with such large additive sources of error (i.e. wide 95% confidence intervals) that their use in determining the population's conservation status was limited. Moreover, changes in total population estimates were directly proportional to changes in egg string counts i.e. both metrics showed identical temporal trends except that total population estimates were subject to arbitrary multipliers unsupported by empirical data. Thus, assessment of the conservation status of the Natterjack Toad population was identical to temporal trends in population productivity i.e. egg string counts.

Linear trends of egg string counts were fitted to values of the current survey and those from previous surveys i.e. 2004-06 and 2011-12 (Becart *et al.* 2007; Sweeney *et al.* 2013). Average percentage change over time in egg string counts were calculated as the difference between the start and end of the *fitted trend line* and not the difference between the first and last values for egg counts (which compares the difference between two arbitrary time-points rather than the overall *mean* change).

We investigated the likely drivers of changes in egg string counts by examining the effects of local weather conditions (temperature and rainfall). The period over which weather parameters are likely to affect Natterjack Toad reproductive behaviour is unknown, for example, is it the conditions at the start of April during the initiation of spawning that are most important or is it the cumulative effect of conditions over a longer period i.e. the preceding winter that influences productivity? Therefore, we tested the effects of the cumulative total rainfall (mm), minimum and maximum air temperatures and mean soil temperature (^{o}C) at various plausible temporal lags i.e. calculated for the 7, 14, 21, and 28 days i.e. 1, 2, 3 and 4 weeks as well as 2, 3 and 4 months prior to each pond visit where weather data were obtained from the Met Éireann Station at Valentia (within 25-50km of all Natterjack Toad breeding sites). Generalized Linear Mixed Models (GLMMs) assuming a negative binomial distribution fitted the number of egg strings at each site visit as a dependant variable, habitat type and year were fitted as fixed factors and one covariate i.e. each of the weather parameters at each temporal lag and the Akaike Information Criterion (AIC) value recorded. For each weather parameter, the temporal lag with the lowest AIC value was taken as the single best variable in predicting variation in egg string production. This allowed the *optimal* temporal lag to be selected for each weather parameter. The final list of candidate predictor variables was then tested for multicollinearity using Pearson's correlation with values >0.5 assumed to be highly collinear. Subsequently, a global GLMM was built including those optimal weather parameters that were not deemed collinear to predict egg string numbers.

To define the influence of weather in driving Natterjack Toad egg production and determine its impact on temporal trends, the global GLMM fitted using the optimal lags in each weather parameter was used to predict egg string numbers but rather than using the observed variability in each weather parameter (i.e. actual conditions) we assumed that optimal conditions were present for each survey, for example, the maximum value for rainfall during the chosen temporal lag for any one survey throughout the time-series and the maximum value for temperature at the chosen lag for any one survey throughout the time-series. In other words, we predicted egg string production for each year whilst neutralising the effects of those weather parameters known to drive interannual variability in productivity. The temporal trend was then compared between that observed in the raw data (which included stochastic variability due to weather) to that predicted under optimal conditions (i.e. the likely change in productivity, or presumed population trajectory, independent of weather). This analysis followed similar methods peer-reviewed and published by Reid *et al.* (2013) for defining the impact of survey bias and error for other taxa.

Modelling the influence of weather at the individual site visit level (i.e. on mean egg string production per pond visit) preserves large sample sizes and provides high statistical power. But it was hypothesised that over winter rainfall determines the number of ephemeral ponds that form each year i.e. wetter years result in greater availability of breeding sites. However, it was not possible to incorporate pond formation rate into models constructed with data from individual site visits (ponds can only be surveyed for egg strings when water is present; therefore, all ponds in the analysis above necessarily contained water). Thus, to investigate the likely causal connection between rainfall, pond formation and egg string production we explored the relationship between total egg string counts per year with both overwinter rainfall and the number of ponds that were available for breeding using Spearman's correlations (due to small sample sizes i.e. data were summarised for 8 years yielding low statistical power; thus any relationships found are likely to have extremely strong effects i.e. large correlation coefficients but low significance i.e. p values). Egg string production was predicted by the number of ponds that formed using linear regression and the residuals were taken as the variation in population productivity independent of both overwinter rainfall and the number of ponds that formed. Thus, the overall temporal trend was compared between annual egg string numbers (i.e. the observed data) and residual variation in egg string production i.e. that which could not be predicted using either the number of ponds that formed or overwinter rainfall.

Using egg string counts as a proxy for population productivity for the purposes of conservation assessment is not an ideal substitute for change in the total population. Egg strings can be infertile and fail to hatch. We would expect a very low percentage of laid eggs to actively contribute to population recruitment due to likely high rates of mortality (from disease, predation, death due to ponds drying out before metamorphosis etc.). Thus, whilst egg string production may be a measure of fecundity it is unlikely to capture recruitment which is more likely to drive true population change. Therefore, we also assessed the temporal trend in toadlet abundance as a second, independent indicator, of breeding success. Toadlet density was estimated at each pond using quadrats (toadlets/m^2) but this cannot be used as an indicator as two ponds of different size (i.e. circumference) might have the same density but very different areas surveyed (i.e. the zone around the pond within which toadlet density was estimated). Thus, estimated toadlet abundance (i.e. density multiplied by the area surveyed) was taken as the most descriptive parameter. Again, we might expect a high mortality rate of metamorphs and thus toadlet abundance is not equal to recruitment but is more likely to be a closer proxy of recruitment than egg string production. No data exist for toadlet mortality rates in Ireland. Nonetheless, we assume that a population with high production of metamorphs is more likely to have a healthier recruitment and trajectory than a population with low toadlet abundance. We tested the relationship between egg string production and toadlet abundance using Spearman's correlation.

2.10 Habitat

A visual record of each pond was taken using digital camera. Four photographs were taken of each site per year in order to track changes over time. In cases when conditions changed noticeably additional photographs were taken. Aquatic and terrestrial habitat data were recorded at each site. In total, 28 environmental parameters were collected at each pond. See Appendix A for the Natterjack Toad Pond Survey data sheet. All the environmental parameters were recorded four times throughout each breeding season:

2.10.1 Aquatic habitat data

Physical data: pond area (m^2) i.e. pond length (a) and width (b) were measured using an Insight 1000 LH Laser Rangefinder. The two dimensions were used to estimate the surface area (A) by using the formula for an ellipse: $A = \pi ab$), percentage of water surface shaded (%), water and air temperatures (^oC), water transparency using Secchi disk (measured in cm), max water depth (in two categories <1m and >1m), pond permanency (refers to the hydroperiod of each pond and was classified as permanent, semi-permanent when the pond was reduced by at least half its size between April and July, and ephemeral where it dried out completely before the end of the breeding season).

Water chemistry: water temperature (at the surface), pH (accuracy ± 0.05) and conductivity (accuracy ± 2% µS/cm) measured with Hanna Combo HI98129, salinity measured with an Extech RF20 portable refractometer (parts per thousands) and dissolved oxygen (as mg/l and % saturation) measured with a YSI 550A (ranging from 0 to 50mg/L). The parameters were taken close to the water edge usually where egg strings or tadpoles were present and avoiding areas with dense vegetation. Three measurements were taken at each location and averaged.

Vegetation structure: percentage of aquatic plant cover at the substratum and water surface, percentage of plant litter cover at the substratum, percentage of filamentous algae at the substratum and percentage coverage of emergent vegetation.

Aquatic macroinvertebrates: a combination of sweep netting and bottle traps was used for sampling macroinvertebrates. For the first method an area of approximately $2m^2$ along the pond edge was swept with a net intensively for 20 seconds. The number of samples taken per each pond depended on the pond size and was calculated as an exponential relationship. Traps were made of 2 litre plastic bottles with a one-way funnel and were baited with cat food. Bottle traps were submerged vertically close to areas with dense vegetation and in a way as to allow an air bubble to form at the top of the bottle for invertebrates to breathe. Traps were fixed with two ropes to a one-metre bamboo pole and were checked within 24h. Predator pressure was estimated as a total number of predatory macroinvertebrates (water beetles and their larvae, dragonfly and damselfly larvae, waterbugs and leeches) in the sweep and bottle trap samples per pond.

2.10.2 Terrestrial habitat data

Surrounding habitat types (within 100m radius of the pond) were defined using Fossitt (2000) as; 1) improved agricultural grassland (GA1), 2) amenity grassland (GA2), 3) wet grassland (GS4), 4) fixed dunes (CD2), and 5) Scrub (WS1). Improved agricultural land is a highly-modified grassland managed for grass production and heavily grazed by livestock. Amenity grasslands in the study were managed as links golf courses having been converted from, and embedded within, fixed dunes. For both, use of fertilisers and herbicides were common. Wet grasslands were characterised as poorly drained abandoned or low management farmland. Fixed dunes were stabilized sand hills covered by vegetation, mainly marram grass (*Ammophila arenaria*). Scrub was dominated by at least 50% cover of shrubs or brambles with canopy height less than 5m.

Percentage bare ground (%) and sward height (divided in three categories: <5cm, 5-20cm and >20cm) within 100m radius of the pond was also recorded. Distance to and type of the potential physical barriers. Presence of terrestrial refuges (long grass, dead wood, stones, scrub etc.). Site management practices (predominant form of land use occurring in the area adjacent to the pond).

2.10.3 Effects of aquatic and terrestrial habitat on breeding activity

We selected 18 variables that best characterised the habitat in order to investigate the effects of aquatic and terrestrial parameters on breeding activity. Differences in the mean values of environmental parameters were tested between ponds with Natterjack Toads present and absent using Mann Whitney-U tests. Each environmental variable was fitted as an independent explanatory variable in a General Linear Model (GLM) where numbers of eggs strings was the dependent variable with multimodel selection used to choose the single best model from all subset regressions using the Akaike Information Criterion corrected for sample size (AICc) based on the lowest value. GLMs were run using IBM SPSS Statistics v24 (dependant variable negative binomial distribution). All predictor variables were tested for multicollinearity with highly correlated variables (correlation coefficient >0.7) excluded from analysis. Variables were standardized to have $x=0$ and $\sigma=1$ prior to the analysis.

2.11 Threats and Pressures

We identified and reported threats and pressures that may impact the Natterjack Toad population at individual ponds and at a wider landscape level. Threats and pressures were categorised according to criteria listed in the *Natura 2000* Standard Data Form and recorded under EU Habitat Directive codes:

- Abandonment of grassland management (e.g. lack of grazing; high sward);
- Natural succession resulting in species composition change (e.g. ponds overgrown with emergent vegetation);
- Interspecific fauna and floral relationships (presence of invertebrate predators such as water beetles, leeches or dragonfly larvae);
- Mixed source pollution to surface and ground waters (poor water quality, algal bloom);
- Abiotic natural processes (e.g. salinity above 4ppt);
- Invasive alien species (e.g. *Crassula helmsii* and *Hippophae rhamnoides*).

2.12 Other amphibian species

Observations of Common Frog (*Rana temporaria*) and Smooth Newt (*Lissotriton vulgaris*) or their spawn or tadpoles were noted at each site (Appendix F).

2.13 General information

At each site, the following general information was recorded:

- Date and time the site was visited.
- Visit number.
- Survey team.
- GPS coordinates.
- Weather conditions: percentage cloud cover, wind strength and presence/absence of rain.

Data on air temperature and rainfall were obtained from the Climatology and Observations Division of Met Éireann for the Valentia Observatory in Co. Kerry.

2.14 Assessment of the success of the Pond Creation Scheme

We provided annual assessments of the success of the Pond Creation Scheme that included the number of ponds with breeding activity, number of egg strings, level of compliance with the habitat management requirements of the scheme which specifies that emergent vegetation doesn't encroach into the pond and that the vegetation in the field surrounding the pond is short (less than 80% of the sward within 100m of the pond should be >20cm tall). Summary of the percentage cover of emergent vegetation and sward above 20cm for the three years of survey is provided in Appendix E. For ponds that failed to meet the requirement recommendations were made.

2.15 Recommendations

Recommendations were made in terms of survey methods, future research needed and priority actions for understanding and achieving favourable conservation status for the Natterjack Toad in Ireland.

3 Results

A total of 4,704 pond visits were conducted from 2016 to 2018. We recorded a total of 7,358 Natterjack Toad egg strings with 3,216 in 2016, 1,457 in 2017 and 2,685 in 2018. First lay date was as early as the 31st March (2017) whilst the last lay date recorded was 13th July (2016) (Table 3).

Table 3 Date and pond ID where first and last egg strings were recorded.

Date	*Area*	*Pond ID*
First lay dates		
4th April 2016	Caherdaniel	C3
31st March 2017	Inch	Inch7
3rd April 2018	Nambrackdarring	IverLough
Last lay dates		
13th July 2016	Caherdaniel Glenbeigh	C3 21A, 43B
15th June 2017	Castlegregory golf course the Maharees	CGC1, CGC3 M1
27th June 2018	Castlegregory golf course Glenbeigh	CGC4 21A

3.1 Monitoring of the traditional breeding sites

A total of 49 traditional Natterjack Toad breeding sites were monitored for activity in addition to a further 20 natural ponds that were discovered to have Natterjack Toads breeding throughout the current survey. Six of the natural sites from the previous 2011-12 survey (Sweeney *et al.* 2013) no longer exist e.g. ponds were destroyed by human activity or did not provide suitable breeding habitat for the Natterjack Toad e.g. very deep sites along a lake shore and were, therefore, not monitored.

3.1.1 Egg strings

In total, we recorded 3,095 egg strings at 47 traditional or natural breeding sites during 2016, 1,363 egg strings at 34 sites during 2017 and 2,608 egg strings at 51 sites during 2018 (Table 4). During 2016-18, between 93% and 97% of the total number of recorded Natterjack egg strings were recorded at traditional or natural sites.

In 2016 and 2018 the most productive area was the Maharees that accounted for 67% (2,169 egg strings) of the total number of egg strings recorded in 2016 and 57% (1,519 egg strings) in 2018. In both years, the most productive pond was M23 with 902 egg strings (28% of all egg strings recorded) in 2016 and 247 egg strings (9% of all egg strings) in 2018. In 2017, the most productive area was Castlegregory Golf Course with 495 egg strings (34% of total number of egg strings) with the most productive pond being CGC2 with 185 egg strings (13% of all egg strings recorded that year).

Several traditional sites were occupied by Natterjack Toad tadpoles although no egg string had been recorded. This may be explained by the late discovery of new breeding sites e.g. pond IDs: Inch 4-7 during 2016, the large size of the water bodies and dense vegetation e.g. at Lough Nambrackdarrig, or poor water quality resulting in low visibility e.g. Tullaree. We retrospectively inferred the presence of at least one egg string at each of these ponds (marked with an asterisks in Table 4) but it is likely that the breeding population size at such sites may have been underestimated due to false negatives i.e. egg strings being missed.

3.1.2 Tadpoles

Tadpoles were recorded at 47 traditional or natural sites (69%) in 2016, 30 sites (44%) in 2017 and 49 sites (71%) in 2018 (Table 4). Only three sites were recorded with 10,000s of tadpoles during each of the three years (pond IDs: LoughGill, CGC2 and Yganavan6).

3.1.3 Toadlets

Toadlets were recorded at 25 sites (37%) in 2016, 20 (29%) in 2017 and 27 (39%) in 2018. The highest number of toadlets was observed at the Maharees in 2016 and 2018 (Table 4).

Table 4 Total number of egg strings recorded and the maximum number of tadpoles and toadlets observed at each traditional or natural Natterjack Toad breeding site during 2016-18.

Pond ID	Egg strings			Tadpoles			Toadlets		
	2016	2017	2018	2016	2017	2018	2016	2017	2018
Maharees									
M1	322	163	335	10 000s	0	10 000s	0	0	1 000s
M6	0	dry	6	0	dry	0	0	dry	0
M7	18	dry	54	1 000s	dry	10 000s	0	dry	10 000s
M9	225	dry	176	10 000s	dry	10 000s	1 000s	dry	1 000s
M9A	392	dry	194	10 000s	dry	10 000s	10 000s	dry	10 000s
M12	24	dry	111	1 000s	dry	10 000s	0	dry	0
M12A	-	-	6	-	-	10 000s	-	dry	0
M16	12	dry	17	10s	dry	1 000s	10 000s	dry	0
M17	121	dry	91	10 000s	dry	10 000s	10 000s	dry	10 000s
M18	0	dry	6	0	dry	100s	0	dry	0
M19	25	dry	34	10 000s	dry	10 000s	1 000s	dry	0
M22	34	dry	33	1 000s	dry	10 000s	0	dry	0
M23	902	64	247	10 000s	100s	10 000s	10 000s	0	10 000s
M24	78	5	32	1 000s	0	10 000s	10 000s	0	0
M25	1	dry	3	1 000s	dry	1 000s	10s	dry	1 000s
M26	15	dry	68	1 000s	dry	10 000s	0	dry	10s
Lough Gill	92	154	106	10 000s	10 000s	10 000s	10 000s	1 000s	1 000s
Sub-totals	**2261**	**386**	**1519**	**10 000s**	**10 000s**	**100000s**	**10 000s**	**1 000s**	**100 000s**
Castlegregory Golf Course									
CGC1	136	101	183	10 000s	1 000s	10 000s	1s	0	1 000s
CGC2	88	185	73	10 000s	10 000s	10 000s	1 000s	10 000s	10 000s
CGC3	1	11	1	0	10s	0	0	100s	0
CGC4	111	156	128	10 000s	1 000s	10 000s	1 000s	100s	1 000s
CGC5	4	7	4	1s	10 000s	10 000s	0	0	1 000s
CGC6	13	21	14	1 000s	10 000s	10 000s	1 000s	1 000s	100s
CGC8	1	14	2	100s	1 000s	10 000s	0	1 000s	0
Sub-totals	**354**	**495**	**405**	**10 000s**	**10 000s**	**10 000s**	**10 000s**	**10 000s**	**10 000s**
Tullaree									
T1	1*	1*	1*	1 000s	1 000s	1 000s	0	0	1 000s
T2	0	2	11	0	100s	10 000s	0	0	1 000s
T3	0	0	4	0	0	1 000s	0	0	100s
Sub-totals	**1**	**3**	**16**	**1 000s**	**1 000s**	**10 000s**	**0**	**0**	**10 000s**
Inch									
Inch1	4	0	79	10 000s	dry	10 000s	100s	dry	0
Inch2	1*	7	36	10 000s	0	10 000s	0	0	0
Inch3	8	0	45	10 000s	dry	1 000s	100s	dry	0

Pond ID	Egg strings			Tadpoles			Toadlets		
	2016	2017	2018	2016	2017	2018	2016	2017	2018
Inch4	1*	0	28	1 000s	dry	1 000s	0	dry	0
Inch5	1*	0	28	10 000s	dry	10 000s	0	dry	0
Inch6	1*	0	125	10 000s	dry	10 000s	100s	dry	0
Inch7	1*	11	50	10 000s	0	1 000s	1 000s	0	0
Inch8*	-	-	1	-	-	dry	-	-	0
Sub-totals	**17**	**18**	**392**	**10 000s**	**0**	**10 000s**	**1 000s**	**0**	**0**
Dooks Golf Course									
D1	0	2	0	1s	1 000s	0	0	100s	0
D2	12	5	0	1s	1 000s	1 000s	0	0	0
D3	7	7	2	0	1 000s	0	0	0	0
D4	0	4	0	0	10s	0	0	0	0
D5	0	0	0	0	0	0	0	0	0
D6	25	30	19	10s	1 000s	100s	0	100s	0
Sub-totals	**44**	**48**	**21**	**10s**	**1 000s**	**1 000s**	**0**	**100s**	**0**
Lough Yganavan									
Yganavan1	0	0	0	0	0	0	0	0	0
Yganavan2				0	0	0	0	0	0
Yganavan3	0	0	0	0	0	0	0	0	0
Yganavan4	50	36	7	100s	10 000s	1 000s	0	100s	0
Yganavan5	0	0	0	0	0	0	0	0	0
Yganavan6	45	24	2	10 000s	10 000s	10 000s	100s	100s	0
Yganavan7	12	9	1*	10 000s	1 000s	1 000s	0	1s	0
Yganavan8	20	31	1*	10 000s	10 000s	1 000s	1 000s	1 000s	100s
Yganavan9	25	21	1*	10 000s	10 000s	100s	1 000s	1 000s	10s
Yganavan10	2	10	1*	10 000s	10 000s	1 000s	10s	0	0
Yganavan11	1	15	10	100s	1 000s	100s	0	10s	1s
Sub-totals	**155**	**146**	**23**	**10 000s**	**10 000s**	**10 000s**	**10 000s**	**10 000s**	**100s**
Nambrackdarrig									
IverLough	1*	9	1*	100s	10 000s	10 000s	100s	1 000s	10s
Sub-totals	**1**	**9**	**1**	**100s**	**10 000s**	**10 000s**	**100s**	**10 00s**	**10s**
Quarry									
IverQU1	0	0	1	0	0	1 000s	0	0	0
IverQU2	1	5	0	100s	10 000s	0	0	0	0
IverQU3	0	13	4	0	100s	1 000s	0	100s	0
IverQU4	1	0	0	100s	0	0	0	0	0
IverQU5	13	9	1	10s	100s	100s	0	0	1s
Sub-totals	**15**	**27**	**6**	**100s**	**10 000s**	**1 000s**	**0**	**100s**	**1s**
Glenbeigh									
21	0	0	1	-	-	100s	-	-	10s
43	5	0	0	10s	dry	dry	0	dry	dry
Sub-totals	**5**	**0**	**1**	**10s**	-	**100s**	0	-	10s
Caherdaniel									
C1	64	88	107	100s	10 000s	10 000s	10s	1 000s	1 000s
C2	148	122	88	1 000s	1 000s	100s	100s	1 000s	10s
C3	30	21	29	100s	100s	1 000s	10s	100s	1 000s
Sub-totals	**242**	**231**	**224**	**1 000s**	**10 000s**	**10 000s**	**100s**	**10 000s**	**10 000s**
Total (Co Kerry)	**3095**	**1363**	**2608**	**10 000s**	**10 000s**	**100000s**	**1 000s**	**1 000s**	**1 000s**

3.2 Monitoring of the artifically constructed ponds

We monitored 100 constructed ponds developed as part of the NPWS Pond Creation Scheme. Two additional ponds were constructed during 2018 (pond IDs: 24C and 24D) and were added to the survey.

3.2.1 Egg strings

Natterjack Toad egg strings were recorded at 17 (17%) constructed ponds in 2016, 10 (10%) in 2017 and 13 (13%) in 2018 (Table 5). The total number of egg strings recorded at all constructed ponds was 124 in 2016, 84 in 2017 and 77 in 2018. During 2016-18 between 3% and 6% of the total number of egg strings were recorded at constructed ponds. The most productive area was Roscullen Island and the most productive ponds were 07A and 07B.

In 2016, egg strings were missed at pond 38A due to poor water quality and only tadpoles were recorded. We inferred retrospectively the presence of at least one egg string at the pond (marked with an asterisk in Table 5). The population size was most likely underestimated due to missed egg strings.

3.2.2 Tadpoles

Tadpoles were found at 15 constructed ponds in 2016, 8 in 2017 and 10 ponds in 2018 (Table 5). The most productive areas were Roscullen Island and Glenbeigh and the most productive ponds were 04A/B, 07A/B and 21A and 43B.

3.2.3 Toadlets

Toadlets occurred at 4 constructed ponds in 2016, 5 in 2017 and 5 in 2018 (Table 5). Detection of toadlets was problematic at ponds with low numbers of egg strings and tadpoles. That does not necessarily mean that the survival rate of egg strings and tadpoles at the constructed ponds is lower compared to the traditional breeding ponds.

Table 5 Total number of egg strings recorded and the maximum number of tadpoles and toadlets observed at each constructed pond in 2016-18.

Site	Pond ID	Egg strings			Tadpoles			Toadlets		
		2016	**2017**	**2018**	**2016**	**2017**	**2018**	**2016**	**2017**	**2018**
Roscullen Island	07A	47	7	21	1 000s	10 000s	1 000s	100s	100s	100s
	07B	22	29	19	10 000s	10 000s	10 000s	1s	100s	1 000s
	10A	0	0	0	0	0	0	0	0	0
	04A	1	0	1	100s	0	10 000s	1s	0	0
	04B	2	10	19	1 000s	10 000s	10 000s	100s	100s	100s
	37A	4	1	1	100s	100s	1 000s	100s	0	1s
	37B	1	0	1	100s	0	1 000s	0	0	1s
	03A	1	0	0	10s	0	0	0	0	0
	14A	0	0	1	0	0	0	0	0	0
	14B	0	3	1	0	0	100s	0	0	0
	38A	1*	0	0	100s	0	0	0	0	0
	38B	5	0	0	0	0	0	0	0	0
	Sub-totals	**79**	**50**	**64**	**10 000s**	**10 000s**	**10 000s**	**10 00s**	**1 000s**	**1 000s**
Killeen	06A	11	0	1	100s	0	0	0	0	0
	06B	1	6	7	0	0	0	0	0	0
	Sub-totals	**12**	**6**	**8**	**100s**	**0**	**0**	**0**	**0**	**0**
Dooks	41A	4	3	1	100s	1 000s	10s	0	0	0
	41B	2	3	0	1s	10s	0	0	0	0
	Sub-totals	**6**	**6**	**1**	**100s**	**1 000s**	**10s**	**0**	**0**	**0**
Glenbeigh	21A	9	19	2	100s	10 000s	10 000s	0	100s	0
	43A	1	0	0	10s	0	0	0	0	0
	43B*	14	13	2	1 000s	10 000s	10 000s	100s	100s	0
	Sub-totals	**24**	**32**	**4**	**1 000s**	**10 000s**	**10 000s**	**100s**	**100s**	**0**
Total (Co Kerry)		**121**	**94**	**77**	**10 000s**	**10 000s**	**10 000s**	**100s**	**100s**	**100s**

3.3 Update of the Natterjack Toad distribution range

During the breeding season extensive pond searches were conducted throughout the Maharees and Inch Peninsula with the discovery of 7 new breeding sites (i.e. previously unrecorded). A new breeding site was discovered along the north shore of Lough Gill in relatively close proximity to the old site that was not possible to access due to deep water and dense vegetation. Banna strand (Q 75048 22208) and Rossbeigh (V 64865 92492) were also searched but no sign of breeding was found, probably due to high water salinity (>20ppt) recorded at ponds formed in dune slacks. In total, 20 new breeding locations were discovered during the 2016-18 survey (Table 6).

The current range and distribution of the Natterjack Toad in Co. Kerry was mapped at a 2km grid cell resolution. The Favourable Reference Range was based on the historical distribution of the species and incorporates likely connectivity between populations (Beebee 2002; NPWS, 2013). The mapped distribution includes all Natterjack Toad records (adults, egg strings, tadpoles and toadlets) from the 2016-18 survey (Figure 4). The Natterjack Toad was present in 19 cells. Thus, the species' distribution increased by 3 cells (19%) since the previous survey during 2011-12 (Sweeney *et al*. 2013) as a result of newly discovered breeding sites at Inch and Lough Yaganavan (i.e. better information; not reflective of actual range extension). Maps of all the surveyed ponds, with an indication of Natterjack Toad breeding activity, are presented in Appendix C.

Table 6 List of newly discovered breeding ponds/sites and their coordinates.

#	ID	Irish grid	Coordinates		Area	Discovery date
			X	Y		
1	43	V6540191396	065401	091396	Glenbeigh	12th April 2016
2	21	V6572291611	065722	091611	Glenbeigh	4th June 2018
3	Inch4	V6530799530	065307	099530	Inch	27th May 2016
4	Inch5	V6544799425	065447	099425	Inch	27th May 2016
5	Inch6	V6559199552	065591	099552	Inch	27th May 2016
6	Inch7	V6569499669	065694	099669	Inch	27th May 2016
7	Inch8	V6683897557	066838	097557	Inch	7th May 2016
8	IverQU5	Q6791992041	067919	092041	Iveragh Quarry	5th April 2016
9	LoughGill	Q6036114363	060361	114363	Lough Gill	14th April 2016
10	M12A	Q6170016554	061700	116554	Maharees	8th May 2018
11	M24	Q6060314878	060603	114878	Maharees	25th April 2016
12	M25	Q6130116016	061301	116016	Maharees	9th June 2016
13	M26	Q6110015727	061100	115727	Maharees	25th April 2016
14	Ross3	Q7551502551	075515	102551	Roscullen Island	25th May 2017
15	Yganavan6	V7026295460	070262	095460	Yganavan Lake	6th April 2016
16	Yganavan7	V7027695408	070276	095408	Yganavan Lake	27th April 2016
17	Yganavan8	V7090696033	070906	096033	Yganavan Lake	27th April 2016
18	Yganavan9	V7075696030	070756	096030	Yganavan Lake	27th April 2016
19	Yganavan11	V7084996066	070849	096066	Yganavan Lake	24th May 2016
20	Yganavan10	V7024595470	070245	095470	Yganavan Lake	5th May 2016

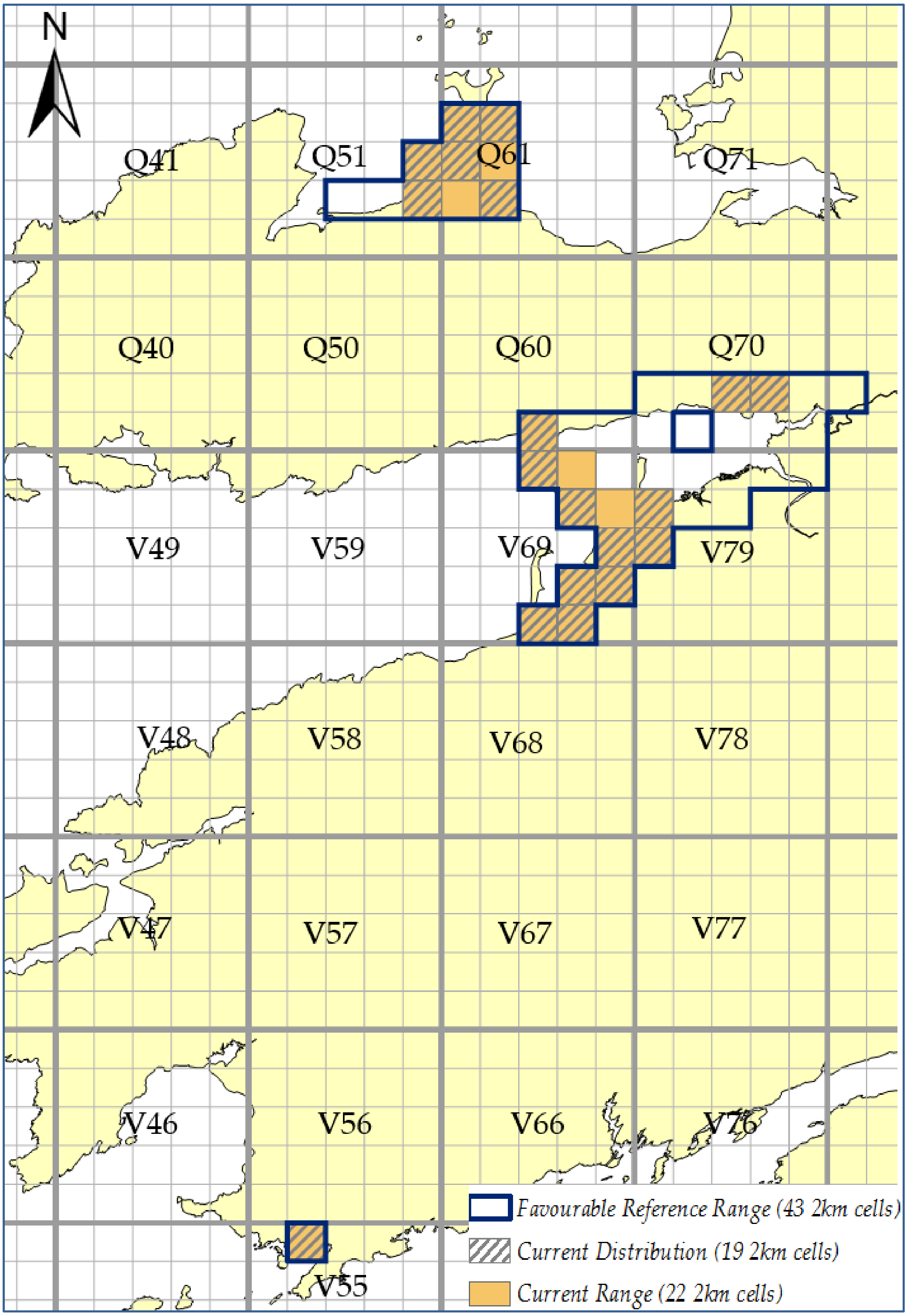


Figure 4 Natterjack Toad distribution (at 2km level) in Co. Kerry, Ireland during 2016-18.

3.4 Uncertainty in population estimation

3.4.1 Error in enumerating egg strings

Variation in egg string counts between successive pond visits was estimated by fitting a sigmoidal curve to the cumulative total number of egg strings each year ±95% confidence intervals (Figure 5). On average, error in egg string counts was ±1.6% between 2016-18 being highest at 2.0% during 2016 and lowest at 1.2% during 2018 (Table 7).

This form of analysis also provided additional information on the temporal pattern of spawning *between* years. During 2016, few toads spawned during early April with most egg strings appearing rapidly during early May i.e. highly synchronous spawning with a short transition from low to high egg string numbers yielding the widest annual confidence interval (i.e. higher uncertainty due to the rapidity of spawning). During 2017 and 2018, spawning started earlier and accrued more consistently despite differing profiles i.e. slopes of the line, for each year (steeper in 2018 than 2017); yielding narrower confidence intervals than those for 2016 i.e. there was less variability around the mean curve resulting in higher confidence in the egg string count. It should be noted that whilst the magnitude of early spawning was variable between years, the asymptote of egg strings was roughly synchronous during late June (13^{th}-27^{th}) each year with relatively little spawning activity (a few 10s of egg strings) from late May onwards (Figure 5).

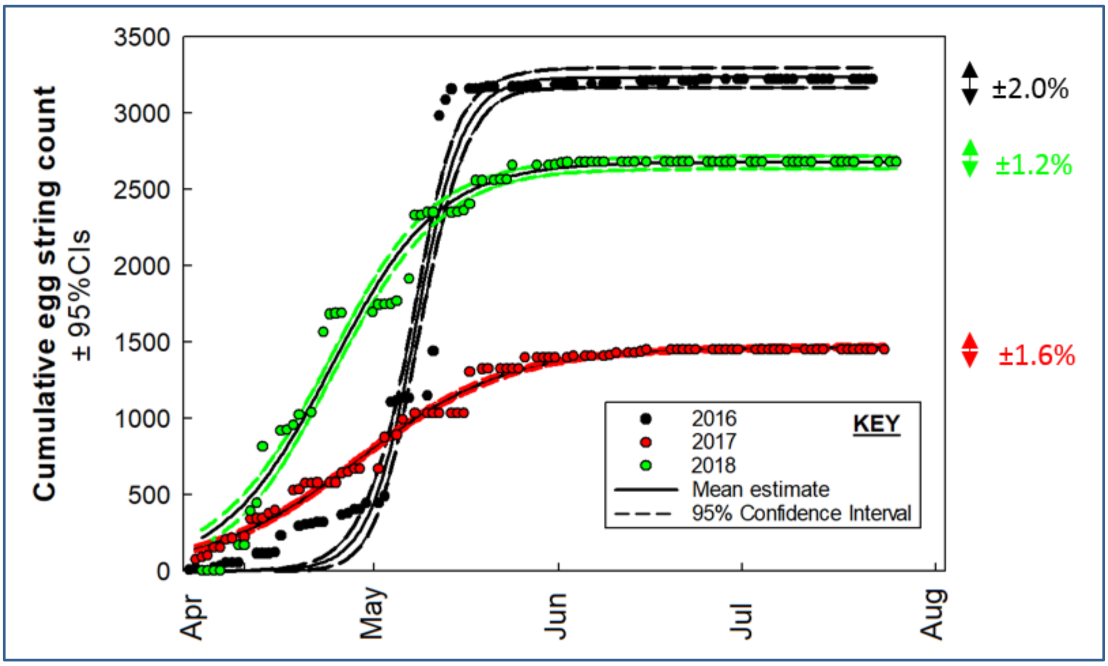


Figure 5 Cumulative Natterjack egg string counts with each pond visit as spawning progressed (April to July) during 2016, 2017 and 2018. Error (95% Confidence Intervals) in population estimates (solid lines) derived entirely from the pattern of temporal variation in egg string counts between pond visits was estimated using a sigmoidal (asymptotic) curve (dashed lines).

Table 7 Error (95% Confidence Intervals), lower confidence estimate (LCL) and upper confidence estimate (UCL) in egg string counts from 2016 to 2018 as derived from Figure 5.

Year	Breeding population estimate	95% Confidence interval	±% error	LCL	UCL
2016	3 222	132	±2.0	3,156	3,288
2017	1 449	36	±1.2	1,431	1,467
2018	2 681	84	±1.6	2,639	2,723

3.4.2 Variability in the proportion of females that spawn

Confidence intervals associated with egg string counts (Section 3.4.1) were propagated up to the female population estimate. Following variation as reported in the literature (see Table 2) we assumed the mean percentage of females that bred annually [95%CIs] to be 58 [52-65]%. This generated substantial errors, for example, for 2016 we estimated that the female population was 5,555 [4,856 - 6,323] individuals i.e. ±13-14% error (Table 8).

Table 8 Female population estimates derived from egg string counts (see Table 6) assuming variation in the percentage of females that breed i.e. 58 [52-65]% following that reported in the literature (Table 1).

Year	Mean	LCL	UCL
a) … assuming the LCL = 52% of females bred			
2016	6 196	6 070	6 323
2017	2 787	2 752	2 821
2018	5 156	5 075	5 237
b) …assuming the mean = 58% of females bred			
2016	5 555	5 442	5 669
2017	2 498	2 468	2 529
2018	4 622	4 550	4 695
c) …assuming the UCL (65%) of females bred			
2016	4 957	4 856	5 058
2017	2 229	2 202	2 257
2018	4 125	4 060	4 189
d) … assuming a mean (58%), LCL (52%) & UCL (65%)			
2016	**5 555**	**4 856**	**6 323**
2017	**2 498**	**2 202**	**2 821**
2018	**4 622**	**4 060**	**5 237**

It should be noted that there are no empirical data for the proportion of female Natterjacks that are likely to breed annually in Ireland. Applying uniform percentage multipliers fails to capture site-specific or interannual variability. Thus, it remains possible that the confidence intervals around the current estimates (Table 8) may be even wider than those reported.

3.4.3 Variability in sex ratios

Confidence intervals associated with the total population estimate incorporated additive errors in egg string counts i.e. not only the proportion of females that breed annually but also the variation in sex ratios as reported in the literature (Table 2). In addition to population estimate permutations that assumed the lower, mean and upper confidence interval for the proportion of females that bred and the sex ratio, we also provided an estimate based on the upper proportion of females that bred (65%) and a sex ratio of 1:1 i.e. a total population estimate directly comparable with previous estimates (Table 2c). By incorporating all sources of potential additive error, the mean population estimate fluctuated from 22,054 [7,891 – 30,905] individuals during 2016 to 9,918 [3,578 - 13,788] individuals during 2017 before returning close to baseline levels during 2018 at 18,351 [6,597 – 25,597] (Table 8e). Thus, the total population could have been as low as 3,578 and as high as 30,905 (an order of magnitude i.e. 10-fold difference) during the three years of study (Figure 6) and without any empirical data on the proportion of females that bred or the sex ratio it is impossible to provide more precise population estimates. Such was the width of the total population confidence intervals that there was substantial overlap between all years meaning we cannot have any confidence that differences in mean estimates are statistically significant i.e. we cannot differentiate between the current trend (a decline from 2016 to 2017 before an increase by 2018) and a straight line i.e. no temporal trend (Figure 6). Such confidence intervals whilst statistically valid are ecologically meaningless and do not reflect real temporal variation in the percentage of females that bred or the sex ratio. Therefore, we cannot support the reporting of total Natterjack Toad population estimates nor their comparison across time (i.e. with previous surveys which adopt arbitrary multipliers). The only variation that is meaningful is that associated with egg string counts. Moreover, change in total population estimates were directly proportional to changes in egg string counts (Figure 6) as they are the only source of variation which was then scaled by various multipliers. *Therefore, all subsequent analyses examined egg string counts only.*

Table 9 Total population estimates derived from egg string counts (see Table 7) assuming variation in the percentage of females that breed (Table 8) and assuming variation in the male:female sex ratio following that reported in the literature (Table 2).

	Year	Mean	LCL	UCL
a) … assuming the LCL (52%) females bred + the LCL for male:female sex ratio (0.3:1)				
	2016	8 055	7 891	8 219
	2017	3 623	3 578	3 667
	2018	6 703	6 597	6 808
b) … assuming the mean (58%) females bred + the mean male:female sex ratio (2.97:1)				
	2016	22 054	21 604	22 504
	2017	9 918	9 796	10 040
	2018	18 351	18 063	18 639
c) … assuming the UCL (65%) females bred + a male:female sex ratio (1:1) **** this permutation is directly comparable to previous population estimates ****				
	2016	9 914	9 712	10 116
	2017	4 458	4 404	4 514
	2018	8 250	8 120	8 378
d) … assuming the UCL (65%) females bred + the UCL for male:female sex ratio (5.11:1)				
	2016	30 287	29 668	30 905
	2017	13 621	13 453	13 788
	2018	25 201	24 806	25 597
e) … assuming the mean (58%) females bred + the mean male:female sex ratio (2.97:1), the LCL (52%) females bred + the LCL for male:female sex ratio (0.3:1) and the UCL (65%) females bred + the UCL for male:female sex ratio (5.11:1)				
	2016	**22 054**	**7 891**	**30 905**
	2017	**9 918**	**3 578**	**13 788**
	2018	**18 351**	**6 597**	**25 597**

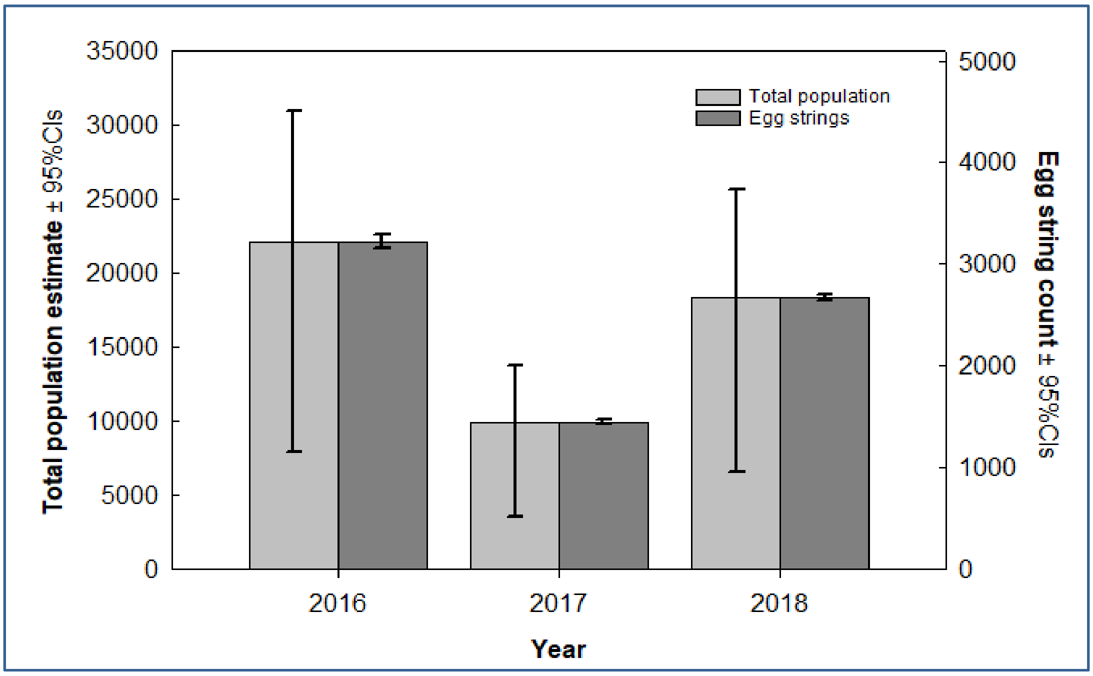


Figure 6 Total population estimates ± asymmetric 95% confidence intervals (left y-axis; light grey) which add errors in eggs string counts to errors in both the proportion of females that breed annually and the population sex ratio and the egg string count ± symmetric 95% confidence intervals (right y-axis; dark grey). Note that the temporal pattern in both parameters is identical (driven by changes in egg string counts) but the measurement of error (whiskers) are vastly different. Translating egg strings into population estimates cannot be done without accepting large uncertainties.

3.5 Spatial and temporal trends in productivity

3.5.1 Spatial trends

The single most productive metapopulation was that of the North Dingle peninsula i.e. Maharees, Castlegregory golf course and Tullaree (Table 10 & Figure 7). In 2016 we recorded the highest number of egg strings for this area since 2004; likely the result of high numbers of ponds forming in sand dune slacks due to overwinter rainfall. Toadlet abundance (density in toadlets/m^2 multiplied by the area surveyed around each pond based on pond circumference) was used as a second indicator of the Natterjack Toad productivity. The highest toadlet abundance was record at the Maharees in 2018 (Table 10 & Figure 8). Toadlet abundance was highly correlated with egg string production (r_s=0.694, p<0.001, n=33), largely driven by the large numbers of both at the Maharees, though this positive relationship remained statistically significant even after excluding the Maharees albeit marginally less strong (r_s=0.619, p<0.001, n=30; Figure 9).

Table 10 The total number of egg strings and toadlet abundance (i.e. density in toadlets/m^2 multiplied by the area surveyed around each pond based on pond circumference) recorded at all sites and areas during the breeding season in 2016-18.

Area	Site	Egg strings			Toadlet abundance		
		2016	**2017**	**2018**	**2016**	**2017**	**2018**
Dingle Peninsula - North							
	Maharees	2 261	386	1 519	479 372	5 280	487 684
	Castlegregory Golf Course	354	495	405	24 960	86 880	53 777
	Tullaree	1	3	16	0	0	20 924
	Sub-totals	**2 616**	**884**	**1 940**	**504 332**	**92 160**	**562 385**
Dingle Peninsula - South							
	Inch	17	18	392	3 440	0	0
	Killen	12	6	8	0	0	0
	Rosscullen island	79	50	64	720	1 120	2 732
	Sub-totals	**108**	**74**	**464**	**4 160**	**1 120**	**2 732**
Iveragh Peninsula - North							
	Dooks Golf Course	50	54	22	0	160	0
	Lough Yganavan	155	146	23	16 080	13 280	178
	Nambrackdarrig	1	9	1	320	0	7
	Glenbeigh	44	59	11	160	1 440	64
	Sub-totals	**250**	**268**	**57**	**16 560**	**14 880**	**248**
Iveragh Peninsula - South							
	Caherdaniel	242	231	224	160	14 080	19 841
	Sub-totals	**242**	**231**	**224**	**160**	**14 080**	**19 841**
Total Ireland (Co. Kerry)		**3 216**	**1 457**	**2 685**	**525 212**	**122 240**	**585 206**

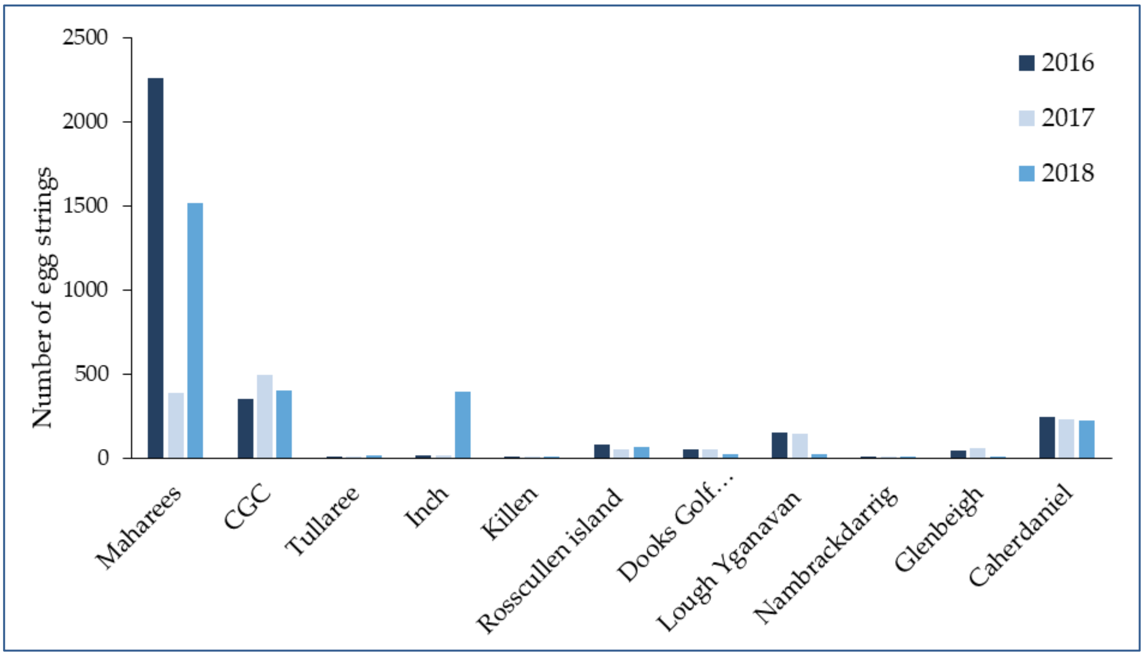


Figure 7 Number of egg strings at each site for 2016, 2017 and 2018.

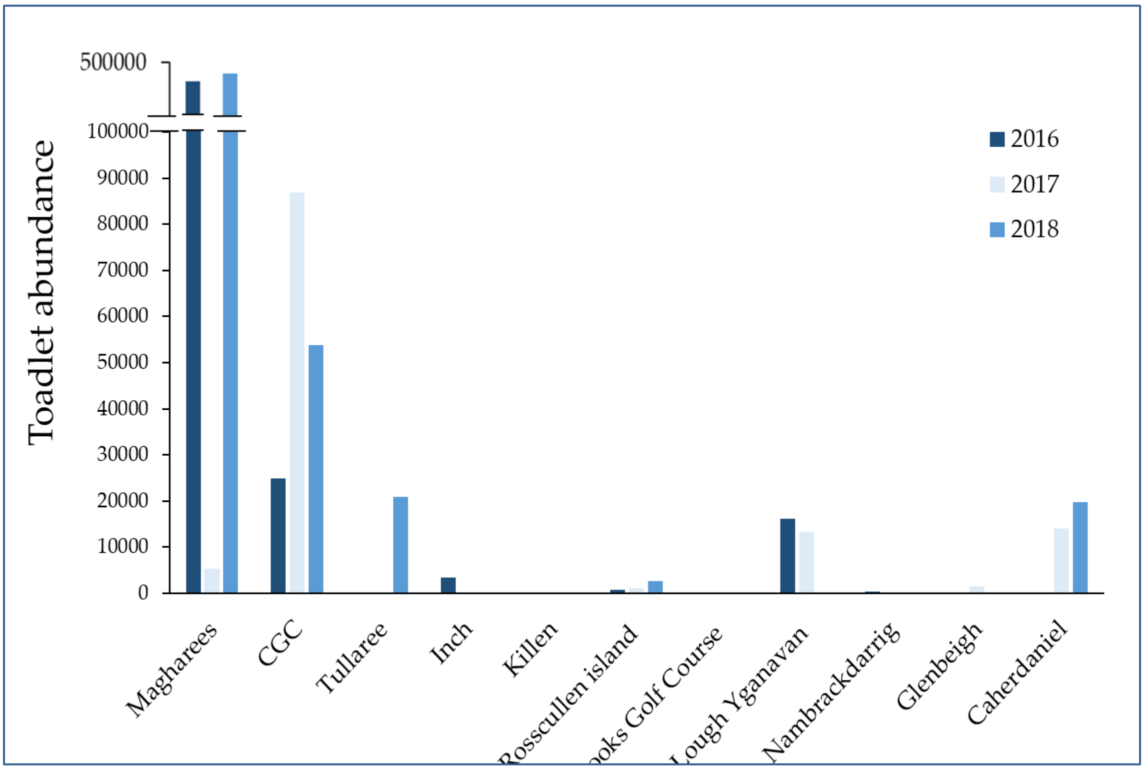


Figure 8 Toadlet abundance at each site for 2016, 2017 and 2018.

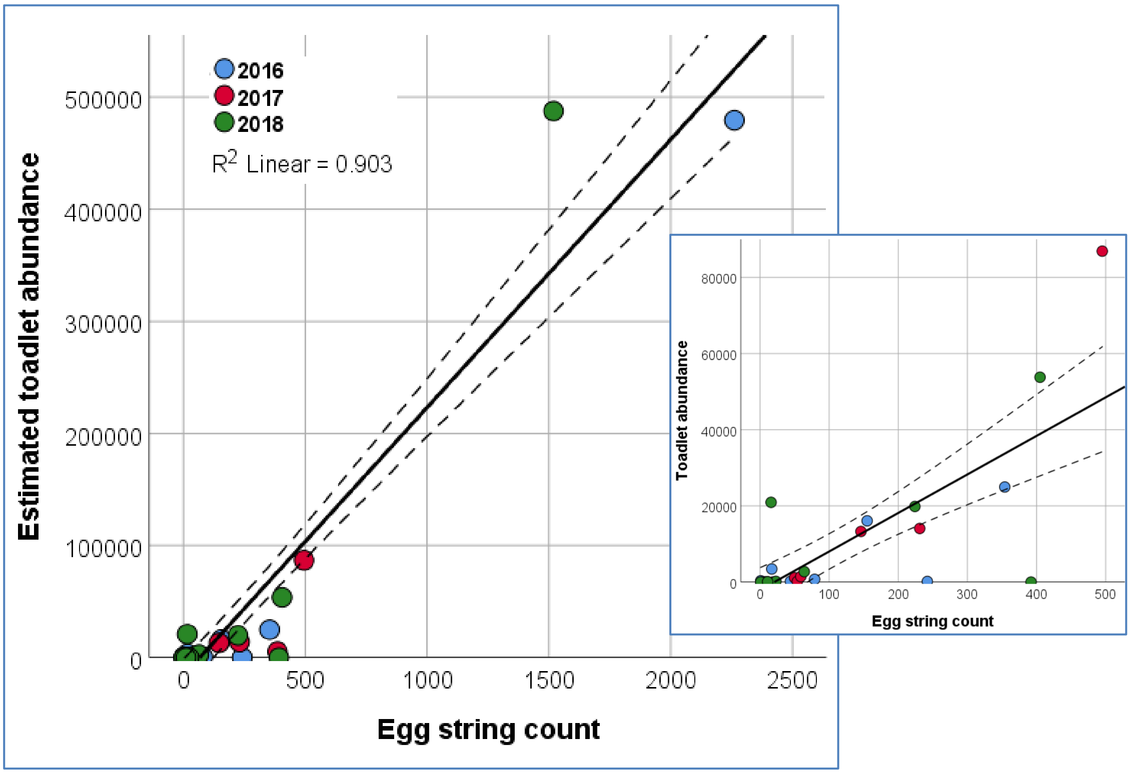


Figure 9 Relationship between egg string counts per metapopulation as one measure of productivity and toadlet abundance as a second measure of productivity. Insert shows same relationship excluding the Maharees.

3.5.2 Temporal trends

The total number of egg strings recorded during 2016-18 was higher than during 2011-12, but lower than those recorded in 2005-06 (Figure 10). Since monitoring began in 2004, egg string counts have declined by 23% (Table 11). Weather conditions in 2011-12 were particularly unsuitable, being unseasonably dry during April and May with low air temperatures and overall, warmer, wetter years appear to be better for toad productivity. However, with only 8 years of time-series data available, neither mean air temperature (r_s=0.534, p=0.173) nor winter rainfall (r_s=0.128 p=0.762) were significantly associated with egg string production at the annual level (Figure 10).

Estimated toadlet abundance during 2016-18 followed a very similar temporal trend as egg string production during those years, with a close positive relationship with overwinter rainfall (Figure 11).

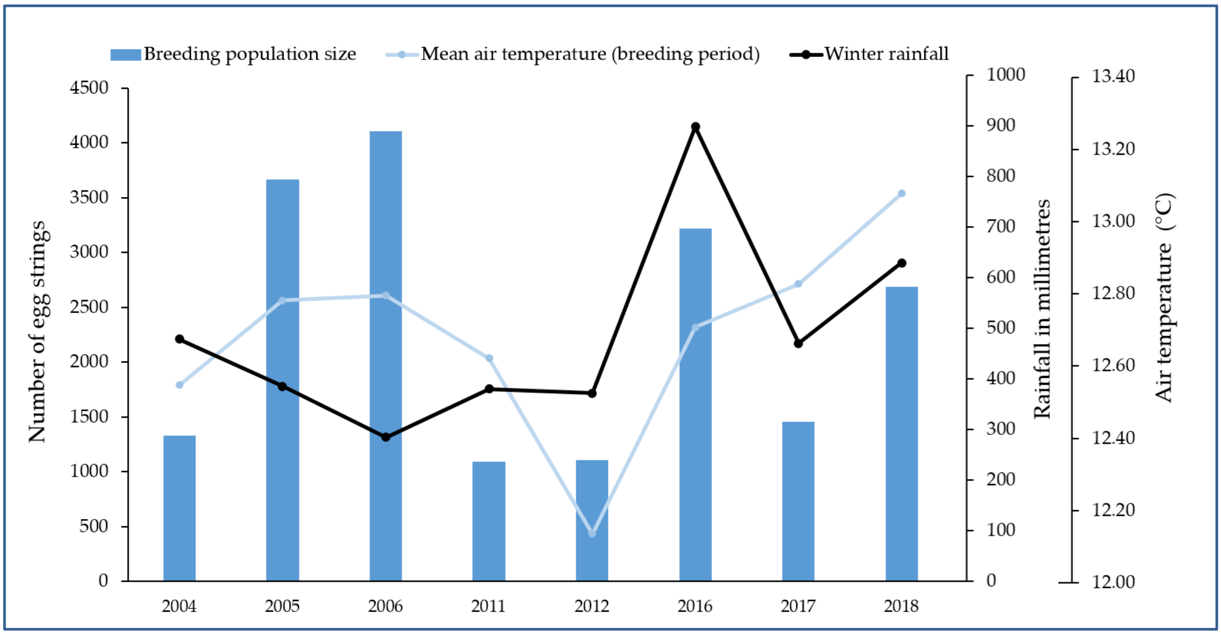


Figure 10 Egg string count, air temperature during the breeding season and annual rainfall for 2004-06, 2011-12 and 2016-18.

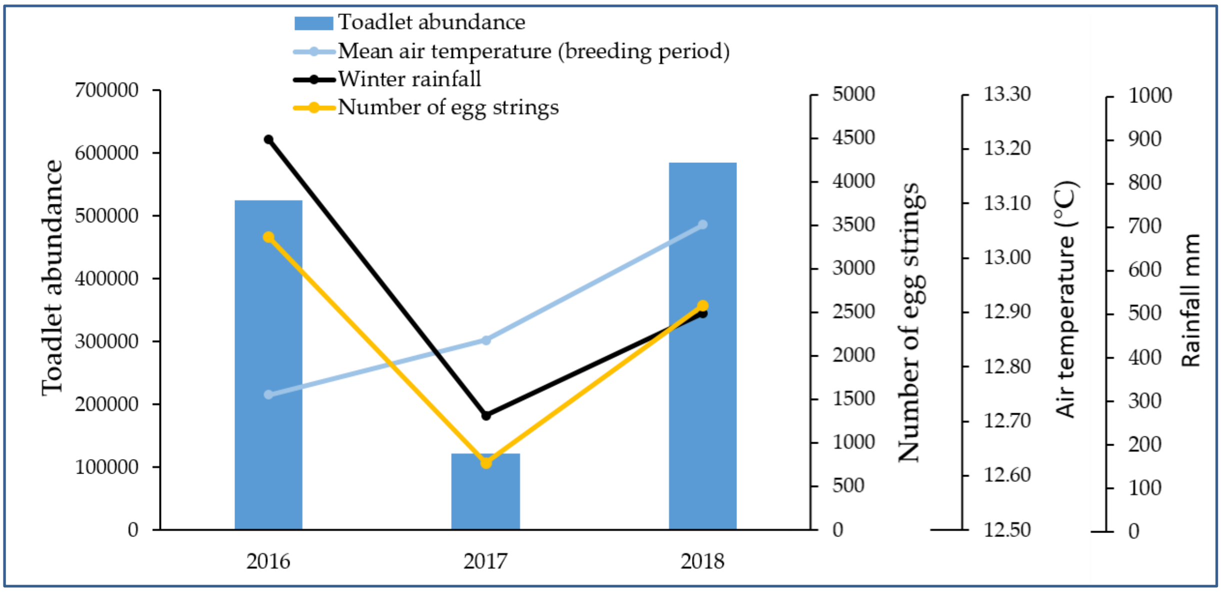


Figure 11 Toadlet abundance in relation to cumulative winter rainfall, average air temperatures during the breeding season and total number of egg strings (*Note*: precise toadlet abundance estimates were available only for 2016-18; previous surveys estimated abundance in orders of magnitude e.g. 1, 10, 100, 10,000 etc.).

3.5.3 Temporal trends at individual sites and metapopulations

The total number of egg strings counted during 2016-18 suggested declines in almost all sites and metapopulations throughout Co. Kerry over the last 14 years (Table 11, Figure 12). The greatest declines over time (>90%) were observed at Rosscullen Island and Dooks golf courses, with the small population at Fermoyle now believed to have died out. Most likely egg string numbers for Inch and Lough Nambrackdarrig are underestimated. The first systematic survey of Inch peninsula was conducted in 2016. Since then five new breeding ponds have been found, however, most sites were discovered late in the breeding season with early egg strings being missed. The Natterjack Toad's breeding area at Lough Nambrackdarrig has become overgrown with terrestrial and aquatic vegetation decreasing the egg string detection and restricting site access. High numbers of tadpoles were observed which suggests missed egg strings. The only population with an increase in egg string count was the Maharees. This is the largest and most important Natterjack Toad population in Ireland.

Table 11 Natterjack Toad egg string count for each year, site, area and overall in Kerry. The slope of linear trends (see Figure 12) are presented as the average change from the start and end of the line of best fit (not the beginning and end value for numbers of observed egg strings) and have been standardised to have a mean of zero and a standard deviation of 1 allowing direct comparisons of coefficients. Similarly, '% C' gives average percentage change values (%) represent the difference in the fitted line not the raw data.

Site	2004	2005	2006	2011	2012	2016	2017	2018	β±SE	% C
Dingle Peninsula - North										
Maharees	228	983	1183	381	224	2261	386	1519	0.063 ± 0.068	114
Castlegregory Golf Course	573	868	992	472	421	354	495	405	-0.132 ± 0.049	-54
Fermoyle	3	0	0	0	0	0	0	0	-0.091 ± 0.062	-100
Tullaree	12	35	51	23	1	1	3	16	-0.109 ± 0.057	-87
Sub-totals	**816**	**1886**	**2226**	**876**	**646**	**2616**	**884**	**1940**	**0.018 ± 0.072**	**14**
Dingle Peninsula - South										
Inch	-	-	-	-	-	17	18	392	0.867 ± 0.498	900
Killen	-	-	-	7	23	12	6	8	-0.142 ± 0.166	-63
Rosscullen island	91	532	873	17	220	79	50	64	-0.105 ± 0.059	-96
Sub-totals	**91**	**532**	**873**	**24**	**243**	**108**	**74**	**464**	**-0.061 ± 0.068**	**-59**
Iveragh Peninsula - North										
Dooks Golf Course	45	568	209	10	2	50	54	22	-0.098 ± 0.061	-96
Lough Yganavan	219	269	419	66	101	155	146	23	-0.125 ± 0.052	-77
Nambrack-darrig	8	12	16	0	0	1	9	1	-0.108 ± 0.058	-87
Glenbeigh	52	67	55	11	23	44	59	11	-0.083 ± 0.064	-48
Sub-totals	**324**	**916**	**699**	**87**	**126**	**250**	**268**	**57**	**-0.120 ± 0.053**	**-86**
Iveragh Peninsula - South										
Caherdaniel	98	333	313	102	92	242	231	224	-0.001 ± 0.073	-6
Sub-totals	**98**	**333**	**313**	**102**	**92**	**242**	**231**	**224**	-0.001 ± 0.073	**-6**
Total Ireland (Co Kerry)	**1329**	**3667**	**4111**	**1089**	**1107**	**3216**	**1457**	**2685**	**-0.035 ± 0.071**	**-23**

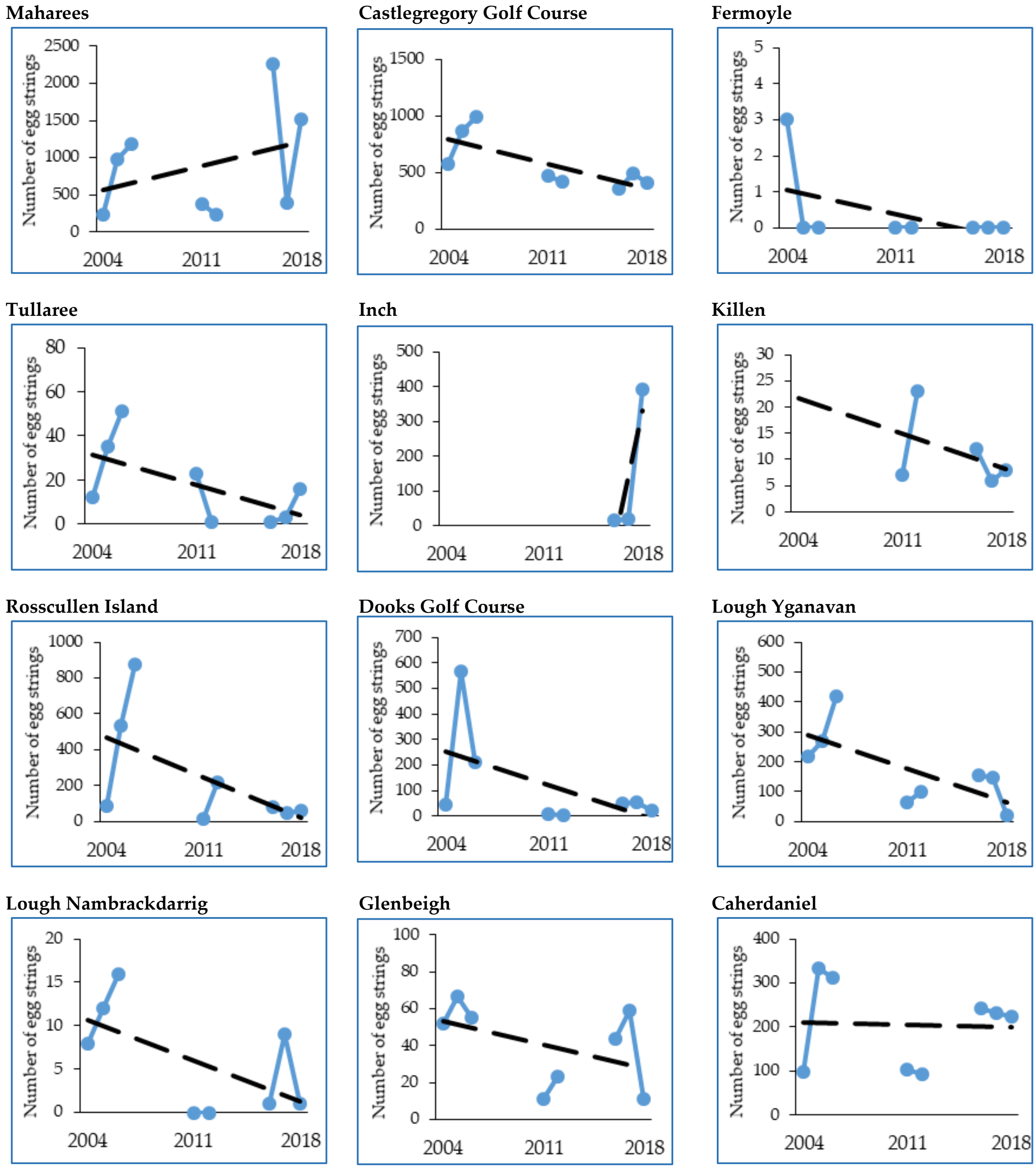


Figure 12 Number of egg strings recorded at each site along with the linear trend.

3.5.4 Weather conditions and breeding population size

3.5.4.1 Impacts of environmental conditions (at the individual pond visit level)

All three temperature variables (max mean temp, min mean temp and mean soil temp) were most predictive of egg string numbers at a temporal lag of 2 months whilst cumulative rainfall had greatest influence at 14 days prior to each pond survey (Table 12). All three measures of temperature were highly collinear (Table 13), thus only one was chosen for inclusion in subsequent analysis i.e. maximum mean temperature, taken as variable with the highest effect (highest β and F values).

In the global model, egg string numbers at each pond visit varied significantly between habitat types and were significantly positively related to rainfall in the 14 days prior to the pond visit but had no relationship with maximum mean temperature (Table 14). Year was fitted to account for any interannual variation not directly attributable to either rainfall or temperature with eggs strings significantly varying between years independent of these covariates.

To neutralise the potential effect of the rainfall we adjusted the model's predicted values and fixed rainfall at its maximum for any 14-day period throughout all survey years (i.e. 200 mm). Accounting for interannual variation in rainfall affected temporal trends in the numbers of eggs strings. In the observed raw data, numbers declined between 2011 and 2012 (Sweeney *et al.* 2013) but after accounting for rainfall numbers increased (Figure 13). Observed numbers of egg strings declined dramatically from 2016 to 2017 before recovering during 2018 (this study). After accounting for rainfall (i.e. the unseasonably dry spring of 2017 that resulted in low numbers of suitable breeding ponds) the predicted values suggested a linear decline of 49% from 2016 to 2018. The predicted data after accounting for rainfall suggested an increase in the number of egg strings from 2011 to 2012 peaking in 2016 before declining by 2018 (Figure 13).

Table 12 GLMM results for the effect of temperature and rainfall at different temporal lag periods prior to each pond visit on the number of egg strings counted. Each model had habitat type and year fitted as fixed factors.

Variable	Lag	AIC	ΔAIC	β ± SE	F	d.f.	d.f.	*p*
Max mean temp	7 days	8619.678	11.948	0.220±0.759	5.800	9	1761	<0.001
	14 days	8609.679	1.949	2.832±0.983	7.279	9	1761	<0.001
	21 days	8619.987	12.257	1.952±1.042	6.53	9	1761	<0.001
	28 days	8624.764	17.034	2.676±1.058	6.938	9	1761	<0.001
	2 months	**8607.73**	**0**	**2.409±1.070**	**6.81**	**9**	**1761**	**<0.001**
	3 months	8624.264	16.534	3.209±1.864	6.286	9	1761	<0.001
	4 months	8626.372	18.642	7.600±2.869	6.838	9	1761	<0.001
Min mean temp	7 days	8664.323	52.090	-1.474±0.503	6.873	9	1761	<0.001
	14 days	8621.406	9.173	0.259±0.572	5.874	9	1761	<0.001
	21 days	8619.704	7.471	0.475±0.588	6.046	9	1761	<0.001
	28 days	8616.932	4.699	0.558±0.586	6.051	9	1761	<0.001
	2 months	**8612.233**	**0**	**0.496±0.685**	**5.879**	**9**	**1761**	<0.001
	3 months	8619.512	7.279	0.621±1.143	5.764	9	1761	<0.001
	4 months	8616.1	3.867	4.643±1.826	6.493	9	1761	<0.001
Rainfall	7 days	8611.558	14.016	-0.523±0.406	6.587	9	1761	<0.001
	14 days	**8597.542**	**0**	**-1.005±0.439**	**7.972**	**9**	**1761**	**<0.001**
	21 days	8614.314	16.772	-0.614±0.482	6.204	9	1761	<0.001
	28 days	8625.893	28.351	-0.159±0.565	5.723	9	1761	<0.001
	2 months	8627.527	29.985	-1.413±0.765	6.709	9	1761	<0.001
	3 months	8609.673	12.131	-2.487±0.911	7.457	9	1761	<0.001
	4 months	8629.661	32.119	0.221±1.013	5.613	9	1761	<0.001
Soil mean temp	7 days	8616.833	6.618	1.350±0.733	6.790	9	1761	<0.001
	14 days	8616.917	6.702	2.604±0.763	8.266	9	1761	<0.001
	21 days	8610.249	0.034	2.165±0.752	7.567	9	1761	<0.001
	28 days	8615.872	5.657	1.946±0.734	7.291	9	1761	<0.001
	2 months	**8610.215**	**0**	**1.544±0.747**	**6.795**	**9**	**1761**	**<0.001**
	3 months	8623.096	12.881	2.318±1.113	6.576	9	1761	<0.001
	4 months	8622.775	12.560	2.235±1.106	6.546	9	1761	<0.001

Table 13 Highly correlated environmental parameters.

Pearson's correlation coefficients	Max mean temp 2 months	Min mean temp 2 months	Rainfall 14 days	Soil temp 2 months
Max mean temp 2 months	-	**0.856**	-0.368	**0.974**
Min mean temp 2 months	-	-	-0.447	**0.887**
Rainfall 14 days	-	-	-	-0.330
Soil temp 2 months	-	-	-	-

Table 14 Output of the final model. Note that rainfall in the 2 weeks prior to each pond survey had the greatest single effect (F value) of any variable on the number of egg strings laid.

Environmental parameters	F	β ± SE	n.df.	d.df.	*p*
Model	5.926	2.461 ± 1.225	10	1684	**<0.001**
Habitat	7.021	Multifactorial	4	1684	**<0.001**
Year	1.188	Multifactorial	4	1684	0.314
Rainfall 14 days	13.849	0.012 ± 0.003	1	1684	**<0.001**
Max mean temp 2 months	7.886	-0.306 ± 0.109	1	1684	0.005

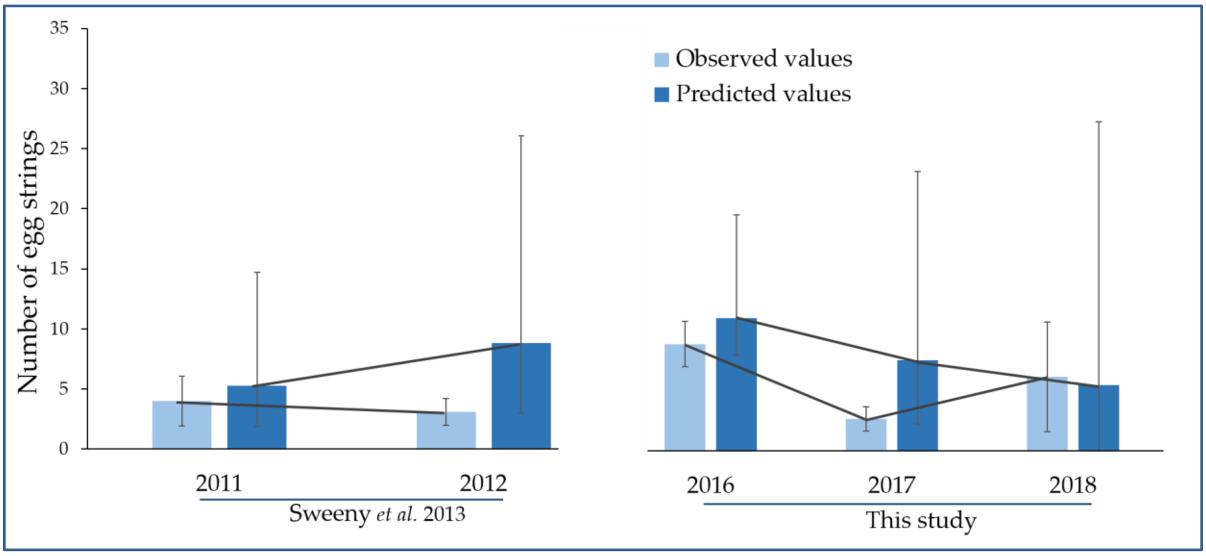


Figure 13 Mean number of egg strings (observed and predicted) per visit with 95% Confidence Intervals (CI). (Note: data for egg string counts for individual pond visits (not the total number per year) were unavailable for 2004-06 and were not included here).

3.5.4.2 Impacts of environmental conditions (at the aggregate annual level)

We investigated the impact of air temperature during the breeding season, winter rainfall (December – March) and number of ponds that formed at sand dune systems (Maharees, Inch, Caherdaniel, CGC and Dooks golf course) on the annual production of egg strings. All variables were standardised to have $x=0$ and $\sigma=1$ and tested for correlations.

The number of temporary ponds that formed annually was significantly correlated with the preceding winter's rainfall ($r_s=0.778$, $p=0.023$) and the cumulative total number of egg strings deposited throughout the entire breeding season (($r_s=0.778$, $p=0.023$; Table 15). Numbers of ponds that formed, rainfall and numbers of egg strings deposited were all independent of maximum, minimum and soil temperatures ($r_s<0.659$, $p>0.076$).

There was a marginally negative linear trend in the total number of eggs strings over time ($\beta \pm$ SE, -0.035 $\pm$ 0.071) which was more strongly negative after accounting for interannual variability in winter rainfall ($\beta \pm$ SE, -0.109 $\pm$ 0.058 Figure 14d&e). The slope of the linear trends ($\beta\pm$SE) and average percentage change value (%) were calculated for the total number of egg strings before and after accounting for interannual variability in winter rainfall. Overall, numbers of egg strings declined by 23% for the time period 2004-2018 (Figure 14d). After accounting for interannual variability in winter rainfall the slope of the linear trend became more steep indicative of a decline by 66% (Figure 14e).

Table 15 Highly correlated variables.

	Number of egg strings	Number of ponds	Rainfall (mm)	Max mean temperature
Number of egg strings	-	**0.778**	0.381	0.571
Number of ponds	-	-	**0.778**	0.659
Rainfall (mm)	-	-	-	0.452
Max mean temperature	-	-	-	-

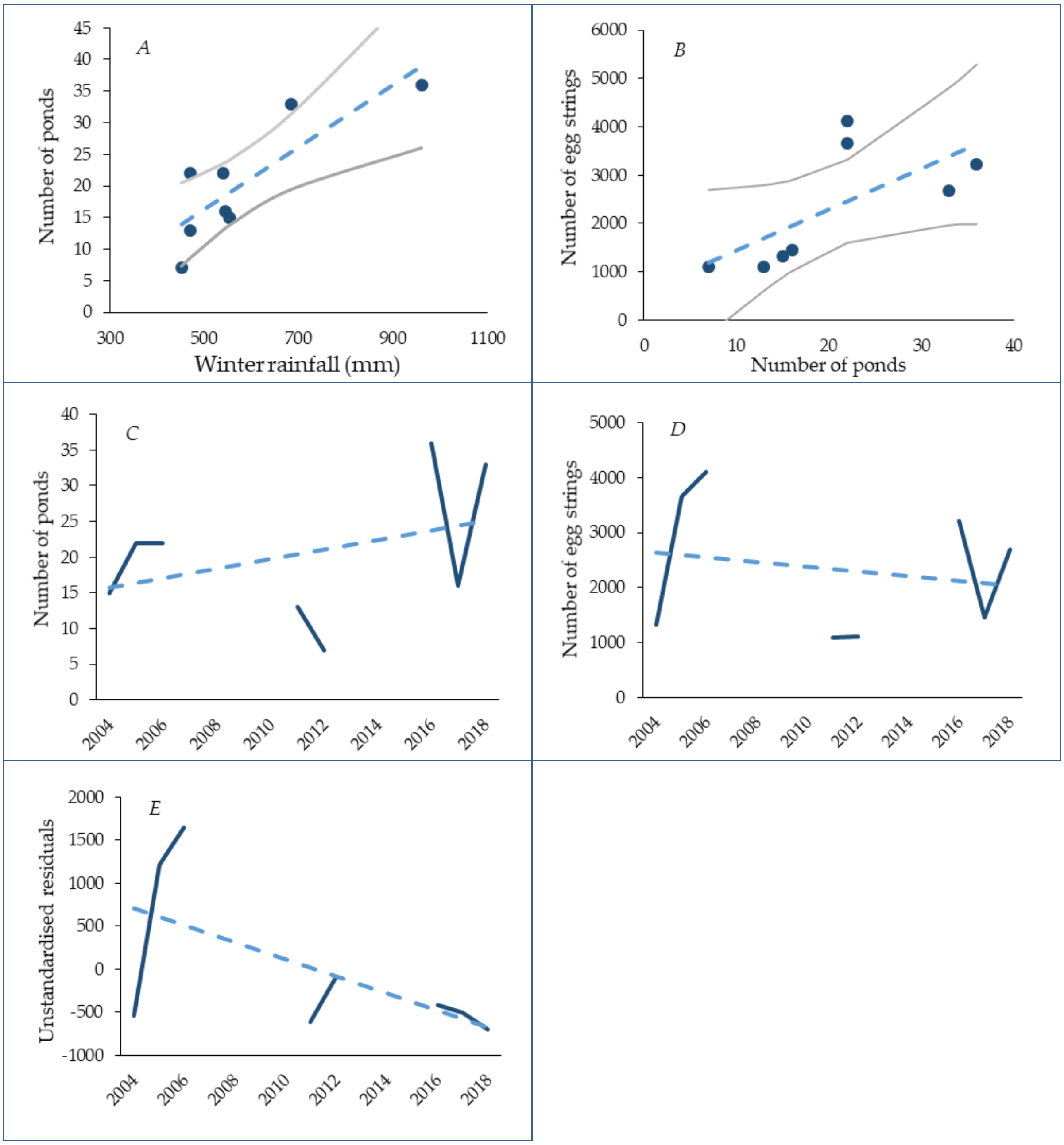


Figure 14 Annual variations in the number of egg strings and formed ponds at sand dune systems: A) relationship between number of formed ponds at the sand dunes and winter rainfall with 95% Confidence Intervals; B) relationship between number of egg strings and number of formed ponds at the sand dunes with 95% Confidence Intervals; C) number of ponds formed each survey year; D) number of egg strings recorded for each survey year; E) predicted values of egg strings from the Linear Regression.

3.6 Terrestrial and aquatic habitats

A total of 18 different environmental parameters were used for the model collected to describe terrestrial and aquatic habitats associated with each pond.

Natterjack Toad breeding was significantly associated with: ponds with a large surface area, neutral pH, high conductivity, high oxygenation, low plant litter, a high coverage of aquatic plants at the substratum and short grassland swards surrounding the pond edges (Table 16).

Pond type was strongly associated with habitat type (r_P=0.822, p<0.001) and land management activity (r_P=0.689, p<0.001) i.e. artificial ponds were mostly constructed on improved grasslands used for agriculture. Conductivity was strongly associated with salinity (r_P=0.721, p<0.001) with brackish water ponds occurring in relatively close proximity (<20m in some instances) to the marine high tide mark resulting in saltwater either seeping through the sand or soil into the pond or occasional saltwater flooding during unusually high tides, for example, at Tullaree.

When environmental variables were fitted simultaneously in a single General Linear Model (GLM), those variables in the single best model, suggested Natterjack Toad breeding activity varied significantly between habitat types (Table 17) with sand dune ponds being most productive (Figure 15). Breeding was more likely in ponds with a large surface area, high conductivity with a high coverage of aquatic plants at the substratum, similar to the results from univariate models above, suggesting these are the key combination of conditions most strongly determining breeding activity. Natterjack breeding activity had a positive trend with the coverage of aquatic plants at the surface and a negative trend with aquatic predator abundance, principally the numbers of predatory water beetles; and whilst both variables were included in the single best model neither was statistically significant at the conventional 95% level yet their inclusion suggests they may contribute to some variation in breeding activity (Table 17).

Table 16 Mean ± 1 standard deviation (SD) values of environmental parameters associated with ponds with and without Natterjack Toads and the statistical results for a test of difference.

Environmental parameter	Natterjack Toad		Mann Whitney		
	Absence	**Presence**	**U**	**Z**	***p***
Size					
Surface area (m²)	106.4 ± 295.0	1152.5 ± 2405.4	9802.5	-9.052	**<0.001**
Area that dried (%)	60.6 ± 27.7	63.4 ± 30.3	21225.0	-1.418	0.156
Water					
Water temperature	16.0 ± 2.0	15.6 ± 1.6	23817.0	-0.132	0.895
pH	6.7 ± 0.7	7.4 ± 0.7	11379.0	-9.383	**<0.001**
Conductivity (µS/cm)	502.9 ± 917.3	618.4 ± 671.5	15253.5	-6.501	**<0.001**
Salinity (ppt)	1.8 ± 2.5	1.6 ± 1.5	22513.5	-1.102	0.270
Oxygen					
mg/l	6.7 ± 2.4	7.2 ± 2.41	16720.5	-5.410	**<0.001**
% saturation	65.5 ± 23.1	78.8 ± 39.3	16268.5	-5.746	**<0.001**
Predator abundance	62.5 ± 50.4	65.1 ± 60.1	8873.0	-1.057	0.291
Vegetation (%)					
Emerged vegetation	24.6 ± 25.7	28.3 ± 26.7	22489.5	-1.134	0.257
Bare substrate	31.5 ± 31.6	17.5 ± 23.7	21624.0	-1.685	0.092
Surface aquatic plants	15.7 ± 22.5	18.3 ± 24.6	23510.5	-0.386	0.699
Plant litter	44.4 ± 32.9	35.6 ± 29.4	17936.5	-4.489	**<0.001**
Substratum aquatic plants	24.8 ± 28.2	53.4 ± 36.2	15654.5	-6.317	**<0.001**
Filamentous algae	6.6 ± 12.7	7.9 ± 17.3	23058.0	-0.845	0.398
Sward height (%)					
<5cm	18.9 ± 23.6	34.5 ± 27.8	17331.5	-5.058	**<0.001**
5-20cm	27.8 ± 25.2	21.6 ± 21.9	19983.5	-3.028	**0.002**
>20cm	53.1 ± 30.7	43.6 ± 27.6	21336.0	-1.988	**0.047**

Table 17 GLMMs results for associations between environmental parameters and number of egg strings.

Environmental parameters	*F*	*β* ± SE	n.df.	d.df.	*p*
Model	19.983	2.411±0.449	9	441	**<0.001**
Habitat type	26.145	Multifactorial	4	441	**<0.001**
Conductivity	8.152	0.743±0.260	1	441	**0.005**
Aquatic plants surface	0.101	0.044±0.140	1	441	0.751
Aquatic plants substrate	12.988	0.545±0.151	1	441	**<0.001**
Surface area	0.572	0.610±0.359	1	441	0.090
Predator abundance	2.886	-0.151±0.199	1	441	0.450

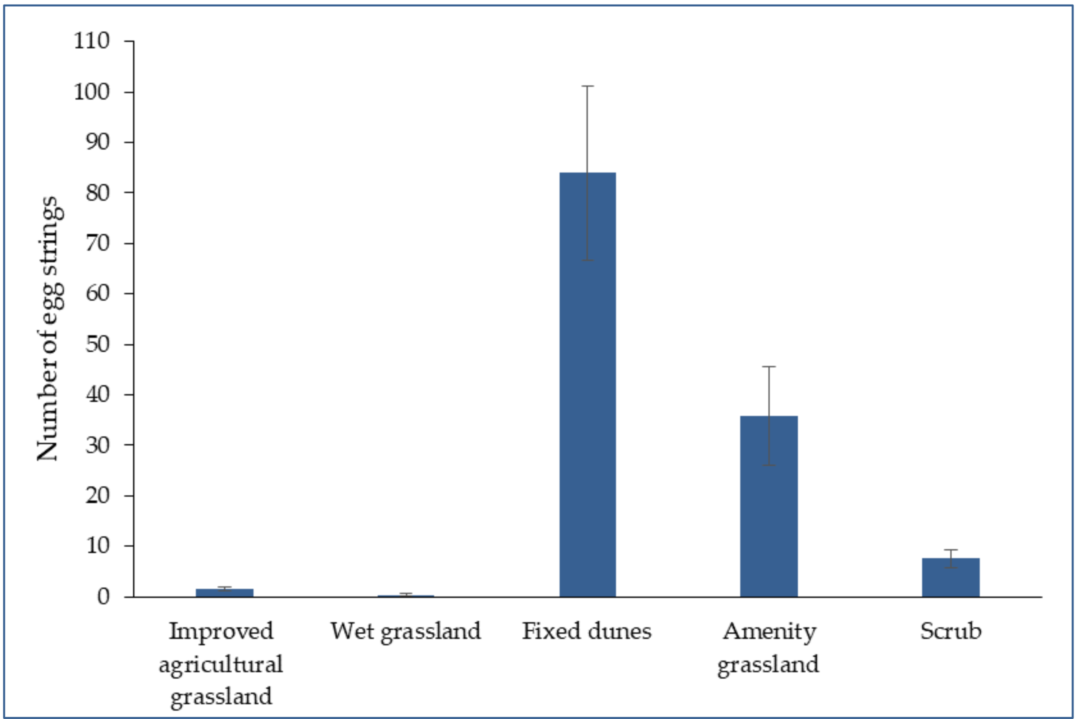


Figure 15 Mean number of egg strings ± 1 standard error (SE) recorded at each habitat type during 2016-18 survey.

3.7 Threats and pressures

Threats and pressures that may have an impact on the Natterjack Toad population at individual sites and wider landscape level are identified and listed in Table 18, following Article 17 guidelines of the Habitat Directive. The most common threat to the Natterjack Toad was poor water quality with 18% of all ponds being affected. Water drainage was only once directly observed in 2016 at M1 (Lough Naparka). However, some of the ponds that dried up, for example, at the Maharees may be as a result of ground water abstraction for the nearby camping areas. The frequency of threats did not differ between all ponds and the subset of ponds used by Natterjack Toads for breeding (Figure 16).

Table 18 List of pressures and threats to the Natterjack Toad in Ireland according to the Article 17 report format of the Habitats Directive for the period 2013-2018.

Code	Description	Surveyed ponds		Natterjack Toad breeding ponds	
		Number of ponds	% of all ponds	Number of ponds	% of all ponds
A06	Abandonment of grassland management (e.g. lack of grazing; high sward)	21	12	9	5
I02	Other invasive alien species (other than species of Union concern) (e.g. *Crassula helmsii* and *Hippophae rhamnoides*)	5	3	5	3
J01	Mixed source pollution to surface and ground waters (poor water quality, algal bloom)	30	18	15	9
K02	Drainage	1	1	1	1
L01	Abiotic natural processes (e.g. salinity above 4ppt)	7	4	1	1
L02	Natural succession resulting in species composition change (e.g. ponds overgrown with emergent vegetation)	13	8	6	4
L06	Interspecific faunal and floral relations relationships	17	10	8	5

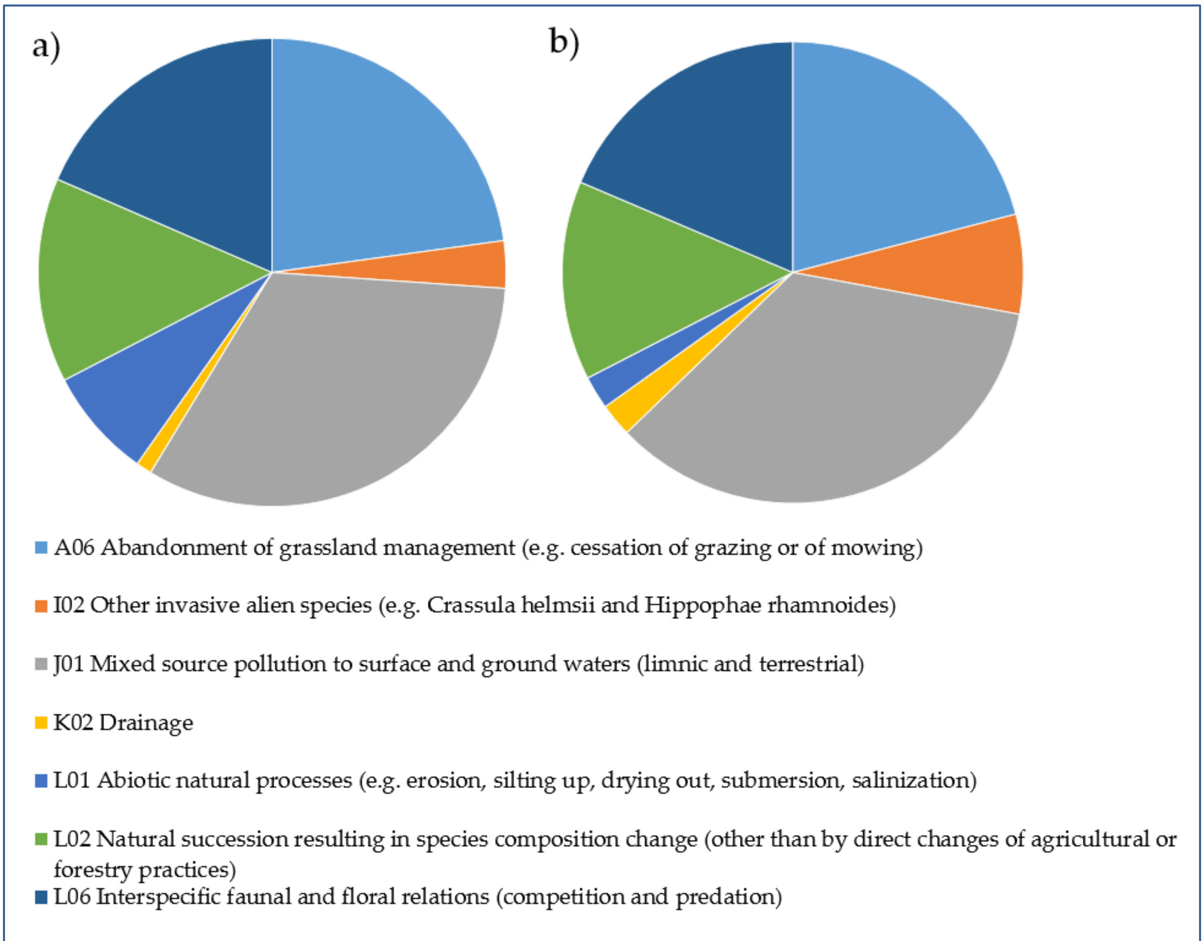


Figure 16 The proportion of a) all ponds and b) Natterjack breeding ponds where each threat was perceived as present was very similar.

3.7.1 Abandonment of grassland management

Natterjack Toads require terrestrial habitats with open areas with no vegetation or very low sward high (Gent & Gibson 1998; Beebee & Denton 1996; Baker *et al*. 2011). 12% of all ponds were overgrown with long rank vegetation (Table 13). A list of sites with 80% of the surrounding sward higher >20cm are listed under A06 threat in Table 19. Furthermore, summary of the percentage cover of the sward higher >20cm for all ponds that are part of the Pond Creation Scheme are listed in Appendix E. Sites where Natterjack Toad breeding activity is present but that were considered overgrown included Tullaree (T1, T2 and T3), Killeen (24A/B), Lough Yganavan (Yganavan9 and 11) and part of the fields at Roscullen Island (10A/B).

3.7.2 Invasive species

Two invasive species were reported at important Natterjack Toad breeding sites: New Zealand pygmyweed *(Crassula helmsii)* at Castlegregory golf course and sea buckthorn (*Hippophae rhamnoides)* at the Maharees sand dunes (see Table 19). Sea buckthorn can have a potential impact on pond hydroperiod in sand dunes and creates unsuitable terrestrial habitat for the toads (Bécart *et.al.* 2007).

3.7.3 Mixed source pollution to surface and ground waters (eutrophication)

Another possible threat to the Natterjack Toad is water eutrophication as a result of a decomposition of organic material in the water and runoff from surrounding agricultural land. A toxic algal bloom occurred every July from 2016-18 at Lough Yganavan when dead fish and invertebrates were found in the lake (Figure 17). Most of the tadpoles at this time had already metamorphosed and left the water but stayed in close proximity to the lake edge. See Table 19 for a list of ponds and sites with poor water quality.

Figure 17 Algal bloom at Lough Yganavan (27th June, 2016). Photograph © Marina Reyne

3.7.4 Pond drying

During 2016-18, three constructed ponds and 28 traditional/natural sites where Natterjack Toad breeding activity was present dried up with the loss of 1,372 egg strings due to desiccation. A list of ephemeral ponds and corresponding number of egg strings lost is shown in Table 20. The greatest loss of egg strings (a total of 485 over the three years) was observed at M1 (Lough Naparka). Reduction in pond hydroperiod can be related to high evaporation, low precipitation, low water table due to water utilisation and direct water drainage. It was notable that during 2017 there was the lowest number of ponds formed due to low preceding winter rainfall. This was followed by reduced breeding activity and egg string desiccation due to ponds drying out before tadpoles metamorphosed principally at the Magharees and Inch sand dune systems.

3.7.5 Abiotic natural processes (salinization)

The Natterjack Toad is among the few amphibian species that can tolerant brackish water. The lethal threshold is suggested to be 4.5ppt for the British population (Beebee, 1985). Ponds with consistently high salinity (above 4ppt) over the three survey years are listed in Table 14. These ponds were not suitable for breeding. At pond 43A where the highest salinity (35ppt) was recorded had one dead egg string present (white centres). Incursion of salt water from adjacent saltmarshes can pose serious threat to egg strings, tadpoles, toadlets and adults at Tullaree where salinity was 4-10ppt. See Appendix D with the average salinity measurements for each pond and year.

3.7.6 Natural succession resulting in species composition change

Ponds with natural succession were shallow with high percentage cover of emergent vegetation that can result in high organic load, low oxygen levels and early desiccation (Table 19). Summary of percentage cover of emergent vegetation for each pond that is part of the Pond Creation Scheme is presented in Appendix E.

3.7.7 Interspecific relations (competition and predation)

A total of 239 invertebrate samples were taken; 122 samples using sweep nets and 118 samples using bottle traps. Ponds with a high number of predatory invertebrates (over 100 captured, Figure 18) are listed in Table 19.

Where ponds do not dry out regularly, fish can play an important role in controlling invertebrate predator numbers (Beebee 2002). Fish occurred at 27 sites (02A/B, 04B, 12A, 15A/B, 16B, 19A, 21A, 25B, 33A/B, 35B, 37B, 38A, 43A/B, 47A/B, 50A/B, 51A, CGC1, CGC3, CGC6, D1, IverM2), excluding Lough Gill, Yganavan and Nambrackdarrig where there are known fish populations. Fish presence was included in the model on the effect of the terrestrial and aquatic habitat on the number of egg strings, however it was not one of the selected parameters that best explain egg string variation among ponds.

Other threats to the Natterjack Toad might include potential competition with the other two amphibian species found in Ireland. High number of Common Frog (*Rana temporaria*) tadpoles can result in slower growth rate of the Natterjack Toad tadpoles (Banks & Beebee, 1987). A list of ponds with Common Frog and Smooth Newt is in Appendix F.

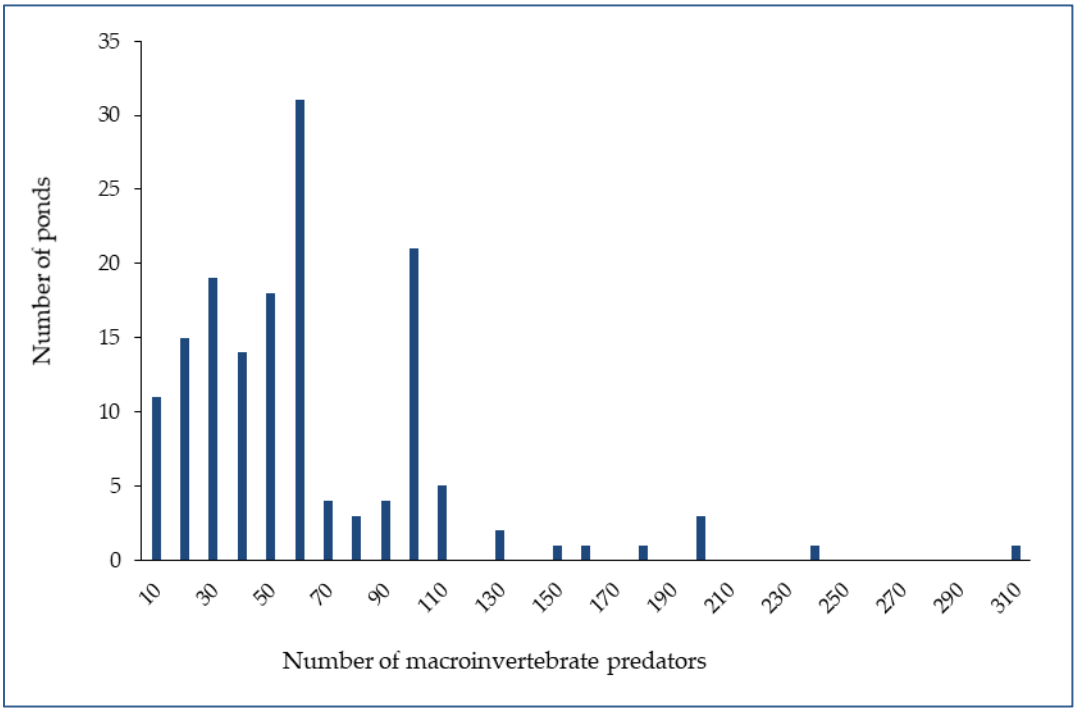


Figure 18 Frequency histogram of number of ponds and number of predatory macroinvertebrates grouped to the nearest 10 bin class

Table 19 List of ponds and corresponding threats and pressures following Article 17 guidelines of the Habitat Directive.

Pond ID	Area	Pond type	Article 17 code	Natterjack Toad (presence/absence)
01A	Keel	Artificial	L06	Absence
02A	Caherfealane Marsh	Artificial	A06	Absence
02B	Caherfealane Marsh	Artificial	A06	Absence
03A	Rosculllen Island	Artificial	J01	Presence in the area
03B	Rosculllen Island	Artificial	J01	Presence in the area
06A	Killeen	Artificial	J01	Presence
06B	Killeen	Artificial	J01	Presence
09A	Rosculllen Island	Artificial	L06	Absence
10A	Rosculllen Island	Artificial	A06	Presence in the area
10B	Rosculllen Island	Artificial	A06	Presence in the area
12A	Iveragh Peninsula	Artificial	A06, J01	Absence
12B	Iveragh Peninsula	Artificial	A06, J01	Absence
14A	Rosculllen Island	Artificial	L06	Presence
17A	Iveragh Peninsula	Artificial	L06	Absence
18A	Iveragh Peninsula	Artificial	J01	Absence
19A	Keel	Artificial	L06	Absence
20A	Rosculllen Island	Artificial	L06	Absence
23B	Iveragh Peninsula	Artificial	L06	Absence
24A	Killeen	Artificial	A06, L01, L02, J01	Presence in the area
24B	Killeen	Artificial	A06, L01, L02, J01	Presence in the area
25A	Boolteens	Artificial	A06	Reintroduction site
25B	Boolteens	Artificial	A06	Reintroduction site
26A	Rosculllen Island	Artificial	A06	Absence
26B	Rosculllen Island	Artificial	A06	Absence
27A	Iveragh Peninsula	Artificial	A06, J01	Absence
27B	Iveragh Peninsula	Artificial	A06, L01, J01	Absence
28A	Keel	Artificial	L06	Absence

Pond ID	Area	Pond type	Article 17 code	Natterjack Toad (presence/absence)
30A	Iveragh Peninsula	Artificial	J01	Absence
30B	Iveragh Peninsula	Artificial	J01	Absence
35A	Iveragh Peninsula	Artificial	A06, L02	Absence
35B	Iveragh Peninsula	Artificial	A06, L01, L02, J01	Absence
36A	Gortnahulla	Artificial	L06	Absence
37B	Roscullen Island	Artificial	L06	Presence
42B	Inch	Artificial	L06	Reintroduction site
43A	Iveragh Peninsula	Artificial	L01	Presence in the area
46A	Inch	Artificial	L01, J01	Absence
46B	Inch	Artificial	L01, J01	Absence
48A	Fermoyle	Artificial	L02	Absence
51A	Kilburn	Artificial	J01	Absence
51B	Kilburn	Artificial	J01	Absence
CGC1	Castlegregory Golf Course	Natural	L06, I02	Presence
CGC2	Castlegregory Golf Course	Natural	L06, I02	Presence
D2	Dooks Golf Course	Natural	L06	Presence
D3	Dooks Golf Course	Natural	L06	Presence
D4	Dooks Golf Course	Natural	L02	Presence
D5	Dooks Golf Course	Natural	L02	Presence in the area
D6	Dooks Golf Course	Natural	L02, J01	Presence
IverM1	Iveragh Peninsula Marsh	Natural	A06, L02, J01	Absence
IverM2	Iveragh Peninsula Marsh	Natural	A06, L02, J01	Absence
M1	Maharees	Natural	L06	Presence
M16	Maharees	Natural	I02	Presence
M17	Maharees	Natural	I02	Presence
M19	Maharees	Natural	I02	Presence
M23	Maharees	Natural	L06	Presence
T1	Tullaree	Natural	A06, L02, J01	Presence
T2	Tullaree	Natural	A06, L02, J01	Presence
T3	Tullaree	Natural	A06, L02, J01	Presence
Yganavan4	Yganavan lake	Natural	J01	Presence
Yganavan5	Yganavan lake	Natural	J01	Presence
Yganavan6	Yganavan lake	Natural	J01	Presence
Yganavan7	Yganavan lake	Natural	J01	Presence
Yganavan8	Yganavan lake	Natural	J01	Presence
Yganavan9	Yganavan lake	Natural	J01	Presence
Yganavan10	Yganavan lake	Natural	J01	Presence

Table 20 List of ephemeral ponds with corresponding number of lost egg strings due to desiccation.

Pond ID	Area	Pond type	Number of egg strings			Total
			2016	2017	2018	
06A	Killeen	Artificial	11	-	1	12
06B	Killeen	Artificial	1	6	7	14
34A	Keel	Artificial	2	-	-	2
43	Glenbeigh	Natural	5	-	-	5
D2	Dooks Golf Course	Natural	-	5	-	5
D3	Dooks Golf Course	Natural	-	7	-	7
D4	Dooks Golf Course	Natural	-	4	-	4
D4	Dooks Golf Course	Natural	-	-	19	19
Inch1	Inch	Natural	-	-	79	79
Inch2	Inch	Natural	1*	7	36	44
Inch3	Inch	Natural	-	-	45	45
Inch4	Inch	Natural	1*	-	28	29
Inch5	Inch	Natural	1*	-	-	1
Inch6	Inch	Natural	-	-	125	125
Inch7	Inch	Natural	-	11	50	61
IverQU1	Iveragh Peninsula	Natural	-	-	1	1
IverQU2	Iveragh Peninsula	Natural	-	5	-	5
IverQU3	Iveragh Peninsula	Natural	1	-	4	5
M1	Maharees	Natural	322	163	-	485
M6	Maharees	Natural	-	-	6	6
M7	Maharees	Natural	18	-	-	0
M12	Maharees	Natural	24	-	111	135
M12A	Maharees	Natural	-	-	6	6
M16	Maharees	Natural	-	-	17	17
M18	Maharees	Natural	18	-	6	24
M19	Maharees	Natural	-	-	34	34
M22	Maharees	Natural	34	-	33	67
M23	Maharees	Natural	-	64	32	96
M24	Maharees	Natural	-	5	-	5
M26	Maharees	Natural	15	-	-	15
Yganavan11	Yganavan Lake	Natural	1	-	-	1
Total Ireland (co Kerry)			**455**	**277**	**640**	**1 372**

3.8 Assessment of the Pond Creation Scheme and translocation program

3.8.1 Pond Creation Scheme

Over 100 artificial ponds were created as part of the Pond Creation Scheme initiated in 2008 by NPWS. All ponds were monitored in 2011-12 and 2016-18. The Natterjack Toad has colonised 22 different new ponds (not all occupied each year) with breeding recorded in seven during 2011, 16 during 2012, 16 during 2016, 10 during 2017 and 13 during 2018. Natterjack Toad breeding activity was recorded for the first time at three previously unoccupied artificial ponds (41A/B and 06B) during 2016-18. At four other ponds (09B, 10A, 23A/B) no egg strings were detected even though breeding activity had been observed in the past (2011-12).

A total of 35 egg strings were recorded in artificial ponds during 2011, 184 in 2012, 121 in 2016, 94 in 2017 and 77 in 2018 (see Table 21).

Table 21 Number of egg strings per constructed pond and survey year.

Site	Pond ID	2011	2012	2016	2017	2018
Roscullen Island	07A	0	18	47	7	21
	07B	10	89	22	29	19
	09B	0	1	0	0	0
	10A	0	3	0	0	0
	04A	2	8	1	0	1
	04B	5	21	2	10	19
	37A	0	1	4	1	1
	37B	0	1	1	0	1
	03A	0	0	1	0	0
	14A	0	6	0	0	1
	14B	0	1	0	3	1
	38A	0	1	1	0	0
	38B	0	5	5	0	0
	Sub-totals	**17**	**155**	**79**	**50**	**64**
Killeen	06A	7	23	11	0	1
	06B	0	0	1	6	7
	Sub-totals	**7**	**23**	**12**	**6**	**8**
Dooks	23A	3	0	0	0	0
	23B	2	0	0	0	0
	41A	0	0	4	3	1
	41B	0	0	2	3	0
	Sub-totals	**5**	**0**	**6**	**6**	**1**
Glenbeigh	21A	6	2	9	19	2
	43A	0	3	1	0	0
	43B	0	1	14	13	2
	Sub-totals	**6**	**6**	**24**	**32**	**4**
Total Ireland (co Kerry)		**35**	**184**	**121**	**94**	**77**

3.8.2 Translocation program

Five translocations were conducted under NPWS guidance during the 2016 breeding season (Figure 19). Approximately 1,000 tadpoles were moved from Inch6 to 42B. The initial plan was to release the tadpoles in both 42A and 42B ponds but the water level in 42A was too low. No tadpoles or toadlets were observed during successive visits. Our team moved around 1,000 tadpoles from Castlegregory Golf Course (mainly from the ditch connecting CGC4 and CGC8) to 47A and 47B. Tadpoles were observed in pond 47B the next week. The water temperature and dissolved oxygen were monitored. On 18th July 2016, one toadlet was found between ponds 33A and 33B. Approximately 1,000 tadpoles were translocated to both ponds earlier in the season by Dr. Ferdia Marnell.

Eight translocation events took place during the breeding season in 2017 (Figure 19). Approximately 500 tadpoles were moved from Inch7 to 42B. Tadpoles were observed during successive surveys, but toadlets were not found at the site. Four egg strings were moved from Lake Yganavan (Yganavan11) to 33A, 02A/B and 25A/B. Tadpoles were observed during the successive surveys at 02A and 25A/B. Toadlets were found at 25A/B. Approximately 1,000 tadpoles were moved from Lough Gill (LoughGill) to 47A/B. Tadpoles were observed during the successive surveys but toadlets were not found. We collected recently hatched tadpoles from Inch7 for the head-start program at Dingle Oceanworld. Toadlets were reintroduced to the original site. Only dead toadlets were found during successive surveys. Lack of water probably led to a high mortality among recently metamorphosed toadlets. Tadpoles were collected from Dooks golf course (D3) and Yganavan Lake (Yganavan6) for the head-start program at Fota Wildlife Park. Most of the toadlets were reintroduced to D1 and 17A. Toadlets were observed during successive pond visits. One egg string was collected from M23 for the head-starting program at Fota Wildlife Park.

In 2018, egg strings and tadpoles were collected from Yganavan lake (Yganavan6) for the head starting program in Fota Wildlife Park and around 3,000 tadpoles were collected from Inch (Inch5) for the program in Dingle Oceanworld. Toadlets were returned to the source populations. No other translocations were conducted by the survey team that year.

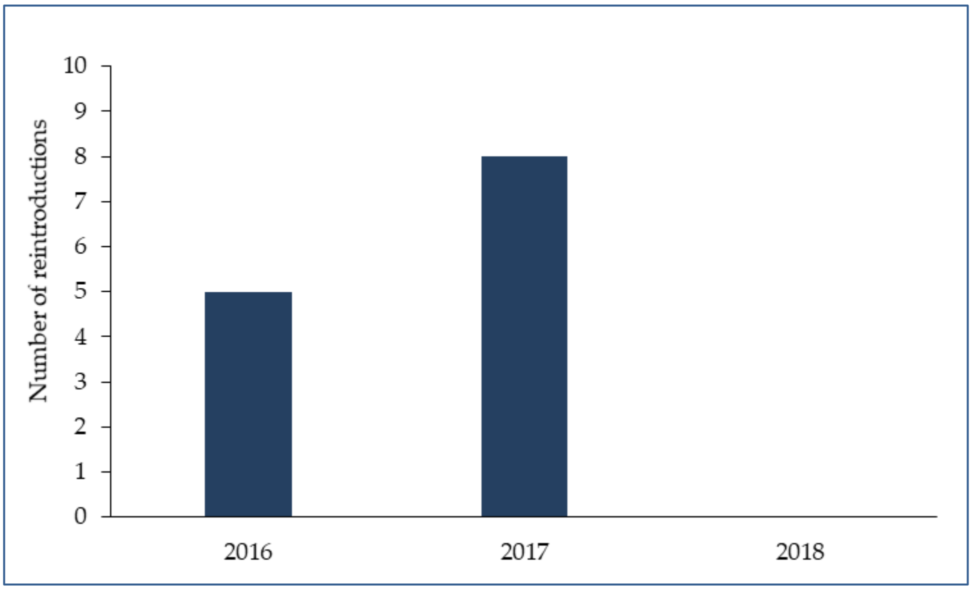


Figure 19 Total number of translocation events undertaken during the 2016-18 survey

4 Discussion

The current three-year survey from 2016-18 of Natterjack Toad (*Epidalea calamita*) breeding activity in Ireland intensively monitored 169 water bodies, both traditional breeding sites and artificially constructed ponds created as part of the National Parks and Wildlife Service (NPWS) Pond Creation Scheme.

Presence of Natterjack Toad breeding activity was mostly associated with natural ponds (traditional breeding sites) which typically had a large surface area (10-fold greater than artificially created ponds). Over 78% of breeding activity was recorded on sand dune systems with Natterjack Toads generally being associated with coastal habitats elsewhere within their range utilising sandy soil for burrowing (Beebee 2002). In Ireland, Natterjack Toad presence was associated with ponds of neutral (rather than acidic) pH; high oxygenation facilitating respiration and rapid development of eggs and tadpoles; higher conductivity indicative of high primary production and high aquatic plant and litter coverage of the substrate providing underwater refuges and a food source for tadpoles (Kopp *et al* 2006). Natterjack Toads were also associated with short terrestrial vegetation in the immediate vicinity of the pond (within 100m) raising the issue of appropriate management which should include regular grazing to ensure swards are well maintained.

Methodological rigour ensured that levels of uncertainty in estimating egg string counts were narrow (±1-2%) providing a high degree of confidence in patterns of interannual variation in fecundity. Egg string numbers declined by 55% from 2016 (3,222; 95%CI 3,156 - 3,288) to 2017 (1,449; 95%CI 1,431 - 1,467) before increasing by 85% to 2,681 during 2018 (95%CI 2,639 - 2,723). The overall decline in the number of egg strings from 2016 to 2018 was 17%.

Ephemeral ponds, such as those formed in sand dune slacks are, by definition, vulnerable to drying out. Global climate change, in particular increasingly extreme overwinter and early spring conditions, make Natterjack Toads vulnerable to the effects of drought, flooding or extreme temperatures. Rapid drying out of breeding sites can lead to accelerated egg and tadpole development and earlier metamorphosis or the complete loss of suitable breeding habitat (O'Regan *et al.* 2014). Natterjack egg string production in Co. Kerry was driven in part by weather conditions prior to and during surveys. At a broad annual scale, overwinter rainfall influenced the number of ephemeral ponds that formed in the landscape most notably on sand dunes systems such as the Maharees (where the majority of the population resides). From 2004 to 2018 egg string production declined by 23% but after variation driven by overwinter rainfall was removed this decline was estimated at 66%. For individual pond visits, cumulative rainfall in the two weeks prior to survey and mean maximum air temperature over the two months prior to the survey influenced egg string counts significantly. Again correction of variability in weather resulted in changes in the interpretation of temporal trends. For example, low productivity observed during 2017 was associated with dry overwinter conditions and few ponds forming in sand dune slacks. Only three ponds retained water for a few days after heavy rain at the Maharees and no ponds formed at all at Inch most likely as a result of the drop in the water table. Accounting for these conditions, corrected values suggested that egg string production exhibited a linear decline between 2016 and 2018. Whilst the statistical effect of weather conditions varied depending on the scale at which the analysis was performed (site visit versus annual counts) the overall conclusion is clear: rainfall significantly influences the availability of breeding sites whilst temperature is likely to influence toad activity levels and spawning phenology. Interannual variability in egg string counts is likely to reflect variability in weather conditions as much as true change in fecundity which broadly appears to be in decline both long-term (2004-2018) and short-term (2016-18).

Previous Natterjack Toad studies in Ireland (Bécart *et al*. 2007; Sweeney *et al*. 2013) translated egg string counts into an estimate of the total toad population by uniformly assuming that 65% of females breed annually and that the sex ratio is 1:1 males:females. These figures are drawn from limited empirical data from populations and locations that may not be applicable to Ireland. There are no empirical data by which to estimate the proportion of females that breed in Ireland or what sex ratio is in operation.

Moreover, these parameters are likely to be highly site-specific with a large degree of spatial variation changing over time. We show that varying these parameters based on the 95% confidence limits for each parameter, as calculated from the published literature, yields additive errors. Variation in the proportion of breeding females could result in a ±13-14% error whilst variation in the range of potential sex ratios inflates this to ±39-64% error in the total population estimate. Therefore, we strongly advise the use of egg string counts for population trend monitoring instead of trying to estimate the population size, unless estimates of the proportion of females that breed and sex ratio can be made for Irish populations synchronous with egg string counts. There is no basis by which uniformly applying fixed multipliers to translate egg string counts into population estimates is warranted.

Given the poor utility of total population estimates and the fact that egg string production may not directly reflect population recruitment and, therefore, conservation status, we also examined temporal trends in toadlet production. Toadlet abundance was used as an additional indicator of Natterjack Toad productivity. Toadlet abundance was highly correlated (r^2=0.90) with egg string counts and thus was largely redundant given it exhibits much the same variation in egg strings whilst requiring substantial additional survey effort. The highest toadlet abundance was observed in 2018 most likely as a result of high air temperatures during the breeding season and fast growth rate. However, rapid development during warmer temperatures can result in small metamorphs thus lower juvenile survival rates (Alvarez & Nicieza, 2002). More information is needed on the post-metamorphosis survival rate and its significance for population viability (Buckley & Beebee 2004).

The most common threats and pressures to the Natterjack Toad included: water pollution, specifically toxic algal blooms at all Lough Yganavan sites and land abandonment as a result of lack of grazing. Global climate change may also present significant challenges i.e. resulting in periods of drought (reducing breeding site availability) or more unpredictable weather patterns (e.g. delayed cold spring conditions reducing adult activity influencing the phenology of spawning).

The Pond Creation Scheme has created over 100 new ponds in agricultural landscapes within the historical range of the toad. Of these, only 22 have been successfully colonised by Natterjack Toads (though not all are occupied each year). Natterjack Toads generally have a patchy distribution at a landscape level (Marsh & Trenham, 2001) and persistence in the landscape depends on dispersal and colonisation of suitable habitats (Semlitsch 2002). Dispersing Natterjack Toadlets choose environments with less resistance and show a preference for open area (e.g. bare sand) actively avoiding agricultural environments (grassy fields) where locomotion is impeded by vegetation density (Stevens *et al*. 2006). Thus, a relatively small proportion of newly created ponds in farmland have been successfully colonised. Moreover, those that have been colonised are in close proximity to the likely source population. For instance, the most productive artificially created ponds at Roscullen Island (Ponds ID 07A/B and 04A/B) were in close proximity to two natural breeding ponds that previously existed in the area. Translocations have been performed to aid colonisation of artificial ponds. Thirteen translocations were performed during 2016 and 2017 either by means of translocating egg strings and tadpoles directly from donor sites or releasing toadlets reared in captivity by Fota Wildlife Park and Dingle Oceanworld. Currently, there are no data available by which to assess translocation success. The use of environmental or eDNA could prove useful in detecting Natterjack Toad presence at these sites via molecular genetic analysis of water samples, potentially detecting the species presence before evidence of breeding is apparent.

Despite limited colonisation of artificial ponds and declines in breeding productivity from previous surveys and within this survey, the known range of the Natterjack Toad in Ireland increased due to the discovery of 20 new breeding sites. For the most part, these sites were not previously included in the Natterjack Toad monitoring and surveillance. Thus, this increase in range is attributable to better information rather than actual range extension.

In summary, whilst the recorded range of the species has increased due to better information, population productivity (a proxy for likely trajectory) has declined (i.e. there has been a medium-term (2004-18) and short-term (2016-18) reduction in egg string counts i.e. fecundity). Natural habitats are in reasonable condition but artificially created ponds need active management, with particular respect to sward height, in order to make them suitable whilst ongoing translocations are needed to overcome problems impeding dispersal and colonisation; related to traversing a landscape of tall grassland swards. Land abandonment and poor sward management are notable threats as well as water pollution though both issues should be addressed through active engagement with farmers and landowners to ensure compliance with habitat maintenance recommendations and to reduce agricultural runoff nutrifying waterbodies.

5 Recommendations

We explore a number of potential recommendations for consideration:

5.1 Survey Methods

Due to the extended Natterjack Toad breeding period (April-July) intensive monitoring over a protracted period is needed for estimating the number of egg strings and toadlet abundance and to provide useful insights into the species' likely population trajectory and conservation status. However, the current survey protocols could be refined to provide greater focus on the parameters that provide the greatest ecologically relevant data and ensure future surveys are efficient in terms of survey effort.

5.1.1 Field survey protocols

Article 17 reporting necessitates conservation status assessment on a 6-yearly basis whilst research has suggested that Natterjack Toad breeding failure for six consecutive years is likely to result in population extinction (Buckley & Beebee 2004), thus regular monitoring is required.

- The vast majority of spawning occurs by late May with no spawning after late June. We suggest that future surveys should plot the cumulative total number of egg strings in real-time throughout the season and when plateau is reached, surveys should stop to save survey effort. Moreover, >90% of all recorded egg strings were from traditional sites with the most productive area being the Maharees and Castlegregory Golf Course. Where the objective is the assessment of overall breeding productivity, future surveys should focus on these specific sites in order to capture the majority of eggs laid for less survey effort. Indeed, surveying a much reduced number of sites more frequently (i.e. every year) would allow interannual variation in productivity to be quantified more precisely;
- Where the objective is to evaluate colonisation of artificially created ponds, we suggest visiting ponds during the peak spawning period only (again assessed during surveys in real-time by plotting cumulative egg counts at traditional sites). Whilst egg strings may well be missed (if laid early or late at artificial ponds) our proposal reduces survey effort such that the probability of detecting egg strings is optimised during the window of survey. Another approach may be to utilise other survey methods, for example, environmental DNA (see below);
- Surveys aimed at establishing the extent of and changes to the range should be conducted in wet years when high winter and spring rainfall have produced the maximum number of breeding ponds;
- Where the objective is to judge the success of translocations, we suggest post-translocation visits in the weeks after introduction to evaluate hatching rates (i.e. disappearance of spawn), and tadpole or toadlet presence;
- To make individual pond visits more efficient and permit a larger number of ponds to be surveyed in a day we recommend reducing the Standard Survey Form (Appendix A) to include only a subset of parameters judged to be ecologically relevant. For the statistical analysis included in this report we recommend that data collection focus on the following: water chemistry (pH and conductivity), vegetation structure (aquatic plant cover at the substrate and emergent vegetation), sward height (judged against the Pond Creation Scheme requirements), and the perceived presence of potential threats and pressures (specifically those listed in this report). Most other parameters could be dropped without much impact on the value of the data collected.

5.1.2 Environmental DNA

Environmental DNA is a new emerging method for species monitoring that can have broad applications in conservation. This method is relatively easy to standardise, doesn't require direct observations of target species and has a higher detection rate compared to traditional field surveys (Ficetola *et al*. 2008; Pilloid *et al.* 2012; Biggs *et al.* 2015). Research and development (R&D) of this method should be prioritised to test protocols for the rapid detection of Natterjack Toad eDNA i.e. species presence/absence using water sampling (negating the need for frequent repeat pond surveys). This could be used to monitor artificial pond colonisation rates detecting species presence before field signs of colonisation are obvious. Moreover, the quantitative Polymerase Chain Reaction (qPCR) is a method that allows the volume of eDNA present per unit volume to be determined providing a method by which to assess relative change in the breeding population size. This requires calibration against known numbers of egg strings before its predictive power can be assessed.

5.1.3 Population size estimation

If an estimate of absolute population size is required, we recommend that in addition to collecting data on egg string counts that work is required on both the spatial and temporal variability of the proportion of female toads that breed annually and sex ratios in an Irish context. For example, adult toads at a number of focal sites could be microchipped using Passive Integrated Transponders (PIT tags) allowing individuals to be reliably identified each year permitting the proportion of the tagged population that breeds to be quantified (Christy 2006). Intensive sampling of a few sites during the peak breeding period over multiple years where individuals are sexed, using skin colouration and the presence of nuptial pads on the thumbs, is also required to accurately define sex ratios. These methods were beyond the scope of the current study impacting the confidence intervals associated with total population estimates. Collecting these data would add considerable survey effort to any future studies.

Natterjack Toad fecundity (egg string production) was significantly influenced by climate and weather. We propose that taking weather parameters, principally winter rainfall and spring temperatures, into account during analysis of population temporal trends is essential to neutralise stochastic sources of environmental variation such that the implicit trajectory of populations can be assessed. It is not sufficient to simply plot raw data as these contain substantial noise making interpretation of temporal trends challenging. Further research is required to fully investigate the drivers of both the phenology of Natterjack spawning and the number of females that breed during any given year. We advise that this work should be undertaking in collaboration with Met Éireann.

5.2 Genetic diversity and population structuring

The Natterjack Toad population in Ireland is at the northwest edge of the species distribution, isolated from other populations in Britain and continental Europe. Small and isolated populations are likely to suffer low genetic diversity, lack of ability to adapt and elevated extinction risk in the face of natural and human induced environmental changes. Cabido *et al.* (2010, 2011) showed that loss of genetic diversity has a negative impact on the Natterjack Toad's immune response and tolerance to herbicides. Populations with low genetic diversity are at higher risk of stochastic extinction than those with greater genetic diversity. A previous study of the genetic structure of the Natterjack Toad in Ireland suggested low genetic diversity and lack of gene flow between populations. However, the study was conducted using only eight microsatellite loci with low level of polymorphism (May & Beebee 2010). A fine-scale genetic population structure study, sampling diversity within- and between all breeding ponds across different metapopulations using a large number of genetic markers would help identify any important distinctions between populations, levels of inbreeding and lack of dispersal. It would also help identify targets for tadpole translocation to maximise current conservation efforts (e.g. Cushman 2006; Noel *et al.* 2007).

5.3 Priority actions

Habitat loss has been identified as the main cause of Natterjack Toad population decline across Europe (Rannap *et al.* 2007). The species requires open areas with short sward, suitable areas for burrowing and shallow warm ephemeral ponds with low predation pressure (Baker *et al*. 2011). We make a number of recommendations for the management of ponds that failed to meet the Pond Creation Scheme's requirements as well as site-by-site priority actions for achieving favourable conservation status for the Natterjack Toad in Ireland:

5.3.1 Management recommendations for the Pond Creation Scheme

There are two main requirements of the Pond Creation Scheme that farmers need to achieve: 80% of the sward surrounding the pond should be <20cm and emergent vegetation should cover <80% of the pond's surface area (Appendix E). Most commonly, land managers failed to comply with grazing recommendations resulting in pond margins becoming overgrown with vegetation (in total 16% of the artificial ponds had swards >80cm consistently over the three years surveyed). Three pairs of ponds (10A/B, 25A/B (a translocation site) and 24A/B) which had Natterjack Toads present required winter clearing of the vegetation surrounding the pond and presence of grazing during the breeding period. Grazing by cattle is the best option to keep short sward, however, the outcome depends on stocking density, grazing regime (frequency and timing) and site characteristics (Baker *et al*. 2011). Presence of cattle can lead to damage by poaching, water eutrophication through organic enrichment and earlier desiccation as a result of daily water intake by cattle (Bridson 1978; Becart *et al*. 2016). At three sites (51A/B, 18A and 30A/B) water quality may be improved by restricting cattle access to the ponds. We recommend deepening only for ponds that consistently dry out before mid-summer (i.e. 06A/B) in order to increase egg string and tadpole survival.

5.3.2 Management recommendations at specific sites

We compared the egg string counts from 2016-18 survey to the 2004-06 survey for each population and provide site-specific recommendations on how to improve the Natterjack Toad's conservation status at these sites:

The highest egg string count for **Tullaree** was 16 during 2016-18 compared to 51 egg strings recorded during 2004-06 survey (Becart *et al.* 2007a). This is one of the smallest, declining populations and most likely vulnerable to local extirpation. The habitat quality at the site is very poor: abandoned overgrown fields with three breeding ponds and very poor water quality (extremely high conductivity/salinity, low water transparency, a high volume of dead and decaying organic matter) and high percentage cover of emergent vegetation i.e. the ponds are in the process of ecological succession to wet grassland. We recommend renovation of the surrounding sward cutting back rank thatch and maintaining a short sward throughout the breeding season. We also recommend clearing pond vegetation. Constructing additional ponds on site should also be considered providing a larger number of potential breeding sites for this otherwise small population.

The largest and most important Natterjack Toad population is at the **Maharees** sand dune system. Numbers of egg strings each year is highly dependent on the number of ponds that form in sand dune slacks determined by overwinter rainfall (Figure 20). In 2016, 15 ponds had breeding activity resulting in the highest number of egg strings recorded in any area and at any point during the three year survey. The total number of egg strings recorded in 2016 was 2,261 representing 70% of the total breeding activity in Co. Kerry. Maintaining the Maharees sand dune system is essential for the survival of the Natterjack Toad in Ireland. Moderate grazing by cattle is important for grassland management on sand dunes. However, livestock can impact the hydroperiod of ponds formed in sand dune slacks and the quality of the water; consequently negatively impacting tadpole survival (Bridson 1978). Restricting cattle access to M12 and M1 may help improve water quality. During the 2016-18 survey a new breeding site was identified along the shore of Lough Gill. Access to the previous site (Lough Gill Sluice

Q6122614626) was not possible due to Health & Safety concerns. It is unknown if the Natterjack Toad is still using this site for breeding considering the dense vegetation and deep water. Trampling and poaching by cattle can increase toadlet mortality. At M23 and M17 large numbers of dead toadlets were observed in cattle footprints. A fence at M17 to restrict cattle access to part of the pond has been destroyed and a replacement is needed. At several other sites (M9, M9A, M24, and M12) tyre tracks from tractors were found across desiccated pond beds where toadlets were still present. Water abstraction from M1 (Lough Naparka) led to early desiccation and the loss of 485 egg strings. Restriction of farming activities at breeding sites between April and July may help boost tadpole and toadlet survival. Another challenge is the continuing spread of invasive sea buckthorn (*Hippophae rhamnoides*) that creates dense scrub unsuitable for toads and can have an impact on the local water table (Bécart *et al.* 2007). Management of this invader close to Natterjack Toad breeding ponds is recommended.

Figure 20 Variation in the number of ponds that formed at the Maharees in April during a) 2016, b) 2017 and c) 2018 as determined by the preceding winter rainfall.

At **Castlegregory golf course**, breeding activity was recorded at all ponds throughout the 3 years of monitoring. However, maintenance of short swards around CGC5 and CGC8 may be beneficial. Populations at Castlegregory golf course and the Maharees should be considered a single metapopulation due to the connectivity between the sites.

Since 2004, no breeding activity has been recorded at **Fermoyle** despite construction of six artificial ponds in the area and therefore the population may be considered locally extirpated. Tadpoles were reintroduced to two of the ponds (47A/B), however, it is too early to evaluate success. We recommend intensive monitoring (7-10 days during the breeding season) of the translocation sites.

In 2004-06, the Natterjack Toad population at **Roscullen Island** was evaluated as the most successful population with the highest growth rate in Ireland (Bécart *et al.* 2007). However, we observed a 96%

decline (Table 11) in the number of egg strings from 2004 to 2018. Thus, the population appears to be in decline and threatened with local extirpation. Reduction in the number of egg strings had been observed since loss of the two natural breeding pools in the area (Ross1 and Ross2). There are 18 artificially constructed ponds in the area; ten of which have been used for breeding. The most successful ponds (07A/B) are overgrown with rushes despite constant presence of sheep. We recommend clearing rushes over the winter season and ensuring the sward remains short during the breeding season. Restriction of sheep and cattle access to 14A/B, 03A/B and 20A/B may improve the water quality.

One of the areas with the lowest number of egg strings recorded and no toadlets present during 2016-18 survey was **Killen**. The two ponds used for breeding (06A/B) dried very early during the breeding season. We recommend deepening the two ponds and restricting sheep access from around the ponds to reduce poaching. In 2018, two additional ponds were constructed (listed as 24C/D) to replace 24A/B that had become unsuitable due to high salinity. The two newly constructed ponds did not retain water in 2018. We recommend improving the management of the current ponds, providing more suitable breeding habitat (construction of additional ponds in close proximity to 06A/B) and connecting the Killen population to the population at Roscullen Island by a series of ponds forming a dispersal corridor.

The population at **Inch** is the least studied as a result of access restrictions to the site and, therefore, there are no data on the change in the breeding population size. The 2004-06 report suggested low numbers of adults, most likely in the low 100s (Becart *et al.* 2007a). Historically the site once hosted a large Natterjack Toad population (Beebee 2002). During 2016-18, we discovered five new breeding sites (Inch 4-8) and recorded 392 egg strings in 2018. Furthermore, this number is most likely an underestimate due to missed egg strings. We recommend conducting extensive searches for breeding ponds throughout the whole peninsula during the breeding peak period. Inch is suitable for incorporation into the reintroduction program as a source of donor egg strings due to their vulnerability to early desiccation.

The number of egg strings at **Lough Yganavan** declined by over 70% (Table 11) and the population is in decline despite recently discovered new breeding areas along the lake shore. The number of egg strings might be underestimated due to the large size of the lake and available habitat. The 2016-18 survey was mainly focused on the North and North-west part of the lake. Extensive searches during the breeding peak resulted in discovery of new suitable sites. During each survey year, algal blooms were observed at the lake, likely a result of run-off from surrounding fields. Control over the development of the area surrounding the lake is needed. In 2018, a boat house was created in very close proximity to one of the main breeding sites (Yganavan6, 9 and 10) that created additional disturbance. Placing of informational signage regarding Natterjack Toad conservation action in the area may be beneficial.

The Natterjack Toad population at **Lough Nambrackdarrig** is one of the smallest populations and is directly threatened with local extirpation. Breeding success and egg to toadlet survival were among the lowest for any site (Bécart *et al.* 2007a). The assessment of the number of egg strings was difficult due to dense vegetation along the lake shore and deep water. However, extensive searches along the lake shore may lead to the discovery of new breeding areas.

The largest decline in the number of egg strings was observed at the **Dooks**. Most of the breeding activity (between 38-86% depending on survey year) was at pond D6. It is a natural pond located on agricultural land and fenced to restrict livestock access to the water. The pond is overgrown with rushes and had very poor water quality due to high amount of organic matter (dead vegetation). We recommend clearing of the pond over the winter months and also deepening it on the South and South-east side (main breeding areas) to retain water for longer during the breeding season. Construction of additional ponds between Dooks golf course and D6 could improve habitat connectivity.

We estimated a 48% decline (Table 11) in the number of egg strings at **Glenbeigh** since 2004-06 when natural breeding sites were lost (Marsh area). All ponds at Glenbeigh quarry are very shallow and IverQU3 existed only in a form of small puddles that dried during each survey year when 1,000s of tadpoles were present. We recommend deepening of the ponds or creating new ponds. Two artificial ponds part of the Pond Creation Scheme (21A and 43B) and one small garden pond were used for breeding. Egg strings were found in two small puddles formed temporarily in the area (21 and 43). We recommend continued management of the artificial ponds in compliance with scheme requirements.

In a previous Natterjack Toad monitoring report Bécart *et al.* (2007a) estimated low toadlet survival at **Caherdaniel** indicating that the population was likely to decline. We observed a small decline (3%) in the number of egg stings since 2004 and it can be assumed that the population is stable. We recommend creating additional ponds in the area and carrying out a high resolution population genetic study. Low genetic diversity and inbreeding might be expected due to the artificial origin of the population (toads were reintroduced to the area in the 1990s) and complete isolation from other populations. Translocations to this site from other metapopulations may be needed to prevent inbreeding depression.

6 References

Alvarez, D. & Nicieza, A. G. (2002) Effect of temperature and food quality on anuran larval growth and metamorphosis, *Functional Ecology* **16** (5), 640-5648.

Aubry, A. & Emmerson, M. (2005) Monitoring of Natterjack Toad (*Bufo calamita*) in Ireland, Breeding season 2004. Report to National Parks and Wildlife Service. April 2005.

Baker, J., Beebee, T.J.C., Buckley, J., Gent, T. & Orchard, D. (2011) Amphibian habitat management handbook. Amphibian and Reptile Conservation, Bournemouth.

Banks, B. & Beebee, T.J.C. (1986) A comparison of the fecundities of two species of toad (*Bufo bufo* and *B. calamita*) from different habitat types in Britain. *Journal of Zoology* **208**, 325-337.

Banks, B. & Beebee, T.J.C. (1987) Spawn predation and larval growth inhibition as mechanisms for niche separation in anurans. *Oecologia* **72**, 569-573.

Banks, B. & Beebee, T.J.C. (1988) Reproductive Success of Natterjack Toads *Bufo calamita* in Two Contrasting Habitats. *Journal of Animal Ecology* **57** (2), 475-492.

Bécart E., Aubry A. & Emmerson M. (2006) Monitoring of the natterjack toad population (*Bufo calamita*) in Ireland, Breeding season 2005. Report to the National Parks and wildlife Service. March 2006.

Bécart, E., Aubry, A. & Emmerson, M. (2007) Monitoring the conservation status of Natterjack Toad (*Bufo calamita*) in Ireland, 2004-2006. *Irish Wildlife Manuals*, No. 31. National Parks and Wildlife Service, Department of the Environment, Heritage and Local Government, Dublin, Ireland.

Beebee, T.J.C. & Denton, J.S. (1996) The Natterjack Toad conservation handbook, English Nature, Peterborough, UK.

Beebee, T.J.C. & Griffiths, R.A. (2000) Amphibians and Reptiles. *A Natural History of the British Herpetofauna*. Harper Collins New Naturalist. London. 270 pp.

Beebee, T.J.C. (1979) A review of scientific information pertaining to the Natterjack Toad (*Bufo calamita*) throughout its geographical range. *Biological Conservation* **16**, 107-134.

Beebee, T.J.C. (1985) Salt tolerances of Natterjack Toad (Bufo calamita) eggs and larvae from coastal and inland populations in Britain. *Herpetol. J.* **1**, 14–16.

Beebee, T.J.C. (2002) The Natterjack Toad (*Bufo calamita*) in Ireland: current status and conservation requirements. *Irish Wildlife Manuals*, No. 10, National Parks and Wildlife Service, Department of the Environment, Heritage and Local Government, Dublin, Ireland.

Beja, P., Kuzmin, S., Beebee, T., Denoel, M., Schmidt, B., Tarkhnishvili, D., Ananjeva, N.B., Orlov, N.L., Nyström, P., Ogrodowczyk, A., Ogielska, M., Bosch, J., Miaud, C., Tejedo, M., Lizana, M. & Martinez Solano, I. (2016) *Epidalea calamita*. The IUCN Red List of Threatened Species 2016: e.T54598A86640094. Downloaded on 09 November 2016.

Biggs, J., Ewald, N., Valentini, A., Gaboriaud, C., Dejean, T., Griffiths, R.A. & Dunn, F. (2015) Using eDNA to develop a national citizen science-based monitoring program for the great crested newt (*Triturus cristatus*). *Biological Conservation* **183**, 19–28.

Boomsma, J. & Arntzen, J. (1985) Abundance, growth and breeding of Natterjack Toads (*Bufo calamita*) in a 4-year-old artificial habitat. *Journal of Applied Ecology* **22** (2), 395-405.

Bridson, R.H. (1978) A preliminary investigation into the factors affecting success of the Natterjack Toad (*Bufo calamita*) at Vaerlaverock National Nature Reserve. Report to Nature Conservancy Council, South West (Scotland) Region.

Buckley, J. & Beebee T.J.C. (2004) Monitoring the conservation status of an endangered amphibian: The Natterjack Toad *Bufo calamita* in Britain. *Animal Conservation* **7** (3), 221-228.

Bull, J.J. (1980) Sex determination in reptiles. *The Quarterly Review of Biology* 55:1, 3-21

Cabido, C., Garin-Barrio, I., García-Azurmendi, X., Rubio, X. & Gosá, A. (2010) Population differences in vulnerability to glyphosate of Natterjack Toad tadpoles. 2nd International Symposium on the conservation of amphibians: *Bufo calamita*. Donostia/San Sebastian (Spain).

Cabido, C., Garin-Barrio, I., Rubio, X & Gosá, A. (2011) Pesticide vulnerability and genetic diversity: a cross-breeding experiment with two populations of Natterjack Toad. 3rd Congress of the Spanish Society of Evolutionary Biology. Madrid (Spain).

Christy, M.T. (2006) The efficacy of using Passive Integrated Transponder (PIT) tags without anaesthetic in free-living frogs. *Australian Zoology* **30** (2), 139–142

Cushman, S.A. (2006) Effects of habitat loss and fragmentation on amphibians: A review and prospectus. *Biological Conservation* **128** (2), 231–240.

Cushman, S.A. (2006) Effects of habitat loss and fragmentation on amphibians: A review and prospects. *Biological Conservation* **128** (2), 231–240.

Denton, J.S. (1991) The terrestrial ecology of the Natterjack Toad *Bufo calamita* (Laurenti) and the common toad *Bufo bufo* (Linnaeys). PhD thesis, University of Sussex.

Denton, J.S., Hitchings, S.P. & Beebee T.J.C. (1995) Natterjack Toad Species Recovery Programme Project 1992-1995, Final report. English Nature Research Reports No. 151. English Nature, Peterborough.

Denton, J.S. & Beebee, T.J.C. (1993) Reproductive strategies in female-biased population of natterjack toads, *Bufo calamita*. *Animal Behaviour* **46**, 1169-1175.

Denton, J.S. (1991) The terrestrial ecology of the Natterjack Toad *Bufo calamita* (Laurenti) and the common toad *Bufo bufo* (Linnaeus). PhD thesis, University of Sussex.

Elmberg J. (1990) Long-term survival, length of breeding season, and operational sex ratio in a boreal population of common frog, *Rana temporaria*, *Canadian Journal of Zoology* **68**, 121-127.

European Topic Centre (2012) Species : *Bufo calamita* Assessment of conservation status at the European biogeographical level, https://nature-art17.eionet.europa.eu/article17/reports2012

Faucher, L., Godé, C. & Arnaud, J. F. (2016) Development of Nuclear Microsatellite Loci and Mitochondrial Single Nucleotide Polymorphisms for the Natterjack Toad, *Bufo (Epidalea) calamita* (Bufonidae), Using Next Generation Sequencing and Competitive Allele Specific PCR KASPar. *Journal of Heredity* **107** (7), 660-665.

Ficetola, G. F., Miaud, C., Pompanon, F. & Taberlet, P. (2008) Species detection using environmental DNA from water samples. *Biology Letters* **4** (4), 423–425;

Fossitt, J.A. (2000). *A Guide to Habitats in Ireland*. Heritage Council, Kilkenny.

Gasc J. P., Cabela A., Crnobrnja-Isailovic J., Dolmen D., Grossenbacher K., Haffner P., Lescure J., Martens H., Martínez Rica J. P., Maurin H., Oliveira M. E., Sofianidou T. S., Veith M. & Zuiderwijk A. (1997) *Atlas of amphibians and reptiles in Europe*. Collection Patrimoines Naturels, 29, Societas Europaea Herpetologica, Muséum National d'Histoire Naturelle & Service du Patrimoine Naturel, Paris, 496 pp.

Gent, T. & Gibson, S. (1998) *Herpetaufauna Workers' Manual.* Joint Nature Conservation Committee, Peterborough.

Goldberg, C.S., Turner, C.R., Deiner, K., Klymus, K.E., Thomsen, P.F., Murphy, M.A., Spear, F.S., McKee A., Oyler-McCane, S.J., Cornman, R.S., Laramie, M.B., Mahon, A.R., Lance, R.F., Piliod, D.S., Strickler, K.M., Waits, L.P., Fremier, A.K., Takahara, T., Herder, J.E. & Taberlet, P. (2016) Critical considerations for the application of environmental DNA methods to detect aquatic species. *Methods in Ecology and Evolution*, **7** (11), 1299–1307.

Gomez-Mestre, I., Tejedo, M. & Merila, J. (2003) Local Adaptation of Anura amphibian to osmotically stressful environments, *Evolution* **57** (8), 1889-1899.

Hawlitschek, O., Morinière, J., Dunz, A., Franzen, M., Rödder, D., Glaw, F. & Haszprunar, G. (2016) Comprehensive DNA barcoding of the herpetofauna of Germany. *Molecular Ecology Resources* **1**, 242-253.

King, J.L., Marnell, F., Kingston, N., Rosell, R., Boylan, P., Caffrey, J.M., FitzPatrick, Ú., Gargan, P.G., Kelly, F.L., O'Grady, M.F., Poole, R., Roche, W.K. & Cassidy, D. (2011) *Ireland Red List No. 5: Amphibians, Reptiles & Freshwater Fish*. National Parks and Wildlife Service, Department of Arts, Heritage and the Gaeltacht, Dublin, Ireland.

Kopp, K., Wachlevski, M. & Eterovick, P.C. (2006) Environmental complexity reduces tadpole predation by water bugs, *Canadian Journal of Zoology* **84**, 136-140.

Loman, J. & Madsen, T. (2010) Sex ratio of breeding Common toads (*Bufo bufo*) – influence of survival and skipped breeding, *Amphibia-Reptilia* **31** (4), 509-524.

Marsh, D. M. & Trenham, P. C. (2001) Metapopulation dynamics and amphibian conservation. *Conserv. Biol.* **15**, 40–49.

May, S. & Beebee, T.J.C. (2010) Recent introduction or ancient ancestry? Use of genetic evidence to investigate the origins of range edge populations in Natterjack Toads (*Bufo calamita*). *Conservation Genetics* **11** (1), 293–300.

McKee, A.M., Spear, S.F. & Pierson, T.W. (2015) The effect of dilution and the use of a post-extraction nucleic acid purification column on the accuracy, precision, and inhibition of environmental DNA samples. *Biological Conservation* **183**, 70–76.

Noël, S., Ouellet, M., Galois, P. & Lapointe, F.J. (2007) Impact of urban fragmentation on the genetic structure of the eastern red-backed salamander. *Conservation Genetics* **8** (3), 599–606.

NPWS (2013) The Status of EU Protected Habitats and Species in Ireland. Species Assessments Volume 3. Version 1.0. Unpublished Report, National Parks & Wildlife Services. Department of Arts, Heritage and the Gaeltacht, Dublin, Ireland.

O'Regan S.M., Palen W.J. & Anderson S.C. (2014) Climate warming mediates negative impact of rapid pond drying for three amphibian species. *Ecology* **95** (4), 845-855.

Pilliod, D.S., Goldberg, C.S., Arkle, R.S., Waits, L.P. & Richardson, J. (2013) Estimating occupancy and abundance of stream amphibians using environmental DNA from filtered water samples. *Canadian Journal of Fisheries and Aquatic Sciences* **70** (8), 1123–1130.

Prohl, H. (2002) Population differences in female resource abundance, adult sex ratio, and male mating success in *Dendrobates pumilio*, *Behavioral Ecology* **13** (2), 175-181.

Rannap, R., Lõhmus, A. & Jakobson, K. (2007) Consequences of coastal meadow degradation: the case of the natterjack toad (*Bufo calamita*) in Estonia. *Wetlands* **27**, 390–398.

Raw, K. & Pilkington, G. (1988) Bringing back the Natterjack Toad. *RSPB Conservation Review* **2**, 81-84.

Reid, N., Dingerkus, S.K., Stone, R.E., Buckley, J., Beebee, T.J.C., Marnell, F. & Wilkinson, J.W. (2014) Assessing Historical and Current Threats to

Common Frog (*Rana temporaria*) Populations in Ireland. *Journal of Herpetology* **48** (1), 13-19.

Reid, N., Lundy, M.G., Hayden, B., Lynn, D., Marnell, F., McDonald, R.A. & Montgomery, W.I. (2013) Detecting detectability: identifying and correcting bias in binary wildlife surveys demonstrates their potential impact on conservation assessments. *European Journal of Wildlife Research* **59** (6), 869-879. DOI: 10.1007/s10344-013-0741-8

Semlitsch, R. D. (2002) Critical elements for biologically based recovery plans of aquatic-breeding amphibians. *Conserv. Biol.* **16**, 619–629.

Shaw, W. (2006) Conservation of Natterjack Toad (*Bufo calamita*) breeding habitats in County Kerry, Ireland. Report to the Heritage Council, Ireland.

Skelly, D & Werner, E. (1990) Behavioural and life-historical responses of larval American toads to an Odonate predator. *Ecology* **71**, 2313-2322.

Skelly, D.K. (1997) Tadpole communities. *Am. Sci.* **85**, 36–45.

Stephan, T., Ulbrich, K., Grosse, W-R. & Meyer, F. (2001) Modelling the extinction risk of isolated populations of natterjack toad *Bufo calamita*. *Web Ecology* **2**, 47-56.

Stevens, V.M., Leboulengé, É., Wesselingh, R.A. & Baguette M. (2006) Quantifying functional connectivity: experimental assessment of boundary permeability for the Natterjack Toad (*Bufo calamita*). *Conservation Ecology* **150**, 161.

Sweeney, P., Sweeney, N. & Hurley C. (2013) Natterjack Toad monitoring project, 2011 - 2012. *Irish Wildlife Manuals*, No. 67. National Parks and Wildlife Service, Department of Arts, Heritage and the Gaeltacht, Dublin, Ireland.

Appendices

Appendix A - Natterjack Toad POND Survey field sheet 2016-18

Natterjack Toad

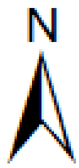
Site name			Date	
Survey team			Time	
Pond ID			Coordinates	X
				Y
Visit No.			% Cloud cover	
Wind	calm		Rain (present/absent)	
	medium			
	strong wind			

Habitat characteristics

Pond width (m)				Pond length (m)		
% of surface shaded				Photo ID		
Air temp (°C)				Water temp (°C)		
Water transparency(cm)						
Max water depth (m)	<1m			% emergent vegetation		
	>1m			Emergent veg height	<1m	
					>1m	
Water pH	1			Sward height within 100 m of the pond	<5cm	
	2				5-20cm	
	3				>20cm	
Water conductivity	1			% of bare ground (pond)		
	2					
	3			% aquatic plant cover (surface)		
Water salinity	1			% plant litter (substratum)		
	2					
	3			% aquatic plant cover(substratum)		
Dissolved oxygen	1	Mg/l		% filamentous algae(substratum)		
		% sat				
	2	Mg/l		Water pollution	Poor	
		% sat				
	3	Mg/l			Average	
		% sat			Good	

Natterjack Toad population data

Adult males (*n*)			Adult females (*n*)		
Adults (*n*) (sex unknown)			Calls heard?	Yes	
				No	
Egg strings (*n*)			Water depth where eggs are present		
Tadpoles (tick)	1s		Toadlets	1s	
	10s			10s	
	100s			100s	
	1,000s			1,000s	
	10,000s			10,000s	



Quadrant	Toadlet		

Sweep	Tadpoles

Land management

Predominant habitat	Tick
Sand dune system	
Scrub	
Bog and heathland	
Improved grassland	
Semi-natural grassland	
Marsh	
Lake	

Activity	
Farming activity	
Golf course	
Discontinues land use (low degree of human activity)	

Pond permanency	
Permanent	
Semi-permanent (>50% size reduction 1st April - 15th July)	
Ephemeral (dried before 31st July)	

Presence of terrestrial refuges?	Yes	
	No	
Type of refuge present: e.g. burrows, dead wood, long grass, hedgerows, stones, scrub, stone walls		

Frequency	Fossitt (2000) habitat types present (<100m radius of pond)	Code	% cover (<100m)
>50% of sites	Wet grassland	GS4	
	Improved agricultural grassland	GA1	
	Scrub	WS1	
	Drainage ditches	FW4	
30-50% of sites	Other artificial lakes and ponds	FL8	
	Reed/sedge swamps	FS1	
	Hedgerows	WL1	
	Earth banks	BL2	
	Marram dunes	CD2	
	Fixed dunes	CD3	
	Mixed sediment shores	LS5	
	Bare ground		
Other (list)	Amenity grassland	GA2	
	Marsh	GM1	
	Horticultural land	BC2	
	Arable crops	BC1	
	Dune scrub and woodlands	CD4	
	Machair	CD6	
	Lake	FL	
		Total	100%

Grazing pressure	Tick
Frequent (4)	
Common (3)	
Occasional (2)	
Rare (1)	
None (0)	

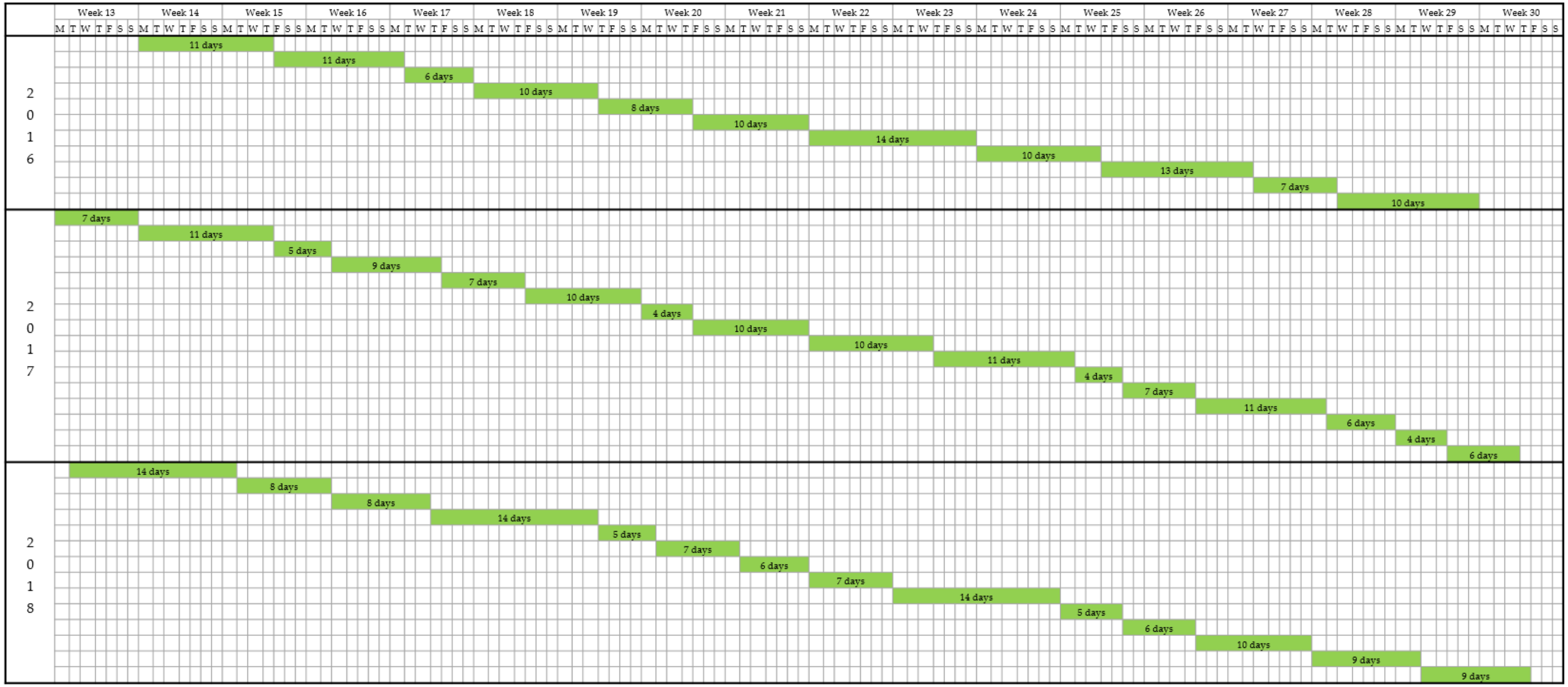
<table>
<tr><td rowspan="2">Distance to nearest physical barrier (m)</td><td rowspan="2"></td><td rowspan="2">Grazing damage e.g. poaching</td><td>Yes</td><td></td></tr>
<tr><td>No</td><td></td></tr>
<tr><td>Barrier type?</td><td colspan="4">e.g. salt water, walls</td></tr>
</table>

Main PRESSURES:	Intensity (importance)	Tick	Area affected (%)
A04.03 Abandonment of pastoral systems, lack of grazing	High (+++)		
	Medium (++)		
	Low (+)		
K02.01 Species composition change (succession)	High (+++)		
	Medium (++)		
	Low (+)		
I01 Invasive species e.g. Crassola helmsii	High (+++)		
	Medium (++)		
	Low (+)		
J02.01.03 Infilling of ditches, dykes, ponds, pools, marches or pits	High (+++)		
	Medium (++)		
	Low (+)		
J02.09.01 Saltwater intrusion	High (+++)		
	Medium (++)		
	Low (+)		
J02.07 Water abstractions from groundwater	High (+++)		
	Medium (++)		
	Low (+)		

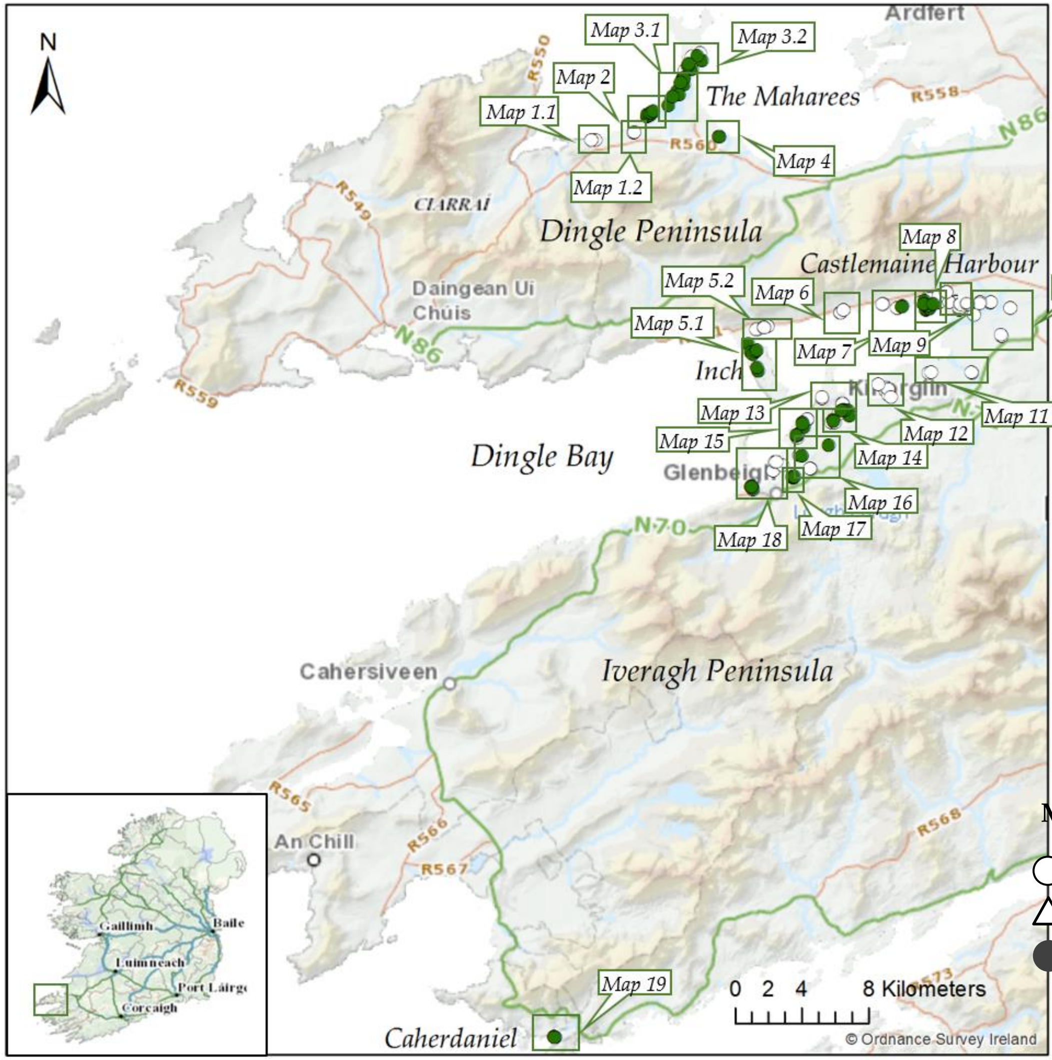
Pond disturbance:	None	
	Some	
	Heavy	

Notes:	

Appendix B - Schedule of pond surveys with the intervals between each visit



Appendix C – Maps of toad breeding sites



Map 1.1. Fermoyle 1
Map 1.2. Fermoyle 2
Map 2. Castlegregory Golf Course
Map 3.1. Maharees
Map 3.2. Maharees
Map 4. Tullaree
Map 5.1. Inch 1
Map 5.2. Inch 2
Map 6. Lack
Map 7. Killeen and Aughlis
Map 8. Roscullen Island
Map 9. Cortnahulla and Keel
Map 10. Keel and Boolteens
Map 11. Iveragh Peninsula 1
Map 12. Iveragh Peninsula 2
Map 13. Iveragh Peninsula 3
Map 14. Lough Yganavan
Map 15. Dooks Golf Course
Map 16. Iveragh Peninsula and Lough Nambrackdarrig
Map 17. Iveragh Quarry
Map 18. Glenbeigh
Map 19. Caherdaniel

Map Legend:

- Natural pond
- Artificial pond
- No pond in 2016-18
- Breeding activity in 2016-18
- No breeding activity in 2016-18

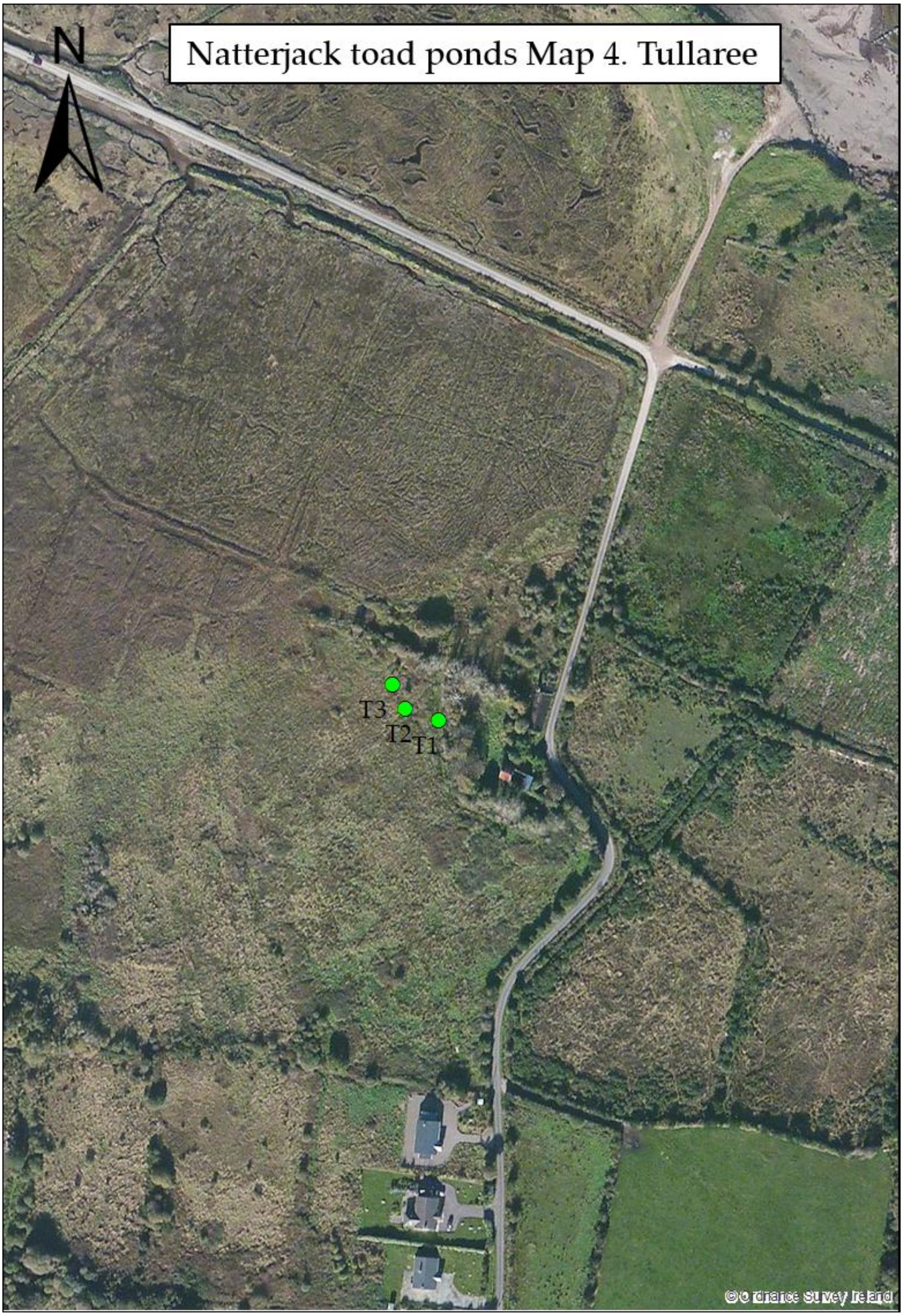

Natterjack toad ponds Map 1.1. Fermoyle 1
N
50A
50B
48A
48B
Meters
0 25 50 100 150 200
© Ordnance Survey Ireland

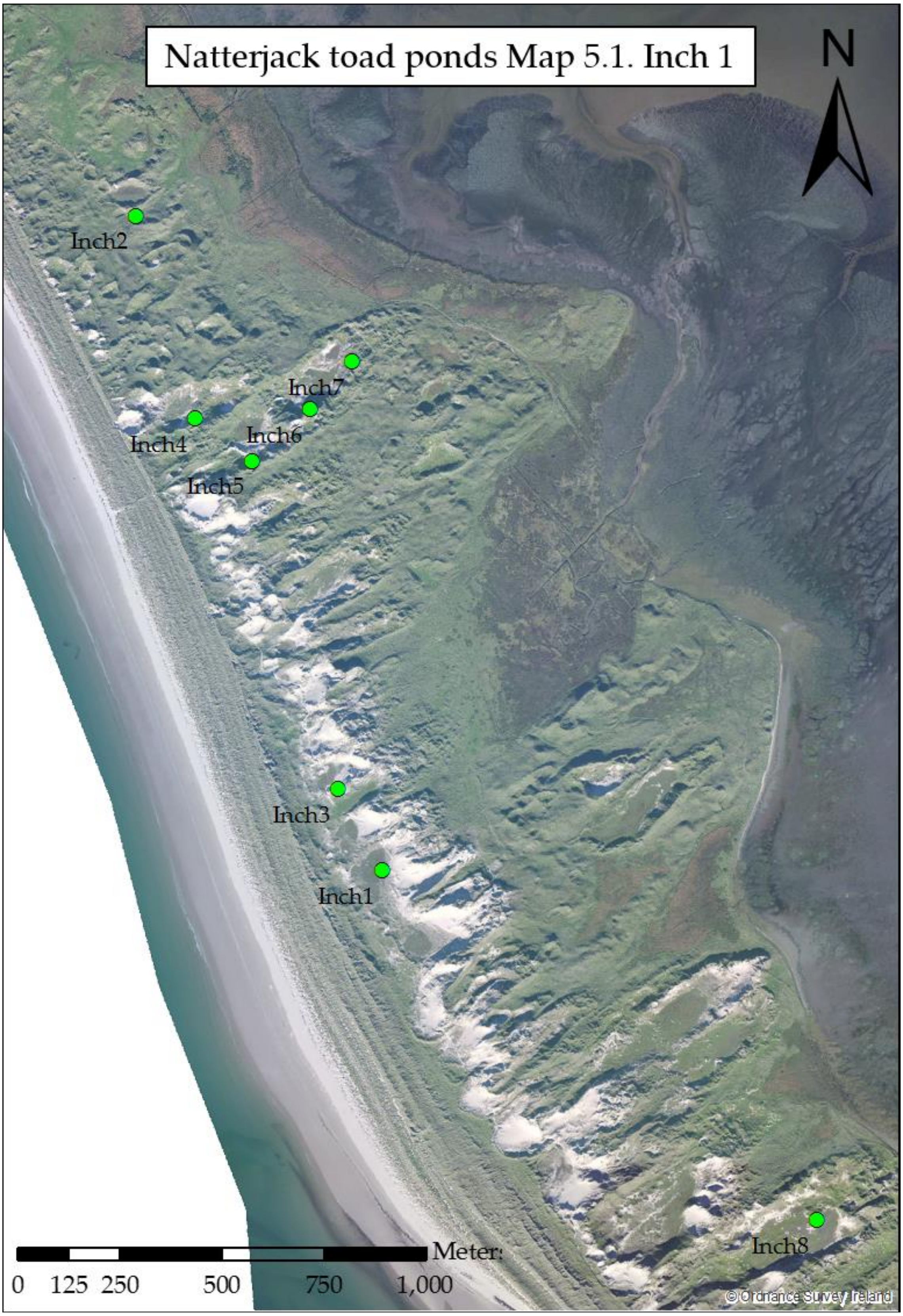

N
Natterjack toad ponds Map 1.2. Fermoyle 2
47B
47A
Meters
0 37.5 75 150 225 300
© Ordnance Survey Ireland


Natterjack toad ponds Map 2.
Castlegregory Golf Course
N
CGC8
CGC5
CGC4
CGC6
CGC2
CGC3
CGC1
Meters
0 50 100 200 300 400
© Ordnance Survey Ireland


N
Natterjack toad ponds Map 3.1. Magharees
M16
M17
M18
M25
M26
M19
M22
M23
M24
LoughGill
Meters
0 100 200 400 600 800
© Ordnance Survey Ireland


Natterjack toad ponds Map 3.2. Magharees
N
M4
M7
M6
M8
M1
M9A
M9
M12A
M12
Meters
0
75
150
300
450
600


Natterjack toad ponds Map 4. Tullaree
N
T3
T2
T1
© Ordnance Survey Ireland


Natterjack toad ponds Map 5.1. Inch 1
N
Inch2
Inch7
Inch4
Inch6
Inch5
Inch3
Inch1
Inch8
Meter:
0 125 250 500 750 1,000
© Ordnance Survey Ireland


Natterjack toad ponds Map 5.2. Inch 2
N
08A
08B
46A
46B
42B
42A
Meters
0
75
150
300
450
600


Natterjack toad ponds Map 6. Lack
N
45B
45A
44B
44A
Meters
0 50 100 200 300 400


Natterjack toad ponds Map 7.
Killeen and Aughils
N
39B
39A
24D
24C
24B
24A
06B
06A
Meters
0 75 150 300 450 600
© Ordnance Survey Ireland


Natterjack toad ponds Map 8.
Roscullen Island
N
26B
26A
20A
20B
03A
03B
14B
14A
Ross3
15B
15A
09A
09B
38B
38A
37B
37A
07A
07B
Ross1
04B
04A
Ross2
10A
Meters
0 50 100 200 300 400

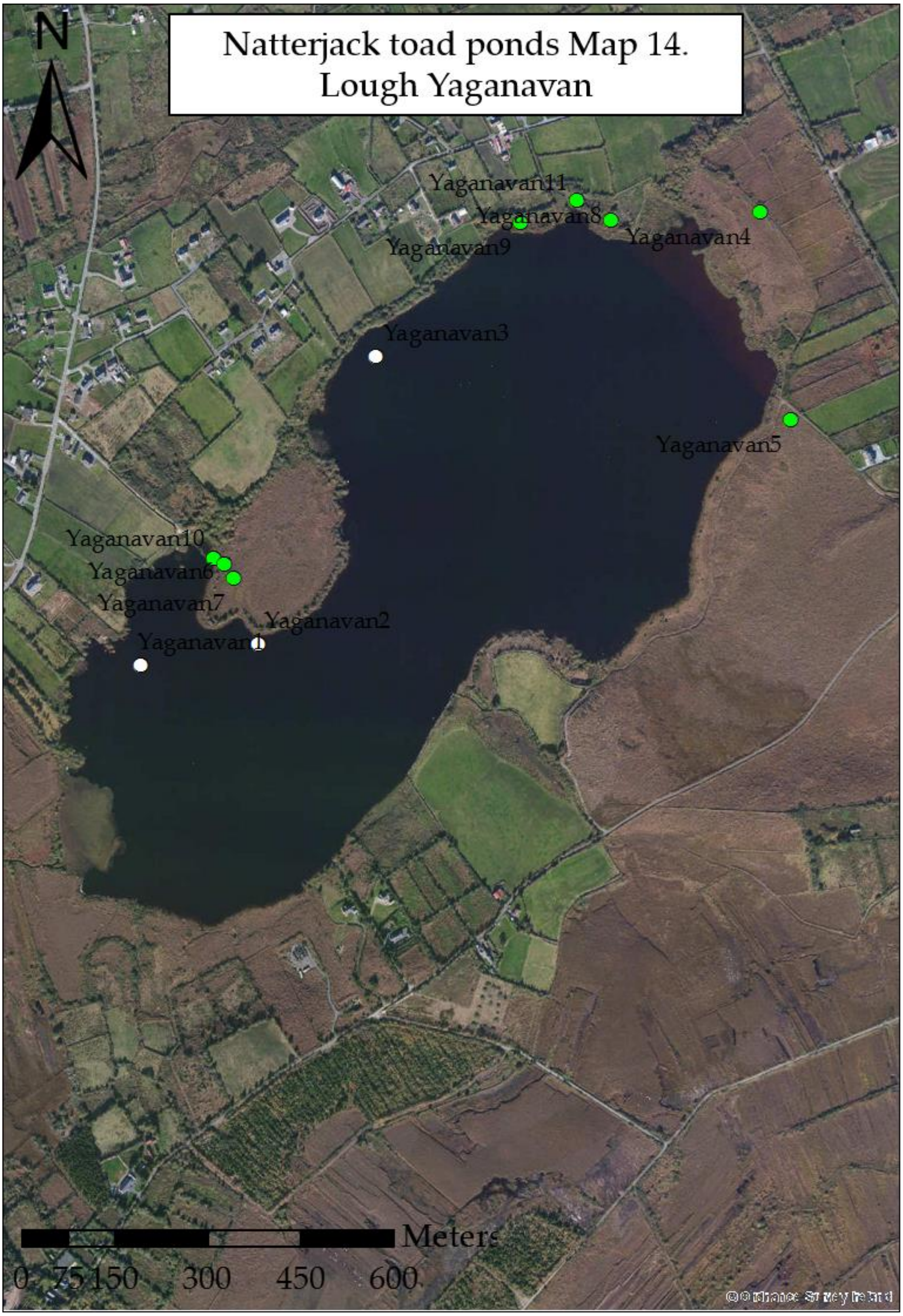

N
Natterjack toad ponds Map 9.
Cortnahulla and Keel
36A
36B
05A
05B
33B
33A
02A
02B
49B
49A
28B
28A
01B
01A
© Ordnance Survey Ireland


Natterjack toad ponds Map 10.
Keel and Boolteens
N
34B
34A
32B
16A
16B
25B
25A
19B
19A
51B
51A
Meters
0 125 250 500 750 1,000
© Ordnance Survey Ireland


Natterjack toad ponds Map 11.
Iveragh Peninsula 1
N
29A
29B
35B
35A
Meters
0125250 500 7501,000
© Ordnance Survey Ireland


N
Natterjack toad ponds Map 12.
Iveragh Peninsula 2
31B
30A
30B
18A
18B
31A
Meters
0 62.5125 250 375 500
© Ordnance Survey Ireland


N
Natterjack toad ponds Map 13.
Iveragh Peninsula 3
27B
27A
17A
17B
Meters
0 75 150 300 450 600
© Ordnance Survey Ireland

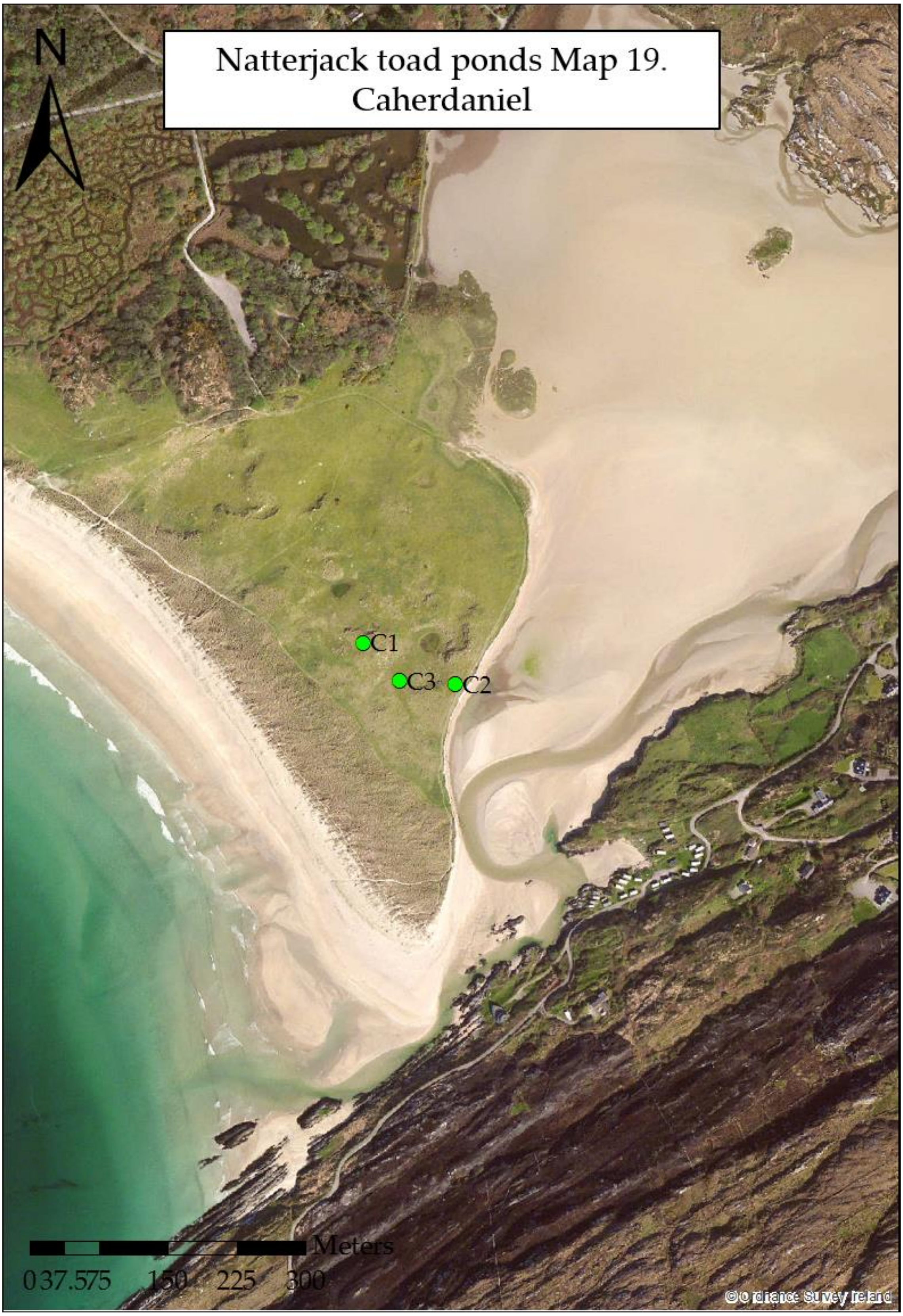

N
Natterjack toad ponds Map 14.
Lough Yaganavan
Yaganavan11
Yaganavan8
Yaganavan9
Yaganavan4
Yaganavan3
Yaganavan5
Yaganavan10
Yaganavan6
Yaganavan7
Yaganavan2
Yaganavan1
Meters
0 75 150 300 450 600


Natterjack toad ponds Map 15.
Dooks Golf Course
N
23B
23A
41A
D6
41B
D5
D4
D2
D1
Meters
0 62.5 125 250 375 500


N
Natterjack toad ponds Map 16. Iveragh Peninsula 4 and Lough Nambrackdarrig
IverLough
11B
11A
13B
13A
12B
12A
Meters
087.5175 350 525 700
© Ordnance Survey Ireland

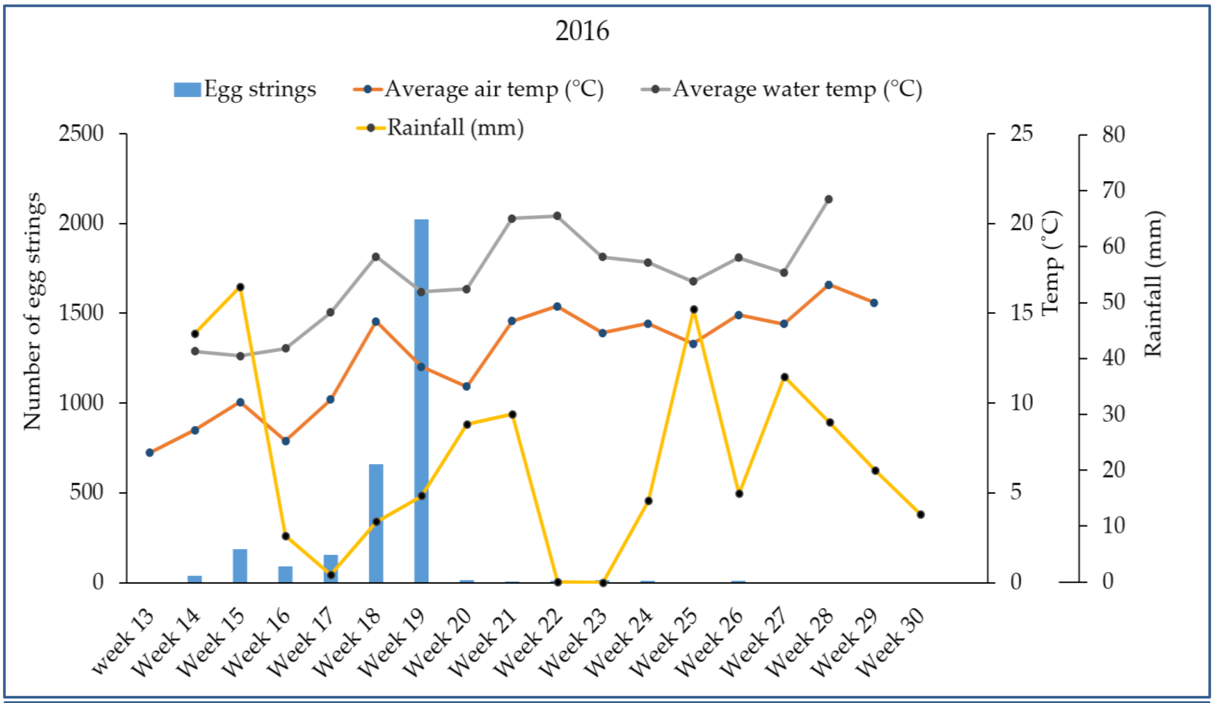

Natterjack toad ponds Map 17.
Iveragh Quarry
N
IverQU4
IverQU1
IverQU5
IverQU3
IverQU2
Meters
0 25 50 100 150 200
© Ordnance Survey Ireland

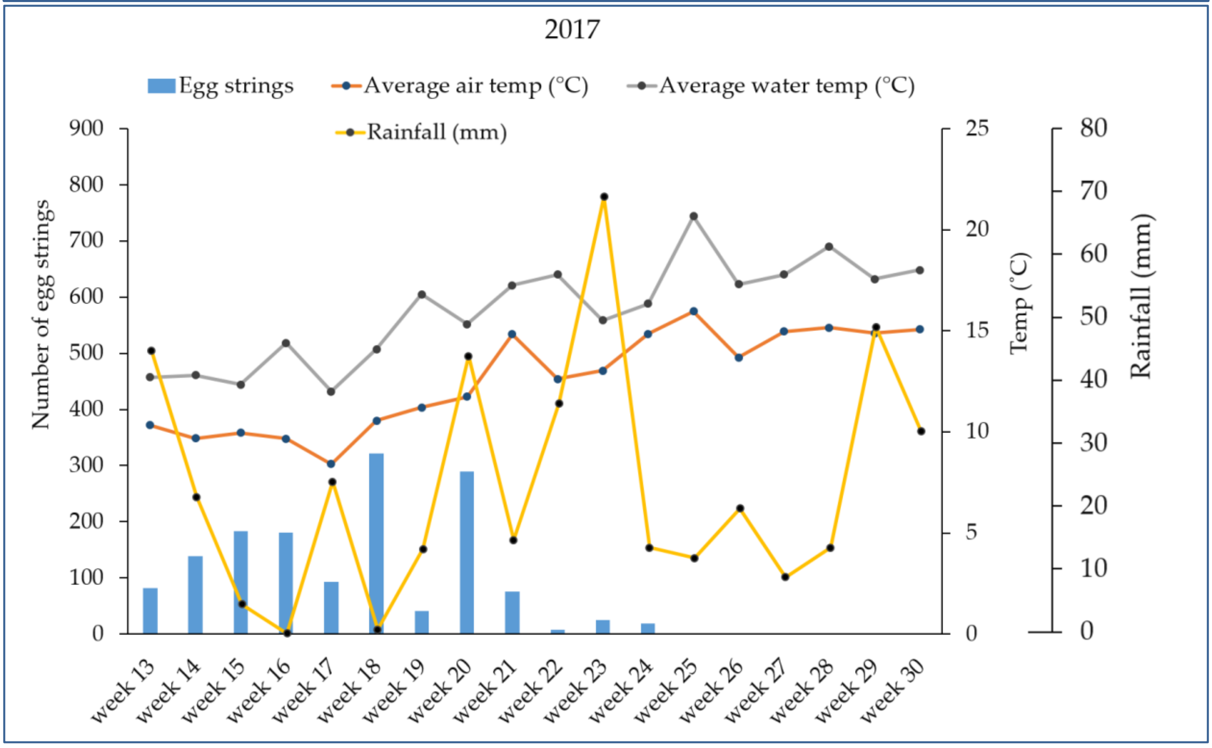
Natterjack toad ponds Map 18.
Glenbeigh
N
IverM2
IverM1
40B
40A
21
43B
43A
21A
43
21B
Meters
0 75150 300 450 600
© Ordnance Survey Ireland

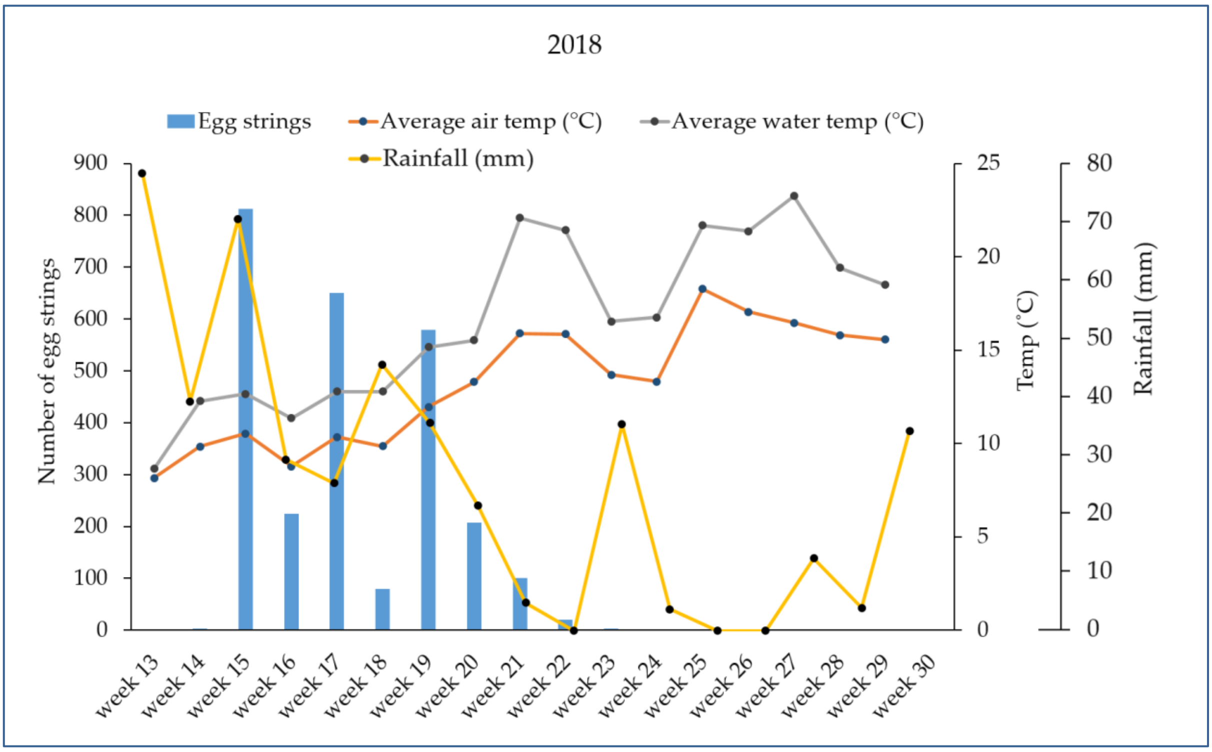

Natterjack toad ponds Map 19.
Caherdaniel
N
C1
C3
C2
Meters
0 37.5 75 150 225 300
© Ordnance Survey Ireland

Appendix D – Egg string production

D1. Egg string production with weekly average water and air temperatures for 2016, 2017 and 2018.






2018
Egg strings
Average air temp (°C)
Average water temp (°C)
Rainfall (mm)
Number of egg strings
Temp (°C)
Rainfall (mm)
900
800
700
600
500
400
300
200
100
0
25
20
15
10
5
0
80
70
60
50
40
30
20
10
0
week 13
week 14
week 15
week 16
week 17
week 18
week 19
week 20
week 21
week 22
week 23
week 24
week 25
week 26
week 27
week 28
week 29
week 30

Appendix E - Water chemistry

E. Average water temperature, pH, conductivity, salinity and oxygen for each pond and year

Pond ID	Water temperature °C			pH			Conductivity µS/cm			Salinity ppt			Oxygen mg/l		
	2016	2017	2018	2016	2017	2018	2016	2017	2018	2016	2017	2018	2016	2017	2018
01A	16.86	15.52	21.38	6.55	6.20	6.42	99.75	123.58	108.83	1.58	0.67	0.58	8.03	5.99	4.78
01B	17.52	15.54	17.55	6.47	6.14	6.95	95.52	97.75	74.22	1.58	1.50	1.00	7.25	5.30	9.23
02A	18.58	15.48	15.60	7.29	6.30	6.53	220.42	179.83	291.67	2.50	1.08	0.44	9.39	2.39	5.99
02B	17.99	15.60	21.91	6.90	6.37	7.15	3999.00	1430.50	3999.00	9.08	1.58	1.92	9.04	3.75	4.55
03A	17.08	14.51	19.58	6.86	6.56	6.82	239.17	416.08	272.00	2.50	0.17	0.58	6.96	4.81	5.49
03B	17.38	15.98	19.38	6.86	6.05	6.73	93.71	113.33	97.17	2.67	0.33	0.42	8.81	5.84	7.16
04A	14.80	13.69	16.86	6.76	6.70	6.41	554.25	462.58	1270.50	2.75	0.83	0.00	5.64	2.93	2.25
04B	15.52	14.27	17.60	7.08	6.51	6.71	436.40	458.75	843.08	2.83	0.67	0.50	6.96	5.92	2.95
06A	16.10	19.20	17.12	6.31	6.21	6.80	514.39	2658.33	2196.00	2.11	10.00	2.33	8.58	11.26	3.75
06B	16.09	20.68	16.93	6.77	7.69	7.04	3642.11	2234.83	3999.00	11.33	2.17	5.89	8.69	6.48	3.77
07A	16.64	14.71	15.47	6.54	6.50	6.56	697.63	595.50	568.33	2.50	0.75	0.00	8.00	6.24	4.11
07B	16.73	14.57	15.59	7.25	6.99	6.74	605.10	588.83	562.56	2.42	0.58	0.22	8.63	9.43	2.72
08A	17.44	15.42	13.70	7.17	7.40	8.17	181.67	236.11	160.89	2.33	1.11	0.67	5.69	6.87	9.99
08B	20.05	15.68	13.40	7.13	7.36	7.79	216.33	252.33	181.00	2.67	1.11	0.00	6.06	8.55	11.24
09A	17.71	16.35	16.14	6.02	6.21	5.67	184.23	192.42	138.42	1.75	0.50	0.00	8.87	8.92	6.05
09B	17.19	16.37	15.88	5.96	5.99	5.88	185.02	168.58	146.25	1.83	0.67	0.58	6.06	8.02	4.11
10A	15.63	13.62	17.52	5.19	5.09	6.16	915.75	220.58	171.42	3.00	0.42	0.00	7.33	9.69	6.04
10B	15.38	14.06	16.86	4.78	6.02	5.86	1831.52	2976.50	3471.67	3.92	2.67	4.08	7.62	4.72	7.97
11A	16.64	14.11	15.63	6.76	6.20	6.52	147.25	119.00	83.67	2.11	2.00	0.67	4.91	3.70	7.33
11B	15.70	14.93	17.29	6.19	5.58	6.52	168.17	128.25	91.33	2.33	2.00	0.00	3.89	5.26	15.56
12A	16.74	14.24	15.79	7.23	6.56	6.63	274.42	277.92	256.67	1.89	1.75	0.42	10.53	6.91	5.66
12B	16.17	14.92	14.33	6.99	6.48	6.57	519.58	2143.67	477.75	3.00	4.00	0.00	7.87	5.91	5.24
13A	17.86	14.69	16.93	6.74	6.70	6.14	136.75	119.50	73.83	1.67	1.42	0.83	8.94	6.61	8.20
13B	17.36	14.49	16.58	6.68	6.44	6.20	148.08	142.25	96.17	2.11	1.67	0.25	9.07	5.90	6.25
14A	17.21	14.68	18.47	6.94	7.03	7.01	323.23	456.58	378.08	2.92	0.50	0.00	5.27	5.53	4.65
14B	19.16	16.88	18.66	6.86	6.52	7.05	412.75	589.92	331.00	1.92	0.58	0.00	5.14	4.96	4.79
15A	17.67	16.12	16.59	6.87	5.71	5.95	155.56	154.08	126.17	1.92	0.42	0.00	8.39	4.85	2.32
15B	17.62	16.18	16.71	6.98	6.00	6.39	136.54	113.50	114.50	1.83	0.58	0.00	7.30	5.63	2.01
16A	15.63	14.38	14.92	6.45	5.81	6.04	110.44	98.92	49.00	1.58	1.00	1.17	6.23	5.68	5.55

Pond ID	Water temperature °C			pH			Conductivity µS/cm			Salinity ppt			Oxygen mg/l		
	2016	2017	2018	2016	2017	2018	2016	2017	2018	2016	2017	2018	2016	2017	2018
16B	15.51	14.18	14.27	6.55	5.86	5.93	115.23	105.50	61.22	1.50	1.08	1.33	6.57	5.14	4.91
17A	15.51	13.88	11.90	7.53	6.44	6.80	126.83	139.33	93.78	1.78	1.17	1.22	10.63	9.69	11.12
17B	15.09	15.36	11.43	7.18	6.24	6.62	120.17	131.89	78.83	3.00	0.33	0.33	11.30	8.21	10.22
18A	18.45	15.38	13.82	6.54	6.75	5.88	1057.58	408.83	96.00	2.58	1.42	1.00	6.37	6.10	6.31
18B	19.23	17.26	15.36	6.93	6.61	6.13	312.00	893.67	149.78	2.00	1.25	1.00	6.80	5.87	1.29
19A	16.67	15.13	18.03	6.36	6.22	6.18	160.08	182.42	99.42	1.92	1.08	0.50	7.76	13.21	5.86
19B	16.77	15.13	18.94	6.37	6.01	5.99	203.42	179.67	110.42	1.33	0.92	0.75	6.28	4.56	5.20
20A	18.30	17.50	19.19	7.85	7.77	7.96	170.96	315.00	244.00	2.17	0.67	0.67	10.35	10.84	6.81
20B	18.13	17.39	17.17	7.82	7.42	8.42	156.81	194.75	121.22	2.75	0.67	0.89	9.82	5.02	14.23
21A	14.47	12.38	16.83	7.63	7.28	6.81	234.42	214.58	123.83	1.33	1.83	0.00	9.57	7.01	6.48
21B	15.27	12.98	17.16	7.19	6.40	6.27	230.08	171.25	98.42	1.78	1.67	0.00	9.18	8.76	7.72
21	-	11.30	19.09	-	5.56	6.86	-	134.33	173.50	-	3.00	0.00	-	8.63	3.63
23A	14.87	14.01	14.45	7.17	6.84	6.69	171.42	191.58	140.33	2.11	1.08	0.00	6.40	3.80	3.15
23B	15.25	14.55	15.48	7.63	6.98	6.47	195.17	168.25	153.71	1.44	0.92	0.00	7.29	7.04	5.11
24A	9.22	17.40	15.12	7.83	6.29	7.13	3999.00	3999.00	3553.67	5.33	3.67	7.67	5.58	9.19	5.45
24B	15.74	17.01	14.89	6.98	6.63	7.05	3999.00	3999.00	3999.00	6.25	13.67	12.22	5.95	8.03	3.75
25A	14.32	15.53	16.84	6.82	6.20	6.20	434.19	354.58	316.92	2.78	1.08	0.75	7.28	3.89	3.58
25B	17.14	15.33	16.72	6.25	6.45	6.46	360.69	341.25	252.58	1.42	1.33	0.67	9.44	5.27	4.88
26A	16.95	17.63	16.87	6.54	5.92	6.14	96.08	97.08	78.33	1.67	0.75	0.83	7.14	6.03	4.00
26B	18.10	16.64	15.50	5.89	5.78	5.60	119.98	125.92	116.33	1.50	0.33	0.00	6.83	6.66	4.33
27A	17.82	16.74	16.56	6.81	5.61	6.66	2596.08	1350.42	2970.33	3.22	2.25	2.22	7.38	8.92	7.25
27B	17.71	16.80	17.10	7.41	5.32	6.97	3999.00	2159.42	1957.78	13.33	2.25	0.56	11.05	6.87	4.74
28A	17.02	15.68	20.47	6.41	6.25	6.73	136.08	167.33	173.75	2.08	0.50	0.00	6.92	4.89	4.20
28B	16.98	15.77	17.62	6.36	6.34	6.47	167.13	189.42	162.89	2.00	0.42	0.00	7.60	3.94	2.78
29A	20.46	17.15	20.13	5.60	5.86	5.38	200.52	143.43	142.25	1.92	1.17	1.25	8.40	7.76	6.40
29B	15.10	17.27	19.07	6.24	5.66	5.60	306.33	286.67	152.00	1.67	0.00	0.22	10.44	28.46	8.74
30A	16.91	14.02	17.48	5.65	5.95	5.58	211.17	161.00	145.08	2.33	1.00	0.00	6.41	6.38	7.34
30B	17.40	14.33	18.89	5.63	5.44	5.39	169.21	135.58	127.83	2.04	1.25	0.00	4.51	5.98	6.17
31A	18.19	15.63	16.00	6.69	6.91	6.10	190.83	331.25	183.92	2.00	1.00	0.75	8.66	6.50	5.55
31B	15.78	14.62	16.94	6.57	6.79	6.18	195.33	210.25	143.83	3.00	1.25	0.42	3.72	5.38	5.57
32A	16.11	15.20	17.05	6.31	5.81	5.92	128.77	144.08	90.89	2.25	1.33	1.33	6.75	3.85	6.19
32B	16.39	15.31	16.80	5.93	5.75	5.79	120.77	104.89	86.67	1.75	0.78	0.67	7.47	4.88	3.81
33A	16.65	10.84	15.55	7.27	6.96	6.89	334.88	417.58	467.08	1.75	0.75	0.58	7.28	5.53	2.28
33B	15.51	13.59	15.64	6.95	6.75	6.78	603.29	477.92	760.33	2.17	0.67	0.00	6.53	5.54	3.82
34A	12.26	13.77	9.87	6.55	5.86	5.80	125.00	129.50	73.67	1.33	1.00	1.50	4.66	6.11	4.70
34B	14.10	14.06	15.60	6.06	5.51	6.15	85.81	201.89	84.78	1.67	0.44	0.67	5.73	3.32	4.42
35A	21.58	16.30	16.48	7.05	6.25	6.74	238.79	606.50	160.67	2.25	1.00	0.33	9.30	10.19	6.13

Pond ID	Water temperature °C			pH			Conductivity µS/cm			Salinity ppt			Oxygen mg/l		
	2016	2017	2018	2016	2017	2018	2016	2017	2018	2016	2017	2018	2016	2017	2018
35B	18.97	15.60	14.26	6.76	6.28	6.44	3848.08	3999.00	2201.78	8.83	10.50	1.78	10.90	7.65	8.28
36A	18.27	16.71	14.57	7.14	6.39	6.14	107.19	92.17	73.33	1.50	0.50	0.00	7.59	7.41	3.00
36B	17.82	16.75	15.79	7.79	6.73	7.55	140.60	125.17	98.00	1.83	0.50	0.44	13.33	9.03	6.34
37A	16.83	14.35	17.42	7.13	6.64	7.31	558.15	802.25	790.67	2.08	0.92	0.00	8.89	5.03	6.71
37B	16.91	15.14	17.55	6.93	6.08	6.78	616.31	340.67	457.92	2.50	0.58	0.00	5.93	5.83	5.53
38A	18.35	17.03	17.76	6.35	5.86	6.01	254.06	281.17	245.58	2.08	0.75	0.50	9.05	7.32	6.02
38B	17.73	15.63	17.07	6.46	5.81	6.13	253.63	271.33	178.33	2.42	0.56	0.33	8.88	5.60	6.27
39A	15.87	19.15	15.27	5.79	6.21	6.91	1015.71	214.83	310.83	3.08	0.50	0.67	3.98	5.55	4.54
39B	17.20	20.90	15.72	6.64	6.84	7.23	115.17	157.67	110.83	1.89	0.33	1.17	6.69	10.00	9.98
40A	15.83	13.40	14.29	7.52	6.76	6.89	140.25	123.25	103.08	2.67	1.42	1.33	8.97	7.50	6.99
40B	15.27	13.59	15.24	7.28	6.67	6.40	149.25	122.92	92.83	1.67	1.42	0.00	7.45	8.85	7.93
41A	15.25	14.18	14.68	6.96	7.02	7.16	253.42	449.33	173.33	2.11	1.42	1.67	10.28	4.87	8.43
41B	15.15	13.87	14.85	7.65	6.94	7.01	264.25	482.67	182.44	2.67	0.75	0.00	8.87	5.02	7.69
42A	21.72	15.83	16.52	7.50	6.89	7.94	177.89	211.67	142.56	0.67	1.00	2.56	11.02	6.48	4.72
42B	17.90	15.88	20.51	7.60	7.36	7.90	201.33	216.92	254.83	2.08	0.50	0.17	6.10	3.72	6.40
43	14.66	dry	dry	6.74	dry	dry	731.67	dry	dry	3.00	dry	dry	9.59	dry	dry
43A	15.27	10.84	17.06	8.04	8.15	7.12	3999.25	3999.00	3099.00	34.00	29.50	18.17	9.98	7.48	4.70
43B	14.73	12.49	16.65	8.65	8.60	8.02	1240.33	762.75	499.50	4.33	4.08	1.08	10.18	8.67	9.45
44A	17.15	21.69	13.42	7.49	8.16	7.51	3487.17	541.83	3759.22	4.25	0.33	1.11	7.28	10.35	4.95
44B	26.17	18.74	12.84	7.85	8.43	7.74	1657.00	365.67	816.00	1.00	0.50	0.89	15.20	12.02	2.24
45A	15.29	18.48	19.13	6.71	6.83	7.41	252.50	277.42	364.83	1.50	0.33	0.33	3.92	4.18	11.80
45B	15.23	18.68	18.21	6.66	6.66	7.08	176.17	288.50	287.00	2.33	0.50	0.00	5.28	3.64	6.23
46A	19.24	18.47	18.44	7.70	7.37	7.53	3999.00	3999.00	3999.00	14.75	17.42	12.08	12.59	7.53	8.51
46B	19.00	17.83	18.25	8.03	7.68	7.68	3999.25	3999.00	3999.00	16.58	21.58	21.58	11.51	8.05	6.15
47A	15.93	14.50	15.52	7.54	7.46	7.50	345.67	362.67	268.89	2.00	1.22	0.11	7.31	7.34	4.14
47B	16.90	15.32	15.25	7.52	7.61	7.65	222.00	224.11	231.25	1.83	1.56	0.00	6.83	5.84	7.13
48A	16.39	13.27	11.08	7.55	7.27	7.81	586.17	661.78	378.00	1.83	1.67	0.17	5.41	3.62	6.28
49A	17.77	15.98	21.08	6.67	6.48	6.91	132.58	145.58	182.42	1.58	0.75	0.42	7.39	4.14	7.00
49B	17.89	13.76	20.59	6.93	6.39	6.98	290.85	366.42	265.58	1.42	1.00	0.58	7.93	6.86	7.90
50A	18.24	12.80	11.13	8.22	8.07	8.18	433.17	343.33	228.50	2.08	2.33	0.00	8.77	13.15	7.52
50B	17.14	16.32	11.48	7.94	8.29	8.55	420.75	281.00	246.50	2.17	1.00	0.00	8.95	8.32	9.02
51A	15.60	13.59	15.29	6.34	6.36	6.38	175.69	234.75	184.58	2.50	1.33	0.25	7.14	3.29	3.22
51B	15.87	13.93	15.67	5.57	6.26	6.15	150.44	131.83	103.42	2.67	0.92	0.00	7.77	5.11	3.64
C1	15.29	16.27	15.67	8.69	8.42	6.15	488.50	391.83	103.42	2.78	1.83	0.00	9.76	10.51	3.64
C2	15.48	16.04	16.76	8.87	8.51	7.94	404.17	372.92	402.67	2.78	1.75	0.60	10.78	9.55	8.52
C3	14.20	15.39	16.40	7.74	7.89	7.56	702.42	540.33	459.58	3.00	1.75	0.50	7.55	8.82	5.89
CGC1	14.89	15.24	14.84	7.82	7.80	8.02	428.67	579.42	436.67	2.08	1.25	0.33	6.49	5.68	5.91

Pond ID	Water temperature °C			pH			Conductivity µS/cm			Salinity ppt			Oxygen mg/l		
	2016	**2017**	**2018**	**2016**	**2017**	**2018**	**2016**	**2017**	**2018**	**2016**	**2017**	**2018**	**2016**	**2017**	**2018**
CGC2	14.72	15.12	15.25	7.81	8.07	8.29	455.50	429.58	402.92	1.92	1.58	0.25	7.30	7.81	9.55
CGC3	15.38	15.12	15.76	7.84	7.72	7.95	521.83	547.25	553.17	2.08	0.50	0.50	10.67	9.52	7.94
CGC4	14.52	14.17	13.82	7.74	7.54	7.74	553.67	602.58	581.67	1.92	1.75	0.42	5.09	6.02	5.79
CGC5	14.84	14.21	14.57	7.76	7.68	7.75	518.33	477.08	482.58	2.08	1.17	0.25	6.97	4.98	6.70
CGC6	14.94	14.23	14.29	7.63	7.20	7.67	549.58	552.50	569.50	2.00	1.83	0.00	3.84	4.69	4.51
CGC8	15.53	14.63	15.24	8.35	7.90	8.03	710.67	429.00	511.25	2.08	1.25	0.33	8.38	8.45	10.07
D1	12.38	12.26	13.20	7.21	7.13	6.61	299.83	311.50	219.86	2.56	1.50	0.11	5.62	3.81	3.46
D2	13.78	12.38	14.32	6.76	7.25	6.37	188.00	152.44	82.44	2.00	2.11	0.00	7.40	8.67	7.99
D3	14.10	12.60	14.46	7.50	7.00	6.49	225.25	156.89	130.56	2.56	1.67	0.22	8.62	8.06	7.80
D4	dry	11.92	12.64	dry	6.71	5.72	dry	370.17	109.33	dry	2.17	0.50	dry	3.59	25.97
D5	12.45	9.47	12.63	5.54	5.50	5.60	235.00	150.33	121.67	4.00	2.00	0.00	4.72	3.51	3.68
D6	16.04	13.56	13.98	7.27	6.89	6.98	516.17	646.67	520.78	2.78	1.11	0.22	10.31	2.07	4.40
Inch 1	16.98	N/A	19.29	8.64	N/A	8.50	451.83	N/A	402.33	2.67	N/A	0.33	11.54	N/A	12.28
Inch 2	16.94	11.73	16.28	8.27	8.09	7.92	493.00	562.67	482.67	3.33	2.00	0.00	9.55	14.46	9.87
Inch 3	17.49	N/A	19.27	8.85	N/A	10.43	433.83	N/A	473.83	2.83	N/A	0.00	11.41	N/A	11.05
Inch 4	22.83	N/A	18.06	7.74	N/A	8.26	463.33	N/A	368.00	3.33	N/A	0.00	10.12	N/A	11.67
Inch 5	19.52	N/A	17.82	8.53	N/A	8.34	365.00	N/A	271.00	2.67	N/A	0.17	9.02	N/A	11.19
Inch 6	16.77	N/A	17.35	8.31	N/A	8.22	417.33	N/A	343.17	2.00	N/A	0.17	10.48	N/A	13.25
Inch 7	19.31	12.10	17.83	8.30	7.60	8.35	397.00	470.67	292.33	4.00	1.33	0.22	8.37	15.89	11.80
Inch 8	-	-	dry	-	-	dry	-	-	dry	-	-	dry	-	-	dry
IverLough	15.96	16.11	15.77	6.31	5.38	5.87	142.08	127.08	102.42	1.33	0.67	0.00	7.79	5.32	6.26
IverM1	14.01	12.09	10.65	6.51	6.49	6.06	1883.83	2013.67	2292.67	2.78	2.78	0.00	3.63	1.46	0.96
IverM2	14.50	12.74	12.67	6.23	6.56	6.45	3849.00	3058.25	3999.00	3.00	3.83	13.56	3.42	3.40	2.45
IverQU1	15.74	14.41	13.11	6.80	6.30	6.50	155.58	86.33	145.56	1.56	1.00	1.67	7.25	6.29	6.04
IverQU2	16.36	15.29	15.13	7.23	5.75	5.62	126.25	99.00	88.44	1.33	1.00	0.00	9.53	7.88	8.71
IverQU3	dry	15.38	16.75	dry	5.74	5.52	dry	88.33	46.44	dry	1.11	0.00	dry	9.44	9.85
IverQU4	15.68	15.40	11.97	6.66	5.62	6.44	189.33	22.00	140.67	4.00	1.33	0.17	3.00	10.21	3.49
IverQU5	19.38	16.02	19.71	7.02	6.45	6.75	669.00	3085.58	1851.42	2.67	7.50	3.50	11.87	7.60	8.74
LoughGill	19.01	15.73	17.85	8.88	8.59	8.43	2423.75	3047.22	1989.56	2.22	2.56	1.22	9.42	10.26	11.90
M1	16.14	13.07	14.69	8.30	8.84	8.16	1970.47	679.67	556.89	3.44	1.50	1.33	8.56	11.08	6.22
M12	16.20	dry	14.28	8.95	dry	7.94	650.50	dry	570.67	4.00	dry	0.83	12.53	dry	8.19
M16	17.68	dry	15.84	8.24	dry	7.70	495.69	dry	704.50	1.67	dry	1.33	9.01	dry	2.81
M17	17.78	dry	16.37	8.99	dry	8.09	425.27	dry	399.44	1.58	dry	0.00	8.46	dry	6.41
M18	17.49	dry	13.96	8.44	dry	7.83	589.21	dry	663.00	2.67	dry	2.67	9.79	dry	11.37
M19	18.78	dry	15.40	8.24	dry	8.23	495.58	dry	492.17	2.11	dry	0.33	9.16	dry	9.19
M22	20.80	dry	15.92	8.73	dry	8.32	543.93	dry	456.50	1.50	dry	0.00	10.61	dry	10.30
M23	19.66	11.90	17.50	8.70	8.18	8.26	511.54	551.67	412.22	1.58	3.33	0.00	8.63	12.63	8.98

Pond ID	Water temperature °C			pH			Conductivity µS/cm			Salinity ppt			Oxygen mg/l		
	2016	2017	2018	2016	2017	2018	2016	2017	2018	2016	2017	2018	2016	2017	2018
M24	23.22	12.13	16.75	8.48	8.43	8.16	412.67	429.33	443.83	1.00	3.00	0.83	9.31	13.80	9.43
M25	20.12	dry	15.49	8.62	dry	8.67	564.67	dry	528.17	1.00	dry	0.42	10.14	dry	12.20
M6	11.74	dry	9.15	8.70	dry	8.17	550.50	dry	540.17	3.33	dry	2.67	10.56	dry	9.66
M7	12.73	dry	13.30	8.90	dry	7.53	564.00	dry	568.00	3.33	dry	1.50	11.54	dry	7.44
M8	13.43	dry	13.30	9.17	dry	7.53	766.00	dry	568.00	3.33	dry	1.50	12.50	dry	7.44
M9	16.46	dry	14.10	8.58	dry	8.25	694.54	dry	561.33	1.83	dry	0.00	9.35	dry	9.42
M9A	16.30	dry	14.32	8.12	dry	8.11	733.23	dry	673.11	3.08	dry	0.44	6.96	dry	9.32
Ross3	-	14.13	8.97	-	6.81	-	-	1126.67	-	-	0.00	-	-	2.82	-
T1	16.66	16.90	17.80	7.12	7.16	7.31	3981.67	3845.83	2223.67	5.17	9.08	2.83	1.98	2.05	3.24
T2	16.88	15.89	17.15	7.29	7.33	7.46	2846.71	3084.50	2498.08	4.25	6.58	8.00	4.17	2.53	4.04
T3	17.08	16.06	17.61	7.24	7.27	7.40	3959.06	3640.50	3057.25	6.92	9.75	9.25	4.95	3.50	6.31
Yganavan2	17.14	-	-	6.89	-	-	145.17	-	-	1.56	-	-	9.38	-	-
Yganavan4	18.25	16.15	18.12	6.80	6.42	6.15	152.83	141.33	110.08	1.33	0.83	0.75	9.46	9.99	9.85
Yganavan5	17.11	11.33	-	7.04	6.19	-	140.25	127.67	-	1.33	2.67	-	9.77	10.57	-
Yganavan6	17.62	16.49	16.76	6.77	6.22	6.27	155.17	126.12	116.75	2.33	0.92	0.50	8.72	6.28	7.23
Yganavan7	18.42	15.90	19.17	6.90	6.44	6.40	137.67	133.00	136.92	2.33	1.17	1.33	9.59	9.25	10.11
Yganavan8	19.96	17.44	17.91	7.01	6.17	6.52	138.33	131.83	110.08	1.00	0.58	0.08	9.90	9.67	10.01
Yganavan9	20.13	16.03	17.31	6.96	6.26	6.26	137.22	133.33	109.75	1.78	1.25	0.67	9.29	9.86	9.82
Yganavan10	18.65	15.24	16.83	7.01	6.77	540.36	141.56	150.17	117.17	2.11	1.00	0.08	7.48	7.35	8.85
Yganavan11	24.13	15.88	16.93	6.45	6.25	6.51	260.00	161.33	177.00	2.00	0.67	1.11	10.45	8.04	9.41

Appendix F - Compliance with the Pond Creation Scheme

F1 Level of compliance by year with the management requirements of the Pond Creation Scheme.

Pond ID	Emergent vegetation (% cover)			Sward height (% cover >20cm)		
	2016	2017	2018	2016	2017	2018
01A	60	0	10	100	70	90
01B	80	0	40	100	70	90
02A	0	0	30	40	100	90
02B	30	40	10	40	100	90
03A	60	80	20	30	50	20
03B	0	80	20	40	50	30
04A	20	70	40	10	60	50
04B	0	10	10	10	60	50
06A	40	40	0	60	50	20
06B	10	0	0	30	50	20
07A	30	40	30	10	70	70
07B	30	40	80	20	80	70
08A	10	70	0	20	30	20
08B	10	70	10	10	30	20
09A	10	10	10	100	60	60
09B	0	10	10	100	40	60
10A	20	10	10	80	80	100
10B	80	10	20	60	100	100
11A	30	10	10	10	100	100
11B	40	70	0	80	100	100
12A	10	20	10	100	100	100
12B	40	40	10	100	100	100
13A	10	0	30	40	60	80
13B	20	20	10	60	40	80
14A	40	30	10	30	70	60
14B	0	30	10	40	60	60
15A	40	60	10	60	100	70
15B	20	30	10	10	100	60
16A	10	0	10	10	10	90
16B	10	0	10	30	20	90
17A	0	0	0	10	100	100
17B	10	0	10	20	90	100
18A	30	10	10	10	60	20
18B	30	10	0	20	10	20
19A	10	10	10	40	40	90
19B	10	0	10	40	40	90
20A	40	40	0	30	70	40
20B	40	20	10	40	70	40
21A	10	10	10	100	60	100
21B	10	10	10	100	70	100
23A	80	60	60	10	70	70
23B	30	30	10	100	70	70
24A	30	30	50	60	100	100
24B	90	70	30	100	100	100
25A	0	0	0	100	80	80
25B	40	20	10	60	100	100
26A	40	20	30	100	100	90
26B	20	10	0	100	100	100
27A	0	0	0	80	70	90

27B	0	0	10	80	50	90
28A	40	40	0	40	60	40
28B	0	30	20	40	70	40
29A	40	10	10	20	60	70
29B	0	10	10	40	100	70
30A	80	30	0	20	50	70
30B	40	80	0	40	80	60
31A	0	0	10	100	20	20
31B	0	10	0	100	50	20
32A	10	0	10	80	80	100
32B	40	10	10	80	80	90
33A	40	30	10	70	40	30
33B	30	20	30	70	60	20
34A	40	20	10	20	100	30
34B	90	10	30	100	90	30
35A	20	20	10	70	100	80
35B	70	90	90	70	80	80
36A	20	70	30	20	40	30
36B	10	10	0	60	30	30
37A	30	50	10	20	20	10
37B	30	20	20	20	70	70
38A	80	80	0	30	70	60
38B	80	90	0	30	70	60
39A	80	100	0	90	100	70
39B	10	90	0	70	100	70
40A	10	10	10	100	60	70
40B	10	10	10	100	70	70
41A	20	30	10	100	20	10
41B	510	10	0	20	30	10
42A	80	20	20	60	50	20
42B	80	80	10	70	50	20
43A	10	0	10	20	80	40
43B	10	0	10	30	60	40
44A	0	0	0	30	30	20
44B	0	0	0	30	30	20
45A	10	10	0	100	80	70
45B	80	90	0	100	80	70
46A	20	20	10	60	40	20
46B	30	30	20	70	30	20
47A	40	50	20	50	60	70
47B	20	50	10	100	60	70
48A	90	90	60	100	20	10
49A	20	10	10	100	20	30
49B	50	40	20	40	30	30
50A	20	10	90	30	50	30
50B	90	10	10	30	70	30
51A	30	10	20	70	50	10
51B	10	10	10	70	70	10

Appendix G – Other amphibian species

G1. List of ponds where other amphibian species occurred (1 – presence, 0 – absence).

Pond ID	Irish grid	Area	*R. temporaria*	*L. vulgaris*
01A	Q7780402073	Keel	1	1
01B	Q7779802100	Keel	1	1
02A	Q7758302601	Caherfealane Marsh	1	1
02B	Q7760802554	Caherfealane Marsh	1	0
03A	Q7573302621	Roscullen Island	1	0
03B	Q7582002631	Roscullen Island	1	1
04A	Q7586002108	Roscullen Island	1	1
04B	Q7601702145	Roscullen Island	1	1
07A	Q7585702321	Roscullen Island	1	1
07B	Q7592102319	Roscullen Island	1	1
08A	Q6629201130	Inch	1	0
08B	Q6632801118	Inch	1	0
09A	Q7656902517	Roscullen Island	1	1
09B	Q7659702532	Roscullen Island	1	0
10A	Q7578902054	Roscullen Island	1	0
10B	Q7579202102	Roscullen Island	1	1
11A	V6822293359	Iveragh Peninsula	1	0
11B	V6824293367	Iveragh Peninsula	1	0
12B	V6886292537	Iveragh Peninsula	1	1
13A	V6937693289	Iveragh Peninsula	1	0
13B	V6838193286	Iveragh Peninsula	1	0
14A	Q7555802525	Roscullen Island	1	1
14B	Q7552602529	Roscullen Island	1	0
15A	Q7625302531	Roscullen Island	1	0
15B	Q7525102551	Roscullen Island	1	1
16A	Q7964902505	Boolteens	1	1
16B	Q7969902527	Boolteens	1	1
18B	V7353696945	Iveragh Peninsula	1	0
19A	Q7867601841	Keel	1	1
19B	Q7871201774	Keel	1	0
20A	Q7595102835	Roscullen Island	0	1
20B	Q7599602738	Roscullen Island	1	0
21	V6572291611	Iveragh Peninsula	1	0
21A	V6544291334	Iveragh Peninsula	1	0
21B	V6544091247	Iveragh Peninsula	1	1
23A	V6870095508	Iveragh Peninsula	1	0
23B	V6870095508	Iveragh Peninsula	1	1
25B	Q8087302194	Boolteens	0	1
26A	Q7656302826	Roscullen Island	1	1
26B	Q7655502909	Roscullen Island	1	1
27A	V6958196760	Iveragh Peninsula	1	0
28A	Q7784802125	Keel	1	1
28B	Q7782302204	Keel	1	1
29A	V7596698304	Iveragh Peninsula	1	0
30A	V7344097383	Iveragh Peninsula	1	1
30B	V7356697324	Iveragh Peninsula	1	0
31A	V7370296852	Iveragh Peninsula	1	0

Pond ID	Irish grid	Area	*R. temporaria*	*L. vulgaris*
32A	Q7907402536	Boolteens	1	1
32B	Q7902702452	Boolteens	1	1
33A	Q7720502534	Caherfealane Marsh	1	1
33B	Q7721902558	Caherfealane Marsh	1	1
34A	Q7832002429	Keel	1	1
34B	Q7830802462	Keel	1	0
35A	V7858698292	Iveragh Peninsula	1	0
35B	V7853198342	Iveragh Peninsula	1	0
36A	Q7700303137	Gortnahulla	1	1
36B	Q7703403140	Gortnahulla	1	1
37A	Q7571802408	Roscullen Island	1	1
37B	Q7568202405	Roscullen Island	1	0
38A	Q7626302411	Roscullen Island	1	1
38B	Q7626302417	Roscullen Island	1	1
39A	Q7087902051	Aughils	1	0
39B	Q7068601913	Aughils	1	1
40A	V6663492433	Iveragh Peninsula	1	1
40B	V6665392425	Iveragh Peninsula	1	1
41A	V6842895317	Iveragh Peninsula	0	1
41B	V6850495032	Iveragh Peninsula	1	1
42A	Q6567300896	Inch	1	0
42B	Q6565100885	Inch	1	0
43	V6540191396	Iveragh Peninsula	1	0
43B	V6534291510	Iveragh Peninsula	1	1
44A	Q7066801893	Lack	1	0
44B	Q7068601913	Lack	1	0
45A	Q7087902051	Lack	1	0
45B	Q7084402081	Lack	1	0
47A	Q5830212716	Gowlane	1	0
49A	Q7786802414	Keel	1	1
49B	Q7788302433	Keel	1	0
51B	Q8031000560	Kilburn	0	1
C1	V5348658416	Caherdaniel	1	0
C2	V5357858375	Caherdaniel	1	0
C3	V5352258378	Caherdaniel	1	0
CGC1	Q5906913690	Castlegregory Golf Course	1	0
CGC2	Q5910613783	Castlegregory Golf Course	1	0
CGC3	Q5925213758	Castlegregory Golf Course	1	0
CGC4	Q5926513897	Castlegregory Golf Course	1	1
CGC5	Q5935913961	Castlegregory Golf Course	1	1
CGC6	Q5938613875	Castlegregory Golf Course	1	1
CGC8	Q5944114000	Castlegregory Golf Course	1	1
D1	V6807894380	Dooks golf club	0	1
D2	V6806694493	Dooks golf club	1	1
D3	V6803294531	Dooks golf club	1	1
D4	V6813594556	Dooks golf club	1	1
D5	V6813894556	Dook golf club	1	0
D6	V6842395218	Dook golf club	1	1
Inch 2	Q6516000028	Inch	1	0
Inch 3	Q6565998617	Inch	1	0
Inch 4	Q6530799530	Inch	1	0
Inch 5	Q6544799425	Inch	1	0
Inch 6	Q6559199552	Inch	1	0

Pond ID	Irish grid	Area	*R. temporaria*	*L. vulgaris*
Inch 7	Q6569499669	Inch	1	0
IverLough	V6996793950	Lough Nambrackdarrig	1	0
IverM2	V6682392944	Iveragh Peninsula Marsh	1	0
IverQU1	V6784692073	Iveragh Peninsula Quarry	1	1
IverQU2	V6784191994	Iveragh Peninsula Quarry	1	1
IverQU3	V6780892015	Iveragh Peninsula Quarry	1	0
IverQU4	V6781192059	Iveragh Peninsula Quarry	1	1
IverQU5	V6791992041	Iveragh Peninsula Quarry	1	0
M12	Q6177416542	Maharees	0	1
M12A	Q6170016554	Maharees	1	1
M16	Q6124616000	Maharees	1	1
M17	Q6127315956	Maharees	1	1
M18	Q6122315952	Maharees	1	1
M19	Q6131415593	Maharees	1	1
M22	Q6089515184	Maharees	1	1
M23	Q6099614997	Maharees	1	1
M24	Q6060314878	Maharees	1	1
M26	Q6135215934	Maharees	1	1
M6	Q6110015727	Maharees	1	0
M7	Q6209817218	Maharees	1	0
M9	Q6155516731	Maharees	1	1
M9A	Q6158916858	Maharees	1	1
Ross3	Q7547302509	Roscullen Island Area	1	0
Yganavan10	V7024595470	Yganavan lake	1	0
Yganavan11	V7084996066	Yganavan lake	1	1