The Irish Naturalists' Journal Volume 28 Issue 12

The natterjack toad *Bufo calamita* in Co Kerry, Ireland: conservation status, current and foreseeable threats

EMELINE BÉCART, AURÉLIE AUBRY, PÁDRAIG WHELAN AND MARK C. EMMERSON

Department of Zoology, Ecology and Plant Science, University College Cork, Cork
and
Biodiversity Lab, Environmental Research Institute, University College Cork, Lee Road, Cork

Over the past decade, many studies have reported and investigated the causes of the observed global decline in amphibian populations. The natterjack toad *Bufo calamita* is one of three amphibian species found in Ireland and the least widespread, being naturally confined to coastal areas in Co Kerry. The natterjack's distribution in Ireland has largely contracted since the species was first recorded in 1805. As with many other amphibian species worldwide, natterjacks are mainly threatened by habitat loss and fragmentation. Whilst studies are needed to better assess threats to natterjacks in an Irish context, the species is most likely threatened by changes in land usage. Here we also detail a number of threats that are of secondary importance for the viability of toad populations in Ireland.

Many studies have reported and investigated the causes of the observed global decline in amphibian populations (Alford and Richards 1999, Houlahan *et al.* 2000, Alford *et al.* 2001, Gardner 2001, Blaustein and Kiesecker 2002). This global amphibian decline was first reported in 1989 at the First World Congress of Herpetology in Canterbury, U.K. The most common causes reported for these declines are habitat modification and loss, the introduction of non-native competitive or predatory species, diseases, chemical pollution, climate change and UV-B radiation. It is apparent that these causes are diffuse in nature rather than attributable to any one consistent driving mechanism. The driving factors and their effects vary greatly between species and individual populations of amphibians, and it is often difficult to consider only one factor as many interact in synergy to the detriment of amphibian populations. Ireland hosts three amphibian species: the common frog *Rana temporaria* L. (1758), the smooth newt *Triturus vulgaris* L. (1758) and the natterjack toad *Bufo calamita* Laurenti (1768). Whilst the common frog and the smooth newt are relatively common across the country, the natterjack toad (see Plate 6) in contrast has historically been confined to coastal areas in Co Kerry. The species is native to 22 countries in Europe (IUCN 2006 (International Union for Conservation of nature and Natural resources)) and whilst it is widespread in south-west and central Europe, it is less common and in decline towards the northern limit of its range, notably in Estonia, Sweden, Denmark, Belgium, Britain and Ireland (Beebee 1979, 1983, 2002; IUCN 2006). The natterjack toad is thus listed in the IUCN *Red List of Threatened Species* as a species of Least Concern (LC), "in view of its wide distribution, presumed large population, and because the total population is unlikely to be declining fast enough for listing in a more threatened category" (IUCN 2006). Under European law, the species is, however, strictly protected and for that purpose is listed on Annex IV of the Habitats and Species Directive (92/43/EEC). In Ireland, all breeding sites are included in Special Areas of Conservation (SACs), designated under the EU Habitats Directive. Irish natterjack toad populations seem to have undergone a severe decline and range contraction over the first half of the 20th century (Beebee 2002, Bécart *et a.l* in press). Habitat destruction due to human activities appears to be one major factor to this decline.

Here we will outline how natterjack toad distribution and population size has varied over the last two centuries in Ireland, and we will discuss the main threats to the species in an

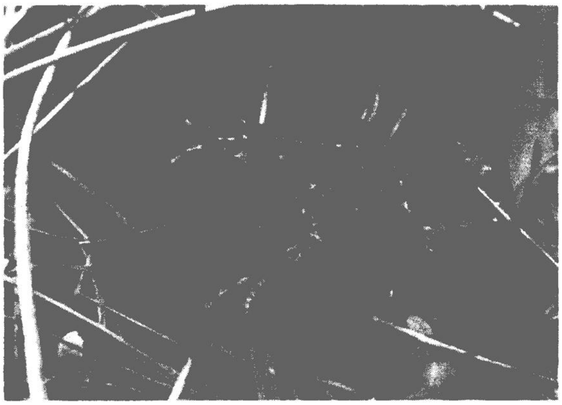

Plate 6. Natterjack toad *Bufo calamita*, Cnádán

Irish context. The issues covered here mirror the general and global causes of amphibian declines detailed elsewhere (Gardner 2001, Blaustein and Kiesecker 2002).

I. Historical status in Ireland

In Ireland, naturally occurring natterjack toads have only been recorded in Co Kerry, and there is no fossil evidence to suggest that they have ever existed elsewhere in the country (Beebee 1983, 2002; Gleed-Owen *et al.* 1999, Korky and Webb 1999). In that context, they are part of the so-called Lusitanian fauna and flora, a small group of species characteristic of the Iberian Peninsula and south-west Ireland, with few or no other populations in-between these two regions (Beebee 1984, 2002; Rowe *et al.* 2006). The toad's restricted distribution in Ireland might result from the specific climatic conditions in Co Kerry, combined with the rocky nature of the coastline in that part of the country, which might have limited the toads dispersal (Beebee 1984). However, there are still some uncertainties regarding the natterjack toad's origins in Ireland. There has been a long standing controversy over whether the species is native to Ireland (Beebee 1984, Gleed-Owen *et al.* 1999, Korky and Webb 1999, Rowe *et al.* 2006). Because the toad only occurs in Co Kerry, it was initially hypothesized that natterjack toads had been introduced accidentally through sand ballast carried by ships from Iberia to the head of Dingle Bay, at a time of a thriving sea trade between the two regions, and/or from Liverpool Bay (Beebee 1984, 2002; Korky and Webb 1999). This hypothesis, however, does not explain the presence of the species outside of Dingle Bay. The mountainous terrain that toads would have had to cross to reach these other areas is likely to have acted as a physical barrier to natural dispersal. It has also been speculated that natterjacks migrated from the continent through Britain after the last glaciation, across land bridges (Korky and Webb 1999). Recent genetic studies, applying phylogeographical analysis, rejected this hypothesis, finding evidence that Irish natterjack toads are more related to natterjacks from north-west England (Cumbria) than Iberia or south-east England (Beebee and Rowe 2000, Rowe *et al.* 2006). These authors concluded that although Iberia has been a long-term refugium over millions of years for many species, a north European refugium enabled natterjacks to persist since the last glacial maximum 20 000 years BP, enabling the species to directly re-colonize Ireland and north-west England.

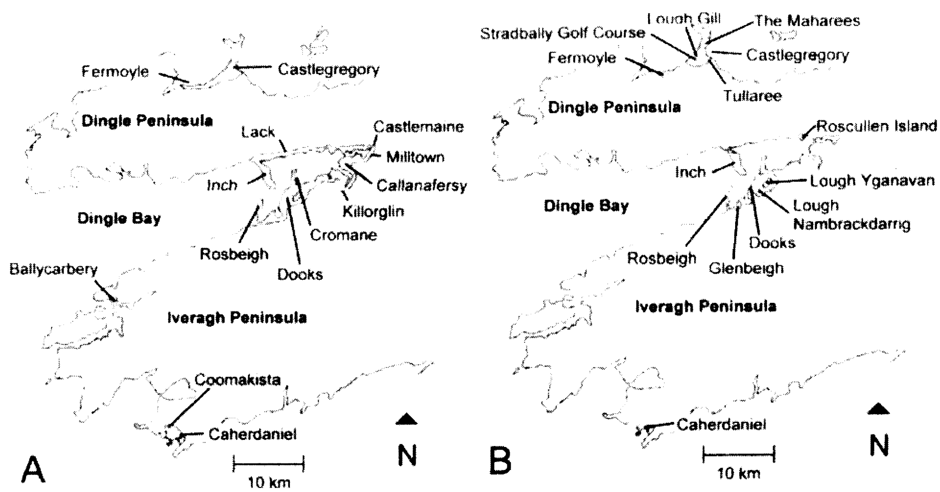

Figure 1. Natterjack toad *Bufo calamita* population distribution (grey areas) in Co Kerry: A) during the period 1805 –1971; and B) at present (adapted from Beebee 2002).

Natterjack toads were first recorded in Ireland in 1805 at Callanafersy (Castlemaine Harbour, see Fig. 1) (Gresson and O'Dubhda 1974). At that time, natterjacks were probably present all around Dingle Bay, from Inch Peninsula on the north side of the bay, to Rosbeigh on the south side (Gresson and O'Dubhda 1974). In the 1870s, natterjacks were recorded on the south-west of the Iveragh Peninsula. It is only in the 1960s that natterjacks were recorded on the north side of the Dingle Peninsula (Gresson and O'Dubhda 1974), although the toads were probably present there long before their discovery (Beebee 1984). Today, only some of these historic populations still persist: in the north of the Dingle peninsula, at Inch Peninsula and Roscullen Island, in the north of the Iveragh Peninsula and at Caherdaniel (Korky and Webb 1999, Beebee 2002) (see Fig. 1). Contemporary Irish natterjack populations are subject to restricted habitat availability and, based on historical records, appear to have undergone a severe range contraction (*e.g.* Castlemaine Harbour) (see maps Fig. 1). At a number of sites populations have become extinct, for example in the south-west of the Iveragh Peninsula (Ballycarbery, Coomakista and Caherdaniel) where it is suspected that the breeding habitat was destroyed following drainage of the land (Gresson and O'Dubhda 1974 Beebee 1984, 2002). In 1991, a breeding population of natterjacks was re-established at Caherdaniel, with the creation of two breeding ponds commissioned by the National Parks and Wildlife Service (NPWS) (Korky and Webb 1999, Beebee 2002). The toads were also introduced by the NPWS at the Raven Nature Reserve, Co Wexford, during the same year. Despite these measures, the future of the species at some sites is still uncertain, when one considers the human impacts on the existing habitat along with other natural pressures.

II. Threats

1. Habitat degradation

1.1 Restricted distribution and habitat fragmentation

In Ireland, a major cause for natterjack toad populations' decline appears to be habitat degradation (Gresson and O'Dubhda 1974 Beebee 1979, 1983, 2002; Denton *et al.* 1995, Bécart *et al.* in press). Habitat degradation is driven by factors such as changes in land use, industrial and housing developments, leisure activities, and plant succession following grazing abandonment. Many historically known breeding sites have disappeared since the 1800s (Castlemaine Harbour and south-west of the Iveragh Peninsula (see Fig. 1)), the most likely reason being the drainage of land (Gresson and O'Dubhda 1974 Beebee 1984, 2002), along with diverse forms of land development. Consequently, the number and availability of breeding ponds has reduced and concomitantly the natterjack populations at these sites have also declined, with some local populations becoming extinct. A direct consequence is the isolation of the remaining populations, notably at Fermoyle, Inch, Roscullen Island, Glenbeigh and Caherdaniel (see Fig. 1). The loss of breeding ponds along with reduced connectivity between populations (isolation) can increase the probability of local extinction (Rowe *et al.* 1999, Rowe *et al.* 2000; Scribner *et al.* 2001, Beebee 2002). Such local extinctions can occur via breeding failure and a reduction in genetic variability and gene flow. Rowe and Beebee (2005) showed that inbreeding had detrimental effects on *B. calamita* population viability in the U.K. Inbreeding effects can manifest as low fecundity, reduced juvenile survival and growth rates, and reduced individual survival to environmental stressors (Keller and Waller 2002, Rowe and Beebee 2005). In addition, the species is at the edge of its biogeographical range in Ireland, and natterjacks are completely isolated from the core population on the continent. Their dispersion is thus very limited. Consequently, risks of extinction due to stochastic demographic events, limited dispersal and environmental conditions are much more important (Holt and Keitt 2000, Fahrig 2002, Holt *et al.* 2005, Bahn *et al.* 2006). Also, these effects can be particularly detrimental within the Irish natterjack's range where populations are relatively isolated, *e.g.* populations in Fermoyle and Roscullen Island, and populations on the Iveragh Peninsula (Fahrig 2002, Bahn *et al.* 2006).

1.2 Changing land use

Natterjack toads usually breed in ephemeral ponds, but these are often subject to desiccation, compromising tadpole survival (Beebee 1979, Banks and Beebee 1988). Land use practices can seriously affect both the formation and permanency of the ponds. In dune systems, ponds form in slacks over the winter and after rainfall. These ponds are shallow and ideal for toad breeding, but have a very short hydroperiod. For instance, in the Maharees dune system (see Fig. 1), historically up to 25 ponds have been documented (Beebee 2002). Recently, fewer ponds have been forming, considerably reducing the availability of breeding habitat for natterjacks at this site (Bécart *et al.* in press). Annual precipitation has not declined in the last 30 years (European Climate Assessment and Dataset (ECAD), Valentia Observatory database, Aubry and Emmerson 2005) and local temperatures have not risen exceptionally (ECAD). Therefore, a recent change in climate is unlikely to explain the reduction in the number of ponds forming. A lowering of the water table through changes in water resource utilization could be a possible explanation (Beebee 2002, Bécart *et al.* 2006). Intense activity around the ponds can also increase the risk of early desiccation of ponds (Bridson 1978, Beebee 1979). The Maharees dune system is used as pasture for cattle and horses, which also use the ponds to drink. The daily water consumption by a cow can be as high as 40 litres (Irwin 1992, Bécart *et al.* 2006). Such water consumption rates might cause a significant reduction on the water levels in the pond, especially during dry periods, and when the number of ponds is reduced.

The presence of cattle within dune systems is, however, an important tool for sand dune grassland and natterjack conservation management. Grazing by livestock (*e.g.* cattle, horses and ponies), along with grazing by rabbits, regulates vegetation growth and limits grass encroachment and vegetation succession in dune systems (Kooijman and Van der Meulen 1996, Ten Harkel and Van der Meulen 1996, Olff and Ritchie 1998, Provoost *et al.* 2002, Hoffmann *et al.* 2005). Vegetation succession can also lead to unsuitable habitat for natterjack toads (terrestrial as well as aquatic) (Briggs 2004, Rannap 2004) and favour the establishment of other more competitive species (see below) (Beebee 1977, Beebee and Denton 1996, Denton *et al.* 1997). Moderate grazing by livestock can also help restore dune slacks and prevent a drop in the water table that occurs due to water consumption by encroaching scrub and tall grass species (Grootjans *et al.* 2002). Further study is, however, needed in Ireland to investigate (1) the impact of livestock on the water-holding capacity and hydroperiod of dune slacks, especially in the Maharees dune system; (2) the impact of livestock on the slacks' water quality; and (3) the direct impact of livestock on natterjacks' survival. Whilst moderate trampling seems to favour restoration of natural dune grassland species (Provoost *et al.* 2002, Hoffmann *et al.* 2005), trampling and organic enrichment caused by livestock in natterjack ponds can severely reduce the survival of aquatic and terrestrial early life stages of the toads (Bridson 1978). Livestock grazing is widely recognized as the best management measure for both sand-dune grassland and natterjack toad habitats. However, it is important that such management measures are carefully monitored and regulated, and maintained at sustainable levels (Beebee and Denton 1996, Denton *et al.* 1997, Olff and Ritchie 1998).

1.3 Competitive species encroachment

Competitively aggressive species can colonize areas after habitat modifications (see examples in Alford and Richards 1999, and Gardner 2001), and in the process competitively exclude existing species. In some parts of Britain, the common toad competitively excludes natterjack toads especially after changes in land use practice (Beebee 1977). In Ireland, the common toad is not present. However, the common frog, which shares some of the natterjack toad's habitat, could be a potential competitor. Both species share similar feeding resources at the larval stage (Griffiths 1991, Griffiths *et al.* 1991, Bardsley and Beebee 2001). Common frogs breed earlier in the season, and when the two species' life history stages overlap, frog tadpoles are in an advanced stage of development when natterjack tadpoles hatch (Griffiths 1991, Griffiths *et al.* 1991, Beebee and Denton 1996, Bardsley and Beebee 2001). At that stage frog tadpoles have a competitive advantage over the smaller toad tadpoles. It has already been shown that in the presence of the common frog, both the growth and survival rates of natterjack tadpoles are reduced, as well as their size at metamorphosis (Griffiths 1991, Griffiths *et al.* 1991, Bardsley and Beebee 2001). Both direct and indirect interference mechanisms can be the source of such inhibition: the former via competition in the exploitation of the food resource, the latter via release of growth inhibitor (*e.g. Anurofeca richardsi*) by larger frog tadpoles (Griffiths 1991, Griffiths *et al.* 1991, Griffiths *et al.* 1993, Griffiths and Foster 1998, Bardsley and Beebee 2001). In addition, frog tadpoles may behave as predators of natterjack eggs and larvae (Beebee 1979, Banks and Beebee 1987). Whilst natterjacks are found mainly in open habitats, common frogs are found in later vegetation stages, where scrubs and trees dominate (Marnell 1998). The alteration of natterjacks' habitat through vegetation encroachment can thus lead to an increase in the number of common frogs and be detrimental to natterjack toads, not only because suitable habitat is lost, but also because competition pressure at early life stages might strongly reduce the survival of natterjacks at those sites (Griffiths 1991, Denton *et al.* 1997, Bardsley and Beebee 2001).

2. Diseases

Considerable interest is being focussed on the role of emerging infectious diseases (EIDs) in the decline of amphibian populations. These are diseases whose incidence has increased, or whose distribution has expanded (geographically or to new host populations). These spreading diseases may have developed new levels of pathogenicity, or simply, they may have only recently spread to new areas (Daszak *et al.* 2001). In particular, a chytridomycete fungus (*Batrachochytrium dendrobatidis*) was found to be the cause of amphibian population declines in pristine regions of Australia and Central America (Daszak *et al.* 2001, Gardner 2001). This chytridomycete is still expanding its range, and has caused dramatic die-offs in several amphibian species all over the world (Daszak *et al.* 2001, Gardner 2001). The chytridomycete fungus has not yet been recorded in Ireland, but these EIDs are of particular concern as they have rapidly appeared and spread to previously uninfected populations (often following anthropogenic activities, see Daszak *et al.* 2001).

Other species of fungi (*e.g. Saprolegnia* sp) are less virulent, but nonetheless affect amphibian populations, and can be a threat to their long-term survival (Kiesecker and Blaustein 1997, Gardner 2001). *Saprolegnia* sp has been recorded from natterjack populations in Britain (Beebee 1979, 1983; Banks and Beebee 1988). *Saprolegnia* is a fish pathogen and its transmission to amphibians mainly occurs at low temperature and low pH (Banks and Beebee 1988, Kiesecker and Blaustein 1997). The fungus' transmission is facilitated when eggs are laid *en masse* in a spawning aggregation. The fungal hyphae grow and spread by direct contact, and produce free-swimming zoospores, which can then colonize other egg masses (Kiesecker and Blaustein 1997). In Ireland, egg strings deposited early in the breeding season, when temperatures are still low, were occasionally surrounded by white fungal hyphae (pers. obs.). It is commonly believed that this fungus belongs to the *Saprolegnia* genus (Beebee 1983), although we have no evidence to support this hypothesis. Further studies are needed to investigate the nature of this fungus and its impact on natterjack survival in Ireland.

3. Pollution

3.1 Pollutants

Pollutants such as industrial chemicals, heavy metals, pesticides, herbicides, fungicides and fertilizers are known to have negative effects on amphibian populations (Rouse *et al.* 1999, Gardner 2001, Blaustein and Kiesecker 2002, Blaustein *et al.* 2003). Amphibians have a moist, permeable skin and unshelled eggs. Therefore, such pollutants are easily absorbed. In Ireland, most breeding ponds are located on farmland or golf courses, and consequently, it is likely that natterjack toads are affected by chemical contaminants. Nitrogen-based compounds (such as ammonium nitrate, which is commonly used as fertilizer) were reported to affect amphibians at various concentrations and at different life history stages, *e.g.* such compounds can alter the feeding behaviour of amphibian larvae and adults, disturb tadpole swimming behaviour, slow down tadpole development, reduce the size at metamophosis, and increase the occurrence of physical malformations (Rouse *et al.* 1999, Hamer *et al.* 2004, Ortiz *et al.* 2004). Oldham *et al.* (1997) shown that ammonium nitrate was highly toxic to adult common frogs (even at concentrations less than the recommended field dosages, both in the lab and under field conditions). Ortiz *et al.* (2004) studied the effect of a range of ammonium nitrate concentrations on six European amphibian species, including natterjack toads. At the conclusion of a 15 day experiment, these authors did not observe any particular effect on natterjack tadpole mortality, but did observe significantly higher abnormality rates and smaller size of tadpoles at high concentrations of ammonium nitrate (200mg $NO_3^- l^{-1}$). Such nitrate concentrations are far above the concentrations found in the field (the maximum is set at 50mg l^{-1} for surface and ground waters, in accordance with the Nitrates Directive (91/676/EEC)). However, under field conditions, it is very likely that ammonium nitrate can have an effect on the species when eggs and tadpoles are more frequently or continuously exposed to the chemical in enriched pond water (via field fertilization as well as continuous livestock input). Several authors have also showed evidence of endocrine effects of some chemicals on amphibians (Carey and Bryant 1995, Guillette and Edwards 2005). These studies show that the effects appear to be dose-dependent and cumulative over time. Investigation should be carried out to better assess (1) the actual levels of nitrates and occurrence of other pollutants in Irish natterjack breeding ponds, and (2) the impact of such chemicals in field conditions throughout natterjack development and at adulthood, in particular when other factors could be interacting (Rouse *et al.* 1999, Hatch and Blaustein 2000, Blaustein *et al.* 2003, Ortiz *et al.* 2004).

3.2 UV-B radiation

The depletion of the ozone layer by chlorofluorocarbons and other anthropogenically produced chemicals, leading to an increase in UV-B radiation at the Earth surface, has been widely recognized as a potential threat to amphibian populations (Alford and Richards 1999, Gardner 2001, Blaustein and Kiesecker 2002, Blaustein *et al.* 2003). UV-B radiation (280-

315nm wavelengths) causes mutation and cell death, slower growth rates, and may lead to dysfunction of the immune system. Exposure of amphibian eggs and larvae to UV-B radiation was shown to be lethal or sub-lethal, altering behaviour, slowing down growth and development, or inducing various kinds of malformations at various stages of the life cycle (Blaustein and Kiesecker 2002, Blaustein and Belden 2003, Blaustein *et al.* 2003). A study by Lizana and Pedraza (1998) in a mountainous area of Central Spain, showed that natterjack toads were resistant to UV-B radiation. Such resistance could be due to an adaptation of the species to breeding in shallow water, where UV-B radiation can be lethal (Lizana 1998, Blaustein and Belden 2003, Blaustein *et al.* 2003). However, a species exposed to a range of different conditions (*e.g.* weather, water chemistry and geographical location) can show differential responses to UV-B (Blaustein and Belden 2003, Blaustein *et al.* 2003). Climatic conditions in northern Spain and Ireland are different and Irish natterjacks may be more vulnerable to solar radiation than Spanish natterjacks, especially as recent genetic studies show that the two populations are not closely related (Beebee and Rowe 2000, Rowe *et al.* 2006). Effects of UV-B radiation on amphibian populations are complex and their impact is highly dependent on other environmental factors (*e.g.* nitrates and other pollutants) and environmental conditions (*e.g.* pH) (Hatch and Blaustein 2000, Blaustein and Kiesecker 2002, Blaustein and Belden 2003, Blaustein *et al.* 2003). Further study needs to be carried out to better understand the impacts, if any, of UV-B on natterjack toad populations in Ireland.

III. Conclusion

The natterjack toad is native to Ireland and has been known in Co Kerry for over two centuries. Although its distribution in Ireland may have declined considerably during the first half of the 20th century, it seems to have remained relatively stable in recent decades (Beebee 2002, Bécart *et al.* in press). Measures such as re-introductions, site improvements and pond creation have been taking place, with the support of the National Parks and Wildlife Service (NPWS) and the Heritage Council (Shaw 2006), to promote the species in its Irish range and prevent further decline. Toad breeding sites are designated as SACs and conservation management actions are being implemented and enforced by the NPWS. However, drainage of land for pasture and various developments (retail, housing and golf courses) are still a major threat to natterjack populations in the country (Gresson and O'Dubhda 1974, Beebee 2002, Bécart *et al.* in press), which might lead to further habitat loss and fragmentation. Populations in Ireland are at the north-western limit of the toad's geographical range, and thus population expansion is limited and isolation risks are amplified. It is, therefore, important that further measures are implemented to ensure the viability of the species in Co Kerry, especially in the face of continued economic development.

As with many other species, natterjack toads in Ireland are experiencing pressures from a number of environmental stressors, either natural or human-induced (*e.g.* temperature, pH, fungal infection, pollutants, UV-B radiation). These factors sometimes interact in synergy and have affected the survival of amphibian populations around the world. We report how such factors could affect natterjack toads in Ireland. Further investigations are now needed to better understand the extent and reality of such threats in an Irish context and provide a better assessment of the long-term viability of natterjack populations in the country. To better assess the current conservation status of the species, recent studies have been carried out using a combination of historical data and information on the species conservation requirements (see Beebee 2002). The National Parks and Wildlife Service and the Irish Research Council for Science Engineering and Technology have recently funded a three-year monitoring programme at all known toad breeding sites in Co Kerry. These projects provide a better understanding of the species' population dynamics in its Irish habitat, as well as a solid base for future investigations to further understand and assess the species' conservation status.

Acknowledgements

We would like to thank Ferdia Marnell and Deirdre Lynn, from National Parks and Wildlife Service, for their support, valuable advice and comments, also the reviewers of the manuscript and the Herpetological Conservation Trust and English Nature for their assistance.

References

ALFORD, R. A. & RICHARDS, S. J. (1999) Global amphibian declines: a problem in applied ecology. *Annual Reviews of Ecological Systems* **30**: 133-165.

ALFORD, R. A., DIXON, P. M. & PECHMANN, J. H. K. (2001) Ecology - global amphibian population declines. *Nature* **412**: 499-500.

AUBRY, A. & EMMERSON, M. C. (2005) *Monitoring of natterjack toad (*Bufo calamita*) in Ireland - Breeding season 2004.* Unpublished report to the National Parks and Wildlife Service. National Parks & Wildlife Service, Dublin.

BAHN, V., O'CONNOR, R. J. & KROHN, W. B. (2006) Effect of dispersal at range edges on the structure of species ranges. *Oikos* **115**: 89-96.

BANKS, B. & BEEBEE, T. J. C. (1987) Factors influencing breeding site choice by the pioneering amphibian *Bufo calamita. Ecography* **10**: 14-21.

BANKS, B. & BEEBEE, T. J. C. (1988) Reproductive success of natterjack toad *Bufo calamita* in two contrasting habitats. *Journal of Animal Ecology* **57**(2): 475-492.

BARDSLEY, L. & BEEBEE, T. J. C. (2001) Strength and mechanisms of competition between common and endangered anurans. *Ecological Applications* **11**(2): 453-463.

BECART, E., AUBRY, A. & EMMERSON, M. C. (2006) *Monitoring of natterjack toad (*Bufo calamita*) in Ireland - breeding season 2005.* Unpublished report to National Parks and Wildlife Service. National Parks & Wildlife Service, Dublin.

BECART, E., AUBRY, A. & EMMERSON, M. C. (in press) Monitoring and conservation assessment of natterjack toad (*Bufo calamita*) in Ireland, breeding season 2004, 2005 and 2006. *Irish Wildlife Manuals.* National Parks & Wildlife Service, Dublin.

BEEBEE, T. J. C. (1977) Environmental change as a cause of natterjack toad (*Bufo calamita*) declines in Britain. *Biological Conservation* **11**(2): 87-102.

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. (1983) *The natterjack toad.* Oxford University Press, Oxford.

BEEBEE, T. J. C. (1984) Possible origins of Irish natterjack toads (*Bufo calamita*). *British Journal of Herpetology* **6**: 398-402.

BEEBEE, T. J. C. (2002) The natterjack toad *Bufo calamita* in Ireland: current status and conservation requirements. *Irish Wildlife Manuals* **10**. National Parks and Wildlife Service, Dublin. On line at: http://www.npws.ie/media/Media,3754,en.pdf. Accessed March 2005.

BEEBEE, T. J. C. & DENTON, J. (1996) *The natterjack toad - conservation handbook.* English Nature, Peterborough.

BEEBEE, T. J. C. & ROWE, G. (2000) Microsatellite analysis of natterjack toad *Bufo calamita* Laurenti populations: consequences of dispersal from a Pleistocene refugium. *Biological Journal of the Linnean Society* **69**(3): 367-381.

BLAUSTEIN, A. R. & KIESECKER, J. M. (2002) Complexity in conservation: lessons from the global decline of amphibian populations. *Ecology Letters* **5**(4): 597-608.

BLAUSTEIN, A. R. & BELDEN, L. K. (2003) Amphibian defences against ultraviolet-B radiation. *Evolution & Development* **5**(1): 89-97.

BLAUSTEIN, A. R., ROMANSIC, J. M., KIESECKER, J. M. & HATCH, A. C. (2003) Ultraviolet radiation, toxic chemicals and amphibian population declines. *Diversity & Distributions* **9**(2): 123-140.

BRIDSON, R. H. (1978) A preliminary investigation into the factors affecting success of natterjack toad (*Bufo calamita*) at Caerlaverock National Nature Reserve. *Report to Nature Conservancy Council, South West (Scotland) Region.*

BRIGGS, L. (2004) Restoration of breeding sites for threatened toads on coastal meadows. In *Coastal meadow management - best practice guidelines*. Ministry of the Environment of the Republic of Estonia, Tallinn, Estonia.

CAREY, C. & BRYANT, C. J. (1995) Possible interrelations among environmental toxicants, amphibian development, and decline of amphibian populations. *Environmental Health Perspectives* **103**(4): 13-17.

DASZAK, P., CUNNIGHAM, A. A. & HYATT, A. D. (2001) Anthropogenic environmental change and the emergence of infectious diseases in wildlife. *Acta Tropica* **78**(2): 103-116.

DENTON, J. S., HITCHINGS, S. P. & BEEBEE, T. J. C. (1995) Natterjack toad – Species recovery programme project 1992-1995. Unpublished *English Nature research report*. English Nature, Peterborough.

DENTON, J. S., HITCHINGS, S. P., BEEBEE, T. J. C. & GENT, A. (1997) A recovery program for the natterjack toad (*Bufo calamita*) in Britain. *Conservation Biology* **11**(6): 1329-1338.

ECA&D. European Climate Assessment and Dataset. Online at http://eca.knmi.nl. Accessed 3 March 2005.

FAHRIG, L. (2002) Effect of habitat fragmentation on the extinction threshold: a synthesis. *Ecological Applications* **12**(2): 346-353.

GARDNER, T. (2001) Declining amphibian populations: a global phenomenon in conservation biology. *Animal Biodiversity and Conservation* **24**(2): 25-44.

GLEED-OWEN, C. P., MARNELL, F., MONAGHAN, N. T. & KORKY, J. K. (1999) Origins of the natterjack toad *Bufo calamita* Laurenti in Ireland: re-examination of subfossil bones from Carrowmore, Co Sligo. *Bulletin of the Irish Biogeographical Society* **23**: 53-59.

GRESSON, R. A. R. & O'DUBHDA, S. (1974) The distribution of the natterjack toad, *Bufo calamita* Laur, in County Kerry. *The Irish Naturalists' Journal* **18**(4): 97-103.

GRIFFITHS, R. A. (1991) Competition between common frog, *Rana temporaria*, and natterjack toad, *Bufo calamita*, tadpoles: the effect of competitor density and interaction level on tadpole development. *Oikos* **61**(2): 187-196.

GRIFFITHS, R. A. (1997) Temporary ponds as amphibian habitats. *Aquatic Conservation: Marine and Freshwater Ecosystems* **7**: 119-126.

GRIFFITHS, R. A. & FOSTER, J. P. (1998) The effect of social interactions on tadpole activity and growth in the British anuran amphibians (*Bufo bufo*, *B. calamita*, and *Rana temporaria*). *Journal of Zoology, London* **245**: 431-437.

GRIFFITHS, R. A., EDGAR, P. W. & WONG, A. L. C. (1991) Interspecific competition in tadpoles: growth inhibition and growth retrieval in natterjack toads, *Bufo calamita*. *Journal of Animal Ecology* **60**(3): 1065-1076.

GRIFFITHS, R. A., DENTON, J. & WONG, A. L. C. (1993) The effect of food level on competition in tadpoles: interference mediated by protothecan algae? *Journal of Animal Ecology* **62**: 274-279.

GROOTJANS, A. P., GEELEN, H. W. T., JANSEN, A. J. M. & LAMMERTS, E. J. (2002) Restoration of coastal dune slacks in the Netherlands. *Hydrobiologia* **478**(1): 181-203.

GUILLETTE, L. J. J. & EDWARDS, T. M. (2005) Is nitrate an ecologically relevant endocrine disruptor in vertebrates? *Integrative and Comparative Biology* **45**(1): 19-27.

HAMER, A. J., MAKINGS, J. I. A., LANE, S. J. & MAHONY, M. J. (2004) Amphibian decline and fertilizers used on agricultural land in south-eastern Australia. *Agriculture, Ecosystems & Environment* **102**(3): 299-305.

HATCH, A. C. & BLAUSTEIN, A. R. (2000) Combined effects of UV-B, nitrate, and low pH reduce the survival and activity level of larval cascades frogs (*Rana cascadae*). *Archives of Environmental Contamination and Toxicology* **39**(4): 494-499.

HOFFMANN, M., COSYNS, E. & LAMOOT, I. (2005) Large herbivores in coastal dune management: do grazers do what they are supposed to do? In Herrier, J-L. *et al.* (eds) *Proceedings 'Dunes and estuaries 2005' - International conference on nature restoration practices in European coastal habitats. VLIZ Special Publication* **19**: 249-267. Koksijde, Belgium.

HOLT, R. D. & KEITT, T. H. (2000) Alternative causes for range limits: a metapopulation perspective. *Ecology Letters* **3**: 41-47.

HOLT, R. D., KEITT, T. H., LEWIS, M. A., MAURER, B. A. & TAPER, M. L. (2005) Theoretical models of species' borders: single species approaches. *Oikos* **108**: 18-27.

HOULAHAN, J. E., FINDLAY, C. S., SCHMIDT, B. R., MEYER, A. H. & KUZMIN S. L. (2000) Quantitative evidence for global amphibian declines. *Nature* **404**: 752-755.

IRWIN, R. W. (1992) Water requirements of livestock. Ministry of Agriculture, Food & Rural Affairs. Ontario, Canada. Online at: http://www.omafra.gov.on.ca/english/engineer/facts/86-053.htm. Accessed 25 November 2005.

IUCN, Conservation International, and NatureServe (2006) *Global Amphibian Assessment.* Bufo calamita – *Natterjack toad*. On line at: www.globalamphibians.org. Accessed on 14 December 2006.

KELLER, L. F. & WALLER, D. M. (2002) Inbreeding effects in wild populations. *Trends in Ecology and Evolution* **17**(5): 230-241.

KIESECKER, J. M. & BLAUSTEIN, A. R. (1997) Influences of egg laying behavior on pathogenic infection of amphibian eggs. *Conservation Biology* **11**(1): 214-220.

KOOIJMAN, A. M. & VAN DER MEULEN, F. (1996) Grazing as a control against 'grass-encroachment' in dry dune grasslands in the Netherlands. *Landscape and Urban Planning* **34**(3-4): 323-333.

KORKY, J. K. & WEBB, R. G. (1999) Resurvey, biogeography and conservation of the natterjack toad *Bufo calamita* Laurenti (Anura: Bufonidae) in the Republic of Ireland. *Bulletin of the Irish Biogeographical Society* **23**: 2-52.

LIZANA, M. & PEDRAZA, E.M. (1998) The effects of UV-B radiation on toad mortality in mountainous areas of Central Spain. *Conservation Biology* **12**(3): 703-707.

MARNELL, F. (1998) Discriminant analysis of the terrestrial and aquatic habitat determinants of the smooth newt (*Triturus vulgaris*) and the common frog (*Rana temporaria*) in Ireland. *Journal of Zoology, London* **244**: 1-6.

OLDHAM, R. S., LATHAM, D. M., HILTON-BROWN, D., TOWNS, M., COOKE, A. S. & BURN, A. (1997) The effect of ammonium nitrate fertiliser on frog (*Rana temporaria*) survival. *Agriculture, Ecosystems & Environment* **61**(1): 69-74.

OLFF, H. & RITCHIE, M. E. (1998) Effects of herbivores on grassland plant diversity. *Trends in Ecology and Evolution* **13**(7): 261-265.

ORTIZ, M. E., MARCO, A., SAIZ, N. & LIZANA, M. (2004) Impact of ammonium nitrate on growth and survival of six European amphibians. *Archives of Environmental Contamination and Toxicology* **47**(2): 234-239.

PROVOOST, S., AMPE, C., BONTE, D., COSYNS, E. & HOFFMANN, M. (2002) Ecology, management and monitoring of dune grassland in Flanders, Belgium. Littoral 2002, the changing coast. In Gomes, F. V. *et al.* (eds) *EUROCOAST, European coastal association for science and technology*. Online at: http://www.io-warnemuende.de/homepages/schernewski/Littoral2000/docs/vol2/Littoral2002_02.pdf. Accessed 9 January 2007.

RANNAP, R. (2004) Boreal Baltic coastal meadow management for *Bufo calamita*. In *Coastal meadow management - best practice guidelines*. Ministry of the Environment of the Republic of Estonia, Tallinn, Estonia.

ROUSE, J. D., BISHOP, C. A. & STRUGER, J. (1999) Nitrogen pollution: an assessment of its threat to amphibian survival. *Environmental Health Perspectives* **107**(10): 799-803.

ROWE, G. & BEEBEE, T. J. C. (2005) Intraspecific competition disadvantages inbred natterjack toad (*Bufo calamita*) genotypes over outbred ones in a shared pond environment. *Journal of Animal Ecology* **74**(1): 71-76.

ROWE, G., BEEBEE, T. J. C. & BURKE, T. (1999) Microsatellite heterozygosity, fitness and demography in natterjack toads *Bufo calamita*. *Animal Conservation* **2**(2): 85-92.

ROWE, G., BEEBEE, T. J. C. & BURKE, T. (2000) A microsatellite analysis of natterjack toad, *Bufo calamita*, metapopulations. *Oikos* **88**(3): 641-651.

ROWE, G., HARRIS, D. J. & BEEBEE, T. J. C. (2006) Lusitania revisited: A phylogeographic analysis of the natterjack toad *Bufo calamita* across its entire biogeographical range. *Molecular Phylogenetics and Evolution* **39**(2): 335-346.

SCRIBNER, K. T., ARNTZEN, J. W., CRUDDACE, N., OLDHAM, R. S. & BURKE, T. (2001) Environmental correlates of toad abundance and population genetic diversity. *Biological Conservation* **98**: 201-210.

SHAW, W. (2006) *Conservation of natterjack toad (*Bufo calamita*) breeding habitats in County Kerry, Ireland.* The Herpetological Conservation Trust, Bournemouth.

TEN HARKEL, M. J. & VAN DER MEULEN, F. (1996) Impact of grazing and atmospheric nitrogen deposition on the vegetation of dry coastal dune grasslands. *Journal of Vegetation Science* **7**(3): 445-452.