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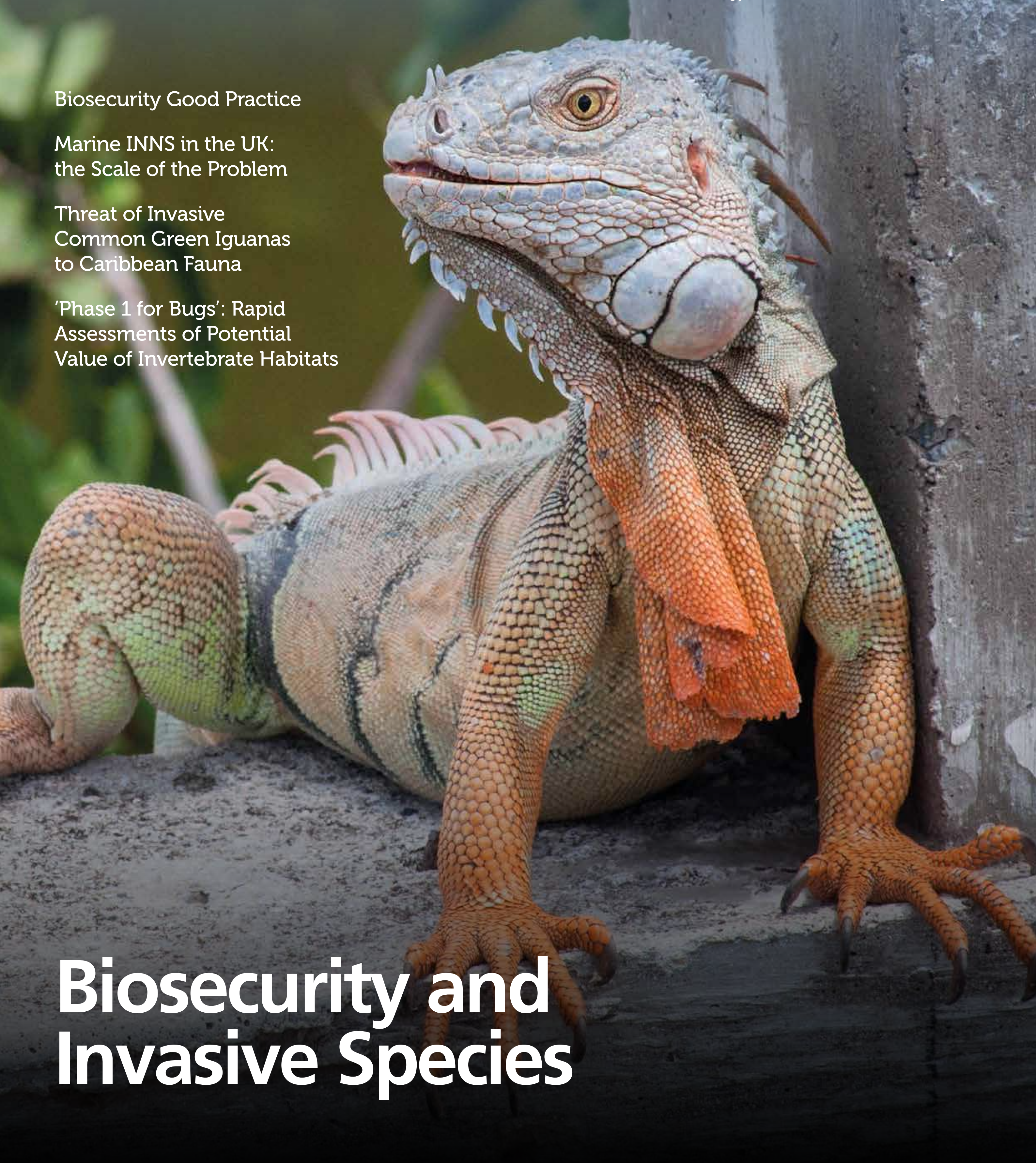

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Biosecurity and Invasive Species

Invasive Signal Crayfish in the UK: Survey Methods to Inform Evidence-based Management

Dan Chadwick
ACIEEM
PBA Applied Ecology

Lawrence Eagle
ACIEEM
PBA Applied Ecology

Eleri Pritchard
University College London

Carl Sayer
University College London

Michael Chadwick
King's College London

Jan Axmacher
University College London

Paul Bradley
MCIEEM
PBA Applied Ecology

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With invasive crayfish becoming increasingly widespread, evidence-based management is crucial to protect freshwater ecosystems. Knowledge of the structure and function of invasive crayfish populations allows for an effective evaluation of management efforts. Recent methodological developments have enabled the first truly quantitative studies of UK invasive crayfish populations in the field. This was achieved by the triple drawdown (TDD) survey approach. In this article, we explore current survey approaches and their limitations, and we introduce the TDD method with its implications for crayfish survey, policy development and management.

Introduction

Crayfish are among the most widespread and damaging freshwater invaders (Twardochleb *et al.* 2013).

Seven species of non-native invasive crayfish are already present in the UK (Ellis 2014), of which three (signal crayfish *Pacifastacus leniusculus*, red swamp crayfish *Procambarus clarkii* and spiny-cheek crayfish *Orconectes limosus*) are currently listed under Schedule 2, Part 1 of the Invasive Alien Species (Enforcement and Permitting) Order 2019. This highlights the significant concern of UK policymakers and environmental practitioners regarding the threat posed to freshwater ecosystems by invasive crayfish. The most widespread invasive crayfish, the signal crayfish, is now present across most of the UK, with the current, notable exception of Northern Ireland.

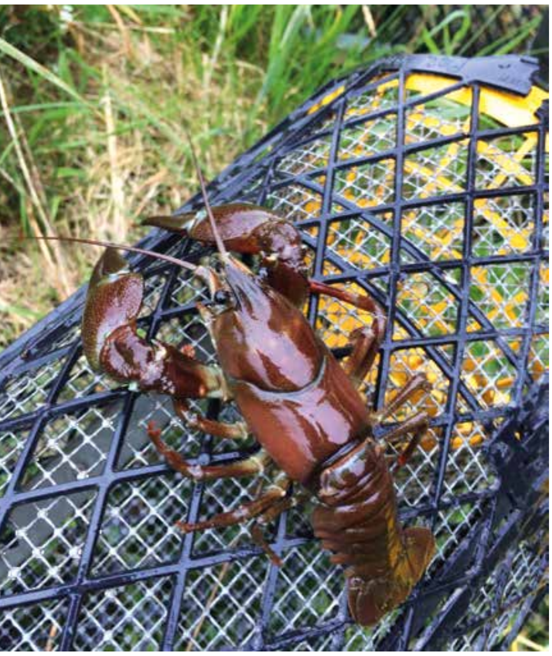

Figure 1. Large male signal crayfish retrieved from a modified (5 mm mesh) baited funnel trap. Photo: Eleri Pritchard.

Signal crayfish in the UK

Introduced in the 1970s in an attempt to establish a new aquaculture industry, the signal crayfish has spread rapidly across the UK by both accidental and intentional means. Its capacity to persist in diverse environmental conditions, a generalist diet and high fecundity make the signal crayfish an extremely effective freshwater invader. It outcompetes the UK's only native crayfish, the white-clawed crayfish (*Austropotamobius pallipes*) and acts as a vector of crayfish plague (*Aphanomyces astaci*), which is fatal to the former (Dunn *et al.* 2009). Signal crayfish invasions have been linked to negative impacts on fish and macroinvertebrate communities (Mathers *et al.* 2016, Galib *et al.* 2021). Burrowing activity further impacts freshwater ecosystems through bank erosion and fine sediment mobilisation (Sanders *et al.* 2021). Despite these negative impacts, their widespread distribution and decades of research, delivery of effective management has remained challenging. We believe that strong limitations and biases of current survey techniques are contributing factors in this respect.

Crayfish survey and management

Different crayfish survey techniques are available to practitioners. Perhaps the most commonly employed methods in the UK are baited funnel traps (Figure 1) and manual searches, which together form the UK Common Standards Monitoring (CSM) methodology for native crayfish survey (Bradley *et al.* 2015). Artificial refuge traps (ARTs), formed by a series of tubes that mimic natural refugia, are also increasingly used for surveys despite taking longer to deploy (Green *et al.* 2018). These sampling techniques can confirm presence and provide semi-quantitative estimates of relative abundance through catch-per-unit effort (CPUE). Environmental DNA (eDNA) is a recently developed technique capable of detecting the presence of both invasive and native crayfish (Chucholl *et al.* 2021). However, additional testing of eDNA is ongoing to determine detection limits and the technique's ability to quantify relative crayfish abundances.

Alongside practical considerations such as water body depth, bedform and access limitations, the information required on a crayfish population determines the most appropriate survey method. When confirming presence only, the main limitation of a method is its probability of failing to detect a crayfish population. Detection probability is largely controlled by the capture efficiency of a method, its appropriate application and the target population's demographics. For example, undertaking manual searches in turbid conditions severely limits the possibility of crayfish detection, an issue exacerbated when surveying low-density populations. Similarly, because trapping tends to select for large adults, it may fail to detect populations dominated by smaller size classes. ARTs capture a wider range of size classes and may therefore prove more suitable in these situations (Green *et al.* 2018). When precise spatial data are required, manual searches or ARTs may be more appropriate than eDNA given the remaining uncertainty over DNA degradation, dilution and dispersal (Cowart *et al.* 2018, Troth *et al.* 2021). In turn, eDNA is likely better suited to rapid catchment-scale surveys than other techniques. While not a limitation of the data itself, biosecurity and impacts on non-target species are also key considerations for method selection. The risks associated with bycatch and transferring invasive species and pathogens increase directly with the number of interactions between watercourses, surveyors and equipment. In this context, methods employing single-use consumables such as eDNA greatly reduce risk compared to traditional survey techniques.

The limitations associated with current survey techniques become increasingly apparent when more detailed demographic data are required. Questions of biomass, density, size class distribution and recruitment cannot be adequately addressed through the aforementioned survey methods. This information is nonetheless crucial for the effective management of invasive crayfish. Juvenile and adult crayfish have distinct dietary and habitat preferences, and accurately recording the density and relative proportions of size classes is therefore key to understanding and predicting ecological impacts.

Management of invasive crayfish is arguably the most data-dependent process, with detailed knowledge of the response of a target population to intervention representing the key to delivering impactful and cost-effective outcomes. There are currently no fully effective methods for the eradication or control of invasive crayfish. Perhaps the most widely tested is intensive trapping, which has been trialled with limited success in both lotic and lentic systems (e.g. Stebbing *et al.* 2014, Krieg *et al.* 2020). Many additional methods have been trialled, including the use of chemicals, habitat destruction and release of sterilised males (Manfrin *et al.* 2019, Peay *et al.* 2019). However, issues with cost, sustainability, species specificity and efficacy can render these options undesirable or impractical. A combination of techniques has been recommended to increase the efficiency of control (Hein *et al.* 2006), for example trapping and netting (García-de-Lomas *et al.* 2020). The limitations of the data generated from survey methods, as discussed, can in some instances also prevent meaningful assessments of the outcomes of management. With these considerations in mind, we developed the novel triple drawdown and tested it against CSM approaches with the aim of generating quantitative data on crayfish populations in the field (Box 1).

Box 1. The triple drawdown method

The triple drawdown (TDD) method was designed to sample crayfish of all sizes in their natural habitat. A waterbody section is completely isolated and drained, typically by use of nets, temporary dams and petrol-driven pumps. All potential refugia such as cobbles and woody debris are then removed (Figure 2). Crayfish are left exposed, allowing them to be easily collected by hand or with small nets. When no more crayfish are found, the site is allowed to re-wet, enticing any remaining animals out of refuges. The site is drained once again, and newly exposed animals are collected. This process continues for at least three 'sweeps' and until a decreasing return of crayfish is observed. Calculations can be made using the exact maximum likelihood method based on sweep depletion values to estimate the total number of crayfish present (e.g. Carle and Strub fisheries approach). In turn, this can be used to generate crayfish density values (total number of crayfish/site area) and to evaluate the efficiency of the method (captured crayfish/ total estimated crayfish). The TDD method was first tested at three sites (≈20 m in length) along a rocky headwater stream in North Yorkshire (full details in the open access publication Chadwick *et al.* 2021). Here, signal crayfish had established a thriving population following illegal introduction in the 1990s.

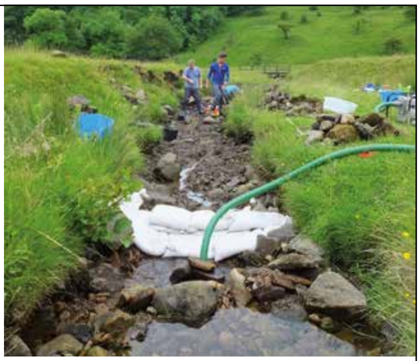

Figure 2. Operatives removing refuges during the first sweep of a triple drawdown in a small rocky headwater stream, North Yorkshire. Photo: Eleri Pritchard.

The TDD proved effective in sampling over 90% of the estimated total signal crayfish population as determined by depletion analyses. Densities of up to 110 crayfish per square metre were recorded, far exceeding all previous estimates for the UK. These hyper-dense populations were dominated by juvenile cohorts, with fewer than 2.5% of individuals large enough to be caught in standard traps. Furthermore, small females (<25 mm carapace length) were found carrying eggs during the TDDs, affirming that crayfish can become sexually mature before reaching 'trappable' size. When compared to trapping and manual search surveys, which were also undertaken prior to the TDDs, the TDD was found to be the only approach to provide consistent and reliable demographic data capturing all size classes (Chadwick *et al.* 2021).

Survey potential and limitations of TDD

The TDD captured crayfish across the full range of size classes and provided accurate density estimates, likely the first fully quantitative crayfish survey generated in the UK. In theory, the TDD could be adapted to operate in various freshwater systems. Dewatering requires a team of skilled operatives and pumping equipment. Therefore, available resources, site specifications (e.g. landowner permission, accessibility and size of water body) and environmental parameters (e.g. water flow or volume and substrate type) are key considerations when assessing feasibility. TDDs should ordinarily be completed during the in-river working window following appropriate permissions from regulatory bodies. Consideration should also be given to the welfare of non-target organisms, as dewatering could potentially have negative impacts on various local flora and fauna. Precautions such as localised fish rescues should be taken to minimise impact, and prolonged dewatering should be avoided by increasing the number of operatives and/or sweeps. At the end of a TDD, all substrate should be carefully returned to the waterbody with the aim of returning a site to how it was. Once complete, biosecurity (at a minimum compliant with Defra's Check, Clean, Dry) should be undertaken, due to the risk of invasive species and disease transfer via survey equipment.

The TDD performed particularly well in the headwater study system, with relatively small sites (15–30 m^2), low summer flows and no fish mortalities observed at sites where present. The TDD is therefore highly suited to small rocky streams with lots of natural in-channel refuges. Testing the TDD in other sites, including small stillwaters and larger rivers, is important to help define the limitations of the method, such as the cost and effort required and non-target selectivity. Until then, we would recommend that the TDD is used to provide, where required, detailed demographic data, to further evaluate current survey approaches or to 'ground-truth' the development of new approaches.

Implications for management

The ability of the TDD to generate comprehensive data on crayfish population demographics provides opportunities to inform management approaches. For example, given the dominance of smaller animals at our study sites (Figure 3), including sexually mature females too small to be caught in traps, it is clear that undertaking trapping

Figure 3. Demographics of invasive signal crayfish populations from a triple drawdown in an upland rocky headwater stream in North Yorkshire, showing the dominance of smaller (<25 mm carapace length) crayfish individuals within the population. Photo: Eleri Pritchard.

for management at our site would fail. It stands to reason that trapping for crayfish control purposes would therefore be ineffective at all other sites where population size structure, density and biomass are dominated by 'non-trappable' individuals.

The TDD can be used to evaluate the success of management interventions, by undertaking TDDs using a before/after control/impact approach. Such an approach allows for the quantification of reductions in crayfish density and biomass, and would identify how interventions impact different size classes. In the past, a decline in trappable CPUE has been used to evaluate management success (e.g. Hein *et al.* 2006). However, increased awareness of the limitations of trapping suggests that a decline in such a metric may not represent a meaningful population-level response. The ability to reliably evaluate management efforts will lead to better-informed policy and management decision-making.

As quantitative survey methods such as the TDD are developed, and evidence builds for techniques such as ARTs and eDNA, practitioners can have greater confidence in the outcomes of future surveys and management. However, prevention remains the most important element to control the spread of invasive crayfish. Best practice and thorough biosecurity are vital when working directly with invasive species and more generally in catchments where invasion is possible, and it should be promoted between all users of the UK's freshwaters.

Conclusions

Effective surveys of UK crayfish populations are crucial for practitioners managing invaded sites. While existing techniques often provide expedient means for confirming presence, approaches need to be developed and tested that enable greater insight into crayfish ecology in our waterbodies. Only then can targeted management be evaluated and refined, with evidence-based research leading effective decision-making. While reliable quantitative methods such as the TDD will not replace contemporary approaches to survey and control, they facilitate the development of applied knowledge due to the high quality of data produced. With invasive crayfish continuing to spread and their impacts on freshwaters becoming better understood, there has never been a more important time to develop evidence-based crayfish policy development and management in the UK.

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Note

Working with Crayfish: Survey Methods, Ecology, Mitigation, Licencing and Invasive Species is a CIEEM course run by Paul Bradley and Dan Chadwick. It is next being run in September 2021: http://events.cieem.net/Events/

About the Authors

This work was led by a team of researchers from University College London (UCL), King's College London (KCL) and PBA Applied Ecology: Dan Chadwick, ACIEEM, Senior Project Ecologist, PBA Applied Ecology, Dr Lawrence Eagle, ACIEEM, Senior Project Ecologist, PBA Applied Ecology, Eleri Pritchard, PhD Researcher, UCL, Paul Bradley, MCIEEM, Director, PBA Applied Ecology, Dr Michael Chadwick, Senior Lecturer, KCL, Professor Carl Sayer, Professor, UCL and Dr Jan Axmacher, Associate Professor, UCL. They are interested in biological invasions and the development of evidence-based conservation and management of freshwater ecosystems. The development of the triple drawdown method was part of Dan's PhD research on crayfish in the UK, funded by the London NERC DTP and in partnership with PBA Applied Ecology.

Contact Dan at: d.chadwick@pba-ecology.co.uk