CITIZEN SCIENTISTS – THE NEXT GENERATION OF ENVIRONMENTAL SENTINELS

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The increasingly rich flow of information between the public and environmental scientists is generating a revolution in how science is being conducted. Science-savvy citizens are actively engaging; to address bottlenecks in biomonitoring and scientific development, filling voids left by a lack of funding, or simply satisfying their own curiosity about the natural world.

Not only are the public donating their time (e.g. crowd-sourcing http://www.climateprediction.net/, or http://www.edgeofexistence.org/instantwild/), but they are also taking part in national and international initiatives to collect targeted field data. Examples include the UK BioBlitz events (http://www.bnhc.org.uk/home/bioblitz/), where participants record on a National database all forms of life they can find in 24 hours, a worldwide study of oceanic phytoplankton abundance, (http://www1.plymouth.ac.uk/marine/secchidisk/Pages/default.aspx); and long running initiatives, such as the breeding bird survey organised by The British Trust for Ornithology, which has been coordinating volunteers across the UK for over 50 years. Citizen scientists are also rapidly filling new roles as environmental sentinels, by tracking the spread of invasive species, such as the USA iMapInvasives partnership (http://www.imapinvasives.org/), or by monitoring the proportion of pollution-intolerant freshwater invertebrate taxa, providing early warnings of pollution events (e.g. http://www.riverflies.org/rp-riverfly-monitoring-initiative).

The Riverfly Monitoring Initiative is a good example of a successful citizen science project focussing on UK rivers. This consists of a network of over 600 active monitoring groups coordinated by the Riverfly Partnership and trained by experts to sample, count, and identify key invertebrate taxa (i.e. Ephemeroptera, Plecoptera, Trichoptera and *Gammarus*) to assess water quality. Each monitoring group takes monthly samples, often from multiple sites along a single river, and, by allocating a score based on the number and diversity of the target taxa, can alert the Environment Agency if a threshold is breached and water quality has been compromised. These data complement those routinely collected by regulatory agencies, but also increase the likelihood that a pollution event or other perturbation will be detected. For instance, in July 2013 a catastrophic point-source insecticide spill wiped out macroinvertebrate populations along about 15 km of the River Kennet in Wiltshire, UK. Action for the River Kennet (ARK) volunteers, who regularly monitor riverfly life, were the first to detect the pollution (Figs 1, 2). The Environment Agency was alerted immediately, enabling them to isolate the point at which the pesticide was entering the river and prevent further release. Subsequently, a consortium of scientists funded by the Natural Environment Research Council (NERC), have been collaborating with the Environment Agency, ARK and other stakeholders, including fishing interests, to gain deeper insights into the full ecological impact of the pesticide spill and how it permeates through the food web over time, as well as tracking the trajectory of recovery (https://sites.google.com/site/kennetrecovery/home). This intimate linking of citizens-government agencies-academic institutions has repaid the initial investment by each community:' data collected by citizen scientists has led to increased understanding of the functioning of the river ecosystem by the various stakeholders and ultimately fuelled more research.

Despite its burgeoning appeal and increasing priority in both science and policy, citizen science should not be viewed as a simple and inexpensive panacea to fill under-resourced regulatory requirements or of filling scientific knowledge gaps. Significant investment (of both time and money) is often necessary for quality-assurance and data-checking, for instance, and these costs are largely hidden by the voluntary nature of much of the work. The need to standardize sampling methods requires the development of monitoring protocols, which also involves specialist expertise, and the material and administrative costs of training and maintaining the monitoring groups are not trivial. To help overcome this problem, some new initiatives, such as uBiome (http://www.nature.com/nbt/journal/v31/n2/full/nbt0213-90a.html), which analyses human ecology, have looked to crowd-funding to support their research. Participants collect samples, but they also donate money in return for individual feedback about their ancestry and state of health and uBiome have already raised over $120,000 in this way.

With regard to biomonitoring, tools designed for citizen scientists often rely on 'structural' measures (e.g. taxon presence/ absence and/or taxonomic diversity). These work well for detecting changes in community composition and in engaging participants in the identification of species and measuring biodiversity. However, this only provides a partial picture, revealing an ecosystem's components but does not demonstrate processes that underpin the system. We believe there is scope in Citizen Science projects for both the public and scientific communities to develop a deeper understanding of ecosystem processes. For instance, 'functional' measures (e.g. detrital breakdown) have not yet been incorporated into the Riverfly Monitoring Initiative, and the Environment Agency typically responds only after the taxonomic diversity and/ or abundance of a sampled community drops below a threshold. This works well as an environmental early warning system following a catastrophic event (as it was conceived), but the chronic, sub-lethal effects of pesticides, which may manifest at a functional-level, cannot be assessed with structural measures alone.

(Photograph copyright Savernake Fishery)

FIGURE 1

The River Kennet with map showing ARK study sites, Stonebridge lane and Elcot Mill, upstream and downstream respectively of the point at which pesticide entered the River Kennet in July 2013. Comparing data collected between these sites, has meant the biological impact and recovery following the pollution can be assessed

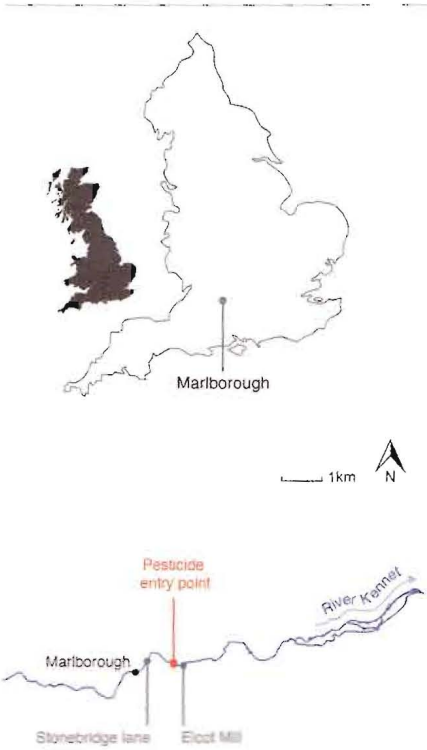
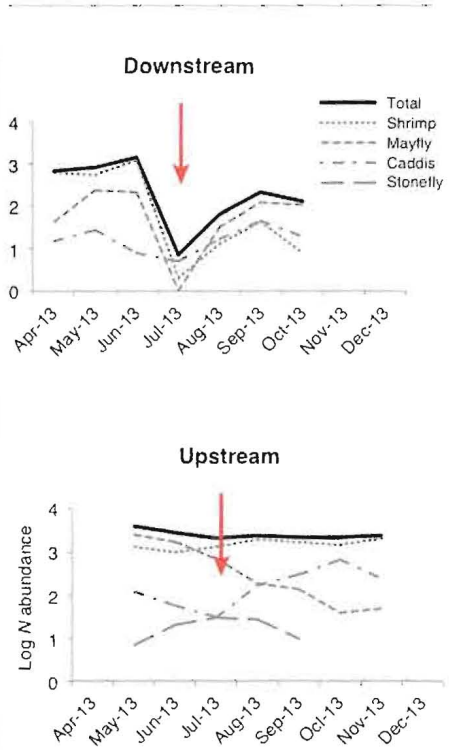


FIGURE 2

ARK riverfly monitoring data collected during 2013 from Stonebridge Lane, and Elcot Mill, upstream and downstream of the point of pollution respectively. The red arrow indicates the timing of the pollution



ARK volunteers and fishermen collecting invertebrates for biomonitoring at one of the routine sampling sites on the River Kennet

For this reason there is scope to design new approaches (e.g., simple measures of ecosystem process rates, such as detrital breakdown, together with the routine 'structural' sampling and diversity measures) which could be measured on a huge scale by Citizen Scientists with relatively little training. This would be of benefit to both science and society but are not yet embedded into the current regulatory or biomonitoring framework.

Functional measures are not the only potential avenue that could be developed for citizen science involvement. Recent progress in the collection and processing of DNA and RNA material for the identification of taxa through next-generation sequencing mean that traditional biomonitoring methods, which require taxonomic skill to identify species, could soon become superseded by automated processing of, for example, soil or water samples (see review by Baird and Hajibabaei 2012). This could mean that specialists may be freed from the need to collect the samples, and focus on processing, analysing, interpreting and collating the huge volumes of 'ecoinformatics' data being generated from samples sent in by citizen monitors.

Citizen 'sentinels' offer a fantastic resource as they can transcend geographic boundaries usually imposed by the considerable financial and logistical challenges associated with despatching specialist teams of scientists to collect data. However, rather than simply acting solely as sample collectors, volunteer monitors are often keen to understand how scientists frame and address a research question, and develop sampling protocols. This familiarisation of the general rules of the scientific process is key to demystifying science and increasing public engagement and promoting informed discussion.

There is huge scope for national and global networks of citizen scientists to measure ecological responses to environmental change at appropriate scales and to contribute to our understanding of, and ability to make predictions about, future global change. The potential to utilise Citizen Scientists to scale-up sample collection in both time and space could ultimately help to unpick the complex responses of natural systems to multiple stressors, which are currently difficult to untangle in small, spatially constrained datasets typical of most professional scientific studies. This potential increase in predictive power could help refine the thresholds for more effective monitoring and management of natural systems in ways we are only just beginning to glimpse: citizen science is clearly here to stay, but its vast potential has still yet to be fully realised.

ARK volunteers, fishermen, John Hounslow (Savernake Flyfishers riverkeeper) and the lead author, Dr Murray Thompson (Imperial College London) collecting timed invertebrates kick samples to help standardize sample collection for QA purposes.

An Environment Agency fish survey in action on the River Kennet following the catastrophic pesticide spill. Data from these surveys can be combined with ARK invertebrate data in order to understand the direct (i.e. toxic) and indirect effect (i.e. loss of prey) of the pollution on fish populations. (Image copyright John Sutton, john.sutton@environment-agency.gov.uk)

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COMMENT

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Citizen science, the involvement of volunteers in science, isn't new (Roy et al., 2012; Tweddle et al., 2012). Indeed within the UK we have a long tradition of scientific discovery by dedicated volunteers and much of our current understanding of UK wildlife is based on inspiring contributions from the naturalist community. However, there has been a recent explosion in the number and diversity of citizen science approaches globally (Roy et al. 2012). The article by Murray et al. eloquently outlines a number of these initiatives, many of which build on the legacy of biological recording.

The importance of citizens as "sentinels" providing monitoring and surveillance for early warning of alien species and pollution events is becoming increasingly recognised. The proposed European regulation on invasive alien species highlights the requirement for surveillance and the UK is in an excellent position to ensure effective early warning of alien species. In 2010 Recording Invasive Species Counts (RISC), an on-line system for capturing information on alien species, was launched following on from the success of the Harlequin Ladybird Survey (www.ladybird-survey.org), which engaged tens of thousands of people in tracking the spread of an alien ladybird. RISC has now been extended to an alert system for invasive alien species of particular concern to the UK (www.nonnativespecies.org/alerts/index.cfm) and is proving extremely successful in terms of numbers of sightings of concern reported (and thankfully most prove not to be invasive alien species). However, it is important that we ensure there are opportunities for both citizens as sentinels and scientists; the latter involving volunteers in every part of the scientific process sharing the creativity and delight of scientific discovery.

The Biological Records Centre (part of the Centre for Ecology & Hydrology) celebrates 50 years of biological recording throughout 2014. The inspiration provided by the many schemes and societies, including those within the Riverfly Partnership, have been inspiring people for decades and provide a rich legacy for citizen science. The Bees, Wasps and Ants Recording Scheme (BWARS: http://www.bwars.com/) is one such scheme. The enthusiasm and generosity of the group of volunteers involved in BWARS has ensured that we have access to records collated by them and shared through the NBN Gateway (https://data.nbn.org.uk/). The decline of pollinating insects, such as bees, is a major concern and such long-term, large-scale volunteer-collected data is critical in contributing to our understanding of the ecology of these insects and the magnitude of their decline. The Big Bumblebee Discovery (http://jointhepod.org/campaigns/campaign/31), launched this year, is a collaborative project between the Centre for Ecology & Hydrology, the British Science Association and EDF Energy. The Big Bumblebee Discovery provides an opportunity for people across the UK to address the question of how landscape factors influence the diversity of bumblebees. The LEAF Open Farm Sunday Pollinator Survey (being run in collaboration with the BES in 2014) also invites people to get involved in recording insects that might be important pollinators. We hope these projects will inspire the next generation of scientists and perhaps some of the participants will become BWARS members and develop the taxonomic expertise and field skills needed to effectively monitor these important insects.

As Murray et al. highlight the potential of citizen science is vast. It will be exciting to see how we can reveal this potential, through mass participatory, collaborative and co-created approaches (Bonney et al., 2009) , with scientists and citizen scientists working in partnership using so-called "big data" to address the challenging ecological questions we face. The new BES Citizen Science Special Interest Group will provide an exciting forum for citizen science and we welcome the involvement of all.

For more information: http://www.britishecologicalsociety.org/getting-involved/special-interest-groups/citizen-science/

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