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Saving Living Diversity in the Face of the Unstoppable 6th Mass Extinction: A Call for Urgent International Action

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Abstract

The global scale and impact of current and increasing human population size is incompatible with the survival of biological diversity and the 6^{th} mass extinction cannot be stopped. For the vast majority of species we have neither the knowledge of when they will go extinct nor the capacity to find out. Conventional conservation measures can only amount to token damage limitation. Advances in molecular biology allow low cost options for storing the genetic diversity of numerous species and maximising future options for restoring species.

Keywords: mass extinction, conservation, cryobanking, land snails, international collaboration

Introduction

We are witnessing a biodiversity crisis: the loss of a large proportion of living diversity resulting from a wide range of events that can all be ultimately attributed to human population growth and human activity. Nothing else is involved. The scale and speed of extinction is widely thought to be unprecedented since the mass extinction event that occurred 65 million years ago, which marked the transition from the Mesozoic to the Cainozoic era of geological time (Ceballos et al. 2010; Barnosky et al. 2011; Laurance et al., 2014; Ceballos et al., 2015). Clearly there is an urgent need to enact conservation measures that will seek to safeguard remaining natural habitats, to evaluate the relative conservation value of transformed habitats and to restore habitat connectivity. However, barring a catastrophic human population reduction, the process of massive extinctions cannot be stopped and can only be moderated to a very limited extent (Naggs and Raheem, 2014). We are shielded from this stark reality by a lack of honesty and willingness to admit collective human culpability. It is not possible to control this situation in the short or medium term and we cannot know how this calamity will play out, other than the fact that there is no happy ending in prospect. The long-term hope must be that at some point in the future mankind will exist in reduced numbers with improved stewardship that will allow a sustainable existence in relative harmony with the natural world. The problem with this scenario is that unless we act with urgency and purpose, there won't be much of a natural world left to live in harmony with.

Perhaps more shocking than widespread apathy is that organisations entrusted with responsibility for recording and understanding biodiversity offer only the pretence of responding to the biodiversity crisis. Almost without exception, international museums with the remit of recording and understanding the natural world exhibit a lamentable failure to address the biodiversity crisis let alone act in a relevant way, although they have the capacity to do so. The international Convention on Biodiversity (CBD) has largely been diverted to a completely different agenda, epitomised by Britain's Darwin Initiative's shift to poverty alleviation as a core objective, driven in part by the way in which government funding is channelled *(Darwin Initiative Secretariat 2014).* This seemingly worthy objective might appear to be beyond criticism but it represents a hijacking of its supposedly biodiversity conservation intent. A CBD target to halt extinctions by 2020 (Hochkirch, 2016) is out of touch with reality. There is a prevailing lack of honesty about the extent to which, by the scale of our existence, human utilisation of the planet to satisfy human needs and voracity is driving extinctions, and about our inability to control the process. While conservation as a scientific discipline has flourished, it has failed to halt the process of massive habitat loss and consequent extinctions (Whitten, et al., 2001; Wunder, 2001). Having witnessed the ongoing and appalling scale of rainforest loss and degradation in large areas of south-east Asia over the past few decades, I am under no illusion as to the magnitude and reality of the biodiversity crisis.

Although human driven species extinction often gains media coverage and arouses episodes of anguish, attention is almost invariably drawn to an iconic vertebrate and usually a mammal species. Just occasionally an invertebrate makes the headlines. It is often overlooked that over 99% of multicellular animals are invertebrates (Lunney and Ponder, 1999), many of which have disappeared and continue to disappear without our having known of their existence (Lydeard et al. 2004; Régnier et al. 2015; Hochkirch, 2016). Here I draw on my knowledge of land snails, a major invertebrate group, to illustrate some key issues in the biodiversity crisis. Snails serve to demonstrate that although extinctions are happening on a massive scale it is more or less a waste of time to attempt to critically evaluate ever more data on current extinctions. The ultimate scale of the current mass extinction will be recognised long after the damage is done but we will have little idea of what has been lost. Research is absolutely necessary for furthering our understanding of the natural world but the broad picture on extinction is clear; we need to focus our efforts on delivering solutions.

More in the realm of science fiction than reality, when faced with mortality, some human beings seek a solution by having their bodies cryogenically preserved in the hope that they can be woken in a future, advanced world, where they can be restored to life. However, the cryogenic storage of viable cells of living organisms has moved beyond the realm of science fiction. Advances in molecular biology allow us to store the genetic diversity of species and potentially restore species should they become extinct (Lerman et al., 2009). This is the new reality that allows us the only route for storing living diversity on a scale that is commensurate with its current levels of loss. It offers a long-term strategy that extends way beyond a human lifetime but as a course of action it is entirely doable and fundable, if the will to do so can be summoned. This is about maximising future options. We may not be able to preserve all living diversity, but we can aim to do so and the sooner we act the greater the chance of preserving as many species as possible before they disappear.

Islands and disappearing snails

Oceanic islands have a special significance for evolutionary biologists as natural laboratories that model events in the wider world. Islands also represent the delicate canary in the coal mine of the world's natural environments. As an outstanding observer of the natural world and armed with a copy of Charles Lyell's newly published *Principles of Geology*, Charles Darwin was well equipped to read landscapes and interpret their history. From the first landing on the voyage of the Beagle at the Cape Verde Islands, Darwin had immediately recognised the impact of human activity on natural habitats. "When the island was discovered, the immediate neighbourhood of Porto Praya was clothed with trees, the reckless destruction of which has caused here, as at St. Helena, and at some of the Canary islands, almost entire sterility" (1845 [1839], p 2). On 8th July 1836, towards the end of Darwin's voyage on the Beagle, a brief stop of a few days was made at the isolated island of St Helena in the Atlantic Ocean. With his notable powers of perception Darwin recognised that the island had been transformed by human occupation and that this had led to the loss of its native forest and numerous species of invertebrates:

> On the higher parts of the island, considerable numbers of a shell, long thought to be a marine species, occur embedded in the soil. It proves to be a Cochlogena, or land-shell of a very peculiar form; with it I found six other kinds; and in another spot an eighth species. It is remarkable that none of them are now found living. Their extinction has probably been caused by the entire destruction of the woods, and the consequent loss of food and shelter, which occurred during the early part of the last century…. There can be little doubt that this great change in the vegetation affected not only the land-shells, causing eight species to become extinct, but likewise a multitude of insects. (Ibid. pp 469 – 471) (figure 1).

Recorded extinctions of land snails are disproportionately high and there is clear evidence for snail extinctions over the past few hundred years that exceed recorded extinctions for all other animal groups combined. From the Hawaiian Islands alone Cowie et al., (1995) estimated that some 570 of the 763 species listed in their catalogue are probably extinct and this does not take account of the approximately 200 species of 'known' but undescribed species of now extinct Hawaiian charopid snails in the Bishop Museum (Naggs et al., 2006). Compare this with the total of 484 human induced extinctions cited by Groombridge (1992) for all animal groups, which includes a mere 191 molluscs. The IUCN Red List

Figure 1: Chilonopsis nonpareil (Perry, 1811) [*Chilonopsis = Cochlogena sensu* Darwin]. There can be little doubt that this medium sized snail had been extinct for many years prior to Darwin's observations of subfossil shells on St Helena in 1836. Nevertheless, some of the shells look as fresh as those of a living snail and they are found with what are likely to be their eggs. Using a shell and preserved eggs this image reconstruction shows what a living example might have looked like. Image prepared by Harold Taylor.

(2015) includes 832 species listed as extinct since 1600 and there are regular calls for more research into establishing detailed information for current extinction levels (Hayward, 2009). Although it is widely recognised that the level of evidence and how it is interpreted vary enormously (Regan et al., 2005), efforts continue to be made to refine and justify hard data. Several commendable and critical studies have attempted to establish reliable, evidence-based assessments of land snail extinctions (Lydeard et al., 2004; Régnier et al., 2009, Régnier et al., 2015). They come up with alarming figures but we should be mindful of Darwin's observation that extinctions of land snails are a visible example of a multitude of other extinctions that do not leave shells as a record of their passing. The 394 insect species recorded as being extinct by the IUCN Red List of Threatened Species bears absolutely no relation to reality (Hochkirch, 2016) and is meaningless. It might seem reasonable to ask, as these researchers do, what detailed evidence is available for current extinction levels. But is this missing the point? Firm figures are often cited but I contend that very few invertebrate risk status evaluations survive close inspection; we simply do not know. A more promising approach is to estimate species loss by extrapolating from known habitat loss, but such model-based studies (e.g. Beck, 2011) do not take us beyond the self-evident reality that such approaches can only provide broad approximations. If we have little idea of how many species there are (Caley et al., 2014; Giller, 2014), how can we begin to know the rate of extinction? Because of massive habitat loss and degradation, we can confidently infer that extinctions are happening on a massive scale but geographical species turnover varies enormously from one area to another, often for no discernible reason, and there is no simple way of linking extinction to habitat loss. When it comes to specifics relating to small animals and invertebrates in particular we are profoundly ignorant. Anyone who is familiar with large reference collections of invertebrates will be aware that many species have not been recorded again since they were first described. Attempts, such as the IUCN Red List system applied to invertebrates are well meaning but illusory. The transition from critically endangered to extinct is indeed a profound and currently irretrievable step and we want to know about when it happens but it is important not to compromise our credibility with unwarranted certainty of the particular when it is the general picture that is of paramount importance. To establish the status of a single invertebrate species could take years of research and still be wrong. Asserting that a particular tiny snail has just become extinct simply exposes researchers to ridicule if just one example should later be found surviving in a remote valley.

Unintended consequences: a global pest, transmitter of human pathogens, wave of extinctions and a vision for saving biodiversity

In 1847 William Benson, a civilian administrator in the service of the East India Company and pioneer in the study of land snails in India (Naggs, 1997), brought two Giant African Snails back with him from Mauritius to India. Released in a Chowringhee garden after Benson left India, the snails slowly spread across Calcutta (Benson, 1858; Blanford, 1868; Godwin-Austen, 1908) and have since been recorded in every continent except for Antarctica. The species has since become a serious agricultural pest and vector for a sometimes fatal disease in humans (Alicata, 1966). Vast sums of money are spent on its control and local eradication but its large size, extended distribution range and the high densities populations often reach render it likely to have the highest biomass of any species of snail (Budha and Naggs, 2005). Following their introduction to a new area, *L. fulica* often reach plague proportions and this is what happened when they were released in Tahiti in 1967. They soon spread throughout the archipelago, including the island of Moorea.

An ill-conceived but widely advocated biological control method for *L. fulica*, based on setting a snail to catch a snail, was initiated with the release of several species of predatory snail in areas where *L. fulica* had become established. The most 'successful' of these introductions was of the voracious predatory species *Euglandina rosea*. There was no evidence that *E. rosea* would be an effective control agent of *L. fulica* and it proved not to be but it was very successful in killing local endemic species. *E. rosea* has caused devastation to the endemic land snail faunas on Indian Ocean and Pacific Ocean islands. Early and thorough evidence of this came to the notice of the scientific community (Tillier and Clarke, 1983; Clarke et al. 1984) because the land snails of Moorea, their abundance and distribution, were known in great detail, most notably the endemic genus *Partula*. The genetics and distribution of *Partula* had been studied for decades as a model system for investigating speciation and evolution (Crampton, 1932; Murray and Clarke, 1980; Murray et al., 1982).

Bryan Clarke was a pioneer of ecological genetics and a central figure in the study of *Partula* (Jones, 2014). After years of studying *Partula* Bryan was deeply shocked to find that *Partula* species were rapidly becoming extinct and this personal experience of extinction drove him to seek, if not a solution, a strategy for addressing the issue of extinction. Bryan was instrumental in setting up an international project for the captive breeding of *Partula* that is coordinated by Paul Pearce Kelly at the Zoological Society of London[1]. Captive breeding of *Partula* was successfully established and *Partula* species that became extinct in the wild remain in captive breeding projects with a long-term aim to return them to their natural homes[2]. The *Partula* story is a flagship example of how zoos can perform an important role in conserving species on the brink of extinction but something far more ambitious was needed to be of any relevance to the scale of extinctions and this led to Bryan, his wife Ann and Anne McLaren setting up the Frozen Ark in 1996[3].

1. See https://www.zsl.org/conservation/regions/oceania/partula-snail-conservation-programme
2. See https://www.zsl.org/zsl-london-zoo/news/release-the-snails
3. See https://frozenark.org/

The initial objectives of the Frozen Ark were to establish repositories of frozen tissue of endangered animals and to at least have a genetic record of animals that might become extinct. The idea was to set up a global consortium of partners in this venture, which currently includes 22 zoos and other research institutions in eight countries. Bryan and Ann soon realised that the prospect of restoring species from viable cells had moved from the realms of science fiction to scientific reality and rather than simply store DNA the cryogenic storage of viable cells became a Frozen Ark objective. The value of biobanking or cryobanking as a conservation tool is recognised in some academic circles (Lerman et al., 2009) but to date the only serious development of cryogenic storage of species viable cells is undertaken at the San Diego Zoo, Institute for Conservation Research, Frozen Zoo project[4]. However, valuable as these initiatives are they do not yet begin to approach the scale that is needed.

Priorities for action and how they can be delivered

Either new institutions are required or existing institutions need to respond to the challenge of establishing a worldwide programme to undertake surveys and store viable cells of the whole range of living diversity. The institutional requirements can be identified as:

1. Secure long-term funding.
2. Teams of appropriate scientific personnel.
3. Expertise in data management
4. Capacity to store cryogenic and conventionally preserved biological collections.
5. The capacity to undertake large-scale collection based surveys.
6. An institutionally shared vision and commitment to utilise these skills and resources to build cryogenic collections as a means of species conservation.

Hochkirch (2016) advocates the establishment of new institutions for invertebrate conservation but, apart from item 6, it would seem that the world's major international museums that encompass life sciences meet all of these criteria. However, in lacking both leadership on this issue and a relevant culture it may

4. See http://institute.sandiegozoo.org/resources/frozen-zoo%C2%AE

be that these institutions cannot respond to the challenge[5,6,7]. Across the world only the Muséum national d'Histoire naturelle (MNHN), Paris, is a major museum that has an ambitious collections programme attempting to make twenty-first century collections to record living diversity, rather than being preoccupied with historical collections that date mostly from the nineteenth century. The MNHN programme[8] is entirely due to the vision, energy and drive of one man, Philippe Bouchet. In 2009 Philippe Bouchet with colleagues at the MNHN and the NGO Pro-Natura International launched ambitious plans to amass enormous collections of reference specimens. They focussed on rich but poorly-known biotas under the programme 'La Planète Revisitée' ('Planet Reviewed') a vast program of surveys planned over 10 years. This massive undertaking is the most praiseworthy of any of the world's collection-based research institutions' initiatives. It has demonstrated that large-scale collecting is still achievable in a bio-politicised world and that traditional morphological collections can be integrated with DNA collections and molecular bar coding on a large scale (Puillandre, et al., 2012). Hopefully, viable cell preparations and storage will be added to their collection protocols. However, commendable as the Planet Reviewed programme is, it is almost entirely directed at marine surveys. The criteria for identifying priorities include areas of highest diversity, endemism and threat. So far, the current wave of extinctions has occurred almost entirely in non-marine environments. This has been most visible on oceanic islands but is occurring largely unrecorded on continental land masses, most notably in tropical rainforests.

Undertaking large-scale collection surveys in tropical forests is far less expensive than the major expenditure involved with marine surveys but it can be more problematic. Until the mid-twentieth century it was possible to collect specimens throughout much of the world with few restrictions. Collecting of invertebrates in particular was perceived as an obscure obsession pursued by a few eccentrics that very few cared about. However, in the past seventy years or so there has been an ever-growing reluctance to allow specimen collections to be made, particularly by non-nationals, and international collecting has become increasingly difficult. The 1992 international Convention on Biological Diversity (CBD) pushed biodiversity

5. https://www.si.edu/Museums
6. http://www.nhm.ac.uk/about-us/our-vision-strategy.html
7. http://www.nhm.ac.uk/research-curation/about-science/science-directorate/science-strategy/
8. See https://www.mnhn.fr/en/research-expertise/scientific-expeditions/our-planet-reviewed

higher up the political agenda of nations and reaffirmed that states have sovereign rights over their biological resources. Whatever the intent of the CBD, the reality has been biodiversity nationalism and barriers to international collaboration. Having run collection-based survey programmes throughout south and much of tropical southeast Asia over the past two decades I have been privileged to work with international colleagues in various productive ways but our collaborations have been significantly hampered by such constraints.

The first step in establishing optimal collaboration is to set up international agreements based on a common vision and shared objectives. Following five years of collaborative projects with colleagues in Vietnam, I established an agreement with the Vietnamese National Museum of Nature (VNMN) in 2010 that allows international partners to work effectively. The key element is to share survey material and allow for duplicate centres for the cryogenic preservation of viable cells in addition to conventional voucher specimens and frozen tissue samples. Supported by the Natural History Museum, the Zoological Society of London and the Frozen Ark, I led a team with UK and Vietnamese colleagues in 2013 with the objective of undertaking a survey project that included viable cell preparations. We successfully carried out a traditional survey, sampling and preserving morphological voucher specimens and, in addition to preserving tissue samples for molecular research, followed with the additional stage of making viable cell preparations. This proved to be relatively straightforward and was a procedure easily incorporated into our existing methodology for processing specimens and transferring frozen samples to cryogenic storage facilities at the Natural History Museum, London. Clearly such surveys need to be integrated with research that refines and assesses the viability of cell preparations. In many instances, it may prove possible to preserve viable zygotes or gametes, obviating the need for cloning to restore species.

The programme in Vietnam serves as a model system, demonstrating that large scale biotic surveys and routine preparation of viable cells in the field are relatively straightforward. The VNMN is committed to the process: it is establishing a new museum with ambitious biobanking facilities, embarking on nationwide biotic surveys and actively pursuing collaborations with international partners. Similar schemes urgently need to be taken up by the international scientific community and government agencies. It is our best hope for maximising options for restoring a biodiverse world (figure 2).

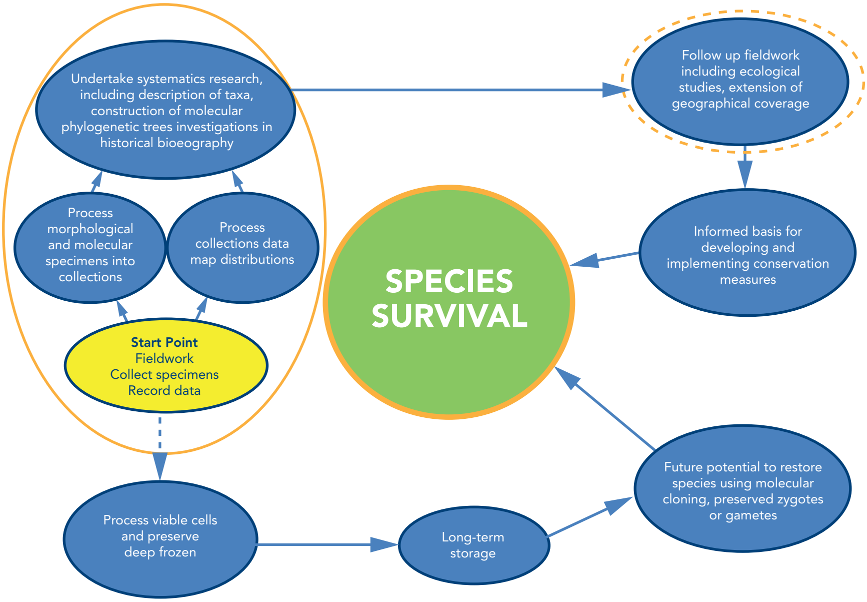

Figure 2: International museums' historical specimen collections are priceless and provide the foundation for naming the world's biota. However, they do not begin to meet the needs of current and future research, which requires state of the art collection methods of preservation, georeferenced localities and habitat data. The rate of extinctions imposes an urgent need for recording the current extent of living diversity and establishing a global inventory. It is a small additional step to include the preservation of viable cells. In addition to providing optimal material for research, preservation of viable cells provides a mechanism for safeguarding genetic diversity and allows for the possibility of restoring species should they become extinct. This offers a long-term option and alternative route for conserving living diversity that complements traditional conservation measures.

Calls for prioritising the description of new species are misplaced in the context of viable cell conservation and the assertion that we can only preserve what we know (Hochkirch, 2016) does not apply to broad-based survey collections: you collect what you find. Obviously, it is desirable to name new species as soon as possible and molecular tools can facilitate this but if viable cells and morphological voucher specimens are preserved, we have a very long time at our disposal to describe them. If they are gone, we have nothing.

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